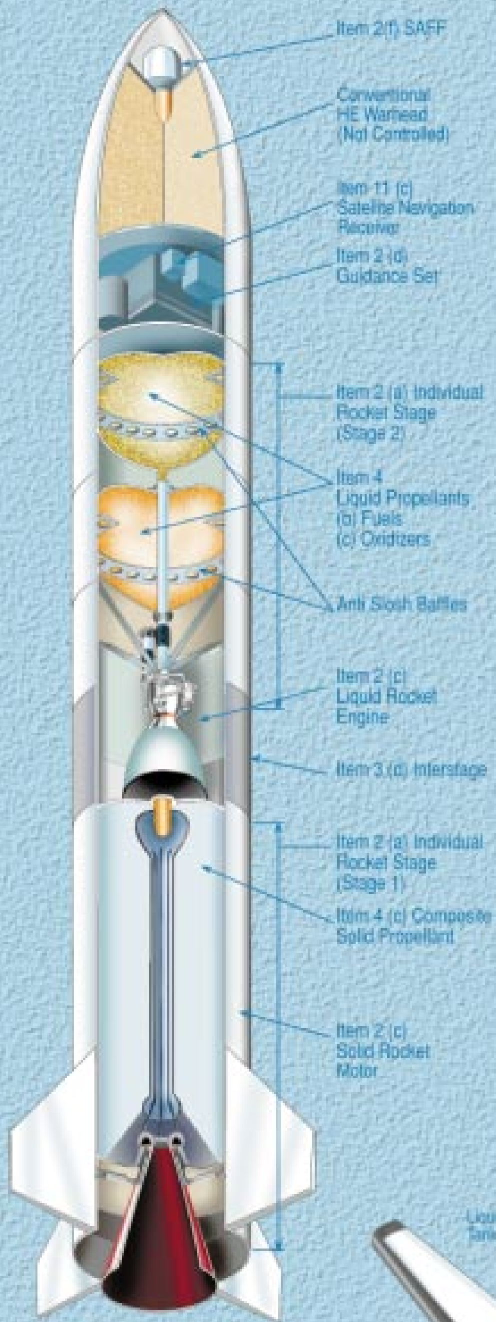
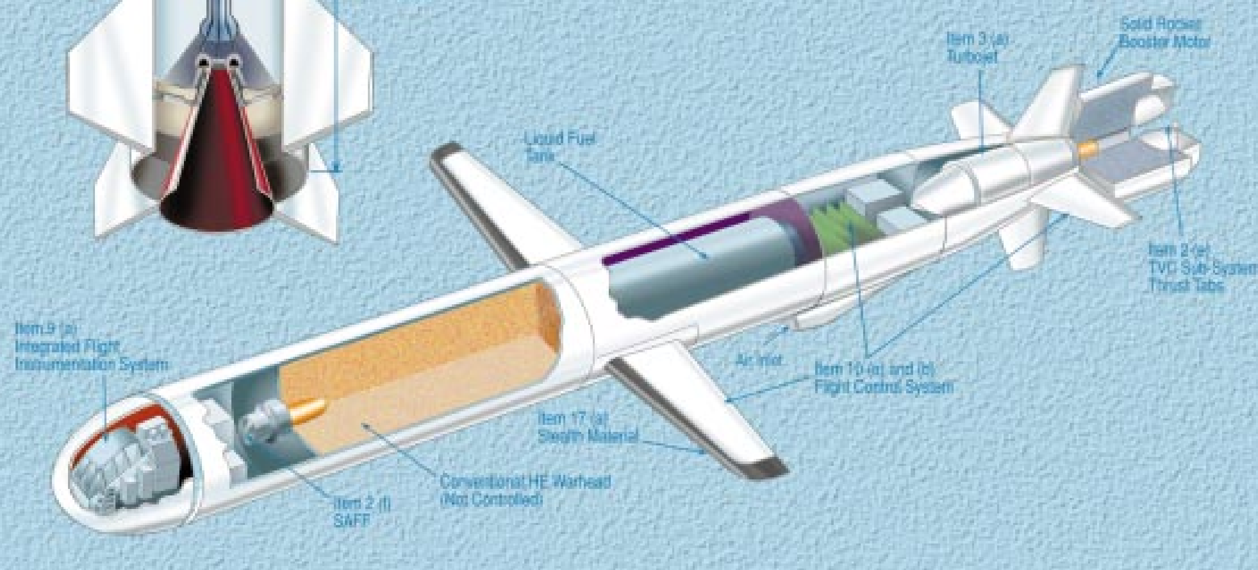


Missile Technology Control Regime

Annex Handbook



Introduction

INTRODUCTION

The Missile Technology Control Regime

The Missile Technology Control Regime (MTCR) is an informal political arrangement to control the proliferation of rocket and unmanned air vehicle systems capable of delivering weapons of mass destruction and their associated equipment and technology. The MTCR was formed in 1987 by Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. Membership has expanded to 29 countries, as of June 1998. The Regime's controls are applicable to such rocket and unmanned air vehicle systems as ballistic missiles, space launch vehicles, sounding rockets, unmanned air vehicles, cruise missiles, drones, and remotely piloted vehicles.

The MCTR is not a treaty but a voluntary agreement among member countries sharing a common interest in controlling missile proliferation. MTCR members meet at least once a year in a plenary session to exchange information, discuss policy issues, and examine ways to improve the Regime. In January 1993, the MTCR revised its guidelines to address delivery systems for all types of weapons of mass destruction—biological, chemical, or nuclear weapons. Originally, the MTCR Guidelines only addressed nuclear weapons delivery systems.

The Regime's documents include the Guidelines and the Equipment and Technology Annex (copies of each are annexed to this publication). The Guidelines define the purpose of the MTCR and provide overall guidance to member countries and those adhering unilaterally to the Guidelines. Each country implements the Guidelines according to its own national legislation. The Guidelines state that the Regime "is not designed to impede national space programs or international cooperation in such programs as long as such programs could not contribute to delivery systems for weapons of mass destruction."

The Equipment and Technology Annex is divided into two sections:

- Category I Annex items include complete rocket and unmanned air vehicle systems, capable of delivering a payload of at least 500 kg to a range of at least 300 km, and their major subsystems and related technology. Exports of Category I items are to be subject to a strong presumption of denial, except that transfers of specially designed production facilities for Category I items are prohibited.

MTCR Members

Original Members in Alphabetical Order

- Canada
- Federal Republic of Germany
- France
- Italy
- Japan
- United Kingdom
- United States

Additional Members in Order of Admission

- Spain
- Netherlands
- Belgium
- Luxembourg
- Australia
- New Zealand
- Denmark
- Norway
- Austria
- Sweden
- Finland
- Portugal
- Switzerland
- Greece
- Ireland
- Argentina
- Iceland
- Hungary
- Russia
- South Africa
- Brazil
- Turkey

- Category II Annex items include propulsion and propellant components, launch and ground support equipment, various other missile-related components, and related technology, as well as certain other missile systems. Exports of Category II items are to be subject to case-by-case review against specified nonproliferation factors.

The Equipment and Technology Annex is modified from time-to-time to improve its clarity and reflect evolving technologies.

The MTCR Annex Handbook

This document is designed to assist in implementing export controls on MTCR Annex items. It explains what MTCR-controlled equipment and technologies are, how they are used, how they work, what other uses they may have, and what they look like.

The MTCR Annex covers an extremely broad range of items. This document emphasizes technolologies most critical to missile design and production.

The Handbook is organized like the MTCR Annex, by item and subitem. Each section follows the same format: the actual MTCR Annex text is reproduced in a highlighted section, followed by the elaboration and pictures. Any MTCR Annex "Notes" relevant to a particular subitem have been moved up with the actual text to allow easier reading. In some cases, the Notes themselves have been elaborated.

Each subitem is discussed separately. When reviewing subitems, the reader should pay attention to the header text in the Item, which may contain additional descriptors for each subitem.

NOTE: The photos included in this handbook are intended to illustrate types of equipment similar to those that the MTCR Equipment and Technology Annex describes. The equipment shown in a specific photo may or may not be MTCR controlled.

Definitions and Terminology (as stated in the MTCR Annex)

Definitions

For the purpose of this Annex, the following definitions apply:

(a) "Development" is related to all phases prior to "production" such as:

—design
—design research
—design analysis
—design concepts
—assembly and testing of prototypes
—pilot production schemes
—design data
—process of transforming design data into a product
—configuration design
—integration design
—layouts

(b) A "microcircuit" is defined as a device in which a number of passive and / or active elements are considered as indivisibly associated on or within a continuous structure to perform the function of a circuit.

(c) "Production" means all production phases such as:

—production engineering
—manufacture
—integration
—assembly (mounting)
—inspection
—testing
—quality assurance

(d) "Production equipment" means tooling, templates, jigs, mandrels, moulds, dies, fixtures, alignment mechanisms, test equipment, other machinery and components therefor, limited to those specially designed or modified for "development" or for one or more phases of "production."

(e) "Production facilities" means equipment and specially designed software therefor integrated into installations for "development" or for one or more phases of "production."

(f) "Radiation Hardened" means that the component or equipment is designed or rated to withstand radiation levels which meet or exceed a total irradiation dose of 5×10^5 rads (Si).

(g) "Technology" means specific information which is required for the "development," "production" or "use" of a product. The information may take the form of "technical data" or "technical assistance."

(1) "Technical assistance" may take the forms such as:

—instruction
—skills
—training
—working knowledge
—consulting services

(2) "Technical data" may take forms such as:

—blueprints
—plans
—diagrams
—models
—formulae
—engineering designs and specifications
—manuals and instructions written or recorded on other media or devices such as:
—disk
—tape
—read-only memories

NOTE:
This definition of technology does not include technology "in the public domain" nor "basic scientific research."

(i) In the public domain" as it applies to this Annex means technology which has been made available without restrictions upon its further dissemination. (Copyright restrictions do not remove technology from being "in the public domain.")

(ii) "Basic scientific research" means experimental or theoretical work undertaken principally to acquire new knowledge of the fundamental principles of phenomena and observable facts, not primarily directed towards a specific practical aim or objective.

(h) “Use” means:

—operation
—installation (including on-site installation)
—maintenance
—repair
—overhaul
—refurbishing

Terminology

Where the following terms appear in the text, they are to be understood according to the explanations below:

(a) “Specially Designed” describes equipment, parts, components or software which, as a result of “development,” have unique properties that distinguish them for certain predetermined purposes. For example, a piece of equipment that is “specially designed” for use in a missile will only be considered so if it has no other function or use. Similarly, a piece of manufacturing equipment that is “specially designed” to produce a certain type of component will only be considered such if it is not capable of producing other types of components.

(b) “Designed or Modified” describes equipment, parts, components or software which, as a result of “development” or modification, have specified properties that make them fit for a particular application. “Designed or Modified” equipment, parts, components or software can be used for other applications. For example, a titanium coated pump designed for a missile may be used with corrosive fluids other than propellants.

(c) “Usable In” or “Capable Of” describes equipment, parts, components or software which are suitable for a particular purpose. There is no need for the equipment, parts, components or software to have been configured, modified or specified for the particular purpose. For example, any military specification memory circuit would be “capable of” operation in a guidance system.

ITEM 1
Complete Rocket and UAV Systems

Complete Rocket and UAV Systems

Complete rocket systems (including ballistic missile systems, space launch vehicles and sounding rockets) and unmanned air vehicle systems (including cruise missile systems, target drones and reconnaissance drones) capable of delivering at least a 500 kg payload to a range of at least 300 km as well as the specially designed “production facilities” for these systems.

Produced by companies in

- Brazil
- China
- Egypt
- France
- India
- Iran
- Iraq
- Israel
- Italy
- Japan
- Libya
- North Korea
- Pakistan
- Russia
- South Korea
- Spain
- Syria
- Ukraine
- United Kingdom
- United States

Rocket Systems

Nature and Purpose: Rocket systems are self-contained flight vehicles, which carry their fuel and oxidizer internally and boost their payloads to high velocity. After burnout, the payload continues on an unpowered, ballistic trajectory either into orbit or to a target on earth. Depending on its range and trajectory, a rocket may or may not leave the atmosphere. Rocket systems normally consist of four elements: 1) the payload, or warhead; 2) a propulsion system, which provides the energy to accelerate the payload to the required velocity; 3) a guidance and control system, which guides the rocket along a preprogrammed trajectory to its destination (not all rockets are guided, however); and 4) an overall structure that holds everything together.

Method of Operation: Before launch, rocket subsystems are checked for operational readiness, and the flight plan or trajectory is programmed into the guidance computer. On ignition, liquid or solid propellants generate the thrust to launch the rocket. If the rocket has multiple stages, each stage terminates its thrust when its fuel is expended or almost expended and is separated from the rest of the rocket, and the next stage is ignited. The guidance and control system guides and steers the rocket in order to maintain the proper trajectory. After the final stage terminates its thrust, the payload is usually released on its final trajectory. In some systems, the payload remains attached to the missile body as it reenters the atmosphere.

Typical Missile-Related Uses: Complete rocket systems controlled under the MTCR as Category I are capable of delivering a payload of 500 kg or more to a ground range of 300 km or more. Rocket systems capable of delivering a payload of less than 500 kg to a ground range of 300 km or more are controlled as Category II items and are described in Item 19 of this handbook. Space launch vehicles and sounding rockets are used to place satellites in orbit or to gather scientific data in the upper atmosphere, respectively. The main difference between them and offensive ballistic missiles is their payload and intended use. With the addition of a weapons payload and different guidance algorithms, space launch vehicles and sounding rockets can be used as ballistic missiles. In fact, many commonly used space launch vehicles have been developed from, and share components with, former and currently operational ballistic missiles.

Other Uses: N/A

Figure 1-1: A solid propellant SRBM.

Appearance (as manufactured): Complete rocket systems are large, long, narrow cylinders. When assembled, rocket systems controlled by Item 1 typically have dimensions of at least 8 m in length, 0.8 m in diameter, and 5,000 kg in weight, with a full load of propellant. Some representative photos of rocket systems are shown in Figures 1-1, 1-2, 1-4, and 1-5. See Figure 1-3 pullout diagram for an exploded view of a ballistic missile. The forward end, or nose, typically has a conical, elliptical, or bulbous fairing that houses the payload, and joins to the cylindrical body in which the propellants are located as shown in Figure 1-3. The blunt aft end is straight, flared, or symmetrically finned for stability during launch and atmospheric flight. The body of the missile houses the rocket motor(s), which supplies the thrust. The missile surface is usually made of metallic or composite materials with heat-absorbing materials or protective coatings. Depending on their intended use, some surfaces may be unfinished.

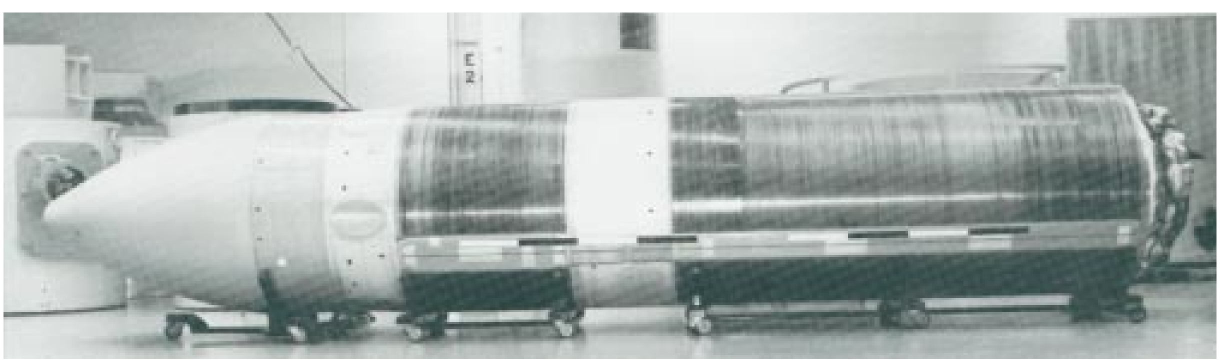


Figure 1-2: A solid propellant, submarine launched ballistic missile.

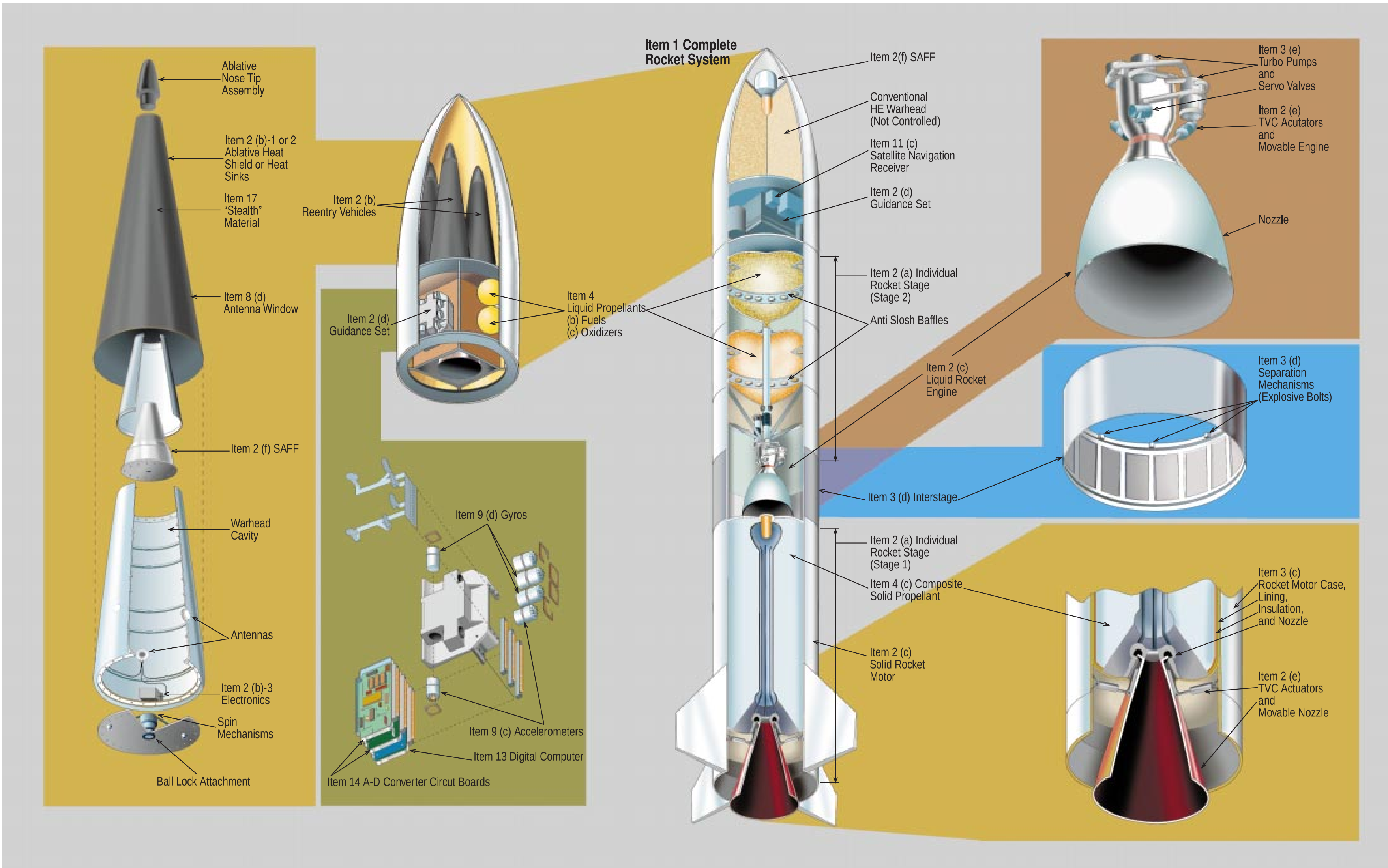


Figure 1-3: Exploded view of MTCR Annex items used in a ballistic missile.

Figure 1-4: A short range liquid fueled ballistic missile.

Photo Credit: AlliedSignal Aerospace

Figure 1-5: A space launch vehicle.

Appearance (as packaged): Because rocket systems controlled under the MTCR are large, a complete rocket system is seldom packaged as a fully assembled unit for shipment from the manufacturer to its point of use or storage. Instead, the major subsystems are shipped in crates or sealed metal containers to an assembly facility near the launch location, where they are assembled, tested for their operational state, and erected for vertical launch. Exceptions include mobile ballistic missiles, which are fully assembled and stored in a horizontal position in a mobile transporter-erector-launcher and moved to the launch point when needed. These packaging and shipping methods are described more fully in later sections of this handbook.

Produced by companies in

- Australia
- China
- Israel
- Russia
- United States

Unmanned Air Vehicles, including Cruise Missiles, Target Drones, and Reconnaissance Drones

Nature and Purpose: Unmanned air vehicles (UAVs) are typically air-breathing vehicles which use aerodynamic lift to fly and thereby perform their entire mission within the earth's atmosphere. The most common mission for UAVs is reconnaissance. They are usually powered by small turbine or piston engines that drive either free or ducted propellers. UAVs tend to fly at relatively slow speeds of 360 to 540 km / hr, usually for several hours. Cruise missiles are distinguished from other UAVs by their use in weapons delivery and by flight trajectories that often minimize their vulnerability to defenses. Cruise missiles can fly at almost any speed, but they are usually powered by small jet engines, which typically operate at high subsonic speeds (less than 900 km / hr). UAVs, including cruise missiles, can fly at altitudes ranging from very low, nap-of-the-earth trajectories to very high altitudes.

Method of Operation: UAVs are launched from many platforms, typically trucks, aircraft, and ships. They may fly autonomous preplanned routes and / or routes controlled by a human operator. After their mission is completed, they usually return to base to be used again. Cruise missiles are frequently carried and launched by aircraft as well as trucks, ships, or submarines. Land- and sea-based cruise missiles usually use a small rocket booster to accelerate them to flying speed. Cruise missiles usually fly preplanned missions specifically designed to defeat defenses by means of terrain masking or defense avoidance, and increasingly by use of stealth technology. Most cruise missiles contain a sensor system that guides them towards their targets by using terrain features or target signatures. Cruise missiles increasingly use inertial navigation systems, updated by satellite navigation receivers in addition to, or instead of, terrain-aided navigation systems to guide them to the vicinity of the target. Once there a terminal sensor is activated to home in on the target. Various types of sensors are used to detect distinctive target signatures or to match preprogrammed scenes of the target area. Once at the target, the cruise missile either detonates the warhead or, if so equipped, dispenses submunitions.

Typical Missile-Related Uses: UAVs are most typically used as reconnaissance platforms and thus carry electronic, video, or photographic payloads to gather or monitor data over unfriendly territory. They are designed to optimize time on station, which, for some systems, can be more than 24 hours. Because of their long range, flexible payload, ease of acquisition, and reasonable cost, UAVs are potential delivery vehicles for weapons. UAVs are also used as target drones, platforms for agricultural monitoring and spraying, scientific data gathering, relaying communications, or electronic warfare. UAVs are becoming more popular for monitoring borders and natural or manmade disasters. Cruise missiles typically deliver weapons payloads weighing 200 to 500 kg to a distance of between 300 and 5,000 km.

Other Uses: N / A.

Appearance (as manufactured): UAVs, including target and reconnaissance drones, often look like airplanes without cockpits for pilots. They vary in appearance because their role-specific designs differ, but many have prominent wings and complex antennae, windows, or domes on the body. Although some UAVs are large enough to have human pilots, most are somewhat smaller. Cruise missiles are UAVs designed or modified for use as weapon delivery systems. Reconnaissance drones usually have long slender wings suited for extended missions at medium-to-high altitude, or they can look more like missiles. An example of the former type is shown in Figure 1-6; notice that it is as large as a manned fighter. Figure 1-7 depicts a jet powered UAV used for reconnaissance missions, sitting on its launcher.

Cruise missiles usually have a cylindrical or box-like cross-section and a fineness ratio (ratio of length to diameter) between 8 to 1 and 10 to 1. They all have a lifting surface, or wings, and most use control fins at the tail (some have ailerons on the wings and / or canards), although the shape and size of these surfaces depends greatly on the intended flight regime and payload. Most of these features of a typical cruise missile are shown in Figure 1-8. Most cruise missiles have a dull finish or coating to make them harder to detect, and ad-

Photo Credit: Teledyne Ryan Aeronautical

Figure 1-6: A large Category I UAV.

Figure 1-7: A jet powered reconnaissance UAV sitting on its launcher.

Figure 1-8:
A land attack cruise missile in flight showing its entire control surfaces and engine inlet.

vanced designs have unique geometric surfaces to reduce radar reflections. These features are shown in Figure 1-9. See Figure 1-10 pullout diagram for an exploded view of a UAV.

Appearance (as packaged): UAVs, including cruise missiles, typically are manufactured in components or sections at different locations and assembled at a military site or a civilian production facility. These sections may vary in size from less than 10 kg and 0.03 cubic meters to 150 kg and 0.1 to 1 m^3. The smaller sections can be shipped in heavy cardboard containers; medium-size sections require heavy wooden crates. However, most modern cruise missiles are shipped fully assembled in environmentally sealed metal canisters, which can also serve as launching tubes. Their wings are folded either within or on top of the missile body, and the tail fins are often folded on longitudinal hinges in order to fit within the launch canister and open after launch to control the missile. The wings of large UAVs are detached from the fuselage, and each section is crated separately for shipping by truck, rail, or cargo aircraft.

Figure 1-9:
An operational cruise missile on its checkout stand showing its nose cone modified to lower radar returns and enhance aerodynamic performance.

Additional Information: A Category I UAV can be as large as an airplane, as shown in Figure 1-6. In fact, any airplane with the necessary range-payload capability can serve as a UAV if outfitted with the appropriate guidance package or remote piloting equipment.

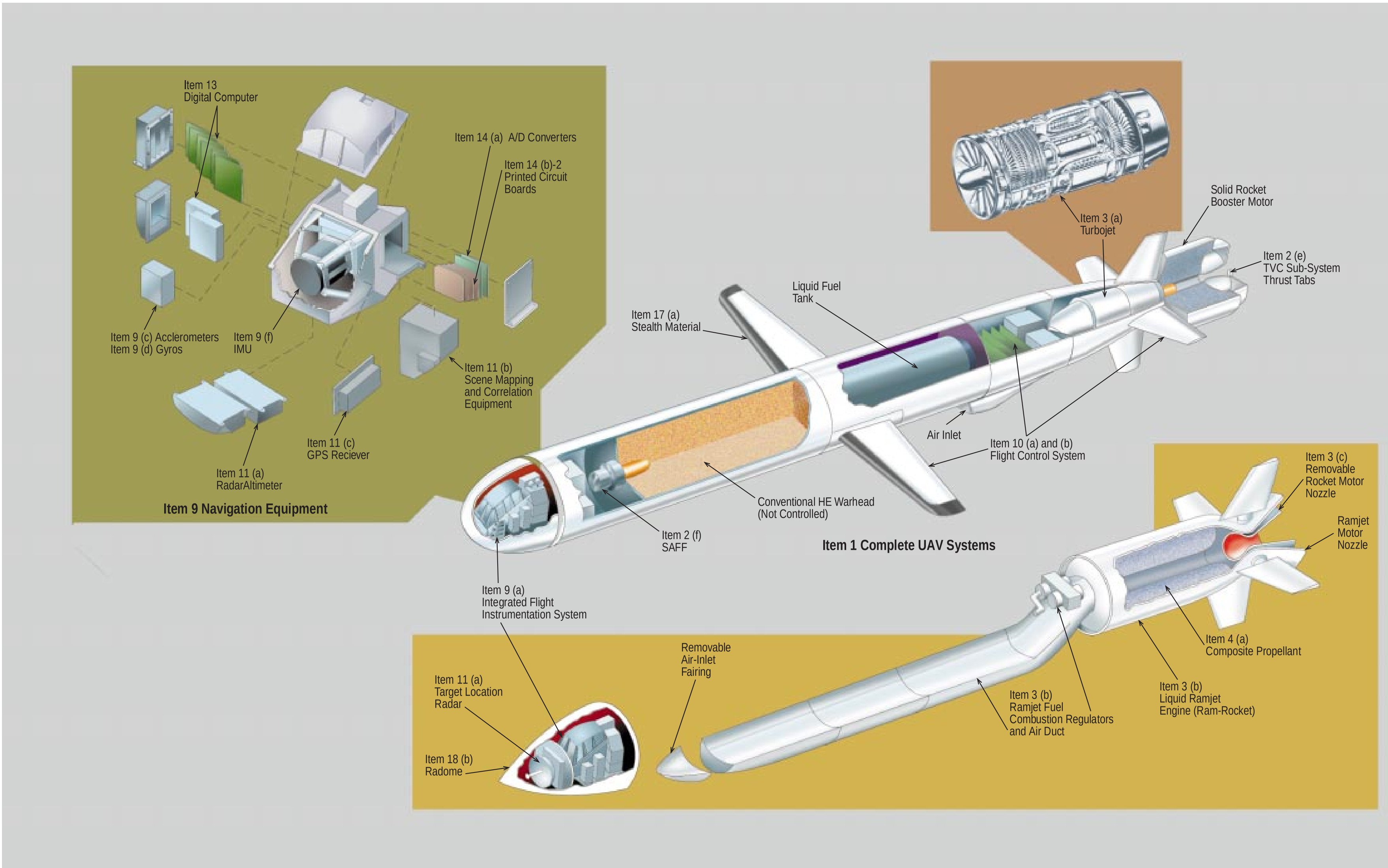


Figure 1-10: Exploded view of MTCR Annex items used in a notional cruise missile (UAV).

Specially Designed Production Facilities and Equipment for the Systems in Item I

Nature and Purpose: Specially designed production facilities include all the special equipment used for the production of complete rocket systems and UAVs. There are many different kinds of specially designed production equipment for such missiles which, when integrated into installations, are considered production facilities. Some of the largest, most important, and most distinctive such equipment are the jigs and fixtures used to ensure proper alignment of individual missile components during assembly of missiles.

Method of Operation: Jigs and fixtures are used to receive, support, align, and assemble individual missile components such as fuel and oxidizer tanks, motor cases, and engine assemblies. Overhead cranes are used to move the missile components from their shipping containers and dollies onto the assembly jig. Laser alignment instruments are sometimes built into fixtures in order to ensure precision fitting, and electrical and electronic test equipment for functional and operational testing are used as necessary during the assembly process.

Typical Missile-Related Uses: Production facilities are used to assemble a complete missile system from its subassemblies and component parts. At the end of each production step, mechanical and electrical fit and function tests are performed to verify that the assembly is ready for the next step. After the missile is assembled and passes all production tests, it is disassembled at prescribed body break points. These separated missile components are loaded into individual containers or crates for shipment to a facility for long-term storage or to the operational launch point for final reassembly and use. However, cruise missiles are typically shipped fully assembled to operational units (depending on the type of launch platform) or for long-term storage.

Other Uses: Assembly jigs and fixtures are usually single-application items designed to produce one type of rocket system or UAV. It is usually not practical to modify them for other uses.

Appearance (as manufactured): Assembly jigs and fixtures used in the production of rocket systems are usually large and heavy structures. Their overall length and width are roughly 20 to 30 percent larger than the missile system that they are designed to assemble. Their weight may total hundreds or even thousands of pounds as shown in Figures 1-11, 1-12, and 1-13.

Appearance (as packaged): Assembly jigs and fixtures for large missiles are often too large and heavy to be packaged and shipped to the production plant as complete units. Instead, component parts are shipped separately in large crates or protected on pallets for assembly onsite. They will be securely fastened to the crate to forestall any movement. Smaller jigs may be individually crated or palletized for shipment.

Figure 1-11:
Solid rocket motor assembly jig for an ICBM.

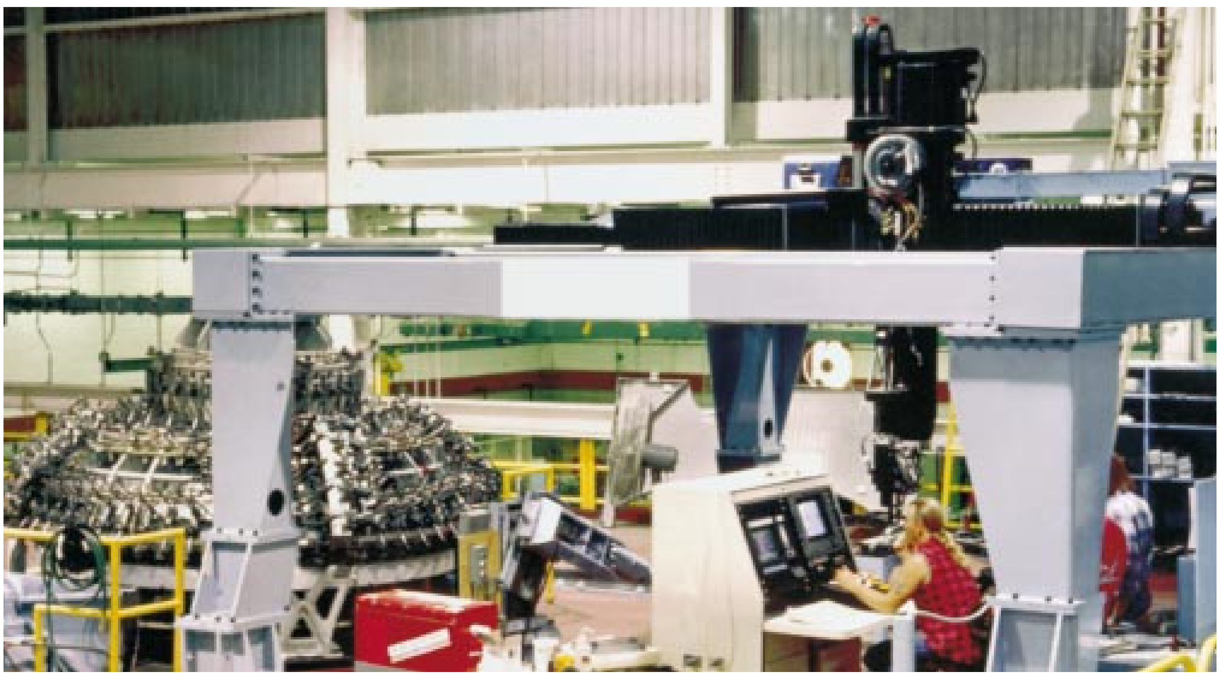


Photo Credit: Sciaky, Inc.

Figure 1-12:
On the left, a very precise hydraulically adjustable welding fixture for a liquid propellant tank end dome; its seven-axis gantry robot welder is on the right.

Additional Information: Assembly jigs and fixtures built to receive and assemble missile components in a horizontal attitude require contoured surface pads or rollers to support the cylindrical body parts with minimal deformation. Rocket assembly systems, which build the rocket in a vertical attitude, require fewer body support fixtures but must allow a high overhead clearance within the building to stack the components and move a fully assembled missile. The primary components of assembly jigs and fixtures are standard structural steel members. Their size and strength are dictated by the requirement to support and maintain alignment of the large and heavy missile components during missile assembly.

Jigs and fixtures are usually assembled by welding or bolting large steel plates and I-beams or tubular members together on the floor of the missile assembly building. In some cases, these fixtures are built on floating pads, not bolted to the floor; such pads isolate the structure from vibration, which might otherwise cause misalignment of their precision reference points. Precision survey devices are used to ensure correct alignment.

Figure 1-13: Modular jig supporting a cruise missile in final assembly.

ITEM 2
Complete Subsystems

Complete Subsystems

Complete subsystems usable in the systems in Item 1, as follows, as well as the specially designed "production facilities" and "production equipment" therefor:
(a) Individual rocket stages;

Produced by companies in

- Brazil
- China
- Egypt
- France
- Germany
- India
- Iran
- Iraq
- Israel
- Italy
- Japan
- Libya
- North Korea
- Pakistan
- Russia
- South Korea
- Syria
- Ukraine
- United Kingdom
- United States

Nature and Purpose: A rocket stage generally consists of structure, engine / motor, propellant, and some elements of a control system. Rocket engines or motors produce propulsive thrust to make the rocket fly by using either solid propellants, which burn to exhaustion once ignited, or liquid propellants burned in a combustion chamber fed by pressure tanks or pumps.

Method of Operation: A launch signal either fires an igniter in the solid propellant inside the lowermost (first stage) rocket motor, or tank pressure or a pump forces liquid propellants into the combustion chamber of a rocket engine where they react. Expanding, high-temperature gases escape at high speeds through a nozzle at the rear of the rocket stage. The momentum of the exhausting gases provides the thrust for the missile. Multistage rocket systems discard the lower stages as they burn up their propellant and progressively lose weight, thereby achieving greater range than comparably sized, single-stage rocket systems.

Typical Missile-Related Uses: Rocket stages are necessary components of any rocket system. Rocket stages also are used in missile and missile-component testing applications.

Other Uses: N / A

Appearance (as manufactured): Solid propellant rocket motor stages are cylinders usually ranging from 4 to 10 m in length and 0.5 to 4 m in diameter, and capped at each end with hemispherical domes as shown in Figure 2-1. The forward dome usually has a threaded or capped opening for inserting an igniter; the rear dome has an attached conical-shaped nozzle or nozzles. The cylinders generally are made of high-strength sheet steel, a composite of filament-wound fiber in a resin matrix, or a combination of both, and either may be cov-

Photo Credit: Chemical Propulsion Information Agency

Figure 2-1: A completed stage for a solid propellant missile.

Figure 2-2: The first stage of a liquid-fueled ICBM.

Photo Credit: Thiokol Corp.

Figure 2-3: A large solid rocket stage being lifted onto its trailer for shipment.

Photo Credit: Zeppelin Technologie GmbH

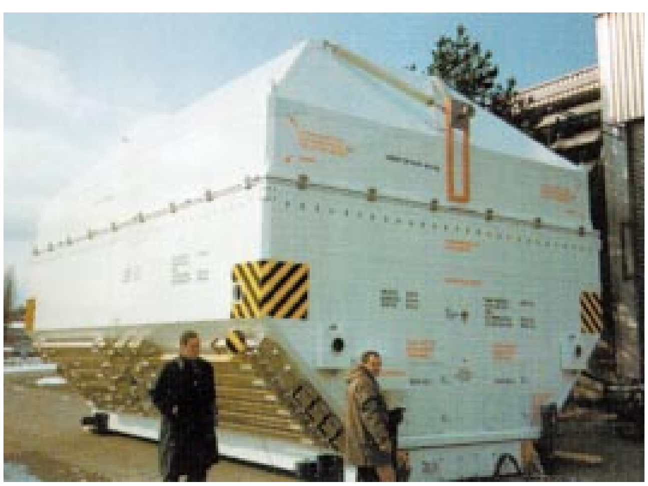


Figure 2-4: Shipping container for a liquid-fuel upper stage.

ered by an insulating material such as cork or rubber sheet. Because these stages are nearly completely filled with high-density, rubber-like propellant, they may weigh 1,600 kg per cubic meter of stage volume.

Liquid propellant rocket engine stages are cylindrical and capped at one end with a hemispherical dome. Most of the space in a liquid stage is filled by propellant tanks, pressure tanks, and pipes and valves connecting the tanks to the engine. The engine itself is mounted in the rear of the stage and occupies only 10 to 15 percent of the overall stage length as shown in Figure 2-2. A conical-shaped nozzle or nozzles are attached to the rear of the stage at the outlet of the combustion chamber. Liquid propellant rocket engine stages are usually made of relatively thin metallic sheets, with internal rings to provide stiffness. Because these stages are empty when shipped, they may weigh as little as 240 to 320 kg per cubic meter of stage volume.

Appearance (as packaged): Virtually all rocket stages are shipped in containers or fixtures specifically designed for them. Smaller solid propellant rocket stages can be shipped in wooden crates with internal restraints and shock mounts. Larger solid propellant stages are more often shipped in specially designed metallic containers, usually cylindrical in appearance and sometimes filled with an inert atmosphere. Very large stages may be simply wrapped with a protective covering as shown in Figure 2-3. Solid propellant stages are supposed to comply with international shipping requirements for explosives and have appropriate markings.

Liquid rocket stages are shipped in the same manner as solid propellant stages or in specially designed fixtures without external packaging as shown in Figure 2-4. Because they are shipped without propellant or pyrotechnics, they may be transported as routine hardware without any constraints or warning labels, and weigh significantly less than solid rocket stages.

(b) Reentry vehicles, and equipment designed or modified therefor, as follows, except as provided in Note (1) below for those designed for non-weapon payloads:

(1) Heat shields and components thereof fabricated of ceramic or ablative materials;

(2) Heat sinks and components thereof fabricated of light-weight, high heat capacity materials;

(3) Electronic equipment specially designed for reentry vehicles;

Note to Item 2:

(1) The exceptions in (b) . . . above may be treated as Category II if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above.

Produced by companies in

- China
- France
- Germany
- India
- Israel
- North Korea
- Russia
- United Kingdom
- United States

Reentry Vehicles

Nature and Purpose: Reentry vehicles (RVs) are sharp- to blunt-tipped, conical-shaped bodies that house and protect the missile payload, or warhead, from the high heat and vibration experienced during reentry. RVs also carry the arming and fuzing equipment to cause the warhead to detonate only when it reaches the target. After booster burnout, the RVs are released from the payload section of the missile, and they fall to earth in a ballistic trajectory and enter the atmosphere at speeds between Mach 2 and 20, depending on range. Some RVs, known as maueuvering reentry vehicles or MARVs, also carry guidance and control equipment that allows them to maneuver to either home in on targets or avoid defenses.

Method of Operation: A missile may carry one or more RVs in its forward, or payload, section. If the missile carries two or more RVs, it usually is covered with a conic or ogival shroud or nose faring that covers the entire payload section at the top of the missile. After motor burnout, the shroud or faring is removed, and the platform, or bus, carrying the RVs may sequentially orient each RV and release it. Reoriented RVs are usually spun up, or rotated, about their longitudinal axis so they reenter the atmosphere in a gyroscopically stable, nosetip-forward attitude and thereby have greater target accuracy. Non-oriented RVs tumble on their trajectories until aerodynamic forces during reentry stabilize them with their nosetips forward. The conic surface of the nose tip and RV usually is covered with heat shield material to withstand the high heat of reentry.

A MARV using terminal guidance may implement a maneuver as it reenters the atmosphere to decrease its speed, and then orient itself to bring a sensor to bear on the target. MARVs may use control surfaces, change their

Photo Credit: National Atomic Museum

Figure 2-5: A very large, older technology RV.

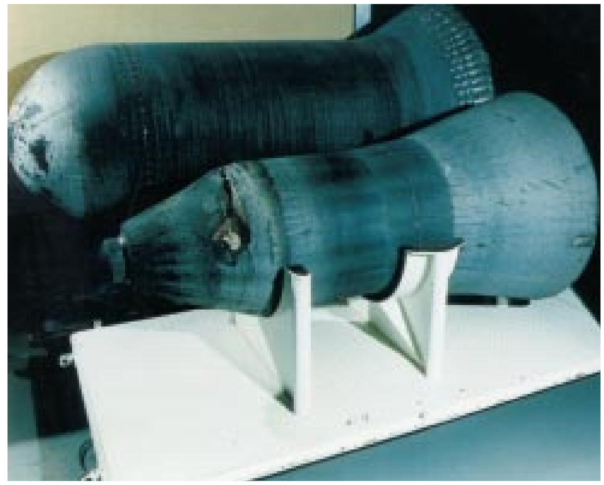


Figure 2-6: Examples of older technology RVs that have been flown.

Photo Credit: National Atomic Museum

Figure 2-7: A modern RV on its payload support bulkhead.

aerodynamic shape, change their weight distribution, or use reaction jets to improve accuracy or turn in ways unpredictable to the defense.

Typical Missile-Related Uses: The principal function of an RV is to achieve accuracy and provide thermal and structural protection to the weapon and the weapon fusing and firing system during reentry. Certain RV-like configurations have been used for the return of manned space vehicles and atmospheric penetration on other planets, but these have not been designed for the accuracies or reentry conditions typically required of a weapon system.

Other Uses: RV structures intended for weapons have few nonmilitary applications. Some RV components have commercial applications, most notably heat-shield materials used in furnaces, steelmaking, and engines.

Appearance (as manufactured): Typical RVs are conical-shaped structures (some with several cone angles), usually with a hemispherically rounded nose tip. The base, or rear, of the vehicle may be hemispherical or blunt. Small fins for aerodynamic stability may be attached at several locations at the rear of the conical surface. The conic surface is covered with a heat shield, which may be naturally colored (black for carbon-based heat shields, tan or yellow for silica-based shields) or may be painted. Older technology RVs using different design approaches are shown in Figures 2-5 and 2-6. Higher technology RVs are usually long, thin cones with sharp nosetips. They may have small ceramic inserts that serve as antenna windows at several locations on the conical surface. A modern, high technology RV is shown in Figure 2-7. Another design approach is

Figure 2-8: Three modern RVs attached to their mounting flange. The small fins at the aft end spin-stabilize the RV as it reenters the atmosphere.

Photo Credit: National Atomic Museum

Figure 2-9: Modern RV mid-sections during manufacture.

shown in Figure 2-8, which clusters three RVs together. This approach does not use a shroud for protecting the RVs during ascent.

RVs intended for multiple-warhead missiles are usually less than 3 m long and less than 1 m in base diameter. RVs used on missiles carrying a single weapon often have diameters equal to that of the uppermost stage, and typically have lengths between 1 to 4 m. RVs, including the weapons they contain, typically range in weight from slightly less than 100 kg to roughly 1,000 kg (with a few historical examples of several thousand kilograms).

The RV structure is usually manufactured in several sections for ease of weapon installation and field maintenance. The forward-most section typically contains some or all of the fusing electronics, the middle section carries the weapon, and the aft section commonly contains timers, additional arming system electronics, and the spin system for those RVs that are spun up after their release from the booster. Several modern RV mid-sections during manufacture are shown in Figure 2-9.

Appearance (as packaged): The RV sections are usually transported together in special containers, either wood or steel, not much larger than the RV itself. They are shock-isolated and supported at several locations inside the shipping container, which may be environmentally controlled. In the field RVs receive special handling because they contain weapons. It is almost always transported separately from the booster and mated to the booster only at the launch site.

Produced by companies in

- China
- France
- Germany
- India
- Israel
- Russia
- United Kingdom
- United States

Heat Shields and Heat Sinks

Nature and Purpose: Heat shields and heat sinks are form-fitting, protective overlays on RVs. Their primary purpose is to protect the RV payload from destruction by the high temperatures caused by air friction as the RV reenters the atmosphere.

Method of Operation: Heat shields protect the RV and its payload by ablation or insulation. In the case of ablation, the heat shield absorbs the heat, which in turn causes its surface to decompose or vaporize and thereby transfer that heat to the airflow. This process keeps the underlying layers cool until they in turn are exposed to the high temperatures. Heat sinks simply absorb the heat of reentry and thereby decrease heat flow to the payload.

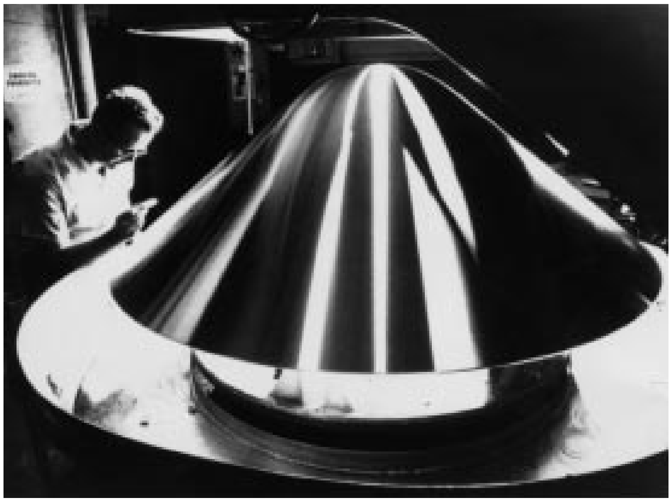


Photo Credit: National Atomic Museum

Figure 2-10: Beryllium-copper heat sink.

Photo Credit: National Atomic Museum

Figure 2-11: Another view of a beryllium-copper heat sink.

Typical Missile-Related Uses: Heat shields or heat sinks provide an external protective coating for RVs and may serve as the aeroshell. Their composition and thickness are a function of the reentry velocity, itself a function of the operational range of the ballistic missile. For ranges less than approximately 1,000 km, simple steel skins can serve as heat sinks. For ranges greater than 1,000 km, composite heat shields or massive heat sinks are required.

Other Uses: Heat shields and components are used in furnaces and engines. The equipment used to make them can be used to make composite tubing for oil drilling. Heat sinks and related technology have many commercial applications, including power production and electronics. There are no commercial uses for heat shields or heat sinks designed to fit RVs. Carbon-based material suitable for heat shields also is used to line engine nozzles and in the manufacture of disc brakes.

Appearance (as manufactured): Heat shields and heat sinks usually have the same size and shape as their underlying RVs; the preceding pictures of RVs indicate what heat shields look like. Two views of a heat sink from a large RV are shown in Figures 2-10 and 2-11. In a few cases, they cover only the forward portion of the RV nose cone. Sizes range from 1 to 3 m in length and less than 1 m in diameter. Shields are generally conical or ogival, with pointed or rounded noses. They are either bonded to the RV or slipped over it in order to achieve a close fit. Their surfaces sometimes display body joints and may have antenna windows installed in them at one or more locations. These windows permit radar or other radiowave transmissions to occur during reentry.

Appearance (as packaged): Heat shields, heat sinks, and their components are small enough to be packaged in conventional shipping boxes or crates for protection from damage. If the heat shields or heat sinks are bonded to the RV, the packaging must support the full weight of the RV in order to protect the entire payload from shock and vibration as well as to protect the surface of the heat shield from damage in shipping.

Additional Information:

Physical Properties: Heat shields and heat sinks are designed to withstand the high temperatures encountered during RV reentry. Heat shields are sometimes composite materials made of resin or ceramic matrices with a fiber reinforcement. The fiber is either white (ceramic or fiberglass) or black (carbon), most commonly in a layered structure. Heat sinks are either metal or highly conductive graphite fiber composites that absorb and transfer the heat to cooler portions of the RV.

Design Features: Heat shields made of filamentary composites are usually tape-wrapped by machine. Less often, they are laid-up by hand, ply-by-ply, with broadgoods (fabric sheets) cut to a prescribed ply-pattern design or even die molded. Tape and lay-up reinforcements permit the orientation of the fibers to improve ablation.

Antenna windows may be bulk ceramic materials or ceramic matrix / ceramic fiber composites and cover either single holes or an array of multiple holes through the heat shield. Ceramic matrix / ceramic fiber composites have a patterned surface resulting from textile reinforcement, which makes them more resistant to thermal shock.

Electronic Equipment Specially Designed for Reentry Vehicles

Nature and Purpose: RVs contain various kinds of electronics. They must have a system to safe, arm, fuse, and fire the warhead (the SAFF system). They may also have radars, telemetry equipment, sensors, guidance systems, computers, and defensive systems such as radar jammers and chaff dispensers. RV electronics are characterized by their relatively small size and their ability to withstand the high temperature, high acceleration, and strong vibration encountered during atmospheric reentry. In addition, RVs for nuclear warheads use electromagnetic pulse protected circuits and radiation hardened microcircuits as described in Items 11(e) and 18(a) respectively.

Produced by companies in

- China
- France
- India
- Israel
- Russia
- United Kingdom
- United States

Figure 2-12: A portion of RV radar electronics.

Method of Operation: The many different types of RV electronic equipment operate much the same as any corresponding avionics equipment; however, a battery usually supplies power for the RV electronic equipment. A power supply converts the battery voltage to whatever is required by the various electronics within the RV. Additionally, all the electronic equipment onboard the RV must be designed to operate reliably in the environments described above.

Typical Missile-Related Uses: Virtually all the electronic components in RVs are specifically designed for them. The most important RV electronic components are those of the SAFF system; their functions are described in Item 2(f). Other electronic equipment is optional and depends on mission requirements. Cables and connections are ordinary but necessary accessories. RVs designed to operate in the hostile X-ray and neutron environments created by nuclear defenses must use highly protected electronic components and cabling, which is clearly identified in its product specifications as capable of operation in such hostile environments.

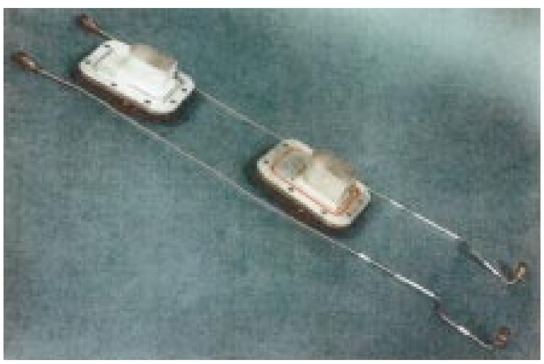


Figure 2-13: An RV radar antenna set.

Other Uses: Barometric switches, power conditioners, and relays are used in general aviation. Standard cabling and connectors (not nuclear hardened) are common to thousands of commercial end uses. In general, distinguishing commercial electronic equipment from equipment specially designed for RVs is difficult because the biggest differences—nuclear hardening, temperature operating limits, and vibration requirements—are not usually visible.

Appearance (as manufactured): The usual components of an RV electronics package are unremarkable in appearance. The largest and most distinctive part is probably the battery, which may be roughly half the size of an automobile battery but is often considerably smaller. Most of the remaining electronic components are small and are usually housed in aluminum boxes. The SAFF system is assembled by the RV manufacturer and is unlikely to be obtained as a prepackaged unit. Very advanced RV designs can use active / passive seekers (radar and optical sensors) coupled to active control systems and stored maps of target features. Figure 2-12 shows some radar electronics. Such equipment may have a disk, conical, or truncated-cone appearance because it is designed to fit tightly into an RV. Any indication of special capabilities to withstand high acceleration or severe vibration may suggest a missile application. An RV radar antenna set is shown in Figure 2-13. An RV radar set in its shipping container is shown in Figure 2-14.

Figure 2-14: An RV radar antenna set packaged for shipment.

Appearance (as packaged): Packaging used is typical for military-grade electronic parts. Sealed bags or containers are used to protect the electronics from moisture and shock. Foam-lined boxes, crates, or metal suitcases may be used for packaging.

(c) Solid or liquid propellant rocket engines, having a total impulse capacity of 1.1×10^6 N-sec (2.5×10^5 lb-sec) or greater;

Note to Item 2:

(5) Liquid propellant apogee engines specified in Item 2(c), designed or modified for satellite applications, may be treated as Category II, if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above, when having all of the following parameters:
(a) Nozzle throat diameter of 20 mm or less, and
(b) Combustion chamber pressure of 15 bar or less.

Produced by companies in

- Brazil
- China
- Egypt
- France
- Germany
- India
- Iran
- Israel
- Italy
- Japan
- Norway
- Pakistan
- Russia
- South Korea
- Sweden
- Ukraine
- United Kingdom
- United States

Solid Propellant Rocket Motors

Nature and Purpose: Solid propellant rocket motors contain both the fuel and the oxidizer inside a single motor casing. No tanks, pipes, pumps, or valves are needed because the fuel and oxidizer are premixed in the proper ratio and cast into a hollow solid form, which is ignited on the inside. The outer casing of the rocket motor often serves as the form in which the propellant is cast. The casing acts as a pressure vessel that keeps combustion gases confined during operation, and is the main structural member that transmits the thrust to the payload. Solid rocket motors are cost effective and low maintenance; they are easily stored, can be stored for many years, and are capable of rapid deployment and launch.

Method of Operation: Once ignited, the propellant burns inside a hollow chamber running down the center of the motor; the hot expanding gases rush out the nozzle end at very high speed and thereby provide thrust. The propellant burns until it is exhausted and thrust terminates. Some motors terminate thrust by opening holes in the motor casing and venting the gases out the sides or through the top.

Typical Missile-Related Uses: Rocket motors provide the thrust to accelerate missiles to the velocity required to reach the intended target. This requisite thrust can be achieved by one large rocket motor or by clusters or multiple stages of smaller motors.

Other Uses: N/A

Appearance (as manufactured): Solid rocket motors are cylindrical tubes with spherical or elliptical domes at both ends. One dome could have a small hole for attaching the igniter; the other dome could have a larger hole

Photo Credit: Alliant TechSystems, Inc.

Figure 2-15: A solid rocket motor with an advanced, extendable nozzle skirt.

Figure 2-16: Solid rocket motors with total impulse close to the lower limit of Item 2 control.

for attaching the nozzle. The igniter may or may not be installed before shipment; if not, the hole is covered by a plate made of steel or other material. The nozzle is usually attached before shipment, with an environmental plug to protect the propellant from humidity and other environmental effects. This plug hides the solid propellant grain within the case from view. When installed, both the igniter and the nozzle are usually bolted in place. A modern solid rocket motor with an advanced extendable nozzle is shown in Figure 2-15. Given current solid propellant technology, approximately 450 kg of propellant is required to deliver the MTCR Item 2 (c) threshold impulse of 1.1×10^6 N-sec. A typical rocket motor containing this amount of propellant would be approximately 4 m in length and 0.5 m in diameter. A rocket motor of this size would usually have a steel case, although composite cases made of glass, carbon, or Kevlar fiber are possible. A solid rocket motor close to this lower limit is shown in Figure 2-16; these particular motors have a total impulse of 1.2×10^6 N-sec.

Appearance (as packaged): Solid rocket motors are usually shipped in steel or aluminum containers or wooden crates. Crates have cradles at several points to support the weight of the motor and are usually lined with foam or cushioning material to protect the motor during shipment. A shipping crate for a solid rocket motor is shown in Figure 2-17. Rocket motors are sometimes packaged in an inert atmosphere to keep the propellant protected from moisture. These containers are typically hermetically sealed, pressurized, and made of aluminum. Temperature storage limits are stated to ensure longevity of the motors. Solid rocket motors have a thick, usually braided, metal strap with clamps at either end leading from somewhere on the motor case to the local electrical ground. This strap discharges any static electricity buildup and helps avoid fires and explosions. When shipped, the motor is grounded to the shipping container, and the container is grounded to the local ground.

Figure 2-17: Wooden shipping crates for a small solid rocket motor at the lower limit of Item 2 control.

Liquid Propellant Rocket Engines

Nature and Purpose: Liquid propellant rocket engines burn fuel and oxidizer, which is fed to them from tanks in the proper ratio by pipes, valves, and sometimes pumps. Thus, these engines are much more complex than solid propellant motors and can contain many precision-machined and moving parts. Unlike solid rocket motors, some liquid rocket engines can be shut off and restarted, and some can be reused after refurbishment. Liquid rocket engines are typically more thrust-efficient than solid rocket motors and are usually preferred for non-military missions. But they are difficult to manufacture, require more maintenance, and take longer to prepare for launch than solid rocket motors. Fuel and oxidizer can also be difficult to handle and store because they are toxic, corrosive, or cryogenic.

Method of Operation: Once a fire command is given, fuel and oxidizer tanks are pressurized; if a pump is used, it is started. Fuel and oxidizer are forced into the injector head, where they are atomized by passing through small injectors, and mixed in the combustion chamber. Upon ignition, the hot, expanding gases rush out the nozzle at very high velocity and thereby give the missile thrust. The thrust loads are transmitted through the combustion chamber to struts, which attach to the missile body at the rear end of a fuel or oxidizer tank.

Typical Missile-Related Uses: Rocket engines provide thrust to accelerate missiles to the velocity required to reach the intended target. This requisite thrust can be achieved by one large rocket engine or by clusters or multiple stages of smaller engines.

Other Uses: N/A.

Appearance (as manufactured): Liquid rocket engines are characterized by a cylindrical or spherical combustion chamber to which a converging/diverging nozzle is attached. The nozzle is usually larger than the rest of the engine. Nozzles cooled by propellants may have sheet metal walls held apart by a corrugated sheet metal, or be composed of a bundle of contoured metal tubes as shown in Figure 2-18. Uncooled nozzles are made of a refractory metal or an ablative composite material. The injector, a flat or curved plate with a large number of individual holes, is attached to the top of the combustion chamber, as shown in Figure 2-19. A number of pipes,

Photo Credit: Aerojet

Figure 2-18: Combustion chamber and nozzle throat of a liquid propellant engine.

Photo Credit: Aerojet

Figure 2-19: The dome of an injector head (top picture) and its underside showing the injectors and baffles.

Produced by companies in

- China
- France
- India
- Iraq
- Japan
- Libya
- North Korea
- Russia
- Ukraine
- United Kingdom
- United States

Figure 2-20: A World War II vintage V-2 liquid rocket engine.

tubes, and pumps are attached to the top and sides of the combustion chamber, as shown in Figure 2-20.

Appearance (as packaged): Liquid rocket engines are rugged devices, but they must be protected from shock and moisture. Typical containers include large wooden crates and metal containers.

(d) "Guidance sets" capable of achieving system accuracy of 3.33 percent or less of the range (e.g. a CEP of 10 km or less at a range of 300 km), except as provided in Note (1) below for those designed for missiles with a range under 300 km or manned aircraft;

Notes to Item 2:

(1) The exceptions in . . . (d) . . . above may be treated as Category II if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above.

(2) CEP (circle of equal probability) is a measure of accuracy; and defined as the radius of the circle centered at the target, at a specific range, in which 50 percent of the payloads impact.

(3) A "guidance set" integrates the process of measuring and computing a vehicle's position and velocity (i.e. navigation) with that of computing and sending commands to the vehicle's flight control systems to correct the trajectory.

Produced by companies in

- Canada
- China
- France
- India
- Israel
- Japan
- North Korea
- Russia
- Ukraine
- United Kingdom
- United States

Nature and Purpose: Guidance sets automatically steer vehicles along a trajectory or flight path. Guidance sets are high quality assemblies of sensitive electronic and mechanical equipment. The heart of any guidance set is the inertial measurement unit (IMU), which contains the gyroscopes and accelerometers that allow the guidance set to sense motion and changes in orientation. Guidance sets can be expensive, with costs ranging from several thousand to several million dollars each; the more accurate, the more expensive.

Method of Operation: Before launch, guidance sets are calibrated and provided information on the vehicle's position, velocity, and orientation. After launch, their gyroscopes and accelerometers, or inertial instruments, sense missile accelerations and rotations, and usually convert them into electrical signals. A computational device converts these signals into deviations from the programmed flight path and issues commands to the missile flight control system to steer it back on course. However, because of errors in the inertial instruments themselves, the missile tends to veer off course over time. Guidance sets that veer off course less than 3.33 percent of range traveled are controlled under this item. Other guidance aids such as a Global

Positioning System (GPS) receiver, terrain reference systems, or gyro-astro compasses can be used to provide one or more mid-course updates on location or orientation to the guidance computer and thereby increase accuracy. (This navigational update equipment is covered in Item 9 of this Annex.)

Figure 2-21: An older technology guidance set, comprised of several components, installed in a missile.

Typical Missile-Related Uses: A guidance set is a common subsystem for any rocket system or unmanned air vehicle (UAV). Ballistic missile guidance sets are usually very specialized pieces of equipment, often built to fit into a particular missile, to endure hostile environments, and to perform with a high degree of accuracy. They are designed to satisfy the stringent size, weight, power, and environmental requirements unique to ballistic missile applications. UAV guidance systems are much less specialized, and they are often supplemented with numerous other sensors and receivers as part of an integrated flight instrumentation system.

Other Uses: Guidance sets and navigation systems of various types are widely used in marine vessels, aircraft, and even some land vehicles.

Figure 2-22: Another view of the older technology, body-mounted guidance set shown in Figure 2-21.

Appearance (as manufactured): The size, weight, and appearance of guidance sets vary with the type of missile because of the structural features of the missile and variations in mission requirements. The size, weight, and appearance also vary with the vintage of design because guidance set technologies have changed significantly over the past 20 to 30 years, from largely mechanical units with stepper motors and cam-type processing to integrated electronic units with software processing. Older designs tend to be larger and heavier (up to 1 m on a side and up to 100 kg); new systems, which are significantly more accurate, may require only 30 cm on a side and weigh a few kilograms. Most sets are enclosed in metallic boxes that have airtight but removable access panels. They are often rectangular, but they can be cylindrical or be comprised of several boxes of various shapes. An older technology approach with multiple distributed components is shown in Figure 2-21; the battery is the light-colored box on the right, and the vertical gyro is in the dark, round-cornered box on the left. The same system from the other side of the missile is shown in Figure 2-22. The light-colored unit on the right is an electrical junction box; the altimeter is the unit on the left without its cover; and the missile destruction system is above the altimeter.

Photo Credit: Sextant Avionique

Figure 2-23: A guidance set using ring laser gyros.

Photo Credit: Litton Guidance and Control Systems

Figure 2-24: A guidance set using hemispheric resonating gyros.

Photo Credit: LFK—Lenkflugkorpersysteme GmbH

Figure 2-25: A guidance set using fiber optic gyros and designed to fit in a small, cylindrical space.

Photo Credit: Honeywell

Figure 2-26: A guidance set comprised of an IMU (on the right) and a separate electronics box.

Guidance sets also have quality electrical connectors, precision-mounting surfaces, and, in some cases, temperature control connections. Some systems have a gimbal-mounted or floated IMU housed in a roughly spherical chamber that bulges out somewhere on the guidance set. Other systems have the IMU separate from the electronics.

Modern strapdown guidance systems are often box-like in appearance. Figures 2-23 and 2-24 show strapdown guidance systems with access panels removed. Some modern strapdown guidance systems deviate from the box-like shape when the application requires the guidance set to fit into a small space. Figure 2-25 shows a strapdown guidance system that is designed to fit into a cylindrical space. A modern guidance set with a separate electronics box is shown in Figure 2-26.

Appearance (as packaged): Guidance sets can be single units or systems comprised of several components and assembled in the missile airframe. Because most guidance sets are very expensive and sensitive to damage from shock, they are shipped in cushioned containers, some of them special and air-tight, to protect them from moisture. These containers usually have labels requesting careful handling. A wide range of container configurations, including special drums, boxes, and metal suitcases, may be used. A shipping container for an ICBM guidance system is shown in Figure 2-27.

Figure 2-27: A shipping container for an ICBM guidance system.

Additional Information: Guidance sets include inertial instruments in the IMU, computational processing—either hardware or software or both—and other miscellaneous electronics and instruments. The IMU, which usually consists of two, three, or four gyroscopes and usually three accelerometers, generally cannot be seen without opening the access panels of the guidance set, but there may be a bulge in the guidance set to accommodate the IMU. Some guidance sets use additional sensor inputs to enhance accuracy, including laser velocity sensors, star-tracking telescopes (gyro-astro compass), horizon sensors, terrain reference systems, or satellite navigation systems such as GPS or GLONASS. Optical devices require a viewing port, which is visible on the outside of the guidance system unless it is covered by a shutter or trapdoor. More information about gyroscopes, accelerometers, gyro-astro compasses, and GPS receivers is available under Items 9 and 11.

(e) Thrust vector control sub-systems, except as provided in Note (1) below for those designed for rocket systems that do not exceed the range / payload capability of Item 1;

Notes to Item 2:

(1) The exceptions in . . . (e) . . . above may be treated as Category II if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above.

(4) Examples of methods of achieving thrust vector control covered by (e) include:
- (a) Flexible nozzle;
- (b) Fluid or secondary gas injection;
- (c) Movable engine or nozzle;
- (d) Deflection of exhaust gas stream (jet vanes or probes); or
- (e) Use of thrust tabs.

Produced by companies in

- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- North Korea
- Russia
- Spain
- Ukraine
- United Kingdom
- United States
- Yugoslavia

Nature and Purpose: Thrust vector control subsystems redirect the axial thrust produced by the hot, expanding gases expelled through the rocket nozzle, and thereby steer the missile.

Method of Operation: There are several different ways of steering a missile. Most operate by redirecting the engine thrust off the missile centerline, which causes the vehicle to turn. Control under this item applies regardless of the specific design or name of the thrust vector control subsystem. Seven different ways of redirecting thrust in a solid propellant missile are shown in Figure 2-28; however, most modern missiles use the flexible nozzle approach. Liquid rocket engines usually redirect thrust by swiveling the entire engine, a process called gimbaling. Both approaches use servo-mechanical actuators attached to the missile frame to push and pull the engine or rocket nozzle into the proper position. Solid and liquid engines also can redirect thrust by deflecting the exhaust gases in the nozzles by means of movable jet vanes or fluid injection. Jet vanes are common on older technology missiles. Fluid injection forces the exhaust flow through the nozzle to deflect thereby causing asymmetric flow and an off-centerline direction of thrust.

Figure 2-28: Seven options for thrust vector control in solid rocket motors.

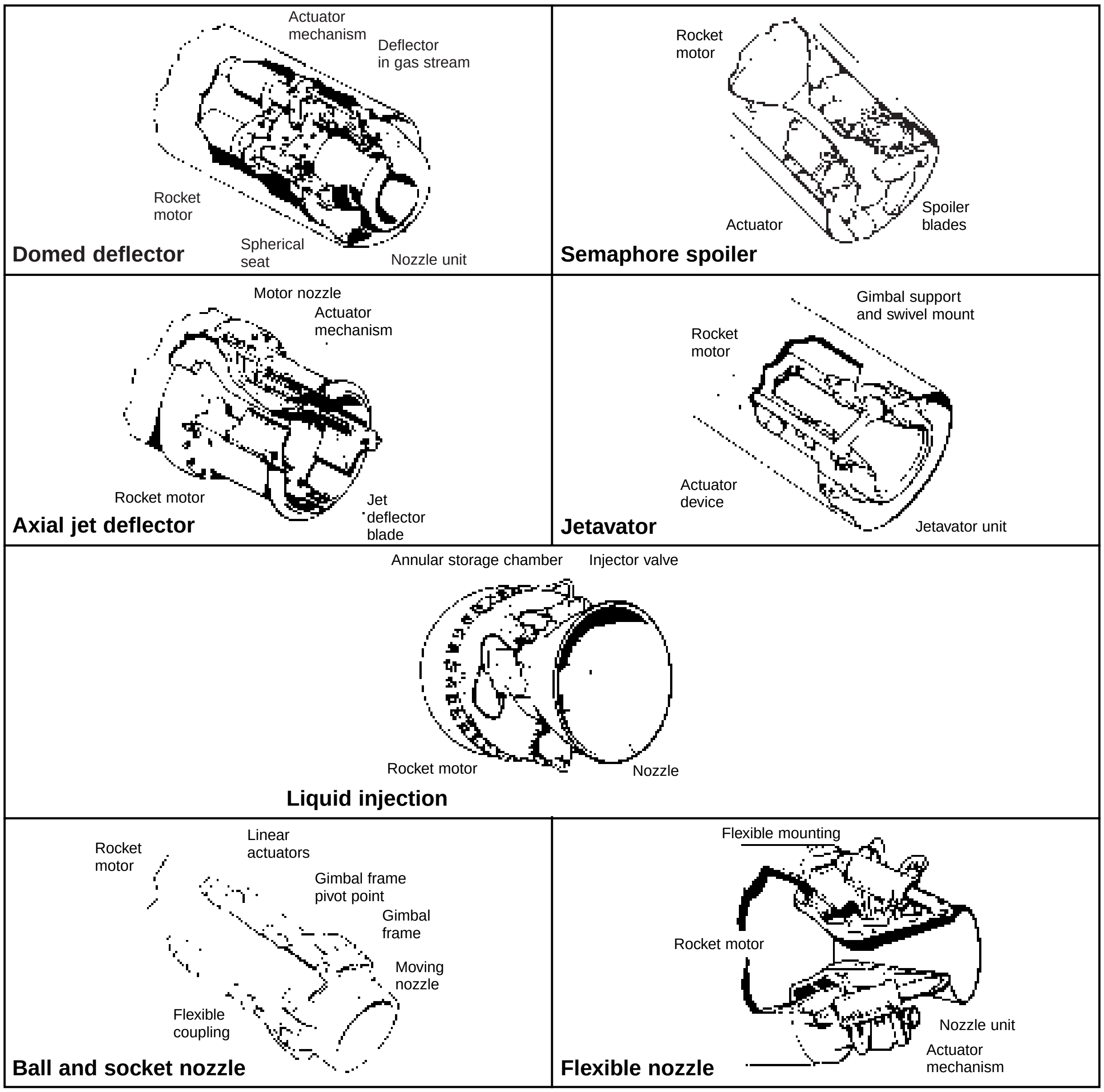


Photo Credit: British Aerospace Defense Limited

Typical Missile-Related Uses: Thrust vector control subsystems change rocket thrust direction to steer the missile in response to commands from the guidance set. They are a required item on virtually any ballistic missile system.

Other Uses: Thrust vector control subsystems are used in advanced fighters, research aircraft, tactical missiles, and spacecraft.

Photo Credit: Moog, Inc.

Figure 2-29: A thrust vector control electronics box for a large liquid rocket engine.

Appearance (as manufactured): Typical thrust vector control assemblies include mounting rings, actuator rods, actuator valves, and hydraulic tubing or pipes. Modern systems also require dedicated control electronics. An example of a thrust vector control electronics box for a large liquid rocket engine is shown in Figure 2-29. A mounting ring for a liquid rocket engine is shown in Figure 2-30. This ring is attached to the throat area of the nozzle and is quite massive so that it can withstand the torque imparted to it under full-thrust conditions. An actuating system is attached to either the mounting ring, the engine itself, or directly to the nozzle.

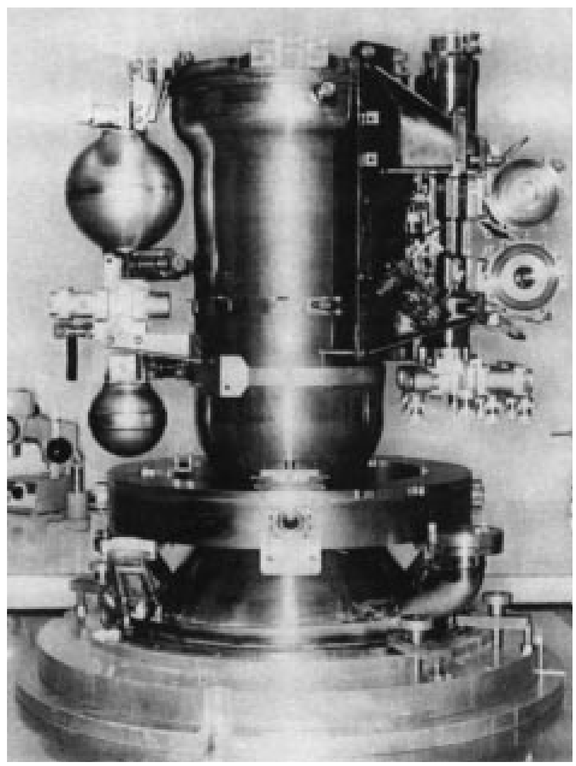


Photo Credit: Aerojet-General Corp.

Figure 2-30: Gimbal ring attached to the throat area of a liquid rocket engine.

Actuator rods are cylindrical, approximately 15 to 45 cm in length and 3 to 8 cm in diameter. They push and pull on the engine or nozzle in response to signals by the guidance system to actuator valves. A gas generator (basically a small solid rocket motor) that powers a small turbopump is one way to pressurize the hydraulic system. Mounting rings and actuator rods are made from high-strength metals such as stainless steel or titanium; actuating valves have stainless steel housings.

The most common way to implement gas or fluid injection thrust vector control is to store the gas or fluid in tanks and then meter its injection into the rocket nozzle through feedlines, valves, sometimes manifolds, and injectors. The tanks are usually cylindrical composite-overwrapped pressure vessels that vary in size and weight. Pressure ratings of 7 MPa (1000 psi) are typical. The gas or liquid feedlines (approximately 1 cm in diameter for smaller engines), control valves, and injectors are often made of stainless steel. Missiles usually use four injectors, sometimes many more. Jet vanes are mounted inside the exhaust nozzle and rotated in response to commands from the missile guidance system to redirect the thrust. They look like small wings usually 30 cm in length and 15 cm in

Figure 2-31: A jet vane for a liquid rocket.

Figure 2-32: Four jet vanes mounted in the aft end of a ballistic missile.

height (sizes vary with engine size). They are made of high-temperature material such as carbon, carbon derivatives, or refractory materials such as tungsten. A jet vane and its actuator are shown in Figure 2-31. Figure 2-32 shows four jet vanes mounted in the aft end of a ballistic missile.

Produced by companies in

For advanced RV fusing systems

- China
- France
- Germany
- India
- Israel
- Russia
- United Kingdom
- United States

Other types of SAFF components, particularly for air vehicles, are commonly available.

Appearance (as packaged): Gimbal rings are usually 15 to 50 cm in diameter and may be shipped as an assembly (double rings) in an appropriately sized aluminum shipping container with a contoured interior. Actuator rods and valves look like commercial rods and valves. Valves are packaged inside plastic bags for protection against abrasive particles. Because these items can be rather heavy, they are shipped secured in robust containers made of metal or wood. Gas or fluid injection tanks are packaged like commercial products such as propane tanks. Injectors and valves are also packaged like any piece of expensive equipment, usually in plastic bags to prevent contamination and in padded containers.

(f) Weapon or warhead safing, arming, fusing, and firing mechanisms, except as provided in Note (1) below for those designed for systems other than those in Item 1.

Notes to Item 2:

(1) The exceptions in . . . (f) above may be treated as Category II if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above.

Nature and Purpose: Weapon or warhead safing, arming, fusing, and firing (SAFF) mechanisms are usually electronic or electro-mechanical devices that keep missile payloads (weapons) safely unarmed until shortly before reaching the target, at which time they fuse and fire the explosives.

Method of Operation: Before launch most SAFF systems ensure that the weapon is safe (unable to detonate) by either mechanically or electrically isolating the weapon from the firing system. After launch, when the payload is away from friendly territory, the SAFF system removes the interlocks and arms the warhead. Arming can occur after a set time from launch or after sensing a preprogrammed trajectory change or certain environmental conditions such as an expected deceleration. Low technology SAFF systems use barometric switches for the safing and arming functions.

The weapon fuse defines when the detonation criteria are met. Common fuses include timers, acceleration sensors, and altitude sensing devices such as barometric switches or active radars. When the payload reaches the predefined criteria, a signal is generated and sent to the firing set. High voltage capacitors are then fired (discharged) and deliver an electric current to the weapon detonators. Payloads can also have crush or contact fuses that sense when payloads strike the targets and begin to break up. These fuses either back up the altitude sensing system or are used for missions requiring target impact. Cruise missiles that dispense submunitions or air burst their weapons fuse and fire when the guidance system determines that the target has been reached. Alternatively, they can use radar or laser altimeters, proximity fuses, and contact fuses. A SAFF system may include some or all of these options for redundancy.

Radar-based fusing systems require a relatively high frequency (S-band or C-band) transmitter and transmissive window materials such as high purity silica to protect the outward-looking antenna from the heat created during reentry. For missile applications, contact fuses are rated between 100 and 500 g. High technology ballistic missile fusing systems using accelerometers require instruments capable of 100 or more g.

Typical Missile-Related Uses: Some form of SAFF system is required on all missile systems to ensure that the weapons are safe until launched and detonate when intended. Because SAFF systems are usually tailored to the internal configuration and function of a specific missile, it is not cost effective to modify them for non-missile applications.

Other Uses: The basic fusing and firing technology involved in a missile SAFF system is used in all munitions items with explosive warheads. Even the more advanced fusing systems, in which the time or altitude of detonation is determined by active radars or integrating accelerometers, are used in advanced artillery shells and submunitions. The firing technology used for missile warheads is used commercially in all activities in which explosives are used, such as road construction, mine excavations, and structures demolition.

Appearance (as manufactured): Components of a missile SAFF system are generally small, aluminum-housed packages with input / output electrical

Photo Credit: Kaman Aerospace Corp.

Figure 2-33: A missile fuse with safety plate and warning label.

Photo Credit: Kaman Aerospace Corp.

Figure 2-34: Another style of missile fuse.

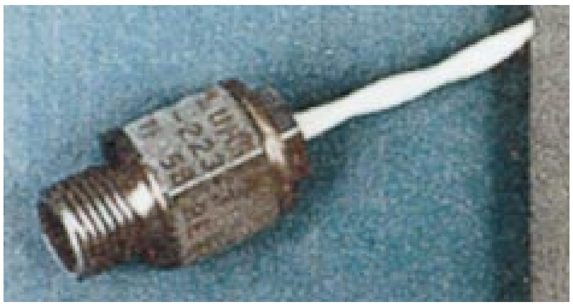


Figure 2-35: A small firing device for an RV that generates a voltage upon impact.

Figure 2-36: An RV SAFF system accelerometer with its associated electronics.

Figure 2-37: An RV launch safety device.

connectors as shown in Figures 2-33, 2-34, and 2-35. Simple fuses are usually housed in aluminum cylinders ranging in diameter from 1 cm for crush fuses to several centimeters for contact fuses. Higher technology fusing systems may involve sophisticated instruments such as accelerometers as shown in Figure 2-36, or active radar transmitters and antennas.

SAFF packages are not obtained as a single unit; instead, they are assembled from individual components and subsystems. Figure 2-37 shows a launch safety device for an RV. Figure 2-38 shows the aft end of an RV with the aft arming and fusing electronics box on the right.

Specially designed production facilities and production equipment for the subsystems in Item 2 resemble aerospace and industrial manufacturing equipment but have attributes specially designed for a given system.

Appearance (as packaged): Like most electronics, SAFF systems are shipped in cushioned containers, some of them special, air-tight containers to protect them from moisture. These containers usually have labels indicating the need for careful handling. A wide range of suitable container configurations, including special drums, boxes, and metal suitcases, may be used. Any of these may in turn be packed in a wooden box with the explosives warning label (when appropriate) as shown in Figure 2-39. Sometimes SAFF devices may be shipped in ordinary cardboard boxes as shown in Figure 2-40.

Figure 2-38: The aft end of an RV with the aft arming and fusing electronics box on the right.

Photo Credit: Kaman Aerospace Corp.

Figure 2-39: A wooden shipping container with explosives warning label.

Figure 2-40: A cardboard box containing missile fuses.

Photo Credit: Kaman Aerospace Corp.

ITEM 3
Propulsion Components and Equipment

Propulsion Components and Equipment

Produced by companies in

- China
- France
- Germany
- India
- Israel
- Japan
- Russia
- South Africa
- Sweden
- United Kingdom
- United States

Propulsion components and equipment usable in the systems in Item 1, as follows, as well as the specially designed "production facilities" and "production equipment" therefor, and flow-forming machines specified in Note (1):

(a) Lightweight turbojet and turbofan engines (including turbocompound engines) that are small and fuel efficient;

Notes to Item 3:

(2) (a) The only engines covered in subitem (a) above, are the following:

(1) Engines having both of the following characteristics:

(a) Maximum thrust value greater than 1000 N (achieved un-installed) excluding civil certified engines with a maximum thrust value greater than 8,890 N (achieved un-installed), and

(b) Specific fuel consumption of 0.13kg / N / hr or less (at sea level static and standard conditions); or

(2) Engines designed or modified for systems in Item 1, regardless of thrust or specific fuel consumption.

(b) Item 3 (a) engines may be exported as part of a manned aircraft or in quantities appropriate for replacement parts for manned aircraft.

Nature and Purpose: The turbojet and turbofan engines of concern are jet engines that can power unmanned air vehicles (UAVs), including cruise missiles, great distances. They are similar in design and operation to the engines that power civilian aircraft, just smaller in size and power. They make long-range cruise missiles operationally practical.

Method of Operation: The gas turbine engine has several subcomponents, including the fan (in the case of a turbofan), compressor, combustion chamber, and turbine. The compressor, which may consist of one or more stages of alternating stationary and rotating airfoil-section blades, draws air in, pressurizes it, and delivers it into the combustion chamber. The combustion chamber is a heat-resistant tube in which air is mixed with vaporized fuel and then ignited. Spark plugs (called ignitors) initiate combustion, which is continuous once ig-

Figure 3-1: A small turbojet engine for a cruise missile on its checkout stand.

Photo Credit: Williams International

Figure 3-2: A small turbofan engine for a cruise missile.

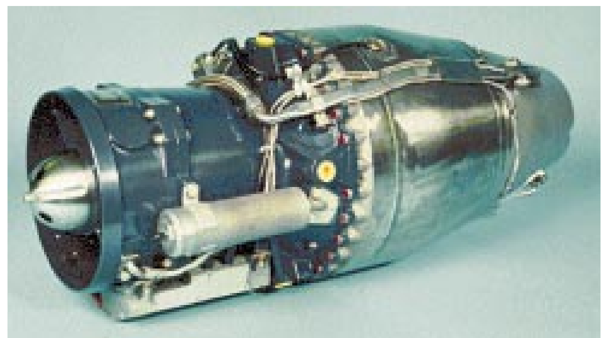


Photo Credit: Teledyne Ryan Aeronautical

Figure 3-3: A small turbojet cruise missile engine.

nition has occurred. The combustion products, or exhaust gases, then pass into the turbine, which consists of one or more stages of alternating stationary and rotating airfoil-section blades. The turbine extracts only enough energy from the gas stream to drive the compressor; the remaining energy provides the thrust. The gas flow then passes into a converging duct, or nozzle, in order to maximize the thrust produced by the engine. In the case of a turbofan, there is a larger diameter multiblade fan stage in front of the compressor.

Typical Missile-Related Uses: These lightweight engines are used to power UAVs, including cruise missiles.

Other Uses: Such engines are generally not uniquely designed for missile purposes and can be used directly in other applications such as aircraft and helicopters. Gas turbine engines are also used in the marine and power-generating industries and in some land vehicles.

Appearance (as manufactured): The basic turbine engine is cylindrical, and those most often used in missiles measure less than 1 m in length and 0.5 m in diameter. Numerous accessories such as an alternator, hydraulic pump, fuel pump, and metering valve, along with associated plumbing and wiring, are visible on the outside of the engine. Small fuel efficient engines typically weigh 30 to 130 kg; such engines are shown in Figures 3-1, 3-2, and 3-3. Engine parts are manufactured from a number of different mate-

Photo Credit: Teledyne Ryan Aeronatuical

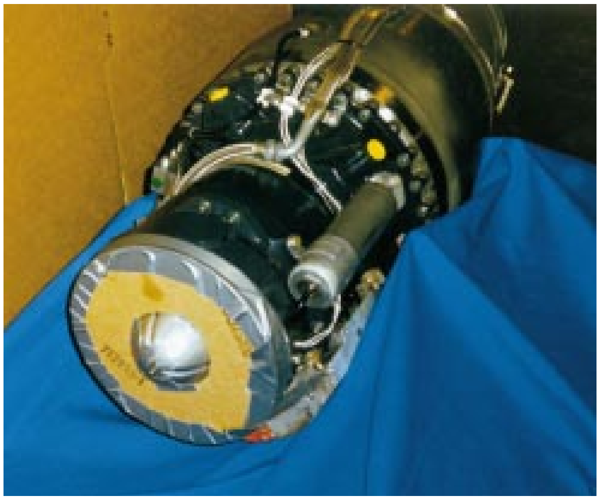


Figure 3-4: A small turbojet engine being prepared for shipment.

Photo Credit: Teledyne Ryan Aeronatuical

Figure 3-5: A small turbofan engine wrapped in plastic inside its shipping crate.

Photo Credit: Teledyne Ryan Aeronatuical

Figure 3-6: A turbojet shipping crate showing the explosive warning labels required because of the starting cartridge.

rials, both metallic and non-metallic in composition. Common metallic materials include aluminum, steel, titanium, and special alloys. Nonmetallic materials such as Teflon, nylon, carbon, and rubber are used for sealing and insulation.

Appearance (as packaged): Engines usually are prepared for shipment in a multi-step process. Covering plates are attached over the engine inlet and exhaust, and secured by adhesive tape, as shown in Figure 3-4. The engine is covered with protective paper, and desiccant bags are taped to the engine wrap. The engine is wrapped in corrugated cardboard, inserted into a polyethylene bag, lowered into the shipping crate, and rested on foam blocks, as shown in Figure 3-5. The box is then filled with foam and sealed. Because cruise missile engines often incorporate self-starting features through the use of pyrotechnic cartridges, when properly packaged their shipping containers usually bear markings indicating the presence of explosives like the orange, diamond-shaped label shown in Figure 3-6.

(b) Ramjet / scramjet / pulsejet / combined cycle engines, including devices to regulate combustion, and specially designed components therefor;

Ramjet/Scramjet/Pulsejet/and Combined Cycle Engines

Nature and Purpose: Ramjet, scramjet, and pulsejet engines are internal combustion reaction jet engines that burn fuel mixed with intake air and expel a jet of hot exhaust gases. Their purpose includes propelling air vehicles,

Produced by companies in

- China
- France
- Germany
- India
- Israel
- Japan
- Russia
- South Africa
- Sweden
- United States

including cruise missiles. Because these engines have very few moving parts (they have no mechanical compressors), they are much simpler and potentially less costly than turbojets. Since ramjets and scramjets can tolerate much higher combustion temperatures than turbojets, they are the only practical option for sustained flight at high supersonic speeds. Combined cycle engines integrate two propulsion systems (e.g., turbojet and ramjet or scramjet) into a single assembly in order to be operable from rest through supersonic speeds. A pulsejet is another type of compressorless jet engine; however, unlike ramjets, combustion takes place intermittently (in pulses), and they can produce thrust at rest.

Method of Operation: Ramjets capture air and direct it into the engine as they move through the atmosphere. The air is compressed by the "ram effect" and slowed to subsonic speeds by diffusion inside the inlet duct. Fuel is added, and the mixture is ignited. Power is produced by the expulsion of hot exhaust gases through a nozzle. Ramjets usually operate between Mach 2 and 3, but can operate over a wide range of speeds from high subsonic Mach numbers to supersonic speeds up to about Mach 4. The primary disadvantage of ramjets is that they cannot generate thrust at zero flight speed so they must be accelerated by some other form of propulsion to the necessary starting speed, typically 650 km per hour or higher. A small solid propellant rocket motor is often used at launch for this purpose and discarded after the ramjet / scramjet is started.

"Scramjet" is a contraction of "supersonic combustion ramjet." It operates like the ramjet, but the air entering the engine is not slowed as much and combustion occurs while the air in the engine is supersonic. Scramjets usually operate at speeds between Mach 5 and 7. Scramjets must be boosted to an appropriate speed (over Mach 4) to permit ignition.

A pulsejet produces thrust by a series of explosions occurring at the approximate resonance frequency of the engine. In one design, air is drawn in through open valves at the front of the engine and is heated by the injected burning fuel. The burning gases expand; as they increase the pressure, they close the inlet valves and escape as a jet through the exhaust duct. As the exhaust gases are expelled, the pressure in the combustion chamber decreases, allowing the front intake valves to open again, than the cycle repeats. The function of the intake valves is to prevent flow reversal at the inlet. However, the prevention of flow reversal can be accomplished without the use of valves, through the proper use of inlet duct area design and an understanding of wave phenomena. By extending the length of the inlet duct or by using flow rectifiers (i.e., passages of lesser resistance to the flow in one direction than in the opposite direction), the effects of flow reversal can be inhibited. Some valveless pulsejet configurations also conserve thrust by turning the intake duct 180 degrees to the freestream (facing aft instead of forward). Pulsejets typically operate at subsonic speeds.

The turbojet / ramjet combined cycle engine operates as an afterburning turbojet until it reaches a high Mach speed, at which point airflow is by-passed around the compressor and into the afterburner. The engine then operates as a ramjet with the afterburner acting as the ramjet combustor.

Photo Credit: Kaiser Marquardt

Figure 3-7: A large ramjet engine on a handling dolly.

Typical Missile-Related Uses: These engines can be used to power cruise missiles and sometimes other types of UAVs. Ramjet and combined cycle engines provide increased speed and performance over turbojets with minimum volume and weight; however, they are not particularly fuel efficient. Ramjets produce substantially more power per unit volume and typically offer much greater range and / or payload capacity than solid rocket motors. Pulsejets have relatively poor performance and low fuel efficiency, but they are relatively easy to design and manufacture.

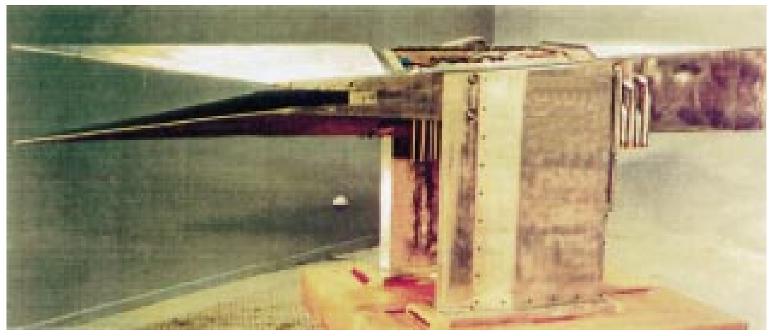


Photo Credit: Kaiser Marquardt

Figure 3-8: A developmental scramjet engine.

Other Uses: Ramjet and combined cycle (turbo-ramjet) engines have been used to power high-speed manned aircraft and helicopters.

Photo Credit: Kaiser Marquardt

Figure 3-9: A developmental scramjet engine.

Appearance (as manufactured): Ramjets can be either mounted in cylindrical pods attached to the missile in various locations or built into the missile body. These engines often resemble a metallic pipe with a conical plug in the inlet to control the air flow and a flared conical nozzle on the opposite end. A typical ramjet for missile use can measure 2 to 4.5 m in length and 0.3 to 1.0 m in diameter, and weigh up to 200 kg. An example of a rather large ramjet is shown in Figure 3-7. A scramjet may look like a simple metallic box with sharp inlets; two developmental scramjets are shown in Figures 3-8 and 3-9. Pulsejets are characterized by their long cylindrical resonator cavity connected to a bulbous control mechanism towards the front, as shown in Figure 3-10.

Photo Credit: Thermo-jet

Figure 3-10: A modern pulsejet engine with a rearward-facing intake.

Appearance (as packaged): These engines are packaged like turbojet engines covered in (a) above; however, they are most likely to be shipped in wooden or metal crates.

Devices to Regulate Combustion in Ramjets, Scramjets, Pulsejets, and Combined Cycle Engines

Photo Credit: Kaiser Marquardt

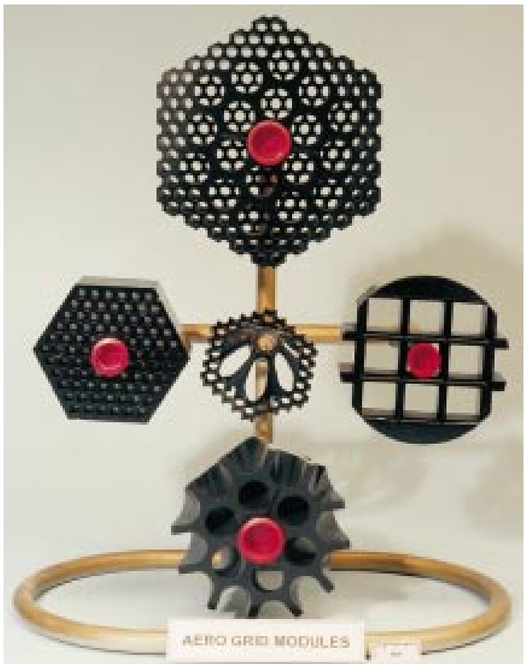


Figure 3-11: Various aerodynamic grids used to straighten the flow of air into a ramjet engine.

Photo Credit: Kaiser Marquardt

Figure 3-12: A complete ramjet flow straightening device before placement into the inlet duct.

Nature and Purpose: Ramjets, scramjets, pulsejets, and combined cycle engines are often required to work over a wide range of velocities, some of which may degrade engine performance. Devices that regulate combustion by altering air- and fuel-flow characteristics in flight are typically integrated into the engine. The essential elements of a system to regulate ramjets are flow dividers, fuel-injection systems, ignitors, flameholding devices, and a power control computer.

Method of Operation: The control system for a ramjet engine performs two basic functions: it maintains the desired engine performance throughout the flight of the vehicle, and it minimizes departure from the desired performance during transients.

Typical Missile-Related Uses: Devices that regulate combustion can make these engines operate efficiently throughout their flight and thereby increase missile speed and range. These devices are usually specific to the engine application and missile configuration for which they are designed.

Other Uses: The flow dividers, fuel injection and metering devices, and flameholders found in ramjets are similar in concept to devices found in afterburning turbojets and turbofans. However, the devices are not interchangeable.

Appearance (as manufactured): Flow straightening devices such as flow dividers, splitter plates, turning vanes, screens, or aerodynamic grids minimize airflow distortion and its adverse effects on fuel distribution and combustion. Sections of various kinds of aerodynamic grids are shown in Figure 3-11. A complete grid assembly as it would be installed in a ramjet is shown in Figure 3-12. These devices are inserted into the inlet duct.

The fuel used in ramjets is fed to the combustion section with the assistance of a pump and varied through

Photo Credit: Kaiser Marquardt

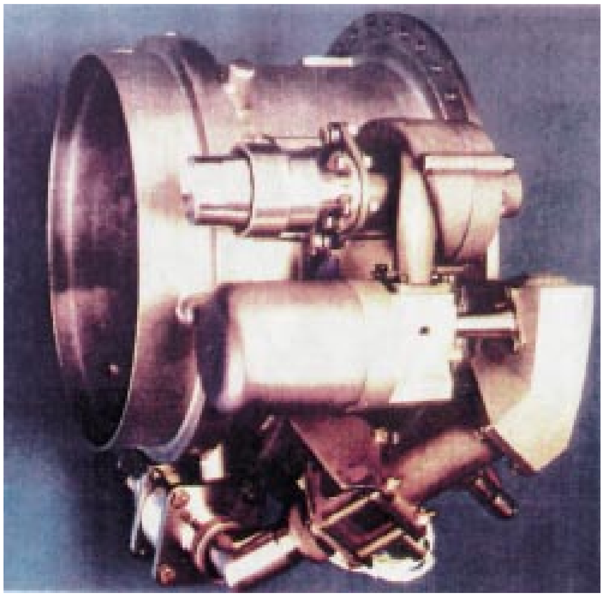


Figure 3-13: A fuel management system for a ramjet engine.

Photo Credit: Kaiser Marquardt

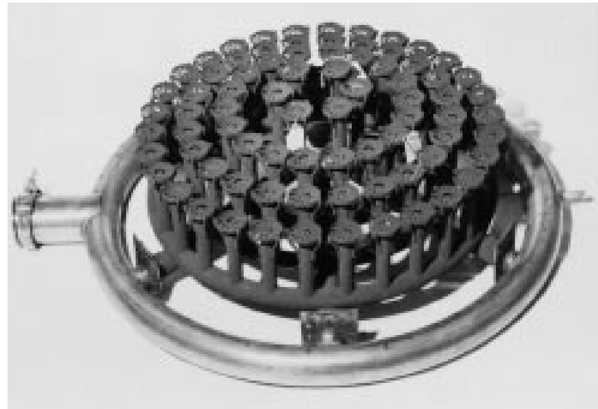


Figure 3-14: A fuel manifold and centrifugal fuel injector assembly for a ramjet engine.

Photo Credit: Kaiser Marquardt

Figure 3-15: A baffle-type flameholder installed in a ramjet engine.

the use of metering devices such as orifices or valves as shown in the fuel management system in Figure 3-13. Fuel injectors disperse the fuel into the air in the combustion section. A fuel manifold and centrifugal fuel injector assembly is depicted in Figure 3-14.

Ignitors for ramjets take one of several forms. Ramjets may use electrical spark, pyrotechnics, pyrophoric, or hypergolic (self-igniting) liquid injectors. Hypergolic liquids are injected into the stagnant region downstream of the flameholder. Surplus quantities of the ignitor liquid may be carried to enable multiple restarts.

Flameholders are used as a means to stabilize the flame produced by combustion and to promote additional combustion. The flameholder is designed to provide a low-velocity region to which the hot combustion products are recirculated to the flameholder. These hot gases then serve as the means for igniting the fresh fuel-air mixture as it flows past the baffle. A rear view of an installed baffle-type flameholder is shown in Figure 3-15.

Ramjet engines require a fuel control (computer) to determine the proper position of the fuel flow metering devices as a function of flight condition. These systems are usually hydro-mechanical or, increasingly, electronic devices. Such devices and the progress in fuel control technology are shown in Figure 3-16, which is annotated with the assembly weights and years produced.

Appearance (as packaged): Aerodynamic grids, combustors, and flameholders are integral with the ramjet and thus are shipped together with the

Photo Credit: Kaiser Marquardt

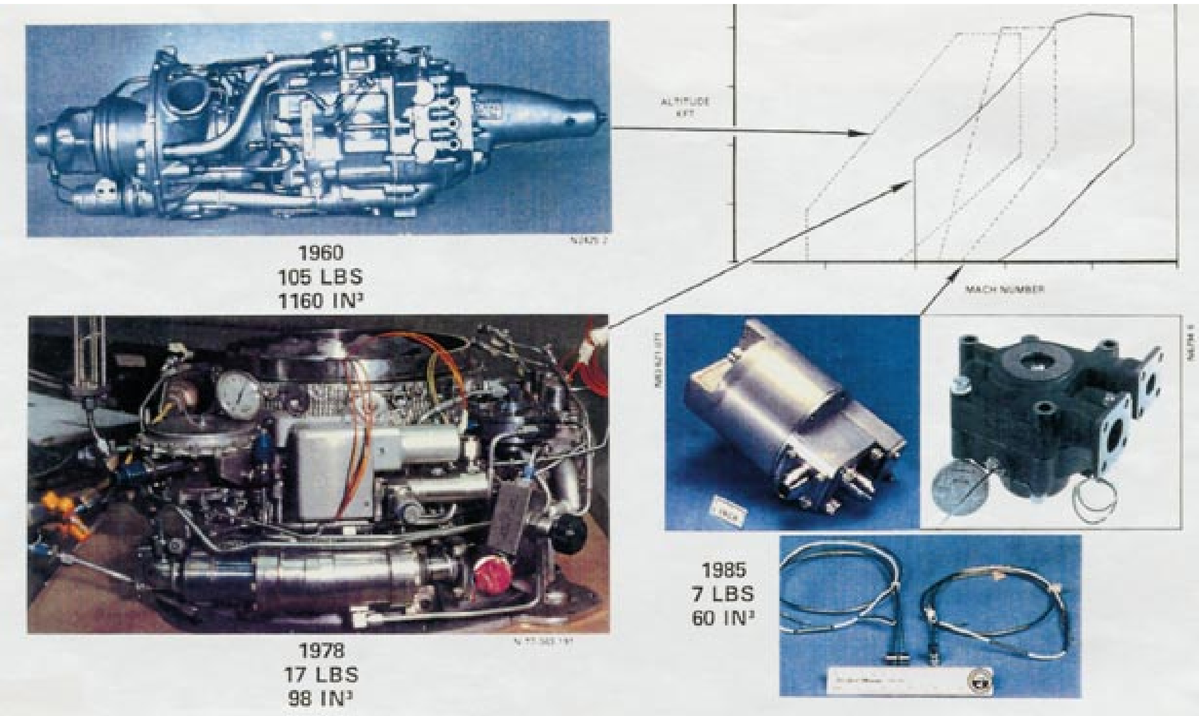


Figure 3-16: Ramjet fuel control technology has progressed significantly since the 1960s.

main engine. The exceptions are the fuel pumps, igniters, or fuel controls, which may be shipped separately and then mounted on the engine body during assembly. These parts are shipped in wooden or cardboard containers.

Produced by companies in

- Brazil
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- Norway
- Russia
- South Korea
- Sweden
- United Kingdom
- United States

(c) Rocket motor cases, "interior lining," "insulation" and nozzles therefor;

Notes to Item 3:

(3) In Item 3(c), "interior lining" suited for the bond interface between the solid propellant and the case or insulating liner is usually a liquid polymer based dispersion of refractory or insulating materials, e.g., carbon filled HTPB or other polymer with added curing agents to be sprayed or screeded over a case interior.

(4) In Item 3(c), "insulation" intended to be applied to the components of a rocket motor, i.e., the case, nozzle inlets, and case closures, includes cured or semi-cured compounded rubber sheet stock containing an insulating or refractory material. It may also be incorporated as stress relief boots or flaps.

Rocket Motor Cases, Interior Lining, and Insulation

Nature and Purpose: Rocket motor cases are the main structural components of solid or hybrid rocket motors. Cases are the cylindrical containers of the propellant. They use special materials to resist the pressures and heat of combustion.

Method of Operation: Rocket motor cases are pressure vessels used to contain the hot gases generated by the propellant combustion process. These hot gases are expanded and accelerated through the rocket motor nozzle to produce thrust. Interior lining and insulation are low-density, high-heat-resistant materials that provide protective layers between the burning propellant and the case.

Photo Credit: Aerospatiale Espace & Defense

Figure 3-17: A large filament-wound solid rocket motor case.

Typical Missile-Related Uses: All solid propellant rocket motors use motor cases and interior lining or insulation. Such cases are usually designed to meet specific requirements of particular missiles. Cases, interior lining, and insulation are critical to maintain the integrity of solid rocket motors.

Other Uses: Motor case materials are used in high-pressure applications such as piping. Some materials used in the interior linings or insulation of rocket motors are used in commercial applications requiring heat-resistant materials.

Photo Credit: Thiokol Corp.

Figure 3-18: Installation of lining inside a motor case.

Appearance (as manufactured): A rocket motor case is a large, steel or composite-filament-wound cylinder with spheroidal or ellipsoidal domes at either end. A motor case for an Item 2(c) rocket motor typically would be larger than 4 m in length and 0.5 m in diameter. Each of the domes usually has a hole; the small hole at the front end is for the igniter or other internal motor hardware, and the large hole at the back end is for the nozzle. A large filament-wound motor case displaying these features is shown in Figure 3-17. An interior lining is a thin layer of special chemicals used to help the solid propellant adhere to the case insulation. The lining is usually applied to the case onsite before propellant casting. The case may or may not have internal insulation in place when shipped. Rocket motor insulation is usually made of synthetic rubbery material such as ethylene propylene diene monomer, (EPDM), polybutadiene, neoprene, or nitrile rubber. Insulation material contains silica or asbestos and resembles a gray or green sheet of rubber approximately 2 to 6 mm thick. Figure 3-18 shows installation of lining inside a motor case. Figure 3-19 shows a motor case under inspection after application of the thermal insulation. Figure 3-20 shows the installation of the internal insulation onto a mandrel prior to the motor case filament winding operation.

Photo Credit: Fiat Avio

Figure 3-19: A rocket case under inspection after application of the thermal insulation.

Photo Credit: Thiokol Corp.

Figure 3-20: Installation of internal insulator prior to motor case filament winding operation.

Produced by companies in

- Canada
- China
- France
- Germany
- India
- Israel
- Japan
- North Korea
- Russia
- South Africa
- Sweden
- Ukraine
- United Kingdom
- United States

Appearance (as packaged): Rocket motor cases are shipped in large wooden or metal crates that contain foam packing or other material to protect them from shock during shipment. Case liners are not likely to be shipped or transferred separately. Insulation material is shipped on large rolls up to 1 m in width and 0.5 m in diameter and sealed in boxes.

Rocket Motor Nozzles

Nature and Purpose: Rocket nozzles are flow constrictors with bell-shaped structures, or skirts, fitted to the exhaust end of a solid propellant rocket motor, a liquid propellant rocket engine, or a hybrid rocket motor. Their design controls the flow of hot exhaust gases to maximize velocity in the desired direction and thereby improve thrust.

Method of Operation: During missile launch or flight, burning propellants create a large quantity of combustion gases, which are forced through the convergent section of the nozzle into its throat, the smallest opening of the nozzle, at sonic speed. These gases then expand to supersonic speeds through the diverging portion of the nozzle and exit from the engine. The increased velocity of the gases increases the thrust.

Typical Missile-Related Uses: Rocket nozzles manage combustion gases to ensure efficient rocket operation. Well designed rocket nozzles improve missile system payload and range capability. Nozzles are used on large individual rocket motor stages that supply the main thrust for a ballistic missile; on the small control motors that steer, separate, or spin up the missile along its flight path; and on booster rockets that launch UAVs, including cruise missiles.

Other Uses: Rocket motors (and hence nozzles) have been used to propel experimental aircraft such as the X-1 and X-15 research airplanes.

Appearance (as manufactured): The shape of a rocket nozzle is similar to an hourglass; one large section faces forward to the combustion chamber, the other large section faces rearward to the end of the rocket. The two sections are connected by the small middle section, or throat, as shown in Figure 3-21.

Figure 3-22 shows a cut-away view of a solid propellant rocket motor and how the nozzle fits into the aft end of the motor. Modern solid rocket nozzles are almost always made from carbon-composite materials or combinations of carbon-composite and silica phenolic materials. Carbon-composite sections are generally black; phenolic sections are often yellowish in color.

Photo Credit: Aerojet-General Corp.

Figure 3-21: A liquid engine with a metal, radiatively cooled lower nozzle skirt.

Figure 3-22: A cut-away view of a solid motor that shows how the nozzle fits into the aft end of the motor.

Photo Credit: Thiokol Corp.

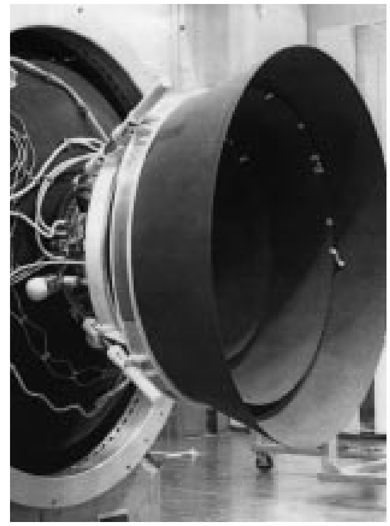


Photo Credit: Alliant TechSystems, Inc.

Figure 3-23: A modern extendable rocket nozzle skirt showing the actuators that increase its length after staging.

Liquid propellant rockets may use carbon-composite nozzles, but usually use metal-based materials such as stainless steel alloys or titanium and columbium (niobium). Metal nozzles are one of several shades of gray as shown in Figure 3-21. Nozzles also may have a metal exterior and a non-metallic interior made of materials that can withstand the high temperature of the exhaust gases, such as bulk graphite or silica phenolic.

Photo Credit: AlliedSignal/Aerospace

Figure 3-24: An engine with a large, regeneratively cooled nozzle.

Nozzle size depends on the rocket size and application. Large nozzles intended for solid propellant rocket motors are increasingly built as movable nozzles. In such an application, the forward end of the nozzle has devices and insulators that allow it to be attached to the aft dome of the motor in a ball-in-socket arrangement. These nozzles may have 2 to 4 lugs on the outside wall to which the motion actuators are fastened, or the actuators may be connected near the throat. Very advanced nozzles can be extendable, which means they are stored in a collapsed configuration and extended to their full dimensions when needed. Such a nozzle complete with its actuators and control mechanism is shown in Figure 3-23. Nozzles intended for liquid rocket engines usually are regeneratively cooled. They are made either by a series of metal tubes welded together to form the nozzle, or by sandwiching a piece of corrugated metal between an inner and outer wall, as shown in Figures 3-24, 3-25, and 3-26. Fuel is injected into the large manifold near the bottom of the

Photo Credit: Boeing

Figure 3-25: Side view of a regeneratively cooled nozzle.

Photo Credit: Boeing

Figure 3-26: End views of regeneratively cooled nozzles.

nozzle; as it flows up through the passages it absorbs heat and cools the nozzle.

Appearance (as packaged): Shipping containers for rocket nozzles are of two types, depending on nozzle size. Small nozzles with an exit diameter no greater than 50 cm have tailored containers, even metallic cases. Larger nozzles usually have tailored shipping containers built from wood or fiberglass. Protective plastic wraps may also be used, depending on the environmental-control capability of the shipping container.

(d) Staging mechanisms, separation mechanisms, and interstages therefor;

Produced by companies in

- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- North Korea
- Russia
- United Kingdom
- United States

Staging Mechanisms and Separation Mechanisms

Nature and Purpose: Separating rocket stages quickly and cleanly is technically challenging. Moreover, it is critical to the successful flight of a multistage missile. Staging mechanisms ensure the safe and reliable separation of two missile stages after termination of the thrust of the lower stage. This separation is achieved by relatively simple separation mechanisms, the most common of which are explosive bolts and flexible linear shaped charges (FLSC). Explosive bolts attach the missile stages together through specially constructed, load-carrying interstages with flanges at the ends and, on signal, explode to allow the two stages to separate. A built-in FLSC is used to make a circumferential cut through the interstage skin and structure to allow stage separation. Mechanical, hydraulic, or pneumatic devices can be used to help separate stages. Similarly, mechanisms like ball locks are used for separating the payload from the uppermost missile stage at the very end of powered flight.

Method of Operation: When the propellant in any missile stage is nearly exhausted, the guidance set signals the separation hardware to release the spent stage. This electronic signal fires detonators which, in turn, trigger separation mechanisms like explosive bolts or FLSC that sever the structural and electrical connection and let the exhausted missile stage drop off. If atmospheric drag forces are not likely to be strong enough to ensure separation, mechanical, hydraulic, or pneumatic compression springs are placed between the two stages to force them apart. Spent stages may require reverse thrusters or thrust termination to prevent collision of the stages prior to next-stage ignition.

Typical Missile-Related Uses: All multi-stage missiles require staging and separation mechanisms. Single-stage missiles with separating warheads also require separation mechanisms.

Other Uses: Prepackaged devices such as explosive bolts have other military applications, most notably in launching weapons or separating external fuel tanks from fighter aircraft. FLSC are routinely used in the oil industry for cutting large pipes. Compression springs are used in the industrial world as shock absorbers and load-levelers.

Photo Credit: Hi-Shear Technology Corp.

Figure 3-27: Three examples of explosive bolts. Notice the electrical connection on the top bolt, which detonates it.

Appearance (as manufactured): Explosive bolts look like large machine bolts, but with a housing section at the head end; three examples are shown in Figure 3-27. Typically, they measure 7 to 10 cm in length and 1 to 2.5 cm in diameter, and weigh 50 to 75 g. The housing section contains the ordnance and has wires or cables leading out of it from the internal detonators, which typically require a DC power source. Built-in staging mechanisms almost always use FLSC, a chevron-shaped, soft metal tube of lead or aluminum filled with explosive, typically RDX or HMX. The FLSC is fastened by metal clips to the interior of the interstage structure holding the two missile stages together and, when initiated by a small detonator, cuts through the structure and skin to release the stages. The tube is a gray metal color, and the explosive is white to whitish-gray in color, as shown in Figure 3-28. The width, height, and weight per unit of length are a function of the thickness of the material it is designed to cut through.

Photo Credit: Ensign-Bickford Co.

Figure 3-28: Short section of flexible linear-shaped charge (on a centimeter scale) designed to cut through a missile stage.

Ball locks do not involve explosives and are sometimes used in payload separation systems. Internally, they use a solenoid / spring / ball-bearing that enables the desired soft disconnect; externally, they appear much like explosive bolts, that is, like a machine bolt with a housing and two wires. Compression springs used for stage separation are long stroke (10 to 20 cm), small diameter (2 to 4 cm) devices mounted in canisters at several locations (minimum of three) in the rim of the interstage. These steel canisters house steel springs or pistons and have built-in flanges for attachment to the interstage. The hydraulic and pneumatic pistons have built-in fluid reservoirs to pressurize the units when the stages are assembled.

Appearance (as packaged): Explosive bolts are shipped in simple cardboard boxes with ample internal foam or other packing to mitigate the effects of shocks. Properly shipped boxes are marked with "Danger-Explosive" or "Danger-Ordnance" symbols and are shipped under restrictions governing explosive materials. FLSC are usually shipped in varying lengths in lined and protected wooden boxes. They are supposed to be marked with the same labels as they are subject to the same shipping restrictions as any ordnance. Ball locks can be packaged and shipped without ordnance restrictions and have

Produced by companies in

- Brazil
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- North Korea
- Norway
- Pakistan
- Russia
- South Korea
- Spain
- Sweden
- Ukraine
- United Kingdom
- United States

no distinguishing features or labels on their packaging. Compression springs are shipped in the uncompressed state in cardboard boxes.

Interstages

Nature and Purpose: An interstage is a cylindrical or truncated-cone-shaped structure that connects two missile propulsion stages. An interstage is, in principle, a simple piece of equipment, but the requisite electrical connections, separation mechanisms, and high strength-to-weight ratios make it rather complex in its adaptation to specific missiles. The purpose of an interstage is to maintain missile integrity during launch and flight, and to ensure stage separation without damage to any missile component or adverse effect on velocity.

Method of Operation: Upon command from the guidance system, the separation mechanism is prompted, first, to release the lower stage from the interstage connecting it to the next stage, and secondly, after a brief pause, to jettison that interstage. In some cases, separation occurs between the interstage and the upper stage; the interstage remains attached to the lower stage. Staging mechanisms are usually activated before the upper stage ignites.

Typical Missile-Related Uses: Interstages are used to carry thrust loads from the lower stage to the upper stages of ballistic missiles during rocket motor burn. Some early designs used simple open-truss structures; later designs incorporate thin-skin shell coverings to reduce drag by creating a smooth aerodynamic fairing between the stages. They also incorporate the separation mechanisms used to jettison the spent lower stage. Dropping a spent lower stage improves missile range (compared to that of a single stage missile) but must be accomplished cleanly and with proper timing to prevent damage to the missile or deviation from its trajectory.

Figure 3-29: Two interstages in their shipping container.

Other Uses: N/A

Appearance (as manufactured): An interstage is a conical or cylindrical hoop-like structure that has the same outside diameter as the rocket stages it connects. It has connecting frames at each end and locations for separation devices on one end. It has structural supports visible inside the structural walls and end rings or frames used to join it to the missile stages. The length of an interstage is usually equal to about half the outside diameter of the engine nozzle on the next stage above. In the past stainless steel and titanium have been used, but current interstages use graphite composite construction with metal end rings. Two interstages in a shipping crate are shown in Figure 3-29. An interstage being positioned for attachment to a solid rocket motor is shown in Figure 3-30.

Figure 3-30: An interstage being positioned for attachment.

Appearance (as packaged): Interstages are usually shipped in tailored wooden containers from the manufacturing facility to the missile stage integrator.

(e) Liquid and slurry propellant (including oxidizers) control systems, and specially designed components therefor, designed or modified to operate in vibration environments of more than 10 g RMS between 20 Hz and 2,000 Hz.

Notes to Item 3:

(5) The only servo valves and pumps covered in (e) above, are the following:
   (a) Servo valves designed for flow rates of 24 liters per minute or greater, at an absolute pressure of 7,000 kPa (1,000 psi) or greater, that have an actuator response time of less than 100 msec.
   (b) Pumps, for liquid propellants, with shaft speeds equal to or greater than 8,000 RPM or with discharge pressures equal to or greater than 7,000 kPa (1,000 psi).

(6) Item 3(e) systems and components may be exported as part of a satellite.

Nature and Purpose: Propellant control systems manage the pressure and volume of liquid or slurry propellant flowing through the injector plate and into the combustion chamber of a rocket engine. High-pressure tanks or turbopumps force liquid or slurry propellants from fuel and oxidizer tanks into the combustion chamber at high pressure. High-pressure tank systems include the tanks themselves, servo valves, and feed lines to keep propellant flow continuous and void-free during the high acceleration of missile launch. Turbopumps are used to increase the propellant pressure to levels required for high-thrust, high-flow-rate engines. Servo valves can be used to control turbopump speed and thereby control thrust.

Method of Operation: Pressure tank systems use a high-pressure tank, often called a “bottle,” which carries a pressurant like nitrogen or helium at up to 70,000 kPa. Pressurant is released to the propellant tanks through a regulator that adjusts the pressure level. The pressurant then pushes the fuel and oxidizer through control valves to the injector at the head of the combustion chamber. Thrust is regulated by opening and closing the control valves the appropriate amount.

Servo valves function to provide nearly exact response with the help of the feedback control system. Their use is almost fundamental to control of high-power systems such as more advanced liquid rocket propulsion. They are complicated electromechanical devices that control the flow of propellant through them by balancing forces on both sides of an actuator piston, which regulates the position of the valve pintle. The control signal typically moves a small (hydraulic amplifier) piston that admits variable pressure to one side of the actuator piston. It moves until a new balance is established

Figure 3-31: A servo valve from a Scud missile.

Figure 3-32: A modern liquid propellant control valve.

Photo Credit: Allied Signal Aerospace

Photo Credit: Boeing

Figure 3-33: A liquid propellant injector plate.

at a new flow rate. Servo valves are usually the most costly, sensitive, and failure-prone of all valves because their orifices can easily be clogged by contaminants.

Turbopumps push propellants into the combustion chamber at pressures up to fifty times greater than the pressure at which the propellants normally are stored. Turbopumps are powered by burning some of the rocket propellant in a gas generator; its exhaust gases power a turbine driving the pump. Turbopumps for missiles typically rotate at 8,000 to 75,000 RPM. Engine thrust is regulated by altering the propellant flow to the gas generator (sometimes with a servo valve), and thereby changing the turbine speed of the turbopump and thus the propellant flow into the combustion chamber.

Photo Credit: Boeing

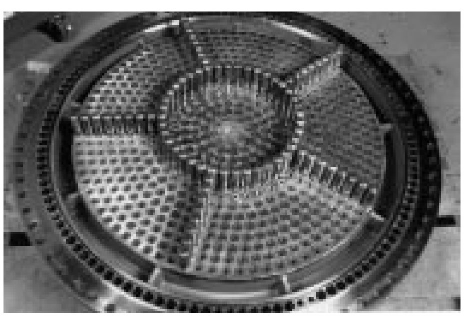


Figure 3-34: Another style of liquid propellant injector plate.

Typical Missile-Related Uses: All liquid propellant rocket engines use either a pressure-fed or a pump-fed propellant delivery system. Pressure-fed systems can be specifically designed for a particular engine or assembled from dual-use components. Turbopumps are usually specifically designed for a particular engine.

Other Uses: Servo valves are common in closed-loop control systems handling liquids. Numerous civil applications include fuel and hydraulic system control in aircraft. Other applications involve precision handling of fluids such as in the chemical industry. Turbine drill pumps are popular in the petroleum and deep well industries.

Appearance (as manufactured): Servo valves look much like on-off valves or line cylinders with tube stubs for propellant inlets and outlets in a metal case. Most valves and housings are made of stainless steel. However, these valves are larger than on-off valves because they have a position feedback device. A servo valve from a Scud missile is shown in Figure 3-31. A modern liquid propellant control valve is shown in Figure 3-32. Two types of liquid propellant injector plates are shown in Figures 3-33 and 3-34.

Turbopumps are usually housed in metal cases and are sized for specific applications. Although they resemble automotive or truck turbochargers, they are much larger and can weigh several hundred kilograms. Turbopumps for rocket engines may have a separate pump and turbine assembly for each propellant (e.g., for the fuel and for the oxidizer), or a single unit that combines both pumps and the turbine drive mechanism. Examples of single- and multi-shaft turbopump assemblies are shown in Figures 3-35 and 3-36, respectively. The ribbing of the housings is typical of turbopumps because they provide good strength and light weight; however, some turbopumps have smooth metallic housings, as shown in Figure 3-37.

Photo Credit: Aerojet

Figure 3-35: A single-shaft turbopump.

Photo Credit: Aerojet

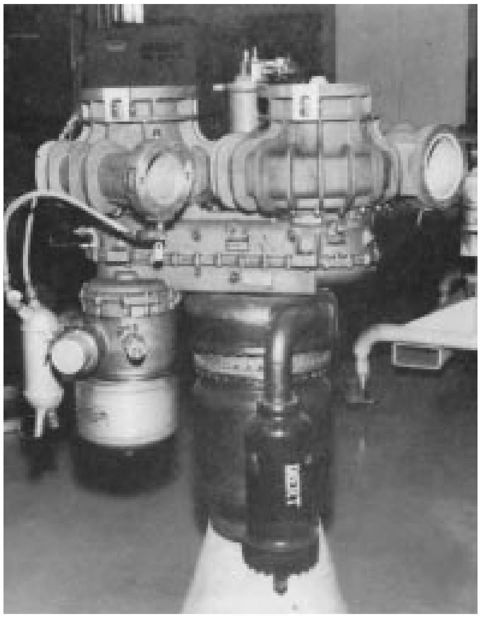


Figure 3-36: A multi-shaft turbopump assembly.

Photo Credit: AlliedSignal Aerospace

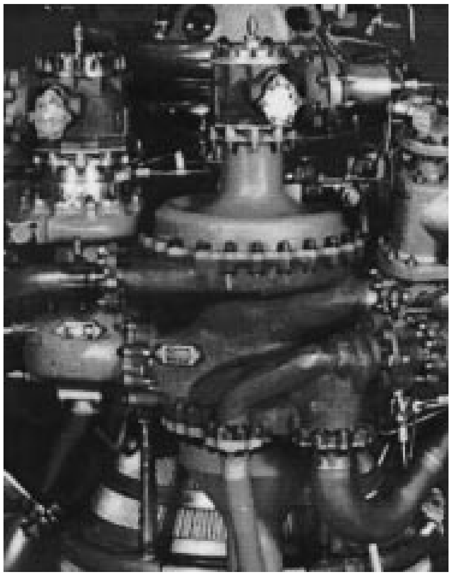


Figure 3-37: A smooth turbopump housing; compare with those in Figures 3-35 and 3-36.

Appearance (as packaged): Servo valves are packaged like other valves, especially on-off valves. Inlets and outlets are plugged to prevent contamination. The valves are placed in vacuum-sealed plastic bags or sealed plastic bags filled with nitrogen or argon to keep the valves clean and dry. They may sometimes be double bagged and are usually shipped inside a container, often an aluminum case with a contoured foam liner. Small turbopumps are often packaged and shipped in aluminum shipping containers. Depending on size and interface features, a large turbopump may be packaged and shipped in a custom-built shipping crate, with pump supports built in. Turbopumps may also be shipped as a breakdown kit in which separate components are packaged for assembly after receipt.

(f) Hybrid rocket motors and specially designed components therefor.

Nature and Purpose: Hybrid rocket motors use both solid and liquid propellants, usually a solid fuel and a liquid oxidizer. Because flow of the liquid oxidizer can be controlled, hybrid motors can be throttled or shut down completely and then restarted. Hybrid rocket motors thereby combine some of the simplicity of solid rocket motors with the controllability of liquid rocket engines.

Produced by companies in

- Japan
- Russia
- United States

Method of Operation: Hybrid rocket motors use either pressurized tanks or pumps to feed oxidizer into the combustion chamber, which is lined with solid fuel. The pumps are driven by a gas generator powered by its own fuel grain or some other source of fuel. The liquid oxidizer burns the solid fuel inside the hollow chamber, and the hot, expanding gases are expelled through the nozzle at supersonic speed to provide thrust. As in a solid rocket motor, the outer casing of the combustion chamber is protected from much of the heat of combustion by the fuel itself because it burns from the inside outward.

Typical Missile-Related Uses: Hybrid rocket motors have the potential to power MTCR Category I missiles, but to date there have been no serious attempts to build and deploy any such missiles.

Other Uses: N / A

Appearance (as manufactured): A hybrid rocket motor has an oxidizer injector mounted in the top of the high-pressure motor case and a converging / diverging nozzle at the bottom. The injector has valves and piping either from a pressure tank or from a tank and an associated pump. The combustion chamber is usually fabricated either from steel or titanium, which may be black or gray, or from filament-wound graphite or glass epoxy, which is usually yellow or brown. The chamber is lined with thick, solid propellant having one of a variety of configurations and looking like a single cylinder with a hollow center, concentric cylinders, or wagon wheels. Nozzles are made of ablative material, which is often brownish, or high-temperature metals, and they may have high-temperature inserts in their throats.

Appearance (as packaged): Hybrid rocket motors may be shipped fully assembled or partially assembled, with tanks and associated hardware packaged separately from the combustion chamber and attached nozzles. Fully assembled units are packaged in wooden crates; components are packaged in wooden crates or heavy cartons. Legally marked crates are labeled with explosives or fire hazard warnings because the missiles are fueled with solid propellant. However, because motors contain only fuel and no oxidizer, they are less hazardous than normal solid rocket motors.

Notes to Item 3:

(1) Flow-forming machines, and specially designed components and specially designed software therefor, which:
- (a) According to the manufacturer's technical specification, can be equipped with numerical control units or a computer control, even when not equipped with such units at delivery, and
- (b) With more than two axes which can be coordinated simultaneously for contouring control.

Technical Note:

Machines combining the functions of spin-forming and flow-forming are for the purpose of this item, regarded as flow-forming machines.

This item does not include machines that are not usable in the production of propulsion components and equipment (e.g. motor cases) for systems in Item 1.

Nature and Purpose: Flow-forming machines are large shop machines used in heavy duty manufacturing to make parts to precision dimensions. Their bases are massive in order to support the structures for mounting rollers, mandrels, and other components. Power supplies, hydraulic rams, and positioning screws are also large enough to resist deflection by the large forming forces.

Produced by companies in

- Germany
- Japan
- Sweden
- Switzerland
- United Kingdom
- United States

Method of Operation: Flow-forming machines use a point-deformation process whereby one or more rollers move along the length of a metal blank, or preform, and press it into a rotating mold or onto a mandrel with the desired shape.

Typical Missile-Related Uses: Flow-forming machines are used to make rocket motor cases, end domes, and nozzles.

Other Uses: Flow-forming machines are used to make numerous parts for the aerospace industry, including commercial aircraft parts, tactical missile components, and liners for shaped charges. They are also used to make automobile wheels, automatic transmission components for automobiles, gas containers, pressure-tank heads, and containers for electronic equipment.

Appearance (as manufactured): Flow-forming machines can be configured either vertically or horizontally, as shown in Figures 3-38 and 3-39, respectively. Vertical configurations can form larger parts because they have protruding servo-driven arms to hold the rollers and more horsepower for deformation. Horizontal configurations do not have roller arms as long as those of the vertical machines.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M, (April 1996).*

Figure 3-38: A vertical flow-forming machine.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M, (April 1996).*

Figure 3-39: A horizontal flow-forming machine.

The related spin-forming process can produce shapes like those made by the flow-forming process. However, spin-forming uses less power to shape the material because it changes the thickness of the material very little from pre-

Photo Credit: Aerojet

Figure 3-40:
A flow-forming machine used to make end domes for propellant tanks.

form to final shape. An example of a flow-forming machine used to make end domes for propellant tanks is shown in Figure 3-40.

Specially designed production facilities and equipment resemble aerospace and manufacturing equipment but with attributes designed for a given system.

Appearance (as packaged): Larger vertical machines usually require that roller areas, vertical columns, and mandrels be boxed separately in wooden crates for shipping. Smaller vertical machines as well as horizontal machines may be shipped in large wooden containers, with the roller arms shipped in the assembled configuration. They are securely fastened to the containers to preclude movement. The control unit and any hydraulic supply and power units are also boxed separately for shipment.

ITEM 4
Propellants

Propellants

Propellants and constituent chemicals for propellants as follows:
(a) Composite Propellants
(1) Composite and composite modified double base propellants;

Produced by companies in

- Argentina
- Brazil
- Canada
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- Norway
- Pakistan
- Republic of Korea
- Russia
- Spain
- Sweden
- Switzerland
- Taiwan
- United Kingdom
- United States

Nature and Purpose: Composite and composite modified double-base propellants are heterogeneous mixtures of fuels and small particulate oxidizers held together by a rubbery material referred to as the binder. They provide a stable, high-performance, solid propellant for rocket motors.

Method of Operation: Selected fuels and oxidizers are mixed in exact ratios and cast (poured and then solidified) directly into rocket motor casings or into a mold for subsequent insertion into a case (cartridge loaded). When ignited, the propellant burns and generates high-pressure, high-temperature exhaust gases that escape at extreme speeds to provide thrust. Once ignited, the propellant cannot be readily throttled or extinguished because it burns without air and at very high temperatures.

Typical Missile-Related Uses: Composite and composite modified double-base propellants are used to provide the propulsive energy for rocket systems, kick motors for satellites, and for booster motors for launching cruise missiles and unmanned air vehilcles (UAVs).

Other Uses: These propellants are used in tactical rockets.

Appearance (as manufactured): Composite and composite modified double-base propellants are hard, rubbery materials resembling automobile tires in texture and appearance. Ingredients such as aluminum or other metal powder gives them a dark gray color; however, other additives may cause the color to vary from red to green to black, as shown in Figure 4-1. A piece of composite-modified double-base propellant surrounded by samples of all its constituent chemicals is shown in Figure 4-2.

Appearance (as packaged): Once the components of the propellants are mixed together, they are poured directly into the missile case and solidify

Photo Credit: British Aerospace Defense Limited

Figure 4-1: Solid propellants vary in appearance on the basis of their requirements.

into a single piece of material to form a completed motor. Thus, these propellants are shipped only as the major internal component in a loaded rocket motor and usually are not encountered separated from a motor. Exceptions are cartridge-loaded systems that fit a cartridge of propellant into a motor case.

Additional Information: The most commonly used fuel component of composite propellants is aluminum powder, which has better performance and greater ease of use than other metal powders that may be used. The oxidizer component of choice is ammonium perchlorate (AP); other oxidizers are metal perchlorates, ammonium nitrate (AN), and ammonium dinitramide (ADN). Metal perchlorates and AN greatly decrease performance and thus have only limited use in specialized propellants. ADN is a new oxidizer with better performance than AP, but it has limited availability and is very difficult to work with. The high explosives HMX and RDX may be used as an adjunct to AP in order to increase propellant performance. The binder used in composite propellants is normally a synthetic rubber; the best one is hydroxyl-terminated polybutadiene (HTPB). Other binders are carboxyl terminated polybutadiene (CTPB), polybutadiene-acrylic acid polymer

Photo Credit: Alliant TechSystems, Inc.

Figure 4-2: Composite-modified double-base propellant and samples of its constituent chemicals.

(PBAA), or polybutadiene-acrylic acid-acrylonitrile terpolymer (PBAN). Elastomeric polyesters and polyethers such as polypropylene glycol may also be used as binders. Composite modified double-base propellant also uses nitrocellulose plasticized with nitroglycerine or other nitrate esters as a binder system.

(b) Fuel Substances
(1) Hydrazine with concentration of more than 70 percent and its derivatives including monomethylhydrazine (MMH);
(2) Unsymmetric dimethylhydrazine (UDMH);

Produced by companies in

- China
- France
- Germany
- Russia
- United Kingdom
- United States

Nature and Purpose: Hydrazine, monomethylhydrazine (MMH), and unsymmetric dimethylhydrazine (UDMH) are liquid rocket fuels. They are used in a wide variety of rocket engines requiring high performance and long storage times. Hydrazine is most often used as a monopropellant (without an oxidizer) by decomposing it into hot gas with a catalyst. Up to 50 percent hydrazine is often mixed with MMH or UDMH fuels in order to improve performance.

Method of Operation: At room temperature and pressure, the hydrazine family of fuels is hypergolic (self-igniting) when mixed with various oxidizers such as nitric acid, chlorine, or fluorine. When used in a bipropellant system, hydrazine releases about half of its energy by decomposing into a hot gas and half by burning with an oxidizer.

Typical Missile-Related Uses: Although hydrazine can be burned with an oxidizer, safe combustion is difficult to achieve. Thus, it is not widely used in conjunction with an oxidizer; however, it is often used as an additive to enhance performance of the more stable-burning MMH and UDMH fuels. MMH and UDMH, which remain liquid over a –50 to +70°C temperature range, are high-performance fuels used for missiles.

Other Uses: Hydrazine is the most current and common propellant for small thrusters for spacecraft attitude control and satellite maneuvering. Hydrazine is also used in electrolytic plating of metals on glass and plastics, pharmaceuticals, fuel cells, dyes, photographic chemicals, and agricultural chemicals, and as a polymerization catalyst and a corrosion inhibitor in boiler feed water and reactor cooling water. MMH is used in aircraft emergency power units.

Appearance (as manufactured): Hydrazine is a clear liquid with a freezing point slightly above that of water, at +1.5°C, and a normal boiling point of 114°C. Its density is slightly greater than that of water, at 1.003 g/cc. It is irritating to the skin, eyes, and lungs, and is highly toxic when taken orally. MMH is a clear liquid with a freezing point of –52°C and a normal boiling point of 88°C. These features make it an attractive fuel for tactical military missiles. Its density is 0.87 g/cc. It is highly toxic. UDMH is a clear liquid with a freezing point of –57°C and a normal boiling point of 62°C. Its density is 0.78 g/cc. It is also highly toxic.

Appearance (as packaged): Anhydrous (water eliminated) hydrazine, MMH, and UDMH are classified as flammable liquids and poisons. Hydrazine products can be stored and shipped in aluminum, 300-series stainless steel, and titanium alloy barrels or tanks. Small purchases are commonly packed in 55-gallon drums; larger orders are shipped in railroad tank cars. Containers of fuel in the hydrazine family are all air purged and are backfilled with an inert gas such as nitrogen to prevent contamination and slow oxidation.

Produced by companies in

- Canada
- China
- France
- India
- Iran
- Japan
- Pakistan
- Russia
- United States

(3) Spherical aluminum powder with particles of uniform diameter of less than 500×10^{-6} m (500 micrometers) and an aluminum content of 97 percent by weight or greater;
(4) Zirconium, beryllium, boron, magnesium and alloys of these in particle size less than 500×10^{-6} m (500 micrometers), whether spherical, atomized, spheroidal, flaked or ground, consisting of 97 percent by weight or more of any of the above mentioned metals;
(5) High energy density materials such as boron slurry, having an energy density of 40×10^{6} J/kg or greater.

Nature and Purpose: The metals aluminum, beryllium, boron, magnesium, and zirconium are good fuels in particle sizes less than 500×10^{-6} m (500 microns). They are used as a constituent fuel to enhance solid and liquid rocket propellant performance. For example, aluminum powder as a fuel additive makes up 5 to 21 percent by weight of solid propellant. Combustion of the aluminum fuel increases the propellant flame temperature by up to 800°K and increases specific impulse by as much as 10 percent.

Method of Operation: Metal powder is added to either the solid propellant grain during rocket motor production or to liquid rocket fuel to form a slurry. Because the surface-to-volume ratio of such small metal particles is very high, the oxidizer envelops and quickly burns each metal particle thereby releasing high energy per weight at very high temperature.

Typical Missile-Related Uses: Aluminum powder is relatively inexpensive and is widely used as a fuel component in solid and liquid rocket engines to increase the specific impulse of the propellant and to help stabilize combustion. Beryllium, boron, magnesium, and zirconium metal fuels may also be used, but, in practice, they have few military missile-related uses. Generally speaking, they are expensive, dangerous to handle, and difficult to control. Beryllium motors have been developed only as upper stages because some of their exhaust products are toxic.

Other Uses: Aluminum powder is used as a main ingredient in aluminum spray paint. Spherical aluminum powder is used as a catalyst and as a component in coatings for turbine shells and in construction materials like foamed concrete and thermite. Magnesium is used primarily in the pyrotechnics industry. Boron is sometimes used in fuel slurry for ducted rockets and solid-fuel ramjets. Zirconium has been used in some high-density composite propellants for volume limited tactical applications. Both boron and zirconium are used in ignition compounds for igniters.

Appearance (as manufactured): Aluminum powder is a gray or dull silver powder, as shown in the upper right of Figure 4-2. The particle size of most propellant grade aluminum powder ranges from 3 to 100 microns, although larger sizes have been used. The particle shape is more or less spherical. Beryllium, magnesium, and zirconium are also gray or dull silver powders. Boron is a dark brown powder. The appearance of boron slurry depends on the liquid to which it is added and the boron particle size; typically, the color is dark brown or black. For example, boron mixed with dicyclopentadiene is a potential ramjet fuel and forms a chocolate-brown slurry with the consistency of honey.

Appearance (as packaged): Aluminum powder is generally packaged and shipped in steel drums with a capacity of 30 gallons or less, similar to the ammonium perchlorate drums in Figure 4-3. Aluminum powder in a 30-gallon drum weighs approximately 180 kg. The other metals, though much less likely to be encountered, are packaged similarly.

Additional Information: Aluminum has a density of 2.7 g / cc, but its bulk density is somewhat less, depending on particle size. Beryllium and its combustion products are very toxic. Boron is difficult to ignite. Zirconium is very dangerous to handle in finely powdered form because it spontaneously ignites in air; thus, it is usually shipped in water.

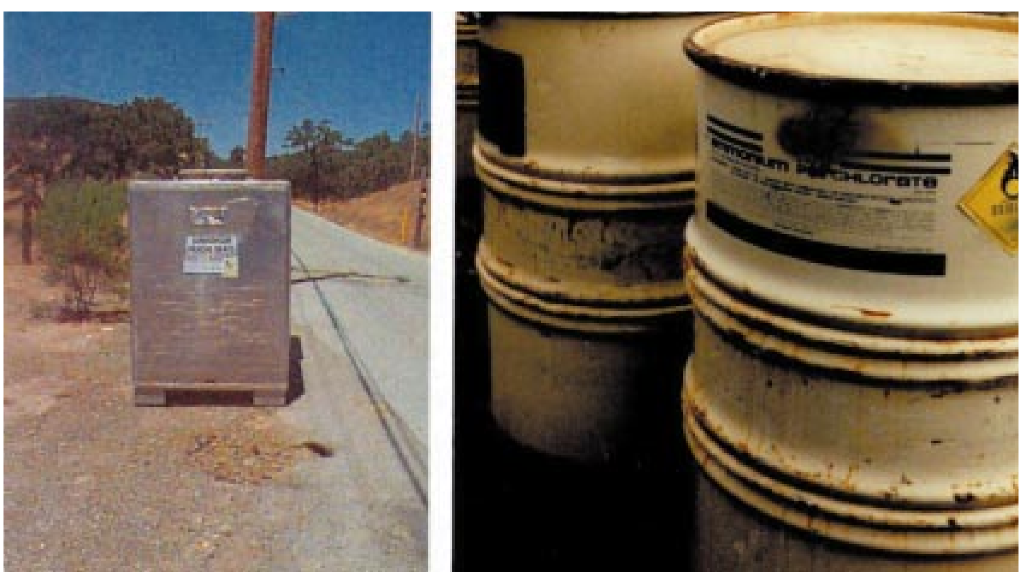


Photo Credits: Left, The Charles Stark Draper Laboratories; Right, Kerr McGee

Figure 4-3: Two different ammonium perchlorate shipping containers.

Produced by companies in

There are no known suppliers of these mixtures because of the extreme fire hazard; however, many countries can create and ship such mixtures.

(c) Oxidizers / Fuels
(1) Perchlorates, chlorates or chromates mixed with powdered metals or other high energy fuel components.

Nature and Purpose: Perchlorates, chlorates, and chromates mixed with fuel components of any kind (e.g., powdered metals) are extremely unstable, likely to ignite or explode, and hard to control in propellants. AP, the oxidizer of choice for most solid propellant applications, is rarely shipped in large bulk quantities mixed with a fuel component because of the associated combustion hazard. However, these mixtures are shipped in components such as ignitors or in small packages (approximately 3 kg).

Method of Operation: The oxygen in perchlorates, chlorates, and chromates is released during combustion, making it available to burn the high-energy fuel in the propellant mixture. Because the oxygen is distributed evenly throughout the mixture, it burns very rapidly without air and is difficult to extinguish.

Typical Missile-Related Uses: AP mixed with powdered aluminum is routinely used in solid rocket motors. Other mixtures of oxidizers and fuels are generally used in missile ignition or delay devices and are rarely used for other purposes in missiles.

Other Uses: When mixed with powdered metals, perchlorates, chlorates, or chromates have commercial use in flares and incendiary devices.

Appearance (as manufactured): The color of these materials varies with the oxidizer and fuel used. Numerous combinations exist, but the most likely (AP and aluminum powder) are light gray materials with a texture resembling table salt.

Appearance (as packaged): Perchlorates, chlorates, or chromates, when mixed with powdered metals, are extreme fire or explosive hazards and are very unlikely to be shipped in such mixtures. Rather, they are shipped separately from powdered metals or other high-energy fuel components and then mixed together as a motor is being cast.

Produced by companies in

- Russia
- United States

For Nitric Acids
- Worldwide

(d) Oxidizer Substances
(1) Liquid
(a) Dinitrogen trioxide;
(b) Nitrogen dioxide / dinitrogen tetroxide;
(c) Dinitrogen pentoxide;
(d) Inhibited Red Fuming Nitric Acid (IRFNA);
(e) Compounds composed of flourine and one or more of other halogens, oxygen or nitrogen.

Nature and Purpose: Oxidizers provide oxygen or halogen to burn the fuel in any rocket motor or engine. By carrying the fuel and oxidizer together, a missile is not dependent on the atmosphere for oxygen and can thus operate in space.

Method of Operation: In solid rocket motors, the oxidizer is mixed evenly with fuels and cast into the motor case before use. In liquid rocket engines, the oxidizer and fuel are injected into the combustion chamber at great pressure, mixed, and ignited. In either case, heat causes the oxygen to dissociate from the oxidizer and become more available to burn with the fuel. Some liquid propellants react spontaneously on contact. Resulting hot gases accelerate through a rocket nozzle to develop reaction thrust.

Typical Missile-Related Uses:

- Dinitrogen trioxide (N_2O_3) is a black liquid at normal atmospheric pressure that decomposes above 3.5°C and freezes at –102°C. N_2O_3 is not often used as a missile propellant.

- Dinitrogen tetroxide (N_2O_4), also known as nitrogen tetroxide (NTO), is a dimer of two molecules of nitrogen dioxide (NO_2) gas. N_2O_4 is a liquid at normal atmospheric pressure and temperature (below 21°C). However, it is a liquid in a small temperature range, so it can only be used on missiles kept in temperature controlled environments such as silos. Therefore, N_2O_4 is not commonly used in mobile and tactical missiles. The freezing point of dinitrogen tetroxide can be depressed considerably with the addition of nitrous oxide (NO) gas up to about 40 percent by weight. The result is mixed oxides of nitrogen (MON), which are green liquids with high vapor pressures. These propellants with a lower liquid temperature range are used in tactical missile systems.

- Dinitrogen pentoxide (N_2O_5) is not normally used as an oxidizer in liquid rocket engines because it is a solid at normal atmospheric pressure and temperature.

- Inhibited Red Fuming Nitric Acid (IRFNA) has a high density and a low freezing-point; it is a commonly available nitric acid oxidizer favored for tactical missiles. IRFNA is widely used in Scud-technology-based missile systems.

- Chlorine trifluoride (ClF_3) and chloryl (per-) fluoride (ClO_3F) are the two most common halogen-based oxidizers. Because they are very toxic and energetic oxidizers, they are difficult to handle. Thus, they are rarely used except for technology development. Other inter-halogen oxidizers have been developed and tested, but they are not used because of cost, handling, and safety considerations. For example, chlorine pentafluoride (ClF_5) and fluorox (ClF_3O) are difficult to make safely and are not available. They were originally developed because fluorine / hydrazine is a very high performing propellant combination, but the fluorine must be kept below its boiling point (–188°C) to keep it from boiling off, and is thus impractical for use as an oxidizer for tactical missiles. The same is true for chlorine. Halogen-based oxidizers are unlikely to be encountered.

Other Uses:

- N_2O_4 is commonly used in satellites and in the orbital maneuvering system of the US space shuttle. A mixture of nitric oxide (NO_2) and N_2O_4 is the precursor for all nitric acid production and is used as a nitrating agent for agricultural chemicals, plastics, paper, and rubber.

- N_2O_5 is used to make explosives and is a nitrating agent in organic chemistry.

- Concentrated nitric acid, the main constituent of IRFNA, is used to make pharmaceuticals and explosives.

- Chlorine and fluorine have many commercial uses. Chlorine is used widely to purify water, to disinfect or bleach materials, and to manufacture many important compounds including chloroform and carbon tetrachloride. ClF_3 is used in nuclear fuel reprocessing, and ClO_3F is used as a gaseous dielectric in transformers.

Appearance (as manufactured):*

- NO_2 is a red-brown gas, and N_2O_4 is a red-brown liquid at room temperature. Depending on temperature and pressure, NO_2 and N_2O_4 form equilibria at various percentages. MONs are mixtures of NO_2 and N_2O_4, and form green liquids with lower freezing points than N_2O_4, which freezes at –11°C and boils at +21°C. The density of N_2O_4 is 1.43 g / ml.

- Red-fuming nitric acid (RFNA) is nearly anhydrous nitric acid that is stabilized with high concentrations of added nitric oxides. In the United States, about 15 percent NO_2 is usually dissolved in the acid, but more can be added to increase the liquid density. Maximum density nitric acid (MDNA) is 56 percent HNO_3 and 44 percent N_2O_4. Because nitric acid is corrosive to most non-noble materials (materials that react chemically), a small amount (approximately 0.75 percent) of hydrofluoric acid (HF) is added to produce IRFNA. Stored in stainless steel or aluminum containers, HF forms protective fluorides, which reduce the rates of wall corrosion. IRFNA freezes at approximately –65°C and boils at approximately +60°C. Its density at normal room temperature is about 1.55 g / ml, depending on the amount of N_2O_4 added.

- Fluorine is a pale yellow, highly corrosive, poisonous, gaseous, halogen element. It is usually considered the most reactive of all the elements. Its freezing point is –220°C, and its boiling point is –188°C, which makes it a cryogenic liquid. Its specific gravity in liquid state is 1.108 g / ml at its boiling point.

*Measurements are at standard temperature and pressure.

- Chlorine is a greenish-yellow gas, highly irritating, and capable of combining with nearly all other elements. It is produced mainly by electrolysis of sodium chloride. Its freezing point is –101°C; its boiling point is –35°C; and its specific gravity is 1.56 g / ml (at –34°C).

- Chlorine pentafluoride (ClF_5), which boils at –14°C at one atmosphere pressure, must be pressurized to maintain and ship in liquid form. Its density is 1.78 g / ml at +25°C. Because chlorine trifluoride (ClF_3) boils at +12°C, it is easier to handle than ClF_5, but it must still be pressurized for shipping. Bromine pentafluoride (BrF_5) boils at +40°C, but other characteristics such as shock sensitivity, toxicity, corrosiveness, and lower specific impulse potential make it an impractical propellant.

- Nitrogen trifluoride (NF_3) is a cryogenic oxidizer that boils at –130°C and has a density of 1.55 g / ml at its normal boiling point. Nitrogen tetrafluoride (N_2F_4) has a higher density and boiling point but is also cryogenic.

Appearance (as packaged):

- Nitric acids and NTO / N_2O_4 variants are usually stored in stainless steel tanks that have been specially prepared. Aluminum tanks and lines are also compatible with nitric acid. Packages for shipping these chemicals use identifying words, warnings, labels, and symbols. MON must be shipped in pressurized containers due to its high vapor pressure and low boiling point.

- IRFNA is usually stored and shipped in aluminum tanks that have been specially prepared. Stainless steel tanks and lines are also compatible.

- Exotic propellants such as chlorine and fluorine are cryogenic liquids and are extremely reactive and toxic. Accordingly, their shipping and handling are tightly regulated. Ordinary metal containers cannot be used to contain them. Super-cooled and pressurized tanks are required to ship in liquid form. Oxygen difluoride (OF_2) can be stored at low temperatures in glass-lined, stainless steel tanks that have been specially prepared.

(2) Solid
(a) Ammonium perchlorate;
(b) Ammonium Dinitramide (ADN);
(c) Nitro-amines (cyclotetramethylene-tetranitramine (HMX), cyclotetrimethylene-trinitramine (RDX)).

Produced by companies in

- Brazil
- China
- France
- India
- Japan
- Russia
- United Kingdom
- United States

Only Russia, Sweden, and the United States have produced ADN.

Nature and Purpose: Solid oxidizers provide oxygen needed to burn solid rocket motor fuel. By carrying fuel and oxidizer together, the rocket does not depend on the atmosphere for oxygen. Nitro-amines are not oxidizers *per se,* but high explosives added to propellants to increase their performance.

Method of Operation: The solid oxidizer is mixed evenly with fuels and cast into a rocket motor. The oxygen disassociates during the burn process and becomes available to rapidly burn available fuel and, by generating gases exhausted at very high speeds, produce thrust.

Typical Missile-Related Uses:

- Ammonium perchlorate (AP) is an oxidizing agent used by most modern solid-propellant formulas. It accounts for 50 to 85 percent of the propellant by weight, depending on the formulation of the propellant.

- ADN is an oxidizing agent for solid propellant. This material is used in a manner similar to AP.

- HMX, commonly called Octogen, and RDX, commonly called Cyclonite, are high-energy explosives often added to solid propellants to lower the combustion temperature and reduce smoke. Usually less than 30 percent of the propellant weight is HMX or RDX.

Other Uses:

- AP is used in explosives, pyrotechnics, and analytical chemistry, and as an etching and engraving agent.

- ADN has no known commercial uses.

- HMX and RDX are used in warheads, military and civilian explosives, and oil well pipe cutters.

Appearance (as manufactured):

- AP is a white or, depending on purity, off-white crystalline solid, similar in appearance to common table salt. AP is shown on the right side of Figure 4-2.

- ADN is a white, waxy, crystalline solid that may appear as thin platelets or small round pills.

- HMX and RDX are white crystalline materials that resemble very fine table salt. HMX is shown on the left side of Figure 4-2.

Appearance (as packaged):

- AP is usually packaged and shipped in 30- or 55-gallon polyethylene-lined drums with oxidizer or explosive symbol markings. Two different types of AP containers and their markings are shown in Figure 4-3.

- ADN is packaged and shipped in a similar manner to AP.

- HMX and RDX are usually packaged and shipped either in water or alcohol (because in dry form they are prone to explode) in 30- or 55-gallon polyethylene-lined drums with oxidizer or explosive symbol markings.

Additional Information:

- AP is generally produced with an average particle size of 200 to 400 microns (70 to 40 mesh). The density of AP is 1.95 g/cc, but the bulk density is less and varies with particle size. AP decomposes violently before it melts. The chemical formula of AP is NH_4ClO_4.

- ADN has a density of 1.75 g/cc and a reported melting point of 92 to 95°C. The chemical formula for ADN is $NH_4N(NO_2)_2$.

- HMX and RDX are generally produced with a particle size of 150 to 160 microns (100-80 mesh). HMX has a density of 1.91 g/cc, a melting point of 275°C, and a chemical formula of $C_4H_8N_8O_8$. RDX has a density of 1.81 g/cc, a melting point of 204°C, and a chemical formula of $C_3H_6N_6O_6$. HMX and RDX also decompose violently at their melting points.

(e) Polymeric Substances
  (1) Carboxyl-terminated polybutadiene (CTPB);
  (2) Hydroxyl-terminated polybutadiene (HTPB);
  (3) Glycidyl azide polymer (GAP);
  (4) Polybutadiene-acrylic acid (PBAA);
  (5) Polybutadiene-acrylic acid-acrylonitrile (PBAN).

Produced by companies in

- China
- France
- India
- Japan
- Russia
- United States

Nature and Purpose: These five polymers are chemicals used as a binder and fuel in solid rocket motor propellant. They are liquids that polymerize during motor manufacture to form the elastic matrix that holds the solid propellant ingredients together in a rubber-like polymeric composite material. They also burn as fuels and contribute to overall thrust. GAP is the only energetic polymer in this group. It provides energy as a result of its decomposition during the combustion process.

Method of Operation: Batch mixers (or, rarely, continuous mixers for very large scale production) are used to blend carefully controlled ratios of rocket motor propellant ingredients into the polymeric substance. The viscous, well blended material is then cast into a rocket motor case, in which it polymerizes and adheres to either an interior liner or insulator inside the rocket motor case. The result is a rocket motor fully loaded with solid propellant.

Typical Missile-Related Uses: These polymeric substances are used in the production of solid propellant for solid rocket motors and hybrid rocket motors. They are also used in the production of smaller solid rocket motors used to launch UAVs and cruise missiles. These binding ingredients greatly affect motor performance, aging, storability, propellant processing, and reliability.

Although all these materials are of concern as potential solid propellant binders, HTPB is the preferred binder. At present, no fielded ballistic missile systems use GAP or PBAA. CTPB and PBAN have largely supplanted PBAA because of their superior mechanical and aging characteristics.

Other Uses: PBAN has no commercial uses. HTPB has extensive uses in asphalt and electronics, and as a sealant.

Appearance (as manufactured): These five polymeric materials are clear, colorless, viscous liquids. Antioxidants are added at the level of one percent or less at the time of manufacture in order to improve shelf life; they impart a color to the materials, which may range from light yellow to dark brown. This color depends on the type and amount of antioxidant used.

The viscosity of these five liquids ranges from that of light syrup to that of heavy molasses. Except for GAP, which is nearly odorless and has a specific density of 1.3, the polybutadiene-based polymers have a very distinctive petroleum-like odor and densities slightly less than that of water (0.91 to 0.94).

Appearance (as packaged): These liquids are usually shipped in 55-gallon steel drums. The interiors of the drums are usually coated with an epoxy paint or other material to prevent rusting. If the liquids are shipped in stainless steel drums, the coating is not necessary. Smaller or larger containers may be used, depending on the quantity being shipped; tank-cars or tank-trucks may be used to ship very large quantities. An example of PBAN in its shipping drum is presented in Figure 4-4.

Photo Credit: The Charles Stark Draper Laboratories

Figure 4-4: Top view of PBAN in a shipping drum.

(f) Other Propellant Additives and Agents
  (1) Bonding Agents
    (a) Tris (1-(2-methyl)) aziridinyl phosphine oxide (MAPO);
    (b) Trimesoyl-1-(2-ethyl) aziridene (HX-868, BITA);
    (c) "Tepanol" (HX-878), reaction product of tetraethylenepentamine, acrylonitrile and glycidol;
    (d) "Tepan" (HX-879), reaction product of tetraethylenepentamine and acrylonitrile;
    (e) Polyfunctional aziridene amides with isophthalic, trimesic, isocyanuric, or trimethyladipic backbone and also having a 2-methyl or 2-ethyl aziridene group (HX-752, HX-874 and HX-877).

Nature and Purpose: Propellant bonding agents are used to improve the bond or adhesion between the binder and the oxidizer, typically AP. This process vastly improves the physical properties of the propellant by increasing its capability to withstand stress and strain. Bonding agents are normally used only with HTPB propellants. Some bonding agents are used as curing agents or crosslinkers with CTPB or PBAN propellants.

Method of Operation: Bonding agents are added to the propellant during the mixing operation at levels usually less than 0.3 percent. The bonding reacts with the AP to produce a very thin polymeric coating on the surface of the AP particle. This polymeric coating acts as an adhesive between the AP and the HTPB binder. The molecular structure stays much the same.

Typical Missile-Related Uses: Propellant bonding agents are used to polymerize propellants (bond the oxidizer) for solid rocket motors. They are also used in smaller rocket motors that launch UAVs, including cruise missiles. MAPO is a curing agent for carboxy-terminated polybutadiene (CTPB) prepolymers and a bonding agent for HTPB prepolymers. BITA is a bonding agent with HTPB. Tepan is a bonding agent with HTPB. Polyfunctional aziridene amides (PAAs) are bonding agents with HTPB and thickeners for CTPB and PBAN.

Other Uses: MAPO is used only in solid rocket propellants. BITA is used with HTPB in the commercial sector, especially in electronics, as a sealant, and as a curing agent for CTPB prepolymers. Tepanol and Tepan are used only in solid rocket propellants. PAAs are used in adhesives in the commercial sector.

Appearance (as manufactured): MAPO is a slightly viscous amber liquid. It has a very distinctive acrid odor. It polymerizes violently if it comes into contact with acids and AP. Its boiling point is 1,200°C at 0.004 bar; its density is 1.08 g/cc; and its chemical formula is $C_9H_{18}N_3OP$. BITA is a light yellow, viscous liquid; when cooled below 160°C, BITA is a pale, off-white, waxy solid. BITA has no sharply defined melting point, a density of 1.00 g/cc, and

Produced by companies in

MAPO
- France
- India
- Japan
- Russia
- United States

BITA
- United States

Tepanol
- United States

Tepan
- United States

PAAs
- United States

The United States is the main producer and supplier of these materials, but some European and Asian countries may have production licenses, and production of these materials may be more widespread because the composition of these materials is open-source information and production methods are not difficult to duplicate.

a chemical formula of $C_{21}H_{27}N_3O_3$. Tepanol is a dark yellow, viscous liquid. It has a very strong odor like that of ammonia. Tepan is much less viscous than Tepanol but identical to it in all other respects including a very strong odor like that of ammonia. PAAs are similar to BITA.

Appearance (as packaged): MAPO is packaged and shipped in standard, 1- to 55-gallon steel cans or drums. BITA is packaged in 1-gallon steel cans, which are usually shipped in insulated containers packed with dry ice and stored at 0°C or less in order to maintain its useful shelf life. Tepanol, Tepan, and PAA shipping and storage conditions are identical to BITA.

Produced by companies in

- France
- Japan
- Switzerland
- United States

(2) Curing Agents and Catalysts
(a) Triphenyl Bismuth (TPB);

Nature and Purpose: Curing agents and catalysts are used to polymerize solid rocket motors; that is, they cause the viscous mixture of liquid polymeric substance and other solid propellant ingredients to solidify into a rubbery composite, which adheres to the inner lining or insulator inside the motor case.

Method of Operation: Triphenyl bismuth (TPB) is added in relatively small quantities to HTPB to trigger a relatively mild chemical reaction known as polymerization. The molecular structure of HTPB stays much the same, but the material converts from liquid to solid form due to molecular cross-linking.

Typical Missile-Related Uses: TPB is used as a cure catalyst in HTPB solid rocket propellants.

Other Uses: TPB is used in some plastics.

Appearance (as manufactured): TPB is a white to light tan crystalline powder. TPB has a density of 1.7 g/cc, a melting point of 78°C, and the chemical formula $C_{18}H_{15}Bi$. A sample of TPB is shown in the lower left of Figure 4-2.

Appearance (as packaged): TPB is packed in brown glass containers because of its sensitivity to light. These containers range in capacity from a few grams to 5 kg. When shipped in larger quantities, TPB may be packed in polyethylene bags inside fiber packs or cardboard cartons.

Produced by companies in

For Catocene
- United States

For Ferrocene derivatives
- China
- France
- Germany
- Japan
- Switzerland
- United Kingdom
- United States

For Borane derivatives
- France
- Russia
- United Kingdom
- United States

For Butacene
- France

(3) Burning Rate Modifiers
(a) Catocene;
(b) N-butyl-ferrocene;
(c) Butacene;
(d) Other ferrocene derivatives;
(e) Carboranes, decarboranes, pentaboranes and derivatives thereof;

Nature and Purpose: Burning rate modifiers are chemical additives to solid rocket propellant, which alter the rate at which the fuel burns. The purpose is to tailor the rocket motor burn time to meet requirements.

Method of Operation: Burning rate modifiers are blended in carefully controlled quantities into rocket motor propellant during production.

Typical Missile-Related Uses: They are added to propellant to modify burn rates and allow designers to tailor the thrust profile to meet requirements.

Other Uses: Some borane derivatives have commercial uses as catalysts in olefin polymerization and as agents in rubber vulcanization.

Appearance (as manufactured):

- Catocene is a slightly viscous, dark red liquid but appears yellow in a thin film or as a yellow stain on white cloth or paper. It is a mixture of six isomers, all with high boiling temperatures. It is insoluble in water but soluble in most organic solvents. It has a density of 1.145 g/cc, slightly greater than that of water. Catocene has the chemical formula $C_{27}H_{32}Fe_2$. Catocene, the commercial tradename for 2,2′-bis (ethylferrocenyl) propane, is probably the most widely used ferrocene in the propellant industry. All ferrocene derivatives contain iron and are added to propellants containing AP.

- N-butyl ferrocene and other ferrocene derivatives are similar in appearance to catocene. Ferrocenes have fewer applications to Category I missiles than to smaller tactical missiles. They increase propellant sensitivity to accidental ignition by friction and electrostatic discharge.

- Butacene is unique as it is both an HTPB binder and a burn rate modifier. It is a very high-viscosity liquid, which resembles a very heavy, dark corn syrup or molasses.

- Carboranes, decarboranes, pentaboranes, and their derivatives are clear, colorless liquids with no distinct odor. The most common carborane derivatives used in solid propellants are n-hexyl carborane and carboranylmethyl propionate. Carboranes may cause nerve damage, according to a few studies. Alkali metal salts of decarborances and pentaboranes are white powders. Most borane derivatives are less dense than water and are toxic. Borane derivatives are used to produce extremely high burn rates in solid propellants. Borane derivatives are extremely expensive to produce, with costs ranging from $2,200 to $11,000 per kg. They are rarely used in ballistic missile propellants.

Appearance (as packaged): All of these materials are shipped in steel containers ranging in capacity from 1 to 55 gal.

Produced by companies in

Any country can acquire the capability to produce these products. Any country that has set up a nitration plant, such as for the production of explosives, could produce a variety of these nitrate esters.

(4) Nitrate Esters and Nitrated Plasticizers
(a) Triethylene glycol dinitrate (TEGDN);
(b) Trimethylolethane trinitrate (TMETN);
(c) 1,2,4-Butanetriol trinitrate (BTTN);
(d) Diethylene glycol dinitrate (DEGDN);

Nature and Purpose: These nitrate esters, also known as nitrated plasticizers, are additives to solid rocket propellants used to increase their burn rate.

Method of Operation: Nitrate esters and nitrated plasticizers are liquid explosives, which contain enough oxygen to support their own combustion. They are generally added to high performance propellants containing HMX and aluminum to achieve higher performance.

Typical Missile-Related Uses: Nitrate esters and nitrated plasticizers are added to double-base propellants to increase their propulsive energy. Because plasticizers do not react with the cure agents and remain liquid at low temperatures, they make solid propellants less likely to crack or shrink in cold temperatures.

Other Uses: Nitrate esters are used as components of military and commercial explosives.

Appearance (as manufactured): Nitrate esters are dense, oily liquids ranging in color from clear to slightly yellow.

Appearance (as packaged): Nitrate esters are shipped in 5 to 55 gallon steel drums marked with labels indicating explosives. Except for BTTN, these nitrate esters are shipped undiluted unless the end-user requests that they be shipped diluted with a solvent. Because of its sensitivity to shock, BTTN is shipped diluted with either methylene chloride or acetone. When diluted with methylene chloride, BTTN has a sweet odor like that of chloroform. When diluted with acetone, it has an odor like that of nail polish. When stabilizers are added (usually at the 1.0% level) the nitrate ester acquires a deep red color.

Produced by companies in

2-NDPA
- France
- Japan
- Switzerland
- United Kingdom
- United States

MNA
- Switzerland
- United Kingdom
- United States

(5) Stabilizers, as follows
(a) 2-Nitrodiphenylamine;
(b) N-methyl-p-nitroaniline

Nature and Purpose: 2-nitrodiphenylamine (2-NDPA) and N-methyl-p-nitroaniline (MNA) are additives that inhibit or reduce decomposition of rocket fuels containing nitrate esters or nitrocellulose. These types of propellants are referred to as double-base, composite-modified double-base, or cross-linked double-base propellants.

Method of Operation: These stabilizers alter the chemical environment within the propellant to reduce decomposition of its constituents.

Typical Missile-Related Uses: These stabilizers make composite propellants less subject to the effects of aging. As a result, they increase the effective lifetime of solid propellant missiles.

Other Uses: 2-NDPA is used in explosives as a nitroglycerin stabilizer. It is used widely throughout the ammunition industry. MNA has no known commercial uses.

Appearance (as manufactured):

- In its pure state, 2-NDPA is a bright yellow, crystalline solid with a density of 1.15 g/cc and a melting point of 74 to 76°C. The chemical formula for 2-NDPA is $C_{12}H_{10}N_2O_2$. When exposed to light, 2-NDPA turns to a dark orange color. A sample of 2-NDPA that has been exposed to light is shown in the lower right of Figure 4-2.

- MNA is also a bright yellow, crystalline solid with a density of 1.20 g/cc and a melting point of 152–154°C. The chemical formula for MNA is $C_7H_8N_2O_2$. A sample of MNA is shown in the upper left of Figure 4-2.

Appearance (as packaged): When shipped in small quantities, 2-NDPA and MNA are packaged in brown glass containers because they are sensitive to light. When shipped in larger quantities, they are packaged in polyethylene bags and placed inside fiberpack or cardboard containers.

ITEM 5
Propellant Production

Propellant Production

Production technology, or "production equipment" (including its specially designed components) for:
(a) Production, handling or acceptance testing of liquid propellants or propellant constituents described in Item 4.

Nature and Purpose: Individual components of liquid propellant production equipment are common to any petroleum distillation facility or large chemical plant. Typical components include reactor tanks, condensers, recovery columns, heaters, evaporators, filter assemblies, decanters, chillers, gas separators, and centrifugal pumps. None of these components by themselves is specially designed for use in making liquid propellants. However, when combined into a propellant production facility, such a facility is generally optimized for the production of a particular propellant and ill suited for making anything else.

The technologies for making liquid propellants are generally well known, although various companies may have proprietary procedures for maximizing yield, minimizing cost, or finding alternative uses for byproducts. Exceptions to this general rule include chlorine pentafluoride (ClF_5) and fluorox (ClF_3O), the manufacturing methods of which are closely held.

Acceptance testing of liquid propellants requires analytical equipment common to most chemical quality control labs, including equipment such as gas chromatographs, atomic absorption spectrometers, infrared spectrometers, and bomb calorimeters. This equipment generally can be used without modification to analyze liquid rocket propellants for acceptance.

Method of Operation: Specific production methods depend on the propellant being manufactured. Many of the constituents used in propellants are commonly produced for commercial purposes but require additional processing to purify, stabilize, inhibit, or blend to achieve certain properties. For example, sulfuric acid or magnesium carbonate is used to purify nitric acid. Commercial nitric acid, usually combined with water as hydrate, contains only 55 to 70 percent acid. Chemical processing is needed to break the hydrates to produce 97 to 99 percent pure, anhydrous (waterless) nitric acid. To form Inhibited Red Fuming Nitric Acid (IRFNA), N_2O_4 is added to the concentrated nitric acid to stabilize it against rapid decomposition, and trace amounts of hydrogen fluoride (HF) are added to reduce corrosion of containers.

Typical Missile-Related Uses: Liquid propellant production and acceptance testing equipment are required to develop an indigenous capability to make propellants.

Other Uses: The equipment and technologies are in common use and widely known in the petroleum and chemical production industries.

Appearance (as manufactured): In general, complete liquid propellant manufacturing facilities are not bought and transferred in one piece; they are assembled from many common pieces of chemical and industrial process equipment. Unless a turnkey plant is shipped, the most likely encountered items are probably the plans, drawings, calculations, and equipment lists associated with a plant design. There is even commercially available software that assists chemical engineers in designing such facilities.

Appearance (as packaged): The size of liquid propellant manufacturing equipment dictates the packaging. Smaller machines are crated in shock-absorbing containers or attached to cushioned pallets isolated from other packages. Larger machines are disassembled for shipping and reassembled onsite, and their components are packaged separately in crates or pallets.

(b) Production, handling, mixing, curing, casting, pressing, machining, extruding or acceptance testing of solid propellants or propellant constituents described in Item 4 other than those described in 5(c).

Nature and Purpose: The production equipment and infrastructure necessary to produce solid rocket propellant are complex and specialized. Facilities and equipment are necessary for preparing the various propellant ingredients, mixing and handling the propellant, casting and curing the propellant inside the motor case, and other specialized operations such as pressing, machining, extruding, and acceptance testing.

Method of Operation: Solid propellant is produced by one of two processes, either batch mixing or continuous mixing. Most missile programs use the batch process to make solid rocket motor propellant. After receipt and acceptance testing of the individual ingredients, ammonium perchlorate (AP) and others are usually ground in a mill to obtain the required particle size. All ingredients, including the binder, AP, metal powder, stabilizers, curing agents, and burn-rate modifiers, are mixed in large mixers to form a viscous slurry. The propellant slurry is poured or cast into the rocket motor case, in which a mandrel creates a hollow chamber running down the center of the motor. The loaded motor case is placed in a large oven to cure the propellant. During curing, the slurry is transformed into a hard rubbery material, or propellant grain. The rocket motor with the cured propellant is then cooled, the mandrel removed, and any final trimming or machining operations done. Finished motors are usually X-rayed to ensure that the propellant grain is homogeneous, bonded everywhere to the case, and free of cracks.

Photo Credit: British Aerospace Limited

Figure 5-1: Tactical motors with cast-cure tooling attached.

In continuous mixing, the same propellant ingredients are continuously measured into a mixing chamber, mixed, and continuously discharged into the motor or other container until the required amount of propellant has been obtained. This type of mixing is difficult because it is hard to precisely measure small amounts of some ingredients such as curing agents required for some propellants. Continuous mixing is not, therefore, used to any large extent.

Typical Missile-Related Uses: Better solid propellants improve missile range and payload capability. Solid propellant production equipment and acceptance testing equipment are required for a nation to develop an indigenous capability to produce propellants for rocket-motor-powered missiles.

Other Uses: N/A.

Appearance (as manufactured): Specialized devices are used to cast propellant by creating a vacuum, which removes air from the propellant as the propellant is poured into the rocket motor case. The size of these devices varies with the size of the rocket motors, but principles of operation are the same. Cast-cure tooling for small tactical motors is shown in Figure 5-1. The equipment and process for a small motor are shown in Figure 5-2. The mixed propellant is poured from the mix bowl into a large casting funnel, which is attached to the rocket motor. A large valve in the neck of the casting funnel isolates the motor in the vacuum from ambient atmospheric con-

Photo Credit: British Aerospace Limited

Figure 5-2: Slurry cast double-base mixing equipment for a small motor.

Photo Credit: Thiokol Corp.

Figure 5-3: A propellant casting pit, with a motor case belowground.

ditions. Once the casting funnel is full of propellant, the valve is opened slowly to allow the propellant to flow into the rocket motor case. Very large motors are sometimes cast in a cast / cure pit, which is an underground concrete structure lined with heating coils. The entire pit is evacuated before casting operations start. A belowground casting / curing pit in operation is shown in Figure 5-3. As with other specialized propellant equipment, the casting equipment is generally constructed on-site; its size depends on the size of the motor and the manner in which the casting operation is done.

Curing equipment ranges in kind and size from large, electrically or steam-heated ovens to large, heated buildings. This equipment is not particularly specialized because the process is a simple one, requiring only that motor temperature be raised for a given amount of time. Large cast / cure pits are permanent, on-site facilities.

The equipment used for acceptance testing of a batch of propellant is identical to the equipment found in an analytical chemistry or a materials testing laboratory. This equipment is used to perform chemical testing to verify the composition; to burn small amounts of propellant or test subscale motors to verify burning rate; and to conduct tensile testing to ensure that the propellant has the physical properties required by the rocket motor design.

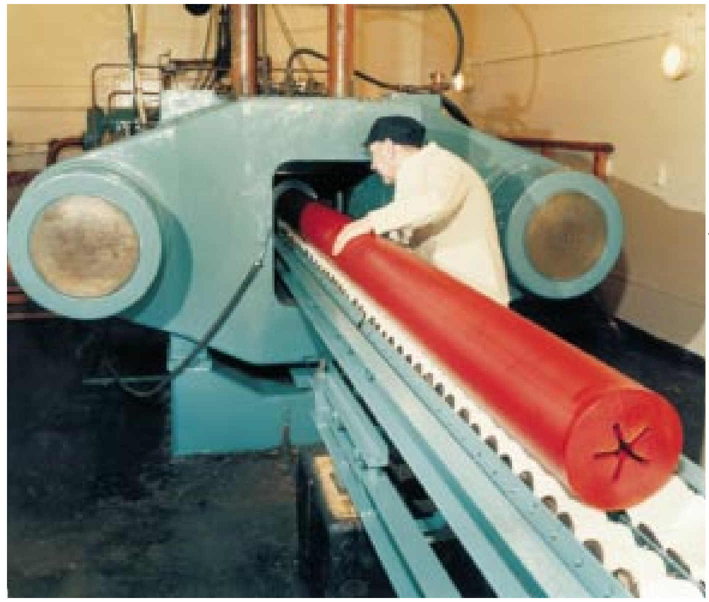


Photo Credit: British Aerospace Limited

Figure 5-4: A solid propellant extruder and grain.

Machining of solid propellant surfaces is generally done by large cutting machines specially modified to accommodate the safety hazards associated with solid propellants. Many of these types of machines are built specifically for a particular rocket motor.

Solid propellant grains for the large rocket motors of interest are usually too large to be directly handled by an extruder. However, some propellants of MTCR interest are extruded in a preliminary processing step. Extrusion is generally limited to propellant grains less than 0.3 m in diameter and has more application to tactical air-to-air, surface-to-air, and air-to-surface missiles. Such an extruder producing a relatively small grain is shown in Figure 5-4.

Appearance (as packaged): The size of solid propellant production equipment dictates their packaging. Smaller machines are crated in shock-absorbing containers or attached to cushioned pallets. Larger machines are disassembled for shipping and reassembled onsite. Their components are packaged separately in crates or on pallets.

(c) Equipment as follows:
- (1) Batch mixers with the provision for mixing under vacuum in the range of zero to 13.326 kPa and with temperature control capability of the mixing chamber and having;
  - (i) A total volumetric capacity of 110 litres or more; and
  - (ii) At least one mixing / kneading shaft mounted off centre;
- (2) Continuous mixers with provision for mixing under vacuum in the range of zero to 13.326 kPa and with temperature control capability of the mixing chamber and having;
  - (i) Two or more mixing / kneading shafts; and
  - (ii) Capability to open the mixing chamber;

<u>Notes to Item 5:</u>

(1) The only batch mixers, continuous mixers usable for solid propellants or propellants constituents in Item 4, and fluid energy mills specified in Item 5, are those specified in 5(c).

Photo Credit: Alliant TechSystems, Inc.

Figure 5-5: A 420-gallon propellant mixing bowl.

Nature and Purpose: Batch mixers are powerful mixing machines for batch quantities of very viscous material. They are derived from machines used to mix bread dough. Their purpose is to mix liquids and powders of differing densities into a uniform blend.

Continuous mixers are powerful mixing machines that operate in a flow through manner. They mix larger quantities than batch mixers for high volume production.

Method of Operation: Batch mixers operate much like a household electric mixer. The bowl holds the ingredients that may be added in sequence while the turning blades mix everything together. Temperature control and vacuum are maintained by surrounding the bowl with a water jacket and covering the bowl with a sealed lid.

Continuous mixers gradually feed all the ingredients simultaneously in their correct proportions through the mix region. The mixing / kneading shafts thoroughly mix the continuous flow of liquids and powders, and the uniform blend is gradually discharged out the large pipe in a steady viscous stream.

Typical Missile-Related Uses: Batch and continuous mixers are used to mix precise quantities of liquid propellant constituents and powdered propellant constituents into a very unifrom blend. This mixture will burn violently if ignited so safety procedures are critical. The blend produced is later cast and cured in another process to create a rubbery composite material that serves as the propellant in a solid rocket motor.

Other Uses: Batch and continuous mixers may be used whenever the production of a viscous blend is required. However, most commerical applications will not require the temperature control and vacuum capabilities specified in Item 5(c).

Appearance (as manufactured): The most distinctive components of a batch mixer are the mixing bowl and the mix blade assembly. The mixing bowls are typically 0.75 to 1.5 m deep and 1 to 2 m in diameter, as shown in Figure 5-5, but may be significantly larger for mixers greater than 450 gallons (1,700 l). They are double-wall constructed; the inner wall is made of highly polished stainless steel, and the outer wall is generally made of cold-rolled steel, sometimes painted. The space between the walls is used for a hot / cold water heating / cooling jacket. The outer wall has two valves for the connection of inlet / outlet water hoses, as shown in Figure 5-5. The bowl is generally welded to a thick steel rectangular plate with wheels at each corner. The wheels may have grooves so that the bowl assembly can be placed on rails for easier movement. Sometimes the upper rim of the bowl is a machined flat surface with a large groove to accommodate an O-ring (gasket); other times the mixer head is provided with one or more such grooves. The purpose of the O-ring is to provide a seal while the mixing operation is under vacuum. The blade assembly consists of two or three large blades, also made of highly polished stainless steel. Most assemblies use twisted-paddle blades, and one of the blades has an opening, as shown in Figure 5-6. Other assemblies use cork-screw-shaped blades. Although it is not evident in the shipping configuration, the blade assembly operates in a "planetary" manner; that is, the central blade rotates in a fixed position while the other one or two blades rotate about their own axes as well as rotating about the central fixed blade. The remaining mixer components include an electric motor, gear assembly, mixer head, and supporting structure.

Photo Credit: Thiokol Corp.

Figure 5-6: Open-blade configuration of a batch mixer.

Appearance (as packaged): Mixers may be shipped as complete units or as components. As precision-machined devices, mixer blades are packaged to protect them from damage and the elements. They are likely to be incorporated into the mixer head and frame assembly, and securely cradled in shock isolation material blocking during shipping. Mixing bowls are large, heavy pieces of equipment also likely to be shipped in large, strong, wooden crates. They are securely attached to the crates to avoid damage. Crates tend to lack any distinctive features or markings.

(3) Fluid energy mills usable for grinding or milling substances specified in Item 4;

Nature and Purpose: Fluid energy mills use high-pressure air to cause particles to rub against one another and thereby grind them down to very small particle sizes, generally 20 microns or less. Particle sizes in this range are not easily obtained by other grinding means such as hammer mills. Fluid energy

Produced by companies in

- China
- France
- Germany
- United Kingdom
- United States

mills are also much safer for grinding explosive materials such as Octogen (HMX) and Cyclonite (RDX).

Typical Missile-Related Uses: Fluid energy mills produce fine-grained AP, HMX, or RDX powders used as oxidizers or burn-rate modifiers for solid rocket fuel.

Other Uses: Fluid energy mills are also used in food, mining, and paint pigment industries.

Appearance (as manufactured): Fluid energy mills are extremely simple devices with no moving parts. Most are flat, cylindrical devices made of stainless steel and measuring 7 to 10 cm in height and 7 to 40 cm in diameter. They have an inlet and outlet port for the attachment of ancillary equipment. The interior of the mill is a tubular spiral that the material to be ground is forced through with high-pressure air. Particle size is controlled by the rate at which the material to be ground is fed in, and the air pressure or airflow rate. Three such mills are shown in Figure 5-7.

Appearance (as packaged): Fluid energy mills are generally shipped in wooden crates with foam or packing material used to protect them during shipment. The crates are not distinctive.

(4) Metal powder "production equipment" usable for the "production," in a controlled environment, of spherical or atomised materials specified in 4(b) (3) or 4(b) (4) including:
  - (i) Plasma generators (high frequency arc-jet) usable for obtaining sputtered or spherical metallic powders with organization of the process in an argon-water environment;
  - (ii) Electroburst equipment usable for obtaining sputtered or spherical metallic powders with organization of the process in an argon-water environment;
  - (iii) Equipment usable for the "production" of spherical aluminum powders by powdering a melt in an inert medium (e.g., nitrogen).

Notes to Item 5:

(2) Forms of metal powder "production equipment" not specified in 5(c) (4) are to be evaluated in accordance with 5(b).

Method of Operation: The most common approach for producing fine metal powders for use as constituents in missile propellants is the molten metal process using equipment specified in Item 5(c)(4)(iii) above. This process scales well and can be used to make large amounts of powdered metal cost effectively. Both the plasma generator and electroburst methods are relatively new in the application and are not in widespread use on production programs. They are currently considered laboratory or R&D processes when compared to the molten metal process.

Photo Credit: The Charles Stark Draper Laboratories, Inc.

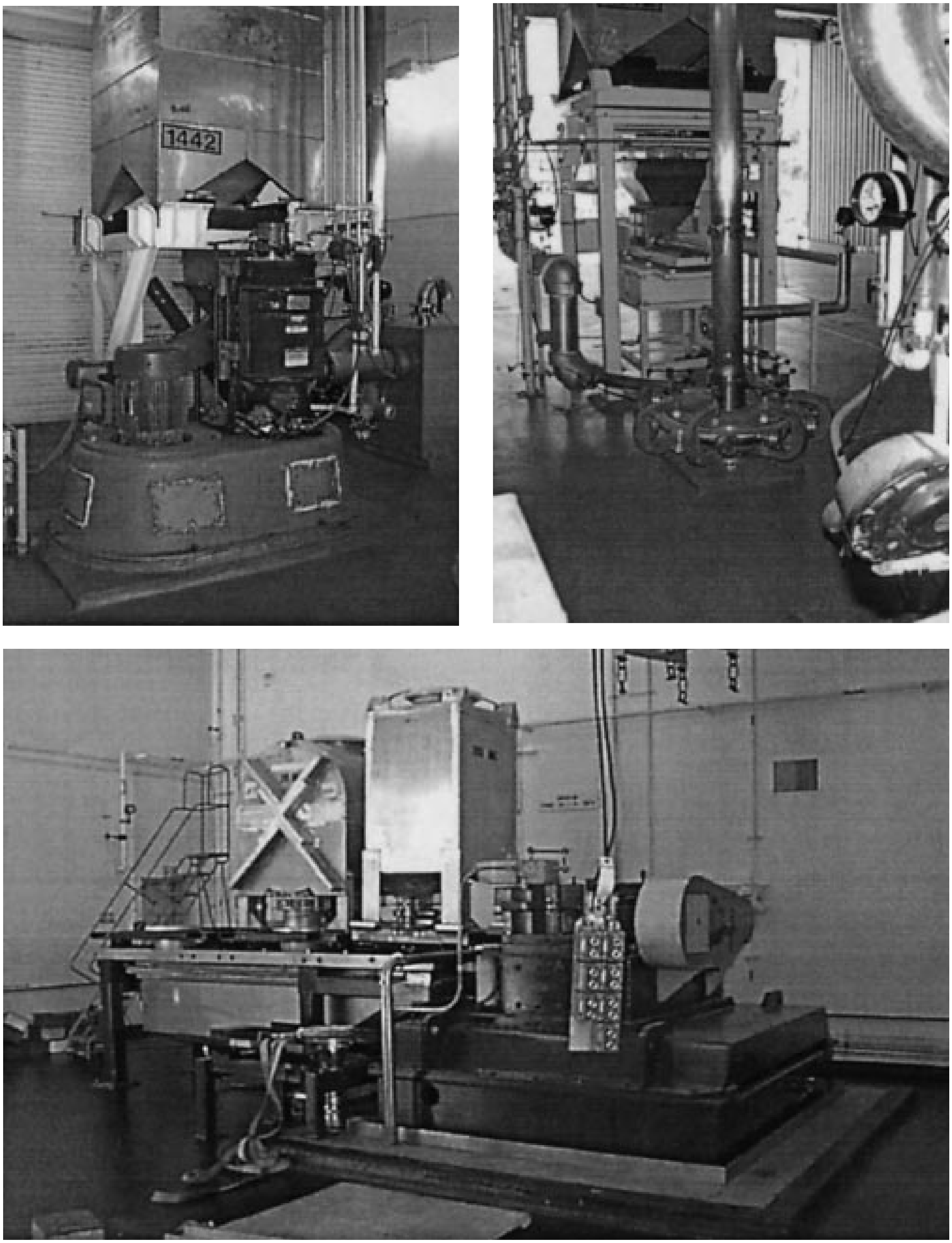


Figure 5-7: Three examples of fluid energy mills showing their various configurations.

In the molten metal process, molten metal is sprayed into the top of a large tank with an inert or controlled atmosphere. This atmosphere may be nitrogen, argon, or a mixture of both gases. A small controlled amount of oxygen is added to the atmosphere inside the tank when a thin oxide coating is desired on the metal powder. The molten metal spray causes small droplets to form, cool, and solidify into spherical particles of powder that fall to the bottom of the tank. The particle size of the metal powder is controlled by the size of the spray orifice.

Typical Missile-Related Uses: Atomized and spherical metallic powder production equipment is used to produce uniform, fine-grained metal powders used as a constituent in solid and liquid rocket fuel. Metallic powder is used to enhance the performance characteristics of the motor. Powdered metals are crucial in modern composite solid propellant motors. Atomized and spherical metallic powders in missile propellant increase missile range and payload capability.

Other Uses: Atomized and spherical metallic powder production equipment may be used to produce metal powders for many commercial applications, from pigments in metallic paints to fillers in structural adhesives.

Appearance (as manufactured): Equipment to produce atomized, spherical metal powder via the method described above is readily assembled from common equipment. The equipment includes a large tank into which the liquid metal is sprayed; a pump attached to the tank to remove the air; a filling system for the inert gas (e.g., tanks and a valve); a heater in which the metal is melted; and a sprayer-and-nozzle assembly that injects the metal into the tank.

Appearance (as packaged): An atomized-metal maker is not shipped as a single unit. Instead, its components are disassembled, packaged, and shipped like most industrial equipment. Smaller pieces are boxed or crated and secured to a pallet. The tank is boxed to protect it from denting. Spray nozzles are packaged separately in protected boxes.

ITEM 6
Composite Production

Composite Production

Produced by companies in

- France
- Germany
- Italy
- Japan
- Netherlands
- Russia
- United Kingdom
- United States

Equipment, "technical-data" and procedures for the production of structural composites usable in the systems in Item 1 as follows and specially designed components, and accessories and specially designed software therefor:

(a) Filament winding machines of which the motions for positioning, wrapping and winding fibres can be coordinated and programmed in three or more axes, designed to fabricate composite structures or laminates from fibrous or filamentary materials, and coordinating and programming controls;

<u>Note to Item 6:</u>

(1) Examples of components and accessories for the machines covered by this entry are: moulds, mandrels, dies, fixtures and tooling for the preform pressing, curing, casting, sintering or bonding of composite structures, laminates and manufactures thereof.

Nature and Purpose: Filament winding machines lay strong fibers coated with an epoxy or polyester resin onto rotating mandrels in prescribed patterns to create high strength-to-weight ratio composite parts. The winding machines look and operate like a lathe. After the winding operation is completed, the part requires autoclave and hydroclave curing.

Method of Operation: First, a mandrel is built to form the proper inner dimensions required by the part to be created. The mandrel is mounted on the filament winding machine and rotated. As it spins, it draws continuous fiber from supply spools through an epoxy or polyester resin bath and onto the outer surface of the mandrel. After winding, the mandrel and the part built up on it are removed from the machine, and the part is allowed to cure before the mandrel is removed in one of a variety of ways. Common types of mandrels include water-soluble spider / plaster mandrels; and segmented, collapsible mandrels. Large motor cases for solid rocket motors are usually manufactured on water-soluble sand mandrels. Nonremovable liners are sometimes also used. For example, metal-lined pressure vessels are made by using a metal liner as the mandrel, which is simply left inside the wound case.

Photo Credit: Thiokol Corp.

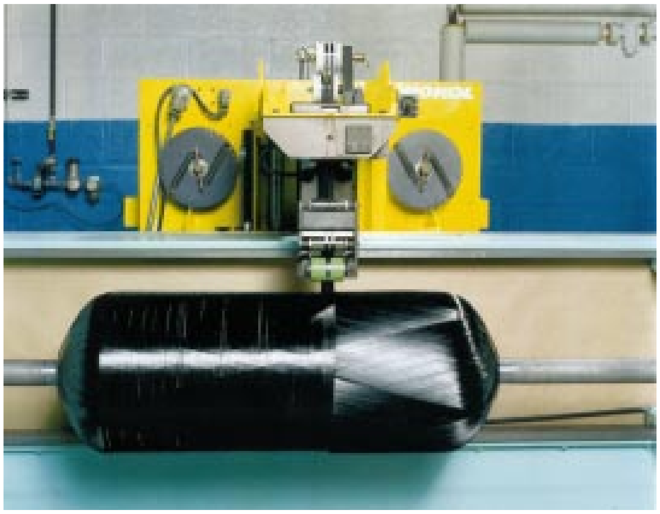


Figure 6-1:
Tabletop filament winding machine.

Typical Missile-Related Uses: Filament winding machines are used to make rocket motor cases, propellant tanks, pressure vessels, and payload shrouds. The high strength and low weight of the resulting structures make increased missile ranges and payload rates possible.

Other Uses: Filament winding machines are used to produce aircraft parts such as tail stabilizers, parts of wings, and the fuselage. They can be used to make liquid natural gas tanks, hot water tanks, compressed natural gas tanks, golf club shafts, tennis racquets, and fishing rods.

Appearance (as manufactured): The size of filament winding machines varies with the size of the part to be made. Filament winders used to manufacture parts 10 cm in diameter measure about 1 × 2 × 7 m and can fit on a tabletop, as shown in Figure 6-1. Winders for large components such as large rocket motor segments (approximately 3 m diameter and 8 m in length) are about 5 × 5 × 13 m and weigh several tons, as shown in Figure 6-2; another view of the same machine, Figure 6-3, shows the multiple spools of fiber. Most older filament winding machines developed during the late 1950s are gear-driven, and settings are made by hand. Most newer winding machines are numerically controlled and can wind complex shapes to meet special requirements.

Photo Credit: Thiokol Corp.

Figure 6-2:
A large multi spindle filament winding machine.

Appearance (as packaged): The size of filament winding machines dictates their packaging. Smaller machines are crated in shock-absorbing containers or attached to cushioned pallets isolated from other packages. Larger machines are disassembled for shipping and reassembled onsite, and their components are packaged separately in crates or on pallets.

(b) Tape-laying machines of which the motions for positioning and laying tape and sheets can be coordinated and programmed in two or more axes, designed for the manufacture of composite airframes and missile structures;

Produced by companies in

- France
- Germany
- Italy
- Japan
- Netherlands
- Russia
- United States

Nature and Purpose: Tape-laying machines resemble filament winding machines but are used in heavier applications that have sufficiently gradual contours or angles to allow the use of thick or wide tapes. The purpose of using a tape-laying machine instead of a filament winding machine is to reduce the number of revolutions of the mandrel needed to wind the part produced. This speeds up production and lowers cost.

Method of Operation: Tape-laying machines operate much like filament winding machines. The head on tape-laying machines can handle tape of various widths. Structures with little curvature use tapes with larger widths (up to about 30 cm). Structures with moderate to large curvature use tapes in smaller widths or apply them on the bias with respect to the principal direction of curvature.

Photo Credit: Thiokol Corp.

Figure 6-3: The filament winding machine with the multiple spools of fiber on the right.

Typical Missile-Related Uses: Tape-laying machines are used to make reentry vehicle heat shields, exit nozzles, igniters, and other parts exposed to high temperatures.

Other Uses: Tape-laying machines can be used to make many of the items made by filament winding machines, but they are most advantageously used to produce items that are largely cylindrical in shape. Examples are certain aircraft parts, tubes for bicycle frames, and water heaters. They are also used to wrap columns for bridge supports, containers, and pipes. They are extensively used to wrap high-temperature, down-hole pipe in oil-drilling operations.

Appearance (as manufactured): The size of tape-laying machines varies with the size of the required parts. Machines are either operator assisted or numerically controlled (NC). NC machines have a keyboard to input data for the desired composite lay-ups. The flatbed, which is the dominant feature of the machine, measures 1 to 2 m in length for the manufacture of small parts and 10 m for very large parts. The weight of large machines with a steel table and gantry could be 1000 to 2000 metric tons. Examples of two tape-laying machines are presented in Figures 6-4 and 6-5.

Figure 6-4: A tape winding machine that resembles a lathe.

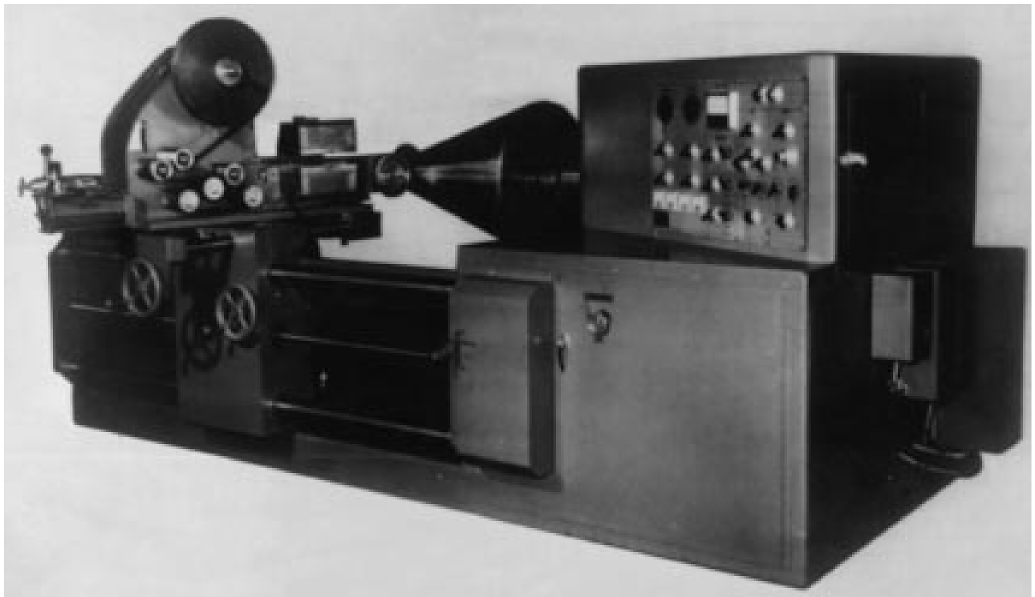


Figure 6-5: A modern, multi-axis numerically controlled tape laying machine.

Appearance (as packaged): The packaging of tape-laying machines depends on their size. Smaller machines can be completely encased in packing crates. Larger machines are disassembled for shipping and reassembled onsite. Their components are packaged separately in crates or on pallets. Very large flatbed tables can also be disassembled for shipment. All packaging is suitably protected for shock and vibration during transportation and handling.

(c) Multi-directional, multi-dimensional weaving machines or interlacing machines, including adapters and modification kits for weaving, interlacing or braiding fibres to manufacture composite structures, except textile machinery not modified for the above end uses;

Produced by companies in

- France
- Germany
- Japan
- Netherlands
- United States

Textile machinery not controlled and readily modified for low-end use can be purchased in many countries.

Nature and Purpose: Multi-directional, multi-dimensional weaving machines are used to interlink fibers to make complex composite structures. Braiding machines provide a general method of producing multi-directional material preforms. The purpose is to systematically lay down fibers along anticipated lines of stress in complex preform configurations and thereby make the parts stronger and lighter than otherwise possible.

Method of Operation: In one system, a weaving mandrel is first installed onto the machine. As the mandrel assembly rotates, circumferential fibers are continuously laid down at the weaving site by a tubular fiber delivery system, which includes fiber-tensioning devices and missing-fiber sensors. At each pie-shaped corridor formed by the weaving network, a radial knitting needle traverses the corridor, captures a radial fiber at the inside of the port, and returns to the outside of the port, where it makes a locking stitch that prevents movement of the radial fiber during subsequent operations. This process is continued and completed by final lacing.

Braiding machines intertwine two or more systems of fibers in the bias direction to form an integrated structure instead of lacing them only in a longitudinal direction as in weaving. Thus, braided material differs from woven and knitted fabrics in the method by which fiber is introduced into the fabric and in the manner by which the fibers are interlaced.

Typical Missile-Related Uses: Multi-directional, multi-dimensional weaving machines are used to make critical missile parts such as reentry vehicle nose tips and rocket nozzles that are exposed to high temperatures and stress.

Other Uses: Weaving machines are used to make a broad range of complex composite parts such as aircraft propellers, windmill spars, skis, utility poles, and sporting goods.

Appearance (as manufactured): A weaving machine has a work area on a rotating table with a network of rods penetrating pierced plates around which the fiber is woven. The work area is surrounded by spooled fiber dispensers and by weaving and lacing needles. The drive motors, cams, and push rods that do the weaving are also mounted on the main frame of the machine.

Weaving machines used to make small parts might measure 2 m in length and 1 m in width. Those used to make large parts might be 10 m long if arranged horizontally or 10 m high if arranged vertically.

Photo Credit: Wardwell Braiding Machine Co.

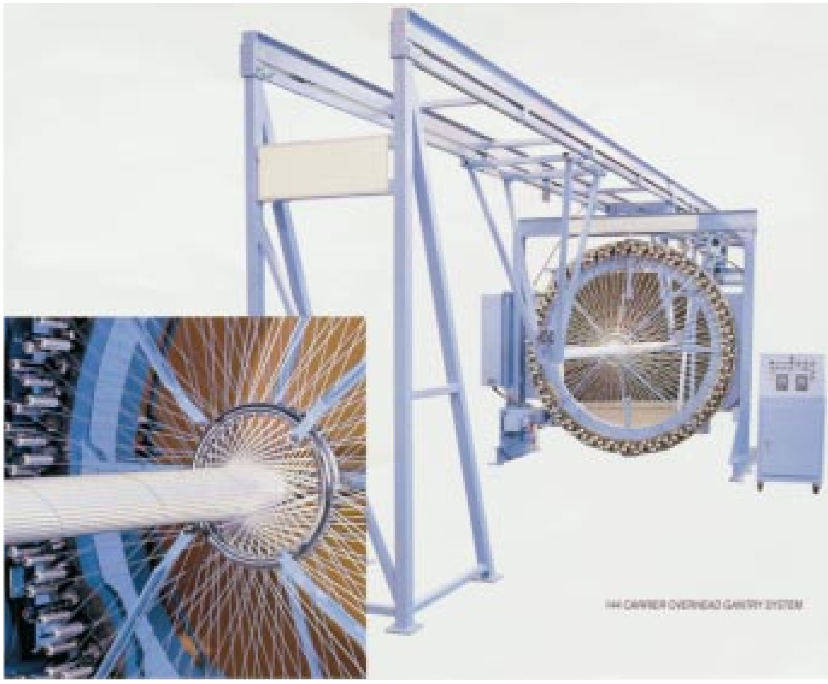


Figure 6-6: A 144 carrier overhead gantry braiding machine.

Braiding machines can be either floor-mounted or have an overhead gantry supporting the spindle on which the preform is made. In either configuration, the fiber is fed to the spindle radially through a large wheel centered on the spindle. The control panel is located at the center of the gantry in order to monitor preform development. A 144 carrier horizontal braider capable of bi-axial or tri-axial braiding is shown in Figure 6-6. Figure 6-7 shows a floor-mounted version. Both machines can be controlled by special software run by a common PC.

Appearance (as packaged): The packaging of weaving machines depends on their size. Smaller machines can be completely encased in packing crates. The components of larger machines are disassembled for shipping and reassembled onsite, and are packaged separately in crates or on pallets. All components are suitably protected from shock and vibration during transportation and handling.

Additional Information: These machines have the intricate fiber handling mechanisms to perform their task with spools and rotation / movement mechanisms integral within each machine. Some machines, particularly those used for reentry vehicle heat shields, are mounted on a bed and rely on rigid rods in at least one direction to stabilize the weave geometry. For weaving machines used to manufacture 3-D polar preforms, the basic network construction needed to do the weaving includes pierced plates with spe-

Figure 6-7: A 144 carrier floor-mounted traverse braiding machine.

Photo Credit: Wardwell Braiding Machine Co.

cially designed hole patterns, plain plates, metallic rods, knitting needles, retraction blades, and, if the process is fully automated, the machinery required to operate the knitting needles and retraction blades. The subelements for other types of weaving depend on the specific design of the machine.

(d) Equipment designed or modified for the production of fibrous or filamentary materials as follows:
   (1) Equipment for converting polymeric fibres (such as polyacrylonitrile, rayon or polycarbosilane) including special provisions to strain the fibre during heating;

Produced by companies in

- Germany
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: Polymeric fibers are precursors to high-temperature carbon and ceramic fibers that have great strength and stiffness at high temperatures. The conversion from a polymer to a high-temperature fiber occurs when the polymeric fiber is stretched and heated while exposed to a specific reactive atmosphere. The equipment controlled under this subitem heats, stretches, and exposes the fiber to the required reactive atmosphere.

Method of Operation: The polymeric fibers are fed into a machine with controlled tensioning, speed, heating, and atmosphere. The fiber path is usually long and complex because the total time for the conversion is lengthy so higher production rates require a longer fiber processing length. The fiber passes through a series of furnaces with controlled temperature and atmosphere, and is driven at higher and higher speeds to convert it into a small-diameter, high-temperature fiber with a high degree of crystallographic order. Critical pieces of equipment include the process controllers, which maintain the desired temperatures at each step, and the textile rollers and drive motors, which carry product through the various heat treatment steps.

Typical Missile-Related Uses: The equipment is used to convert or strain synthetic fibers to produce fibers used in missile applications where great strength and light weight are paramount. These fibers are used in missiles to improve the strength of the motor case, fairing, and propellant tank while reducing weight and thereby increasing the range and payload capacity of the missile.

Other Uses: The equipment is used to convert polymeric fibers for many uses, including aircraft structures, tires, golf clubs, and boat hulls.

Appearance (as manufactured): Describing the appearance of the equipment used to convert polymeric fibers is difficult because of the variety of ways in which equipment layout can occur. The layout is usually tailored to the production building and covers considerable floor space. The most noticeable items are the many precision rollers and the mechanisms for their control. The rollers are typically 8 to 20 cm in diameter by 30 to 120 cm long, with their size related to the ovens in which they are to be used. Drive rollers are used to slowly pull the organic precursor fiber through an oven under controlled tension. The drive rollers are typically made of polished stainless steel or chromeplated steel and are either driven in a manner to keep the filaments at a constant tension or are driven at a preprogrammed rate to elongate the filaments as a part of the process. Thus, rollers may be driven by individual motors on their shafts or proportionately driven by gears from one motor-driven shaft.

The machinery is designed to allow the fiber to make several passes through the heated zone with precise control of the speed of the fiber, the temperature in each zone of the furnace, and the tension on the fiber. The fiber must pass through several of these furnaces because the process requires a wide variety of different reactions. A typical fiber-drawing oven system has many rollers and isolated heating zones in the furnace. The size of the equipment varies widely.

Typically, the vertical-treating oven systems are used for higher temperature thermal treatment. However, the diverse treatments required to produce a carbon or other refractory fiber from a polymeric fiber demand that several pieces of equipment be used. Typical requirements include low-temperature furnaces with critical textile handling systems and high-temperature ovens with fiber handling capability for conversion of the fiber to its final state.

Appearance (as packaged): The ovens, furnaces, and processing equipment needed to produce carbon fibers vary in packaging depending on their size, weight, and sensitivity to environmental factors. Generally, laboratory versions of the equipment can be completely crated and shipped by rail or truck. Larger furnaces designed for commercial use generally have to be shipped in component units and assembled onsite. However, some of the furnaces can be of such large diameter that they must be specially handled as oversize cargo. The weight for these larger furnaces approaches 1000 metric tons or more.

Produced by companies in

- Germany
- Japan
- Russia
- United Kingdom
- United States

(2) Equipment for the vapor deposition of elements or compounds on heated filament substrates; and

Nature and Purpose: The equipment for vapor deposition applies a very thin coating to filaments and thereby changes the properties of the filaments in several different ways. Metallic coatings are conductive and add abrasion resistance; some ceramic coatings protect fibers from reacting with either the atmosphere or adjacent materials. Coatings may also improve the eventual compatibility of the fibers with a matrix material, as is the case for some metal matrix composites.

Method of Operation: This equipment provides a suitable partial vacuum environment for condensing or depositing a coating on filaments. The vapor deposition process has several variations; two of the most important basic processes are chemical vapor deposition (CVD) and physical vapor deposition (PVD).

The CVD process deposits solid inorganic coatings from a reacting or decomposing gas at an elevated temperature. Sometimes this process occurs in a radiofrequency-generated plasma to ensure thermal uniformity and improve the quality of CVD coatings in a process called plasma-assisted CVD (PACVD).

The PVD processes use sputtering, evaporation, and ion plating to deposit the coating on the filaments. The equipment for PVD is similar to the equipment for CVD except that the chamber does not have to operate at a high temperature and does not require a reactive gas supply.

Typical Missile-Related Uses: The equipment for the deposition of elements on heated filaments produces fibers used in rocket motor nozzles and reentry vehicle nose tips.

Other Uses: This equipment coats fibers used in jet aircraft. PACVD is currently an important technique for the fabrication of thin films in the microelectronics industry and has been applied to the continuous coating of carbon fibers.

Appearance (as manufactured): CVD and PVD chamber configurations vary greatly. Some are long tubes with seals at each end that permit the passage of filaments but not gases. Others are large chambers, 2 to 3 m on a side, with room enough to hold the filament spools, filament guide equipment including spreading and tensioning rollers, a hot zone if needed, and the reactant gases. Because of this variation, the only standardized and readily recognizable parts of the equipment are the gas supply system, a large power supply, vacuum pumps, and possibly the instrumentation that controls the temperature. In all cases, the power supplies are of substantial size and weight, typically greater than 0.6 × 0.9 × 1.5 m with water inlets for cooling, pumping, and safety cutoffs. PACVD equipment looks like a conventional CVD or PVD system except that it has a radio-frequency power supply to produce the plasma.

Appearance (as packaged): Packaging varies depending on size, weight, and sensitivity to environmental factors. Generally, laboratory versions of the equipment can be completely crated and shipped by rail or truck. However, even laboratory versions generally have components packaged separately so that the textile spools, motors, and special glassware can receive adequate protection. Larger systems designed for commercial use are usually shipped as components and assembled onsite.

(3) Equipment for the wet-spinning of refractory ceramics (such as aluminum oxide);

Produced by companies in

- Germany
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: Wet-spinning equipment is used to produce long filaments from a mixture of liquids and solids. These filaments are further processed to produce high-strength, high-temperature ceramic filaments for ceramic or metal-matrix composites.

Method of Operation: In wet-spinning of refractory ceramics, a slurry of fiber-like particles is physically and chemically treated and drawn into a filament through an orifice called a spinneret. The chamber in which the filaments are created either rotates or contains an internal mixing device, either of which produce the vortex in which filament entanglement occurs. The material emerges from the spinneret and is solidified by a temperature or chemical change, depending on the binder system used in the wet bath surrounding the spinneret. The bath supports and stabilizes the filaments produced as it cools.

Typical Missile-Related Uses: The wet-spinning equipment is used to make high-grade ceramic fibers for making missile nose tips and rocket engine nozzles. Such fibers are also used to produce some ramjet and turbojet engine parts applicable to cruise missiles.

Other Uses: Wet-spinning equipment is used to make ceramic fibers for producing engine parts for small gas turbine engines, chemical processing containers, and high-temperature structural applications. Ceramic fibers or whiskers can be combined with other composite materials to enhance strength and high-heat resistance in many commercial products.

Appearance (as manufactured): A major component of wet-spinning equipment is the cylindrical chemical reaction chamber. Although glassware is acceptable for laboratory and prototype wet-spinning equipment, stainless steel or glass-lined reaction chambers are used for production grade wet-spinning equipment. Typically, the chamber is tapered at the bottom, where the dies that extrude the filaments are located.

Other equipment associated with the chemical reaction chamber includes a cylindrical vessel (much longer than its diameter) that contains the chemical slurry from which the filament is produced; a pressure gauge and gas exhaust line attached to the vessel; a tube assembly containing sections of both fixed and rotating glass tubes; a ball valve connected to the fixed glass tube; a motor and controller for driving the rotating tube; and a snubber roller and take-up reel for the finished filaments.

Appearance (as packaged): Packaging is typical of any similarly sized industrial equipment. Generally, fully assembled laboratory versions of the equipment can be crated and shipped by rail or truck. Components of larger equipment designed for commercial use are shipped in separate boxes or crates and assembled onsite.

Produced by companies in

- France
- Germany
- Sweden
- Switzerland
- United Kingdom
- United States

(e) Equipment designed or modified for special fibre surface treatment or for producing prepregs and preforms.

Note:
(2) Equipment covered by subitem (e) includes but is not limited to rollers, tension stretchers, coating equipment, cutting equipment and clicker dies.

Nature and Purpose: Fiber surface treatment and prepregging equipment is used to coat fibers in preparation for making high quality composite materials. Surface treatments improve adhesion or change electrical properties of the fibers; prepregging adds enough resin to the fiber (or filaments, roving, or tape) for curing it into a composite.

Method of Operation: The fiber filaments, roving, or tape to be processed in this equipment is passed through a series of dip baths made up of liquid reactants for etching or resins (sizings). A reactant etches or activates the surface of the fiber for additional operations. Materials are fed on rollers through a bath of reactants in a simple dip operation. The number and speed of rollers in the bath determines how long the part is etched or how much sizing is retained. Heaters are used to modify the reactivity of the etch system, to control the viscosity of the sizing bath, to promote chemical reactions that make the sizing stable, and to dry the product.

Photo Credit: Hunting Engineering, Ltd.

Figure 6-8: A machine adding resin to seven lines of roving.

Typical Missile-Related Uses: This equipment is used to surface treat various fibers used in the manufacture of missile parts in order to improve bonding and to give additional strength to missile components such as nose tips, motor cases, and exhaust nozzles.

Other Uses: This equipment is identical to that used to make the fibers for all commercial applications of composite technology from boat hulls to golf clubs.

Appearance (as manufactured): A laboratory bench with small rollers and heater guns is the only equipment needed to treat or prepreg fiber on a prototype basis. For production-level activity, the textile handling equipment is much larger so that multiple lines can be treated at the same time. A machine adding resin to seven lines of roving is shown in Figure 6-8; dry fibers enter from the left and are coated by the wet wheel on the right. A machine processing numerous lines of roving is shown in Figure 6-9. Alternatively, a process may involve heater stacks many stories high. All of the systems have rollers for keeping the textile material moving, maintaining tension on the fiber, and squeezing out excess liquid. They also have an oven with a complex path over the rollers so that the filaments traverse the oven several times.

Photo Credit: Cytec Fibrite, Inc.

Figure 6-9: A machine processing numerous lines of roving.

Appearance (as packaged): The packaging of the equipment, with the exception of small laboratory apparatus, usually requires that components be shipped separately and assembled onsite. The reason is that the base, the vats for holding chemicals, and the textile handling apparatus require different types of packaging protection. The vats for chemicals can be packaged in simple corrugated boxes, but the rollers, which have a precision or special surface finish to avoid damaging the filaments, need cushioning and rigid mounting in substantial crates. Electrical control equipment, if included, will be packaged like other fragile electronics.

Produced by companies in

The autoclave or hydroclave equipment is produced in most industrial countries because it is used in common manufacturing processes. Although general knowledge of these processes is widely known, data on processes for specific applications are proprietary.

(f) "Technical data" (including processing conditions) and procedures for the regulation of temperature, pressures or atmosphere in autoclaves or hydroclaves when used for the production of composites or partially processed composites.

Nature and Purpose: Process control data are used to manage the processing of composites or partially processed composites into useful component parts. The technical data of interest with respect to autoclaves and hydroclaves generally concern processing conditions and procedures, tooling and preparation for cure, and cure control. Because the precise process settings for temperature, pressure, and duration have a critical effect on the strength, impact resistance, and flexural modulus of the parts produced, manufacturers have developed proprietary processes and rarely release the information for production of specific parts. Processing conditions, debulking periods, and procedures are usually individually tailored for the specific part.

Method of Operation: These data are used as guidance in making or partially processing specific, high-heat-tolerant, composite parts in autoclaves and hydroclaves. Cure control can be carried out by a human operator, but more commonly it is carried out by computer. The latter may be based on a prescribed process cycle or may take the form of intelligent processing in which the computer makes decisions on the basis of the combined input of analytical process models, sensors in or near the part being processed, and human knowledge built into the system as artificial intelligence.

Typical Missile-Related Uses: These data are part of the instructions for preparing the preform or composite for use as high-heat-tolerant and ablative components such as reentry vehicle nose tips and rocket motor nozzles.

Other Uses: Similar processes and procedures are used to make the materials for commercial applications of composite technology from boat hulls to golf clubs.

Appearance (as manufactured): In general, technical data can take the form of blueprints, plans, diagrams, models, formulae, engineering designs and specifications, and manuals and instructions written or recorded on other media or devices such as disk, tape, and read-only memories. These data are usually provided in handbooks and graphs as part of either the autoclave or hydroclave manufacturer's documentation, or as a part of the resin manufacturer's recommendations. The manufacturer's documentation refers to each of the subcomponents and compiles specifications and instruction manuals for each of them. These components include items such as solid-state controllers or computers for controlling and monitoring temperature and pressure during the cure operation.

Appearance (as packaged): The data accompanying the equipment and containing the cure information are typically placed in loose-leaf books or a collated set of instructions. Documentation has a report format and accompanies new equipment. Data supplied by manufacturers of resin or prepreg are on data sheets and accompany the raw resin or prepreg material.

ITEM 7
Pyrolytic Technology

Pyrolytic Technology

Pyrolytic deposition and densification equipment and "technology" as follows:

(a) "Technology" for producing pyrolytically derived materials formed on a mould, mandrel or other substrate from precursor gases which decompose in the 1,300 degrees C to 2,900 degrees C temperature range at pressures of 130 Pa (1 mm Hg) to 20 kPa (150 mm Hg) including technology for the composition of precursor gases, flow-rates and process control schedules and parameters;

Nature and Purpose: Pyrolytic deposition is a high-temperature process used to deposit a thin, dense coating of metal or ceramic onto a mold or mandrel in order to form a part. It also can be used to coat another material in order to achieve strong adhesion and bonding between the coating material and the underlying surface. The purpose of these processes is to improve the ability of the coated or densified items to survive the extreme environments in which critical rocket system parts operate.

The general procedures and methods used to create pyrolytically derived materials and their precursor gasses are widely known. However, specific formulae, processes, and equipment settings are usually empirically derived and considered proprietary trade secrets by industry. Controlled data (technology) may take the form of technical assistance including instruction, skills, training, working knowledge, and consulting services. Technology may take the physical form of blueprints, plans, diagrams, models, formulae, engineering designs and specifications, and manuals and instructions written or recorded on other media or devices such as disk, tape, and read-only memories.

(b) Specially designed nozzles for the above processes;

Nature and Purpose: Nozzles for pyrolytic deposition direct an unreacted gas to a surface on which deposition is desired. The nozzles must be movable or located so they can cover the entire surface within a chemical vapor deposition (CVD) furnace at high temperature and pressure.

Produced by companies in

- France
- Germany
- Russia
- United States

Method of Operation: Nozzles used in CVD furnaces deliver cold, unreacted gas to the surface being treated. The gas must be both unreacted so that the coating occurs on the intended surface rather than on the inside of the nozzle, and close to the surface to be treated so that the surface and not the walls of the furnace get sprayed. A nozzle is like a paint spray gun, which must be close to the part being painted.

Typical Missile-Related Uses: These nozzles are required parts of pyrolytic deposition equipment used to make critical, high-heat-tolerant parts such as rocket nozzles and reentry vehicle nose tips.

Other Uses: These nozzles are used to make high-heat-tolerant parts for jet engines.

Appearance (as manufactured): Nozzles for CVD furnaces are designed to tolerate high furnace temperatures either by construction from very high-temperature-resistant material such as graphite or by water-cooling. Nozzle dimensions are approximately half the width of the furnace. Small nozzles are typically made of graphite because it is inexpensive, easily replaced, and lightweight (approximately 0.5 to 2.5 kg). Larger nozzles for production furnaces are often made of metal, require water cooling, may have integral attachment flanges, and weigh upwards of 25 kg.

Nozzles are made in varying lengths, which depend on the size of the furnace and the surface. The larger, more complex, water-cooled nozzles are up to 1.5 m long, with their tubular portion 20 cm in diameter. However, because some portion of most nozzles is custom designed, there is no standard shape or size.

Appearance (as packaged): Packaging for the nozzle and pyrolytic deposition equipment is suitable for preventing damage to a highly durable pipe with somewhat fragile valves and fittings. Typically, several nozzles are shipped together in well protected packaging separate from any large furnace shell.

(c) Equipment and process controls, and specially designed software therefor, designed or modified for densification and pyrolysis of structural composite rocket nozzles and reentry vehicle nose tips.

Nature and Purpose: Specialized equipment and process controls are essential for the densification and pyrolysis necessary to produce structural composites used for rocket nozzles and reentry vehicle nose tips. Specially designed software often is required to operate the equipment and/or control the processes to produce these structural composites. Manufacturing items from this type of material usually requires cycling through various process conditions such as high temperature and/or pressure. Precise control of the conditions during the cycles and their timing is key to ensuring acceptable results. This subitem also includes documentation (technical data) of the various process conditions needed to produce these materials.

Method of Operation: Equipment, process controls, and software for densification and pyrolysis are used throughout the manufacturing process for structural composites to handle, process, and finish the material and the resulting products (i.e., rocket nozzles and RV nose tips).

Typical Missile-Related Uses: This equipment, process controls, and software are used to produce structural composites (including carbon-carbon items) used for rocket nozzles and reentry vehicle nose tips.

Other Uses: These items are also used for diffusion bonding of metals, in powder metallurgy, and for treating metal components.

Appearance (as manufactured): The equipment resembles other manufacturing equipment but can include smaller (research size) items. Process controls can take the forms of technical data such as paper, magnetic, or other media. Specially designed software is usually indistinguishable by visual inspection from commercially available software and can take the form of computer disks, CD ROMs, etc.

Appearance (as packaged): Larger pieces of equipment may be shipped as components, while smaller items may be shipped assembled. These items are usually shipped in crates or on pallets in a similar manner to other industrial equipment. Process controls (including technical data) are shipped like other information on paper, magnetic, or other media. Software can be transferred on disks, CD ROMs, etc., or over networks. Software and technical data may be included in the shipping containers with its respective equipment.

Notes to Item 7:

(1) Equipment included under (c) above are isostatic presses having all of the following characteristics:
   (a) Maximum working pressure of 69 MPa (10,000 psi) or greater;
   (b) Designed to achieve and maintain a controlled thermal environment of 600 degrees C or greater; and
   (c) Possessing a chamber cavity with an inside diameter of 254 mm (10 inches) or greater.

Produced by companies in

- France
- Germany
- Russia
- United States

Nature and Purpose: Isostatic presses are used to infuse carbon into a porous carbon preform of a rocket nozzle or reentry vehicle nose tip under great pressure. This process, referred to as densification, fills up and virtually eliminates voids in the preform and thereby increases the density and strength of the treated object.

Method of Operation: The object to be processed is placed in the appropriate chamber and lowered into the hot zone of the furnace. All water and

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex. *Report No. LA-13131-M (April 1996).*

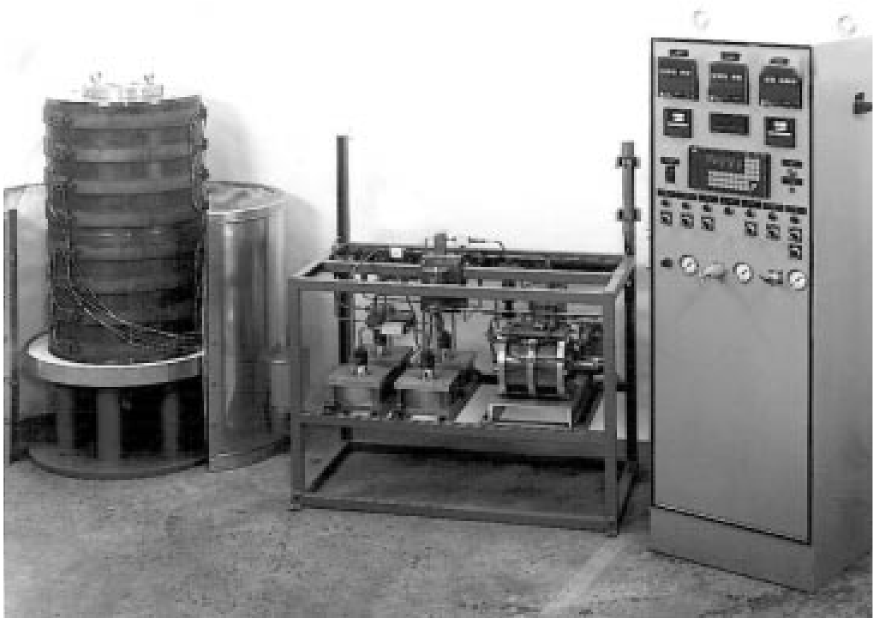


Figure 7-1: A laboratory-sized isostatic press showing its three main components: pressure chamber, pressure generator, and control console.

electrical connections are made and all process instrumentation is connected before the lid is lowered into the furnace and sealed. As the object is heated, it is subjected to great pressure until the proper densification has been achieved. Reaction products are removed by internal plumbing so they do not come into contact with the electric heaters and cause them to short.

Typical Missile-Related Uses: Isostatic presses are used in making nose tips for reentry vehicles and nozzle inserts for rocket motors.

Other Uses: These presses are used in diffusion bonding of similar metals, diffusion bonding of dissimilar metals to form laminates (silver-nickel-silver or copper-stainless), and provision of seamless joints. They are used in various powder metallurgy applications. They are also used to improve the quality of metal castings and forgings by hydrostatically forcing defects to close and bond shut.

Photo Credit: Engineered Pressure Systems, Inc.

Figure 7-2: Two removable high-pressure closures, showing holes for hoses or pipes.

Appearance (as manufactured): Isostatic presses intended for densification are specially modified to operate while a pyrolysis reaction is occurring. A typical laboratory-size system has three main components: a pressure chamber, a high-pressure generator, and a control console, as shown in Figure 7-1. The pressure chamber is usually a vertical, thick-walled cylinder with a removable, high-pressure closure, or plug, at the upper end. Two examples are shown in Figure 7-2. They are water-cooled and have attachments for hoses or pipes. The press may be surrounded by an energy-absorbing shield, shown partially removed on the left of Figure 7-1. This shield may be engineered at the plant where the system operates and often involves installing the chamber belowground. The pressure chamber also has an isolation chamber and plumbing to be sure that gas from the process zone is removed from the exhaust and does not flow to the heater zone.

The high-pressure generator uses air to drive a large piston connected directly to a smaller piston, which pressurizes the gas used in the chamber. These simple pumps operate at pressure ratios between 10 and 1000 and are available with maximum pressures up to about 1,400 MPa. The piston-and-cylinder mechanisms of the pressure intensifiers can be seen in the high-pressure generator system pictured in Figure 7-1.

The control console has an instrument panel with typical industrial temperature and pressure control and recording instrumentation, as shown in the right of Figure 7-1. The console usually includes a computer and a keypad for entering data required to control the operation of the press. Isostatic presses can be quite large. A top and side view, respectively, of two different presses are shown in Figures 7-3 and 7-4. Notice the thick-walled pressure vessel and the large threaded plug in Figure 7-3. Another isostatic press is shown in the background of Figure 7-5.

Appearance (as packaged): The components of an isostatic press system are likely to be shipped separately and assembled at the final work destination. Packaging varies with the requirements of the purchaser, but wooden pallets and crates with steel banding and reinforcement are common. Two wooden crates containing components of an isostatic press system are shown in Figure 7-6; a different crate for a similar press is shown in Figure 7-7. Larger chambers are very heavy because of the thick walls and may be packaged in a cylindrical wooden crate with wide steel banding, as shown in Figure 7-8.

Additional Information: The distinction between a normal hot isostatic press and one modified for use in pyrolytic densification is that decomposition does not occur in the former and does in the latter. To avoid the carbon deposition on the heaters, which would otherwise cause an electrical short, the heater chamber for densification has plumbing connections and controls to pipe carbon decomposition products directly from the heated zone out to gas handling equipment.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex. Report No. LA-13131-M (April 1996).

Figure 7-3: A very large isostatic pressure vessel and threaded plug.

Photo Credit: Engineered Pressure Systems, Inc.

Figure 7-4: Side view of a large isostatic press.

Photo Credit: Engineered Pressure Systems, Inc.

Figure 7-5: An isostatic press in the background, surrounded by a light, metal frame.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex. *Report No. LA-13131-M (April 1996).*

Figure 7-6: Shipping crates for an isostatic press.

Photo Credit: Engineered Pressure Systems, Inc.

Figure 7-7: Alternative shipping crate for an isostatic press.

Figure 7-8: Shipping crate for a very large isostatic press.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex. *Report No. LA-13131-M (April 1996)*

Note

(2) Equipment included under (c) above are chemical vapour deposition furnaces designed or modified for the densification of carbon-carbon composites.

Produced by companies in

- France
- Germany
- Russia
- United Kingdom
- United States

Nature and Purpose: CVD furnaces are used to infuse carbon into a porous carbon preform of a rocket nozzle or reentry vehicle nose tip. This process, referred to as densification, fills up and virtually eliminates voids in the preform and thereby increases the density and strength of the treated object.

Method of Operation: CVD furnaces use either isothermal or thermal-gradient processes for densification. The object to be processed is placed in the appropriate chamber and lowered into the hot zone of the furnace. All gas, water, and electrical connections are made, and all process instrumentation is connected before the lid is lowered into the furnace and sealed. The process sequence of heating and supplying the deposition gases is automated, but furnace operators follow the part development through view-ports built into the furnace walls.

Typical Missile-Related Uses: CVD furnaces are used to make lightweight carbon-carbon rocket nozzles and nose tips. Carbon-carbon pieces are light and strong, and can increase system performance.

Other Uses: CVD furnaces are used in coating optics, some medical instruments and components (e.g., heart valves), and cutting tools; in coating and polishing precision surfaces; and in making semiconductors.

Appearance (as manufactured): CVD furnaces are large, double-walled, cylindrical vessels with gas-tight closures. Typical CVD furnaces are large because they house an internal heat zone, electrically driven heaters, and insulation. Furnaces smaller than 1.5 m in height and 1 m in diameter are considered laboratory scale and are barely able to process a single nose tip or rocket nozzle insert. Process production sizes are larger than 2 m in height and 2 m in diameter. These furnaces have several ports: at least one large port for power feeds, others for instrumentation, and, when temperatures are measured by optical or infrared pyrometers, one or more view-ports.

They are double-walled so that they can be water-cooled during operation. Power cables are large and may also be water-cooled. The actual retort is housed inside the furnace and is heated by a graphite induction or resistive heater to temperatures of up to 2,900°C. Two typical furnaces, without lids in place, are shown in Figure 7-9. An induction power supply with heavy, water-cooled connections between the power supply and the smaller of the two furnaces is also shown. The induction coil, retort, and silicon steel shunts, which prevent inductive coupling to the furnace wall, are shown in Figure 7-10. A typical production setup of CVD furnaces consists of several components, as shown from left to right, in Figure 7-11: an impregnation

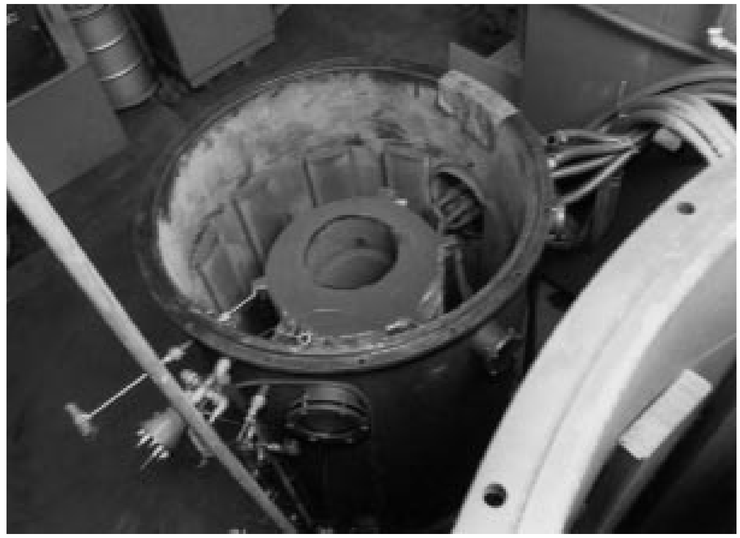


Figure 7-10: Inside of a small CVD furnace showing the retort, heaters, and insulation.

Figure 7-9: Two small CVD furnaces and an induction power supply.

Photo Credit: Alliant TechSystems, Inc.

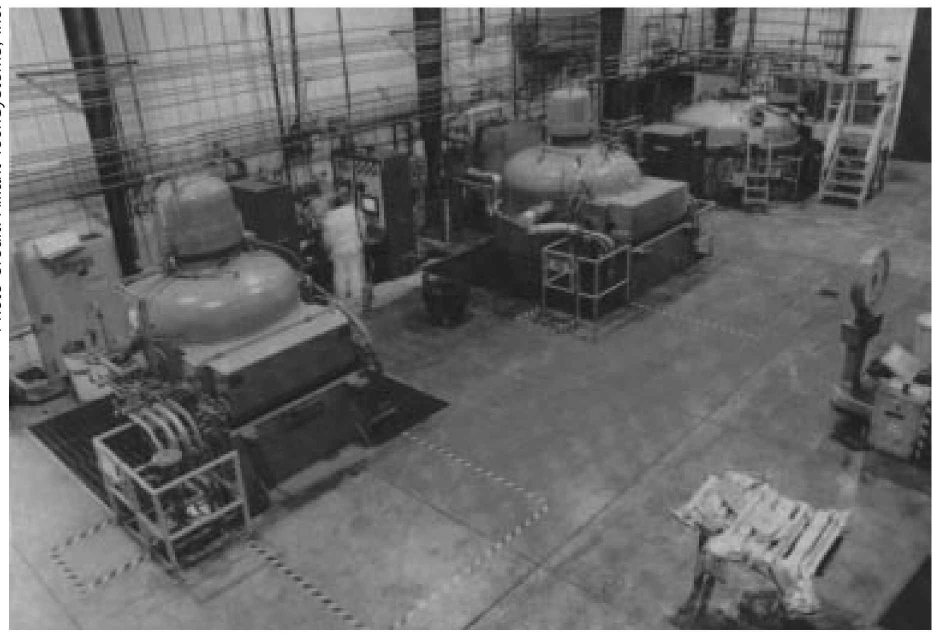


Figure 7-11: A typical production setup for carbon-carbon or ceramic matrix nose tips and nozzles.

vessel for adding a liquid resin to the preform; instrumentation and control panels; a pressure-carbonization furnace with a 69 Mpa capacity; and a CVD furnace for pyrolytic deposition of carbon from a gas.

Appearance (as packaged): Packaging consists of pallets and crates for each part because of the large size and weight of the equipment. The large lids, the power supply, and the body of the furnace often have built-in lift points or rings to help move and assemble them.

ITEM 8
Structural Materials

Structural Materials

Structural materials usable in the system in Item 1, as follows:

(a) Composite structures, laminates, and manufactures thereof, specially designed for use in the systems in Item 1 and the subsystems in Item 2, and resin impregnated fibre prepregs and metal coated fibre preforms therefor, made either with organic matrix or metal matrix utilizing fibrous or filamentary reinforcements having a specific tensile strength greater than 7.62×10^4 m (3×10^6 inches) and a specific modulus greater than 3.18×10^6 m (1.25×10^8 inches);

Notes to Item 8:

(2) The only resin impregnated fibre prepregs specified in (a) above are those using resins with a glass transition temperature (T_g), after cure, exceeding 145 degrees C as determined by ASTM D4065 or national equivalents.

Produced by companies in

- China
- Denmark
- France
- Germany
- Israel
- Japan
- Russia
- South Africa
- Sweden
- United Kingdom
- United States

Composite structures, laminates, and manufactures

Nature and Purpose: Composites and laminates are used to make missile parts that are often lighter, stronger, and more durable than parts made of metal or other materials.

Typical Missile-Related Uses: Composites and laminates can be used almost anywhere in ballistic missiles or unmanned air vehicles (UAVs), including cruise missiles. Uses include solid rocket motor cases, interstages, wings, inlets, nozzles, heat shields, nosetips, structural members, and frames.

Other Uses: Composite structures can be formed into almost any shape to meet required needs; they increase the speed of the production process and give great flexiblity to the final product. They are used in both civilian and military aircraft, recreational products (skis, tennis racquets, boats, and golf clubs), and in infrastructure (bridge repairs and small bridges).

Appearance (as manufactured): Composites take the shape of the object in which they are used, but they are light compared to metallic structures.

The reinforcement used to make a composite often results in a textile-like pattern on the surface of the object, especially when prepregged cloth is used. Even when cloth is not used, the linear pattern of the tape may still be present; however, a covering like paint sometimes conceals this pattern.

Appearance (as packaged): Composite structures are packaged much like other structures, with foam or other materials to protect them from surface abrasions or distortions from stress. Such protection is important because their surfaces are not as hard as metal, and their strength in non-designed directions is much less than that of metal.

Produced by companies in

- France
- Germany
- Israel
- Japan
- Russia
- South Africa
- United Kingdom
- United States

Resin Impregnated Fiber Prepregs and Metal Coated Fiber Preforms

Nature and Purpose: Prepregs and preforms are the basic materials from which composites structures are made. Prepreg is the name given to a cloth-like material made of fibers and impregnated with resins. Prepregs are assembled over a form (e.g., a mandrel or mold) into the desired shape. Sometimes several layers are used to create laminates. Preforms are solid, three-dimensional, fiber structures with the same shape and roughly the same dimensions as the desired part and impregnated with resin. After curing, the preform is machined into the final configuration. Usually, the materials of interest are then cured to temperatures above 175°C to complete polymerization of the resin and to achieve a high glass transition temperature.

Photo Credit: Cytec Fiberite, Inc.

Figure 8-1: Examples of prepreg yarn.

Typical Missile-Related Uses: Prepregs and preforms are precursors to the composites and laminates that can be used almost anywhere in ballistic missiles and UAVs, including cruise missiles. Uses include solid rocket motor cases, interstages, wings, inlets, nozzles, heatshields, nosetips, structural members, and frames.

Other Uses: Prepregs and preforms allow composite structures to be formed into almost any shape to meet required needs. They are used in both civilian and military aircraft, recreational products, and in infrastructure.

Appearance (as manufactured): Prepregs are textile products that are impregnated with a pliable resin. They are manufactured in thin filaments, tapes from submillimeters to centimeters wide, and fabrics up to a few meters wide. They are usually stored on spools or in rolls, just like yarn or fabric. Three examples of prepreg yarn are shown in Figure 8-1. Other than a very slight yellow cast on some of the materials and the stiffness or stickiness of the yarn, this material looks much like unimpregnated yarn. An assortment of yarns, fabrics, and tapes is shown in Figure 8-2. Although a prepreg can still deform, it is considerably less capable of draping than a fabric, tape, or yarn that has no resin; however, they are all still deformable enough to be shaped into a composite structural part. Prepregs may be used to form the approximate shape of a desired part, called a preform. Examples of preforms for rocket nozzle skirts are shown in Figure 8-3. After heating and curing, these preforms are machined to their final shapes and finishes.

Appearance (as packaged): The fibrous materials discussed here must be refrigerated after impregnation with resin. Refrigeration prevents the resin from polymerizing and hardening before the prepreg is used to manufacture composite materials. If the temperature is held at about –20°C, the shelf life of the prepreg is approximately six months. To maintain sufficiently low temperatures during shipment, the prepreg material is packed in special containers for dry ice cooling, or it is shipped in mechanically refrigerated cargo containers. A packing configuration for shipment of prepreg material with dry ice cooling is shown in Figures 8-4 and 8-5.

Photo Credit: Cytec Fiberite, Inc.

Figure 8-2: Examples of fabrics, tapes, and yarns.

Photo Credit: Aerospatiale Espace & Defense

Figure 8-3: Preforms of rocket nozzle skirts.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M (April 1996).*

Figure 8-4: Special cardboard container for holding dry ice packing around a carbon fiber prepreg tape spool during shipping. The dry ice is normally contained in a plastic bag packed around the spool.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M (April 1996).*

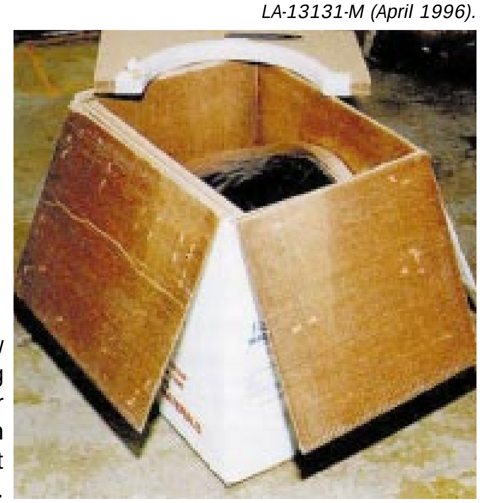


Figure 8-5: View of the prepreg shipping container with the lid open and the support yoke removed.

Produced by companies in

- France
- India
- Japan
- Russia
- United Kingdom
- United States

(b) Resaturated pyrolyzed (i.e., carbon-carbon) materials designed for rocket systems;

Nature and Purpose: Carbon-carbon is a composite of carbon fiber, usually made from pitch, rayon, or polyacrylonitrile (PAN), in a carbon-dominated matrix. It is usually made by using a high-content carbon resin as the initial matrix and then driving off the non-carbon elements through high heat. It is lightweight, highly heat-resistant, thermal-shock-resistant, and malleable for shaping as necessary.

Figure 8-6: A block of carbon-carbon material ready to be machined into a rocket nozzle. The larger cylindrical block is about 70 cm in diameter.

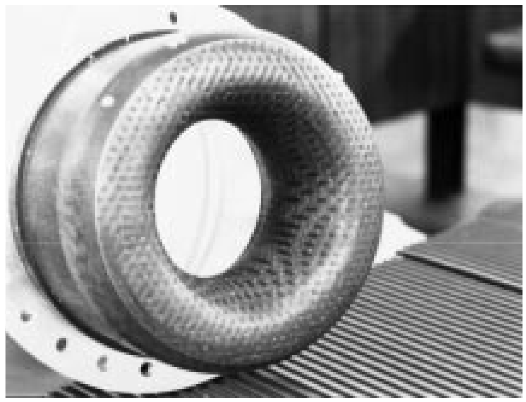


Figure 8-7: A carbon-carbon rocket nozzle throat showing the fabric pattern of the underlying fibers.

Typical Missile-Related Uses: Carbon-carbon materials are used for items such as rocket motor exit cones and nozzles, and RV nosetips, heat shields, and leading edges of control surfaces that must resist the effects of high temperatures and ablation.

Other Uses: Carbon-carbon structures are used in military and civilian aircraft applications such as high-temperature brake shoes, and in other applications requiring high strength and low weight such as wing roots. They can also be used for tooling requiring long life in severe, usually very high-temperature manufacturing environments, such as pouring ladles for steel, heaters for very high-temperature furnaces, and hot press tools.

Appearance (as manufactured): Typical carbon-carbon materials designed for rocket systems are black and have a patterned surface as a result of textile reinforcement. Nosetips and rocket nozzles are usually machined from blocks or billets or can be woven to shape. Blocks of material suitable for rocket systems and a machined rocket nozzle throat are shown in Figures 8-6 and 8-7, respectively. The nozzle throat shows the characteristic fabric pattern on its machined surface.

Appearance (as packaged): Before machining, blocks of carbon-carbon material are rugged enough to be packed in filler and shipped in cardboard boxes. Machined parts require careful packaging because, although the materials is resistant to breaking, it is not hard and can easily be gouged or scraped.

(c) Fine grain recrystallized bulk graphites (with a bulk density of at least 1.72 g/cc measured at 15 degrees C and having a particle size of 100×10^{-6} m (100 microns) or less), pyrolytic, or fibrous reinforced graphites usable for rocket nozzles and reentry vehicle nose tips;

Produced by companies in

- Brazil
- Russia
- United States

Nature and Purpose: Fine-grain recrystallized bulk graphite is used to create very strong, heat-resistant parts. Graphite is the only known substance that doubles in strength as the temperature increases from room temperature to 2,700°C. Carbon particles are combined with pitch, a viscous coal tar residue, in a suitable mold and subjected to heat and pressure. The resulting block can be easily machined into the required part. It also has excellent thermal shock resistance and good thermal and electrical conductivity. Pyrolytic graphite is formed by high-temperature vapor deposition but is not widely used because its uneven thermal conductivity causes it to crack when heated.

Typical Missile-Related Uses: Fine-grain recrystallized bulk graphites are used for reentry vehicle nose tips, thrust tabs, and nozzle throats. A typical billet for a nosetip could be as small as several centimeters in each dimension.

Other Uses: Graphite is used in biomedical applications, in nuclear reactors, as a mold in casting and manufacturing metal parts, and for critically-dimensioned furnace fixtures. Graphite is also the preferred material for electrodes for electric discharge machining. When infiltrated with metals, graphite is used for brushes in electric motors and as bearings in many mechanical applications.

Appearance (as manufactured): Bulk graphite is a very fine, dark gray to black powder. The density of processed graphite ranges from 1.72 to 2.2 g/cc, the latter for pyrolytic graphite. Machined parts made from graphite are black and have a gloss dependent on the machining operation. Fine-grain graphite can be distinguished by its lack of surface pitting and some of the fine details that are often in the manufactured product. Graphite is much softer than metals; a ball point pen can dent the surface. Typical products that demonstrate these features are shown in Figure 8-8.

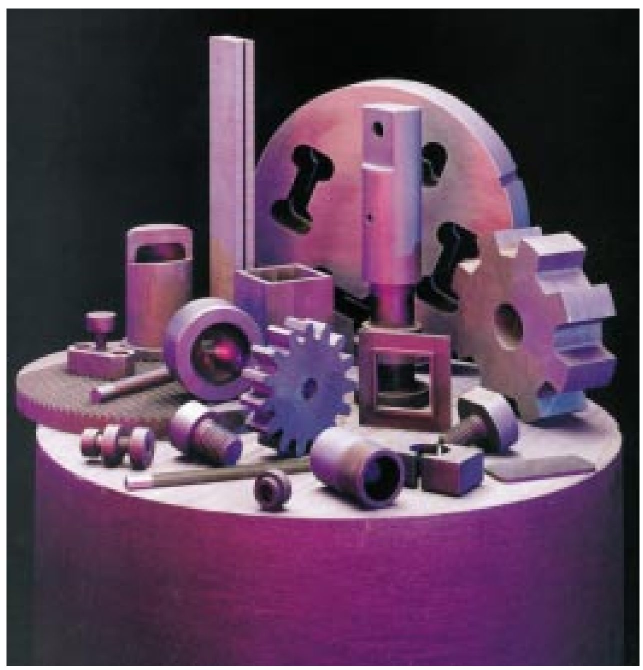


Figure 8-8: Various parts machined from fine grained bulk graphite.

Appearance (as packaged): These materials are packaged to protect their delicate surfaces and often to prevent any surface contamination. Typically, parts are placed in plastic bags or containers, which are packaged in materials normally used for fragile parts (i.e., bubble wrap, foam, etc.).

Produced by companies in

Ceramic Composites
- France
- Germany
- India
- Japan
- Russia
- United States

Silicon Carbide Composites
- France
- Japan
- United States

(d) Ceramic composite materials (dielectric constant less than 6 at frequencies from 100 Hz to 10,000 MHz) for use in missile radomes and bulk machinable silicon-carbide reinforced unfired ceramic usable for nose tips;

Ceramic composite materials

Nature and Purpose: Ceramic composite materials have strength and thermal properties sufficient for some use as heatshield materials. Unlike carbon-based materials, however, ceramics are insulators and do not conduct electricity, and electromagnetic radiation (e.g., radio waves) can pass through them. They are useful in protecting structures and equipment from high heat while still allowing communications to and from the vehicle.

Silicon-carbide reinforced ceramic composites are suitable for use to 1,200°C in an oxidizing atmosphere and to a somewhat higher temperature if coated. Silicon-carbide composites reinforced with filaments are very tough and, with a density of 2.3 g/cc, are considerably lighter than superalloys. These characteristics make them useable for reentry vehicle nosetips.

Typical Missile-Related Uses: Ceramic composite materials have been used in ballistic missile reentry vehicle antenna windows. Silicon-carbide unfired ceramic nosetips are hard and extremely heat-resistant; however, because they tend to chip but not break, they are not widely used.

Other Uses: High-heat-resistant ceramics are used in some gas turbine engines, automobile engines, furnaces, and solar energy receivers. Their uses include grinding rods and balls, furnace tiles, welding cups and nozzles, sandblast nozzles, and a variety of intricate parts for electronic applications. They are a common tooling material for use in manufacturing steps at elevated temperatures. Silicon-carbide reinforced ceramic composites are used in some military jet engines for thrust vector control flaps. Uses for all these materials are growing.

Appearance (as manufactured): Ceramic composite materials used in reentry vehicle antenna windows generally use ceramic filament reinforcement to prevent thermal-stress-induced failure. A block of 3-D silica-silica from which antenna windows are made may have a textile pattern evident on all surfaces. This material is often covered with a clear protective coating as a barrier to moisture. A silicon-carbide reinforced ceramic has the same pattern but is dark gray or black. All of these ceramic materials are very hard, much harder than other composites, and have a surface patterned like the textile reinforcement. They may be found in virtually any size between 1 mm discs and 50 cm cubes, which can be cut and ground to the required configuration by diamond tooling.

Appearance (as packaged): Because of their high cost and brittleness, these composites are packed in shock-absorbent materials. Since silica-silica material is also hygroscopic (i.e., it absorbs water), it is also packed in sealed bags of either mylar or other plastic, often with some type of a desiccant in the larger packing container. Some shippers also fill the sealed bags with dry nitrogen to protect the material from water absorption.

(e) Tungsten, molybdenum and alloys of these metals in the form of uniform spherical or atomized particles of 500 micrometer diameter or less with a purity of 97 percent or higher for fabrication of rocket motor components; i.e. heat shields, nozzle substrates, nozzle throats and thrust vector control surfaces;

Produced by companies in

- Germany
- Japan
- Russia
- United States

Nature and Purpose: These materials are controlled as powders, which can be formed into missile parts by pouring them into a mold and subjecting them to high heat and pressure (i.e., sintering). Parts made from these materials are very hard, dense, and strong. They also have extremely high melting temperatures: tungsten melts at 3,410°C and molybdenum at 2,610°C. Thus, finished parts are resistant to ablation in a high-heat and mass-flow environment such as those experienced in reentry or in missile exhausts.

Typical Missile-Related Uses: Because these materials are so dense and heavy, they tend to be used for smaller parts at critical points: reentry vehicle nosetips, nozzle throat inserts (but not the entire nozzle), and jet vanes, which are used to steer engine exhaust.

Other Uses: Tungsten powder is used in metal evaporation work, glass-to-metal seals, electrical contacts, and as an alloying element for steel. Tungsten carbide tool bits are critical for the metal working, mining, and petroleum industries. Molybdenum is an element used for powder metalurgy.

Appearance (as manufactured): Tungsten, molybdenum, and their alloys as spherical or atomized particles look like many other powder metallurgy products. The particles have a metallic sheen and flow freely because of their spherical shape. These materials are very heavy because both tungsten and molybdenum are high-density materials. Tungsten has a density of 19.3 g/cc, and molybdenum has a density of 10.2 g/cc. For comparison, iron has a density of 7.87 g/cc, and aluminum has a density of 2.7 g/cc.

Appearance (as packaged): These materials are packaged in sealed containers or drums to minimize contact with air and oxidation of the surface of the particles. The containers feel heavy for their size and are secured to a pallet or container to prevent movement.

Produced by companies in

- France
- Japan
- Russia
- Sweden
- United Kingdom
- United States

(f) Maraging steels (steels generally characterized by high nickel, very low carbon content and the use of substitutional elements or precipitates to produce age-hardening) having an Ultimate Tensile Strength of 1.5×10^9 Pa or greater, measured at 20 degrees C.

Notes to Item 8:

(1) Maraging steels are only covered by 8(f) above for the purpose of this Annex in the form of sheet, plate or tubing with a wall or plate thickness equal to or less than 5.0 mm (0.2 inch).

Nature and Purpose: Maraging steel is a particular alloy of steel noted for its high-yield strength. Typical formulations of maraging steel have relatively low carbon content (less than 0.03%) and relatively high nickel content (18 to 25%) as compared to most structural steels.

Typical Missile-Related Uses: The forms controlled by the MTCR (sheets, plates, and tubes) are generally used to make solid rocket motor cases, propellant tanks, and interstages.

Other Uses: These steels are used in special aircraft parts, submarine hulls, fencing blades, pipes, and reactors in the chemical and nuclear industries.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M (April 1996)*

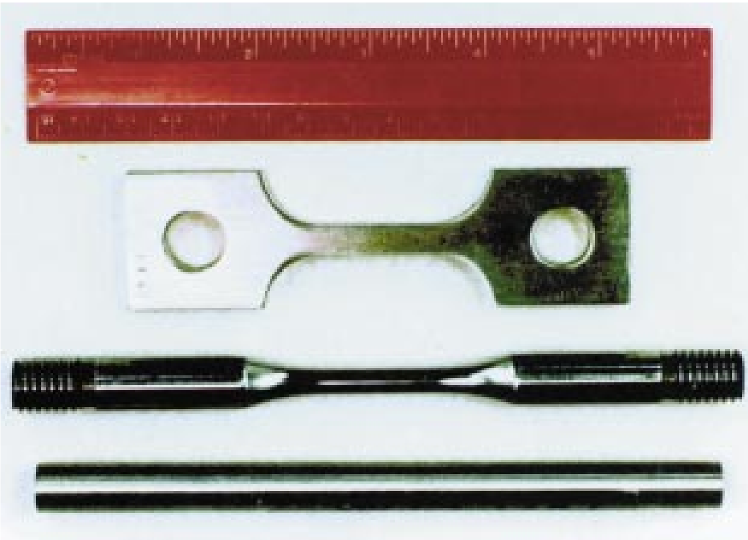


Figure 8-9: Top: stainless steel; middle: heat-treated maraging steel; bottom: zirconium tubing.

Appearance (as manufactured): Maraging steel has a lustrous gray color when clean and freshly prepared. If the metal has been subjected to an aging treatment to improve strength, it may have a dark oxide layer on the surface. This dark layer may also indicate that the maraging steel has been subjected to a controlled degree of oxidation in order to improve corrosion resistance during service. Heat-treated maraging steel and stainless steel and zirconium test samples are shown in Figure 8-9.

Appearance (as packaged): Maraging steel is often shipped in the low-strength, non-heat-treated condition so that it can be formed into the desired shape by the end user. It is bundled and shipped much like stainless steel, which it closely resembles. Sheets and plates are stacked and secured to a pallet. Tubes are bundled and secured to a pallet as well. Both may be covered with plastic sheet to protect them from the elements.

(g) Titanium-stabilized duplex stainless steel (Ti-DSS) having:
  (1) All the following characteristics:
    (a) Containing 17.0 to 23.0 weight percent chromium and 4.5 to 7.0 weight percent nickel, and
    (b) A ferritic-austenitic microstructure (also referred to as a two-phase microstructure) of which at least 10 percent is austenite by volume (according to ASTM E-1181-87 or national equivalents), and
  (2) Any of the following forms:
    (a) Ingots or bars having a size of 100 mm or more in each dimension,
    (b) Sheets having a width of 600 mm or more and a thickness of 3 mm or less, or
    (c) Tubes having an outer diameter of 600 mm or more and a wall thickness of 3 mm or less.

Nature and Purpose: Titanium Stabilized Duplex Stainless Steel (Ti-DSS) is a special alloy of stainless steel noted for its ease of welding and resistance to corrosive liquid propellant oxidizers. Typical formulations for Ti-DSS range from 17 to 23 percent by weight of chromium and 4.5 to 7.0 percent by weight of nickel, and such steel contains traces of titanium which, compared to other stainless steels, makes Ti-DSS particularly resistant to oxidizers such as Inhibited Red Fuming Nitric Acid (IRFNA). Additionally, Ti-DSS is a preferred material for liquid propellant missile applications because it is easily welded using common welding technology and, unlike other forms of stainless steel, does not require heat treatment after welding.

Typical Missile Related Uses: The forms controlled by the MTCR (ingots or bars, sheets, and tubes) are generally of sufficient size to be used to manufacture liquid propellant tanks and rocket engine plumbing.

Other Uses: There are very few known commercial uses for Ti-DSS. Although usable for many stainless steel applications, Ti-DSS is very hard, making it difficult to form into sheets or tubing. This makes it too expensive for common commercial applications. Additionally, although it is especially resistant to IRFNA, it does not perform well when exposed to other similarly corrosive materials such as chemical fertilizers.

Appearance (as manufactured): Ti-DSS is virtually identical in appearance to other stainless steels. It has a very fine grain, which usually requires a magnifying glass or microscope to view.

Appearance (as packaged): Ti-DSS is generally bundled and shipped much like other stainless steels. Sheets and ingots or bars are often stacked and secured to a pallet. Tubes are usually bundled and secured to a pallet as well. Both may be covered with plastic sheet to protect them from the elements.

ITEM 9
Navigation Equipment

Navigation

Instrumentation, navigation and direction finding equipment and systems, and associated production and test equipment as follows; and specially designed components and software therefor:

(a) Integrated flight instrument systems, which include gyrostabilizers or automatic pilots and integration software therefor, designed or modified for use in the systems in Item 1;

Notes to Item 9:

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

Produced by companies in

- China
- France
- Germany
- Israel
- Italy
- Japan
- Norway
- Russia
- South Africa
- Spain
- Sweden
- Switzerland
- Ukraine
- United Kingdom
- United States

Nature and Purpose: Integrated flight instrument systems use a variety of sensors as well as inertial instruments (accelerometers and gyroscopes) to track a missile's flight path. Because they collect and use more data than purely inertial guidance sets, they are often more accurate. The additional sensor data often allow the use of less expensive inertial instruments without a reduction in accuracy. These systems utilize all available information in various and often innovative schemes to navigate accurately. Because manufacturers have used a variety of names for integrated flight instrument systems (e.g., navigation systems), items with other names may actually be MTCR-controlled integrated flight instrument systems.

Method of Operation: Integrated flight instrument systems collect and process in-flight data from active and passive sensors, receivers, and inertial instruments in order to track the missile's flight path. They use one of several hierarchical or voting schemes to derive the best estimate of position and heading for comparison with the preprogrammed flight path. The results are used to generate signals to steer the vehicle along the intended flight path and to trigger other preprogrammed functions at their appropriate time.

Typical Missile-Related Uses: Integrated flight instrumentation systems are required equipment in unmanned air vehicles (UAVs), including cruise

Photo Credit: Litton Guidance and Control Systems

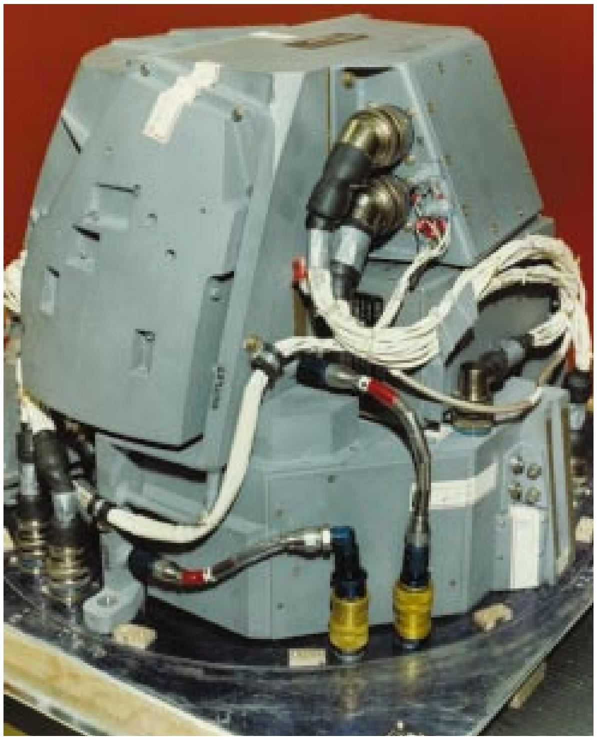


Photo Credit: Litton Guidance and Control Systems

Figure 9-1: The main body of a cruise missile integrated flight instrumentation system.

Figure 9-2: Another view of the same integrated flight instrument system shown in Figure 9-1.

missiles. Systems capable of achieving system accuracy of 3.33 percent or less of the range may be controlled as Category I under Item 2 (d).

Other Uses: Integrated flight instrumentation systems are used in both civilian and military aircraft.

Appearance (as manufactured): The size of integrated flight instrumentation systems varies with the type of vehicle and the vintage of design. Recent designs have been reduced in size to about a half meter on a side and reduced in weight to several kilograms or less. Integrated flight instrument systems vary greatly in appearance because they are designed for different interior configurations of different vehicles, and they use different combinations of subsystems. Like missile guidance sets controlled under Category I, Item 2 (d), most integrated flight instrumentation systems are enclosed in metallic boxes, which often have removable access panels. However, because integrated flight instrumentation systems use more than just an inertial measurement unit (IMU) for navigation information, they often look much more modular than ballistic missile guidance sets that depend exclusively on an IMU. Examples of this modular appearance are shown in Figures 9-1 and 9-2. The components of the system may be distributed throughout the missile with some of their sensors and antennas located well apart from the computer and IMU.

Appearance (as packaged): Although integrated flight instrument systems are not as delicate and expensive as some of the more expensive ballistic missile guidance sets, their packaging is usually robust and includes desiccants and air-tight wrappers for protection against moisture. These systems are usually shipped in cushioned containers with labels indicating the need for careful handling.

(b) Gyro-astro compasses and other devices which derive position or orientation by means of automatically tracking celestial bodies or satellites;

Notes to Item 9:

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

Produced by companies in

- France
- Germany
- Russia
- United Kingdom
- United States

Nature and Purpose: Gyro-astro compasses are precision assemblies of sensitive optical and electro-mechanical equipment used for navigation. They provide an in-flight orientation update and thereby increase the navigational accuracy.

Method of Operation: These devices use an optical sensor to detect a distant point-source of light in a known direction. Typically, these sensors rely on stars, but they can also use satellites travelling in known orbits. The guidance computer compares the expected direction of the star on the current trajectory with its measured direction and sends signals to the flight control system to make any necessary course corrections.

Typical Missile-Related Uses: Gyro-astro compasses are used in missiles that fly a portion of their trajectory above the atmosphere.

Other Uses: Gyro-astro compasses are used in space probes and some aircraft as well as on some ships to aid in navigation.

Appearance (as manufactured): Improvements in optical sensor technology have reduced the size and weight of such sensors, and are likely to continue to do so. Although gyro-astro compasses vary considerably in design, the optical sensors, or telescopes, all have a visible optical lens, which may be protected by an automatic shutter or trap door. Many telescopes are gimbal-mounted (i.e., mounted inside one or more pivoting cages) and thus can be automatically pointed to locate an optical reference. A typical unit might measure less than half a meter and weigh less than 10 kg. A photograph of a gyro-astro compass is shown in Figure 9-3. Compasses without gimbals consist of little more than an optical sensor with precision mounting surfaces, a shutter, and supporting electronics. Their metal cases often measure only 5 to 7 cm on a side and weigh approximately 0.5 kg.

Photo Credit: Litton Alenia Difesa

Figure 9-3: A high resolution gyro-astro compass.

Appearance (as packaged): Because gyro-astro compasses are delicate mechanisms, they are usually packed in robust shipping containers that prevent damage from moisture and mild shock. Shipping containers usually have warning labels indicating that they contain costly assemblies of sensitive optical, electrical, or mechanical equipment.

Produced by companies in

- China
- France
- Germany
- Israel
- Italy
- Japan
- North Korea
- Norway
- Russia
- South Africa
- Sweden
- United Kingdom
- United States

(c) Accelerometers with a threshold of 0.05 g or less, or a linearity error within 0.25 percent of full scale output, or both, which are designed for use in inertial navigation systems or in guidance systems of all types;

Notes to Item 9:

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

(3) Accelerometers which are specially designed and developed as MWD (Measurement While Drilling) Sensors for use in downhole well service operations are not specified in Item 9 (c).

Nature and Purpose: Accelerometers are sensitive pieces of electromechanical equipment used in measuring acceleration, which is the rate of change of speed in a given direction. Acceleration is integrated once to provide velocity and integrated again to provide distance traveled from the point of origin or launch. Two of the most important performance parameters are the threshold, the smallest measurement detectable, and the linearity error, the maximum error from the actual value measured.

Missile accuracy is directly dependent on the quality of the missile's accelerometers and gyros; missiles that fly for a long time without external updates require high quality accelerometers. Missiles that use sensor systems like Global Positioning System receivers, stellar fixes, or terrain-matching sensors to make mid-flight corrections can use lower quality accelerometers. Much of the cost of inertial-grade accelerometers results from the extensive calibration testing that must be performed on each unit.

Method of Operation: Accelerometers receive electrical power, sense acceleration and gravity, and provide measurement information as an electric signal. Information from the accelerometer, along with information on time, local gravity, orientation, and possibly other measurements, allows vehicle speed, heading, and position to be estimated by the guidance set or integrated flight instrumentation system. Several different types of accelerometers exist, each with its own method of operation.

Many pendulous accelerometers (often referred to as force balance, force to balance, or force rebalance accelerometers) use a small weight on a flexible hinge that is supported against the forces of gravity and acceleration by a magnetic field. Numerous variations of this design exist, but the principles are much the same. The small weight is held in a null position by an electromagnet. As the acceleration changes, the weight moves, and control circuitry changes the current in the electromagnet to bring the weight back to the null position. The amount of current required for this repositioning, or rebalancing, is proportional to the acceleration.

A spinning mass gyroscope with an unbalanced mass added along its spin axis can be used as an accelerometer. The gyroscope revolves about a pivot perpendicular to its axis of spin at a rate proportionate to acceleration including gravity. The sum of these revolutions serves as a mechanical integration of acceleration to provide an output proportionate to velocity rather than acceleration. Accelerometers of this type are known as pendulous integrating gyroscopic accelerometers (PIGAs). PIGAs can be very expensive and have been used in some of the most accurate long-range ballistic missile systems.

Other accelerometer designs also exist such as vibrating element accelerometers that vary the tension and frequency of a vibrating element. Chip accelerometers use a flexible portion of the microcircuit semiconductor to vary electrical resistance and produce an electrical output. Accelerometers of this type are currently at the low end of the performance range, but design efforts will continue because of the potential for substantial cost reduction. Such modern accelerometers are already used in IMUs requiring less accuracy such as UAVs, including cruise missiles.

Typical Missile-Related Uses: Accelerometers are used in missile guidance sets or integrated flight instrumentation systems. Typically, three accelerometers mounted perpendicular to each other provide all the acceleration measurement information necessary for inertial navigation. They can be installed in a gimbal structure (see Item 2 (d)), mounted in a floating ball, or affixed (strapped down) to the missile frame. Combined with gyroscopes, they make up an IMU or inertial sensor assembly (ISA). Depending upon mission requirements, some UAVs, including cruise missiles, can make due with only one or two accelerometers.

Other Uses: Accelerometers are used in both civilian and military aircraft and space systems, in oil well drilling stress testing, as inertial navigators in cars and other land vehicles, and in electronic equipment, manufacturing, gravity meters, robotics, and carnival rides (roller coasters). However, most of these uses do not require the high stability and highly calibrated accuracy of inertial-grade accelerometers.

Appearance (as manufactured): Accelerometers vary greatly in appearance because many designs exist. They are usually cylindrical, metallic, and shiny from precision machining. The larger accelerometers used in ballistic missiles are several centimeters in length and can weigh up to several kilograms. Those used in UAVs, including cruise missiles, are smaller and lighter; they may measure only a few centimeters on a side and weigh less than a kilo-

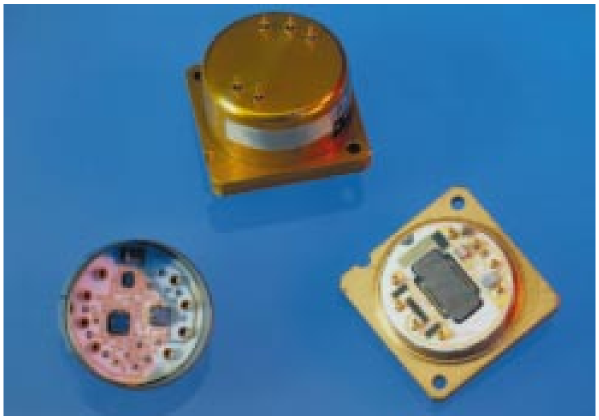


Photo Credit: Litton Sextant Avionque

Figure 9-4: An integrated circuit accelerometer.

Photo Credit: Lockheed Martin Federal Systems

Figure 9-5: Two force rebalance accelerometers that can be built with any of a wide range of performance capabilities.

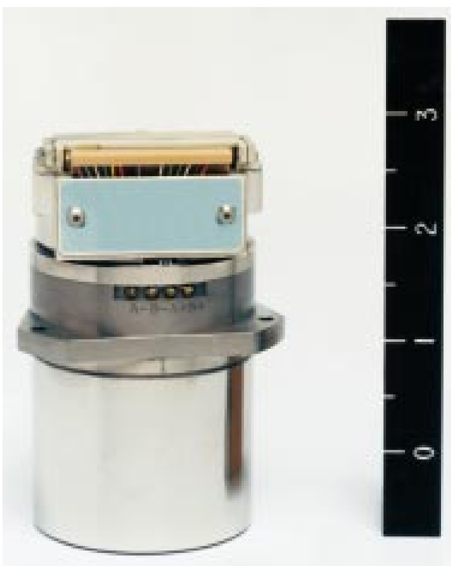


Photo Credit: The Charles Stark Draper Laboratories, Inc.

Figure 9-6: A pendulous integrating gyro accelerometer (PIGA) next to an inch scale.

gram. Many accelerometers of MTCR concern have high quality electrical connections and precision mounting surfaces for accurate alignment. Many accelerometers are factory-sealed instruments, not usually disassembled or even opened for service by any customer. A modern integrated circuit accelerometer is shown in Figure 9-4. The model and serial number on the exterior of the accelerometer should appear on the associated documentation, which contains information about accuracy.

Distinguishing MTCR-controlled from other accelerometers simply by visual inspection can be difficult because, although different models of an accelerometer have different performance capabilities, they may look identical. Two force rebalance accelerometers covering a wide range of performance are shown in Figure 9-5. One variant of a sophisticated gyroscopic accelerometer is the PIGA shown next to an inch scale in Figure 9-6. Relevant information unique to each model- and serial-numbered accelerometer can be derived from the associated documentation (often called calibration sheet or cal-data), including the g-threshold and linearity error. A major factor that makes an accelerometer accurate enough for use in sophisticated missile guidance sets is the exhaustive testing needed to compile the calibration data. Thus, the detail and amount of the calibration and error modeling data associated with each accelerometer are key indicators for determining the missile-related use of an accelerometer.

Appearance (as packaged): Because they are designed to be sensitive to acceleration, precision accelerometers are vulnerable to damage from relatively minor impact. They are usually protected from physical shock in small, high quality packages with thick, contour-fitted foam lining much like a package for a fine pocket watch. For shipping, one or more of these special boxes are packed in yet another box or other container with cushioned lining of some sort. The documentation on the accuracy of each model- and serial-numbered accelerometer is usually contained in its package.

(d) All types of gyros usable in the systems in Item 1, with a rated drift rate stability of less than 0.5 degree (1 sigma or rms) per hour in a 1 g environment;

Notes to Item 9:

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

(2) In subitem (d):

(a) Drift rate is defined as the time rate of output deviation from the desired output. It consists of random and systematic components and is expressed as an equivalent angular displacement per unit time with respect to inertial space.

(b) Stability is defined as standard deviation (1 sigma) of the variation of a particular parameter from its calibrated value measured under stable temperature conditions. This can be expressed as a function of time.

Produced by companies in

- Austria
- Canada
- China
- France
- Germany
- Israel
- Italy
- Japan
- North Korea
- Russia
- South Africa
- Sweden
- United Kingdom
- United States

Nature and Purpose: Gyroscopes, or gyros, are sensitive pieces of electromechanical or electro-optical equipment that measure rotation about one or more sensitive axis. Gyroscopes are usually mounted with accelerometers in the guidance set or integrated flight instrumentation system. They measure any change in the angular orientation of the accelerometers, so that the direction of the accelerometer measurements is known. One of the most important performance parameters is drift rate stability, usually measured in fractions of a degree per hour. This determines how quickly the gyro loses knowledge of its orientation. For gyros used in strapdown guidance systems, the stability of the scale factor—the factor relating the sensed rotation rate or angle and the gyro output signal—is also critical.

Missile accuracy is directly dependent on the quality of the missile's accelerometers and gyros; missiles that fly for a long time without external updates require high quality gyros. Missiles that use sensor systems like Global Positioning System receivers, stellar fixes, or terrain-matching sensors to make mid-flight corrections can use lower quality gyros. Much of the cost of inertial-grade gyros results from the extensive testing that must be performed on each unit.

Method of Operation: Gyros sense angular shifts (changes in orientation) and provide measurement information, usually as some form of electric signal. The orientation information from the gyros, along with information on time, local gravity, acceleration, and possibly other measurements, allows vehicle speed, heading, and position to be estimated by the guidance set or integrated flight instrumentation system. Several different types of gyros exist, each with its own method of operation. Most inertially guided missiles use either spinning mass gyros or electro-optical gyros.

Spinning mass gyros contain a spinning disk and operate on the gyroscopic principle whereby a proportionate measurable torque is generated perpendicular to the angular disturbance. There are two common types of spinning mass gyros. Single degree-of-freedom (SDF) gyros sense rotation about only one axis, while two degree-of-freedom (TDF) gyros sense rotation about two axes. Since missile guidance systems usually require orientation knowledge for all three axes, three SDF gyros are required, but only two TDF gyros (one axis will be redundant).

An SDF gyro has the spinning mass suspended cross-axis inside a cylinder that floats inside yet another slightly larger cylinder fixed to the guidance platform. Many designs float the inner cylinder in a liquid while others suspend it with gaseous flow. Rotations of the floated inner cylinder are related to input orientation changes by the gyroscopic effect of the spinning mass. Measurement of those rotations or measurement of the force needed to prevent those rotations is the output of the SDF gyro.

The most commonly used TDF gyro is the dynamically tuned gyro (DTG). It uses no floatation fluid, so it is sometimes referred to as a “dry” tuned gyro. A DTG has the spinning mass suspended on a complex gimbaled flex-hinge assembly, essentially an ultra-precision universal joint. The complex hinge assembly is tuned so its error torques cancel at one specific speed, often in excess of 10,000 rpm. Naturally, DTGs need very good speed regulation to operate reliably at the tuned rpm. Older types of TDF gyros consist of a series of mechanical gimbals that isolate the spinning rotor from the case. The angular position of the spinning mass with respect to the case is used to measure the platform’s orientation changes.

Electro-optical gyros generate counter-rotating beams of laser light around a closed path to form an interference pattern that is sensed by a detector. When rotation about an axis not in the plane of the loop occurs, the difference in the effective lengths of the respective paths creates a relative shift of the interference pattern. This shift (known as the Sagnac effect) is observed by the detector, which provides an output proportional to the rotation of the gyro.

There are two common types of optical gyros, the ring laser gyro (RLG) and the fiber optic gyro (FOG), and there are several variations of each. RLGs create their counter-rotating beams of laser light inside gas tubes that are cavities configured in a closed polygonal path, often triangular, but sometimes four or five sided. These cavities are made in glass with a near-zero thermal expansion for higher accuracy. FOGs use long spools of fiber optic cable to carry the counter-rotating beams. An important difference between RLGs and FOGs is that the spool of fiber optic cable gives the FOG a much longer optical path length and, at least theoretically, better accuracy. In practice, however, this improvement is offset by imperfections in the fiber optic cable and cable interfaces. FOGs are under development in several countries, and their performance characteristics are continually improving. They hold much promise for becoming the lowest cost gyro yet devised.

FOGs are designed as single-axis gyros so most missiles that use them will need three to track rotations about all three axes; the same is true of single-ring RLGs. Sometimes multi-axis RLGs are used that contain three or more rings in a single block of glass; only one such unit would be required in a guidance set.

Other types of gyros include the hemispherical resonating gyro, which establishes and monitors a standing vibration wave in a hemispherical cup (somewhat like a small wineglass). There are also designs like small tuning forks that operate by a method that involves Coriolis force. However, any gyro capable of meeting MTCR performance specifications is controlled regardless of its method of operation.

Typical Missile-Related Uses: Gyros are used in a missile's guidance set or integrated flight instrumentation system to sense changes in accelerometer orientation. Designs may use two, three, or four gyros. They usually are mounted perpendicular to each other in order to provide angular measurement information about all three axes. They can be used in a gimbal structure (see Item 2 (d)), mounted in a floating ball, or affixed to a block which is in turn affixed to the missile airframe in a strapdown configuration. Combined with accelerometers, they make up the IMU or ISA.

Other Uses: Gyros are used in non-missile guidance sets, integrated flight instrumentation systems, gyrostabilizers, automatic pilots, and in navigational equipment. Military applications include artillery, tanks, ships, and aircraft. Commercial applications include ships, aircraft, and oil drilling. In most non-missile applications, gyros can be smaller, cheaper, and less complex because operating environments and accuracy requirements are usually less demanding.

Appearance (as manufactured): Modern SDF gyros can be 5 to 8 cm in diameter and 8 to 12 cm long, and weigh up to one kg. DTGs are usually cylindrical with diameters of 4 to 6 cm and lengths of 4 to 8 cm, and generally weigh less than one kg. Older gyros can be somewhat larger, approximately twice the size and weigh several kilograms. Gyros used in UAVs, including cruise missiles, can be much smaller and lighter, perhaps tens of grams.

Many gyros of MTCR concern have precision mounting surfaces for accurate alignment and high quality electrical connections. Because many designs exist, a gyro's appearance can vary greatly. Spinning mass gyros are usually cylindrical, metallic, heavy for their size, and shiny from precision machining. A dynamically tuned spinning mass gyro is shown in Figure 9-7.

Photo Credit: The Charles Stark Draper Laboratory, Inc.

Figure 9-7: A DTG dynamically tuned spinning mass gyro.

Photo Credit: British Aerospace Ltd.

Figure 9-8: A vibrating structure gyro.

Photo Credit: Honeywell

Figure 9-9: Three exposed ring laser gyros without their associated electronics.

Photo Credit: Honeywell

Figure 9-10: A fiber optic gyro with its top removed.

Photo Credit: LITEF

Figure 9-11: A fiber optic, rate sensing gyro. It is 2 × 6.5 × 8 cm.

A vibrating structure gyro is shown in Figure 9-8. Individual optical gyros are usually pad-like and mounted in a low profile, sealed box. A three-ring RLG unit will tend to be cubic and between 4 and 10 cm on a side. It may weigh between fractions of a kilogram to over a kilogram. Some single-axis designs resemble cylinders with diameters exceeding 20 cm. Three exposed RLG bodies are shown in Figure 9-9; an electrode for the gas laser can be seen at the bottom of each ring. The laser light travels the triangular path machined into the glass. Some FOG designs are only 2 to 4 cm in diameter, contain a fiber several hundred meters long, and weigh fractions of a kilogram. A FOG with its top removed is shown in Figure 9-10. A more typical exterior appearance for FOGs and RLGs is shown in Figure 9-11.

MTCR-controlled and uncontrolled gyros may look identical. Relevant information unique to each model- and serial-numbered gyro can be derived from the associated documentation (calibration sheet or cal-data), including the drift rate stability. As with accelerometers, the exhaustive testing needed to compile this calibration data is a substantial part of what makes a gyro accurate enough for use in a missile guidance set. Thus, the detail and amount of the calibration and error modeling data associated with each gyro are critical to determining the missile-related use of a gyro. The cal-data normally cites a serial number that is visible on the gyro.

Appearance (as packaged): Spinning mass gyros are vulnerable to damage from shock, but optical gyros are fairly rugged. Spinning mass gyros are packed in high quality, cushioned containers. Optical gyros do not need as much cushioning material in the package, but they are still likely to be shipped in high quality packages typical of expensive electronic instruments and sensors.

(e) Continuous output accelerometers or gyros of any type, specified to function at acceleration levels greater than 100 g;

<u>Note to Item 9:</u>

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

Produced by companies in

- China
- France
- Germany
- Israel
- Italy
- Japan
- North Korea
- Russia
- United Kingdom
- United States

Nature and Purpose: Continuous output accelerometers and gyros specified to function at acceleration levels greater than 100 g are a special category of accelerometers and gyros, which may include those in Item 9 (c) and (d), respectively. These devices produce uninterrupted signals throughout their specified range and are designed to operate under extreme accelerations in excess of 100 g. All such instruments are controlled under this item regardless of performance specifications. Their purpose is to provide inertial instrument data under heavy accelerations like those experienced by reentry vehicles (RVs) during defense avoidance and reentry deceleration. These instruments may also be used as part of a fuzing system. No accuracy specifications are included because instruments with significantly lower accuracy can be used due to the relatively short period of operation.

Method of Operation: These inertial instruments operate in much the same way as those covered in Item 9 (c) and (d), but they are ruggedized and have a greater operating range (in excess of 100 g).

Typical Missile-Related Uses: These accelerometers can be used as fuses in RVs, and continuous output accelerometers and gyros are used in the guidance sets that steer maneuvering RVs as they evade defenses or terminally guide themselves to a target. Such accelerometers and gyros are fairly accurate and probably nuclear hardened. Continuous output accelerometers rated in access of 100 g are also used in fusing and firing mechanisms for cruise missiles with penetrating warheads.

Other Uses: Continuous output accelerometers and gyros able to operate in a 100-g environment can be used in guided munitions such as artillery shells. Such accelerometers are also used in laboratories for high-g tests that require continuous output.

Photo Credit: Lockheed Martin Federal Systems

Figure 9-12: Two continuous output accelerometers, visually identical to those of Figure 9-5, rated at 100 g.

Appearance (as manufactured): Continuous output accelerometers, as shown in Figure 9-12, may look identical to those covered in Item 9 c. Similarly, gyros specified to function at levels greater than 100 g may also be virtually identical in appearance to those covered in Item 9 d. They all are usually cylindrical or pad-like with precision mounting flanges and high quality

Photo Credit: Litton Guidance and Control Systems

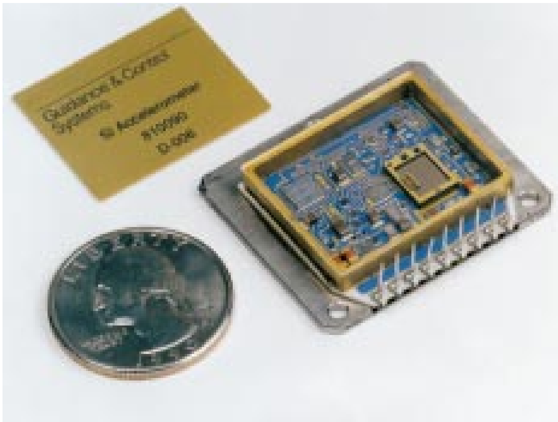


Figure 9-13:
An integrated circuit accelerometer rated at over 100 g.

Produced by companies in

- China
- France
- Germany
- Israel
- Italy
- Japan
- Norway
- Russia
- South Africa
- Spain
- Sweden
- Switzerland
- Ukraine
- United Kingdom
- United States

electrical connectors. Because smaller instruments are inherently more g-tolerant, they tend to be smaller than most other accelerometers and gyros. There are even miniature high-g accelerometers integrated into circuit elements, as shown in Figure 9-13.

Appearance (as packaged): Because of their rugged nature, these instruments do not need special handling. They are shipped as small hardware items. The documentation on the operating g range of each model- and serial-numbered unit is usually contained in its package.

(f) Inertial or other equipment using accelerometers described by subitems (c) or (e) above or gyros described by subitems (d) or (e) above, and systems incorporating such equipment, and specially designed integration software therefor;

Notes to Item 9:

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

Nature and Purpose: This MTCR Annex item ensures that any of the accelerometers and gyros controlled in Item 9 remain controlled when they are components of a larger assembly or a non-guidance related assembly. Examples of such assemblies include gimbal assemblies with the instruments installed, IMUs, complete guidance sets not controlled under Category I, Item 2 (d), gravity meters, and stabilized platforms for cameras, antennas, or other equipment. Any inertial system, subsystem, or other equipment, regardless of its intended use, is controlled as Category II under this item if it contains one or more of Items 9 (c), 9 (d), or 9 (e).

Typical Missile-Related Uses: This equipment is used in guidance sets and integrated flight instrumentation systems for ballistic missiles and cruise missiles, as described in Item 2 (d) and Item 9 (a).

Other Uses: This equipment can also be used in guidance sets and navigation systems for a whole range of space flight, aviation, gravity mapping, ocean navigation, land navigation, and well drilling uses.

Appearance (as manufactured): The appearance of inertial or other equipment using accelerometers or gyros varies widely. IMUs can be gimbaled; a gimbaled IMU is shown in Figure 9-14. These can be designed to be spherical so as to float inside a liquid-filled chamber, as shown in Figure 9-15.

Photo Credit: The Charles Stark Draper Laboratory, Inc.

Figure 9-14: A gimbaled IMU that contains three accelerometers and three gyros (gimbals are internal).

Figure 9-15: A model of an inertial measurement sphere that contains three accelerometers and three gyros, designed to float inside a liquid-filled chamber (chamber shown open).

Photo Credit: Honeywell

Figure 9-16: A strapdown IMU that contains three accelerometers and three ring laser gyros (in the end opposite the cables).

Photo Credit: Honeywell

Figure 9-17: A strapdown IMU containing three accelerometers and three ring laser gyros.

IMUs can also be designed to be rigidly mounted in a strapdown configuration, as shown in Figures 9-16 and 9-17. Equipment using accelerometers and gyros may also use optical sensors, Global Positioning System satellite receivers, radar units, horizon sensors, computers and software, and other items, depending on the specific application. The equipment has electrical connectors and mounting surfaces, and may have removable access panels for replacing accelerometers, gyros, or other subelements. They vary in size from a few centimeters to a meter on a side.

Appearance (as packaged): Because many accelerometers and gyroscopes are inherently delicate, they are packed in robust shipping containers with cushioning and insulation to prevent damage from shock and moisture. Containers may be wood, metal, or plastic with foam cushioning. The shipping packages are likely to have the cautionary labels usually used on containers of costly assemblies of sensitive electrical or mechanical equipment.

Produced by companies in

- China
- France
- Germany
- Italy
- Japan
- Russia
- Switzerland
- United Kingdom
- United States

(g) Production equipment and other test, calibration and alignment equipment, other than that described in 9(h), designed or modified to be used with equipment specified in a-f above, including the following:
  (1) For laser gyro equipment, the following equipment used to characterize mirrors, having the threshold accuracy shown or better:
    (i) Scatterometer (10 ppm);
    (ii) Reflectometer (50 ppm);
    (iii) Profilometer (5 Angstroms).
  (2) For other inertial equipment:
    (i) Inertial Measurement Unit (IMU Module) Tester;
    (ii) IMU Platform Tester;
    (iii) IMU Stable Element Handling Fixture;
    (iv) IMU Platform Balance fixture;
    (v) Gyro Tuning Test Station;
    (vi) Gyro Dynamic Balance Station;
    (vii) Gyro Run-In / Motor Test Station;
    (viii) Gyro Evacuation and Filling Test Station;
    (ix) Centrifuge Fixture for Gyro Bearings;
    (x) Accelerometer Axis Align Station;
    (xi) Accelerometer Test Station.

(h) Equipment as follows:
  (1) Balancing machines having all the following characteristics:
    (i) Not capable of balancing rotors / assemblies having a mass greater than 3kg;
    (ii) Capable of balancing rotors / assemblies at speeds greater than 12,500 rpm;
    (iii) Capable of correcting unbalance in two planes or more; and
    (iv) Capable of balancing to a residual specific unbalance of 0.2 gram mm per kg of rotor mass;
  (2) Indicator heads (sometimes known as balancing instrumentation) designed or modified for use with machines specified in 9(h) 1;
  (3) Motion simulators / rate tables (equipment capable of simulating motion) having all the following characteristics:
    (i) Two axis or more;
    (ii) Slip rings capable of transmitting electrical power and / or signal information; and
    (iii) Having any of the following characteristics:
      (a) For any single axis:
        (1) Capable of rates of 400 degrees / sec or more; or 30 degrees / sec or less; and
        (2) A rate resolution equal to or less than 6 degrees / sec and an accuracy equal to or less than 0.6 degrees / sec;

(b) Having a worst-case rate stability equal to or better (less) than plus or minus 0.05 percent averaged over 10 degrees or more; or
(c) A position accuracy equal to or better than 5 arc second;

(4) Positioning tables (equipment capable of precise rotary positioning in any axes) having the following characteristics:
(i) Two axes or more; and
(ii) A positioning accuracy equal to or better than 5 arc second;

(5) Centrifuges capable of imparting accelerations above 100 g and having slip rings capable of transmitting electrical power and signal information.

Notes to Item 9:

(4) The only balancing machines, indicator heads, motion simulators, rate tables, positioning tables, and centrifuges specified in Item 9 are those specified in 9 (h).
(5) 9 (h) (1) does not control balancing machines designed or modified for dental or other medical equipment.
(6) 9 (h) (3) and (4) do not control rotary tables designed or modified for machine tools or for medical equipment.
(7) Rate tables not controlled by 9 (h) (3) and providing the characteristics of a positioning table are to be evaluated according to 9 (h) (4).
(8) Equipment that has the characteristics specified in 9 (h) (4) which also meets the characteristics of 9 (h) (3) will be treated as equipment specified in 9 (h) (3).

Nature and Purpose: Alignment, calibration, and test equipment is used to build, calibrate, test, and characterize these instruments to meet the requirements. Gyroscopes, accelerometers, and IMUs are precision instruments that must be accurate and reliable over time. Particularly important is test equipment that subjects an instrument to accelerations and orientation changes while measuring the instrument’s response over time. This equipment is essential to the manufacture of high quality inertial instruments. Any specially designed test, calibration, alignment, and production equipment is controlled even if it is not specified on the list.

Typical Missile-Related Uses: This equipment is required to produce and calibrate inertial instruments for use in missiles of all types.

Other Uses: Most spacecraft, aircraft, and other vehicles using inertial navigation or guidance units require similar equipment and technologies for development, production, test, and calibration. However, many other non-missile applications can use inertial instruments with higher drift rates, lower vibration and acceleration tolerances, and lower stability requirements. Thus, the test, calibration, alignment, and production equipment for non-missile inertial equipment is often less sophisticated and less precise than that required for accurate missiles.

Photo Credit: Digital Instruments

Figure 9-18: A profilometer system used for measuring mirrors.

Photo Credit: Honeywell

Figure 9-19: A typical IMU module tester.

Photo Credit: Litton Guidance and Control Systems

Figure 9-20: Another portable IMU tester connected to a miniature IMU.

Appearance (as manufactured): Specially designed alignment, calibration, test, and production equipment for these guidance and navigation items described in (a) through (f) are usually limited-production items. They are as diverse in size, weight, and appearance as in function, and these features change as the technology changes. Although far from a complete list, short descriptions of some examples are provided below.

Because ring laser gyros sense the phase change of minute wavelengths in light, their accuracy is determined by the quality of their mirrors. The mirrors must be a precise shape and reflect almost all the light falling on them and neither absorb nor scatter it. The following three pieces of equipment are designed to characterize mirrors for use in such gyros.

- A scatterometer (10 ppm) measures the tendency of a mirror to scatter light away from its intended direction to an accuracy of 10 ppm or less. It provides a beam of known intensity and measures the intensity of scattered rays.
- A reflectometer (50 ppm) measures the ability of a mirror to reflect light to a measurement accuracy of 50 ppm or less. It works by shining a beam of known intensity on the mirror and measuring the intensity of the reflected light.
- A profilometer (5 Angstroms) measures the profile of the optical surface of a mirror to an accuracy of 5 Angstroms (5×10^{-10} m) or less. Various methods are used to map the minute variations in optical surface height. This mapping helps determine the localized deviations from theoretical perfect geometry, whether it is designed flat, concave, or convex. A complete profilometer system is shown in Figure 9-18.

The accuracy of inertial guidance systems is determined by the quality of their accelerometers and gyroscopes. Most of the following equipment either characterizes or tests these instruments as they operate separately, as an assembly, or as a complete IMU.

- An IMU Module Tester operates an IMU module electrically, simulates inputs, and collects response data to confirm proper electrical operation. Typical IMU module testers are shown in Figures 9-19 and 9-20.

- An IMU Platform Tester operates a complete IMU platform, that is, the stable element or fully operational strapdown IMU. A three-axes rate table, also referred to as a motion simulator, often is used as part of an IMU platform tester; an example is shown in Figure 9-21. Such tables are controlled under Item 9 (h) (3). An IMU tested by this equipment should correctly sense the earth's gravity and rotation through all orientation changes without misinterpreting it as lateral or vertical movement and without losing track of its initial alignment with respect to a fixed coordinate reference frame.

Figure 9-21: A three-axis rate table for testing IMUs or gyros.

- An IMU Stable Element Handling Fixture safely handles the IMU stable element, that is, the inner portion of a gimbaled or floated IMU, which contains the inertial instruments. Careful handling facilitates numerous necessary manipulations without degrading the stable element during its assembly, test, and adjustment.

- An IMU Platform Balance Fixture determines IMU platform imbalance and thereby facilitates adjustments to establish balance. The center of balance must be established accurately to avoid torques under acceleration and vibration during flight.

Photo Credit: Ideal Aerosmith, Inc.

Figure 9-22: A typical rate table used for tuning gyros.

- A Gyro Tuning Test Station energizes the gyro at the desired voltage over a range of speeds to determine the best operating rate of rotation, or rpm. The best rpm is achieved when the effects of gyro error sources are minimized as indicated by data collected. A typical rate table used as part of a gyro tuning test station is shown in Figure 9-22.

- A Gyro Dynamic Balance Station precisely balances the high-speed rotating members of spinning mass gyroscopes. Balance is critical to gyro performance and longevity. These balancing machines are subject to control under Item 9 (h) (1) if they have the specified performance characteristics.

- A Gyro Run-In / Motor Test Station energizes the gyro or gyro motor at the desired voltage and frequency to accumulate run time and thereby break in the gyro bearings and measure motor performance at the design rpm.

- A Gyro Evacuation and Filling Test Station purges a gyro internal cavity and fills it with the design pressure of a desired liquid or blend of gases. Most gyros and accelerometers will be filled with an inert dry gas to

Photo Credit: A.G. Davis Gage & Engineering

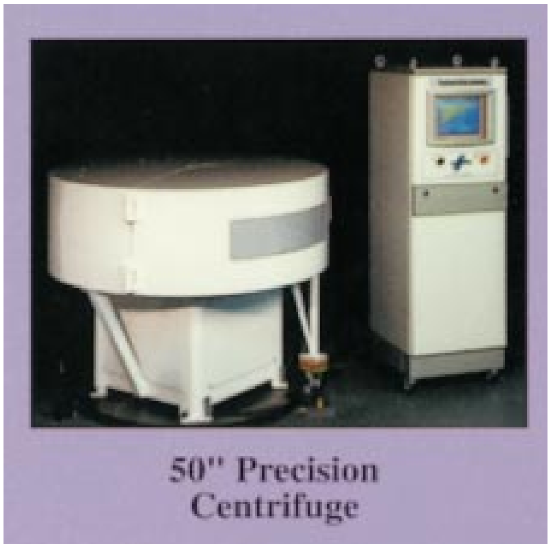


Figure 9-23: A centrifuge used for gyro-bearing testing and its controller.

Photo Credit: Boeing North American, Inc.

Figure 9-24: PIGA accelerometer alignment station control electronics.

improve long term performance. In addition, certain gyros have internal cavities that need either a specific liquid of a given density and viscosity or a specific blend of gases to function properly.

- A Centrifuge Fixture for Gyro Bearings facilitates testing of gyros in a centrifuge to confirm the ability of the bearings to withstand the acceleration forces expected during flight. Centrifuge fixtures are also used to remove excess lubricant from a gyro's bearing retainer rings. A centrifuge is shown in Figure 9-23.

- An Accelerometer Axis Align Station checks accelerometer axis alignment by rotating the accelerometer about its input axis while the input axis is horizontal. This test is often repeated after vibration tests or temperature cycles to determine input axis alignment stabilities. Accelerometer input axis alignment is again checked after installation at the IMU level to determine the slight but important deviations from desired mutual perpendicularity of the input axis. The electronics associated with a pendulous integrating gyro accelerometer (PIGA) alignment station are shown in Figure 9-24.

- Accelerometer Test Stations are used to test the accuracy with which an accelerometer can measure gravity over a range of positions and angles. These data are then used to calibrate the instrument. Accelerometers are mounted to a vertical table surface and tumbled to experience gravitational acceleration while upright and alternately upside down. Several PIGA test stations are shown in Figure 9-25. Accelerometer test stations can run tests that include temperature control, as shown in Figure 9-26. The tests use data recording equipment that take data over a long period of time.

Photo Credit: Boeing North American, Inc.

Figure 9-25: PIGA accelerometer test stations.

- Balancing machines are used primarily to balance spinning mass gyroscopes to a high level of precision. Balancing machines are controlled under Item 9 (h) (1).

- Indicator heads are precision round steel tables that can be rotated and locked in a specific direction repeatedly without loss of accuracy. They are also known as tumble testers, indexing heads, positioning tables, and dividing heads. Indicator heads modified for use in Item 9 (h) (1) controlled balancing machines are controlled under Item 9 (h) (2), and high precision, multi-axis indicator heads (i.e., positioning tables) are controlled under Item 9 (h) (4).

- Controlled motion simulators and rate tables are precision machines that rotate a mounting table about multiple axes at precisely known speeds and angles. They are normally used in guidance development to test instruments and IMU assemblies as described above. Figure 9-21 shows such a rate table; Figure 9-27 shows a two-axis, rate-integrating gyro motion simulator. Rate tables are controlled under Item 9 (h) (3).

- A centrifuge, as shown in Figure 9-23, is used as part of an accelerometer test station in order to determine accelerometer non-linearities over a range substantially in excess of the plus and minus one g available in tumble tests. Centrifuges are controlled under Item 9 (h) (5).

Photo Credit: Litton Guidance & Control Systems

Figure 9-26: A dividing head with a temperature control chamber for testing an accelerometer inside the chamber.

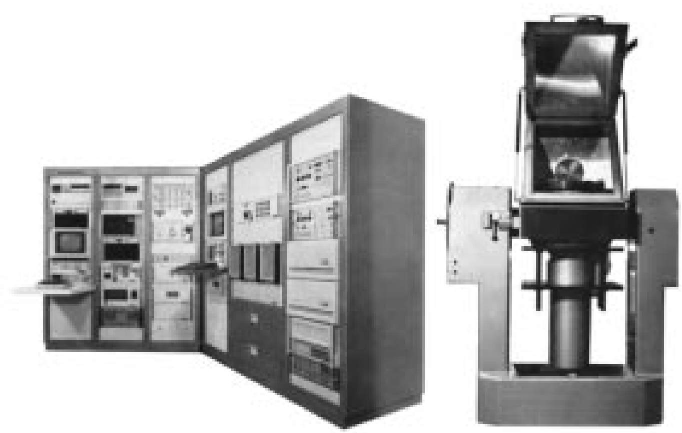


Photo Credit: Contraves Inc.

Figure 9-27: A two-axis rate integrating gyro test station utilizing a motion simulator/rate table.

Appearance (as packaged): Packaging varies greatly with the size, weight, and sensitivity of the specific equipment. However, because most of these items are precision equipment sensitive to shock or rust, packaging is likely to be robust, with padding and coverings to protect against shock and moisture. Much of the equipment can be disassembled and shipped in separate containers or crates.

ITEM 10
Flight Control

Flight Control

Flight control systems and "technology" as follows; designed or modified for the systems in Item 1 as well as the specially designed test, calibration, and alignment equipment therefor:
(a) Hydraulic, mechanical, electro-optical, or electro-mechanical flight control systems (including fly-by-wire systems);
(b) Attitude control equipment;

Note to Item 10:
Items (a) and (b) may be exported as part of a manned aircraft or satellite or in quantities appropriate for replacement parts for manned aircraft.

Produced by companies in

- Australia
- Austria
- Belgium
- Brazil
- Bulgaria
- Canada
- China
- Czech Republic
- Egypt
- France
- Germany
- Greece
- Hungary
- India
- Israel
- Italy
- Japan
- Norway
- Portugal
- Romania
- Russia
- South Africa
- South Korea
- Sweden
- Switzerland
- Turkey
- United Kingdom
- United States

Nature and Purpose: The flight control system provides and controls the steering mechanisms needed for a missile to achieve stable flight and execute subsequent maneuvers without losing stability. It normally receives steering commands from the guidance set, mission computer, or integrated flight instrumentation system.

The flight control system includes the actuators to move control surfaces, aim nozzles, control flows, and activate thrusters. It also includes sensors to detect changes in air vehicle attitude, rate of change of attitude, speed, altitude, throttle setting, air temperature, and air pressure. These sensor outputs are often shared by other mechanisms in the missile. The flight control system is distributed throughout the missile and sometimes overlaps with portions of other systems.

Information transmitted from the sensors to the flight control computer and to the actuators is either analog or digital and may be routed by electrical wires (fly-by-wire). State-of-the-art systems may use optical fibers to provide digital communication between the flight control components (fly-by-light). Optical connections are lighter in weight and greatly reduce susceptibility to the effects of electromagnetic pulse, electromagnetic interference, and lightning.

Method of Operation: When unmanned air vehicles (UAVs), including cruise missiles, need to maneuver (turn, climb, etc.), the integrated flight instrumentation system commands a change in air vehicle heading or altitude. The flight control system sets the actuators on control surfaces to introduce pitch, roll, and / or yaw; holds those settings until the orientation has changed; and then resets the actuators to maintain the new profile. Flight control systems often work in conjunction with a gyrostabilizer or automatic pilot (autopilot), which determines the control surface motions necessary to achieve the desired maneuvers. Autopilots also continuously compensate for environmental disturbances. Ballistic missiles may also use flight control systems that operate similarly, but ballistic missiles use thrust vector control and possibly small steering jets to change missile direction. Some ballistic missiles also use aerodynamic fins while in the atmosphere.

Typical Missile-Related Uses: Flight control systems are required to achieve stable missile flight and execute maneuvers without losing stability. These systems are usually tailored to the flight characteristics and mission profile of the missile and thus tend to be missile-specific. Most missiles, including space launch vehicles (SLVs) and UAVs, use these systems.

Photo Credit: Moog Inc.

Figure 10-1: An electromechanical actuator for thrust vector control of a rocket nozzle.

Other Uses: Components used in missile flight control systems may also be used in military and civilian aircraft.

Appearance (as manufactured): The flight control system is not a single integral unit; it is distributed throughout the missile. The flight control system parts most likely to be encountered include the actuators, electronic assemblies, specialized cables, and some sensors.

Photo Credit: Daimler-Benz Aerospace

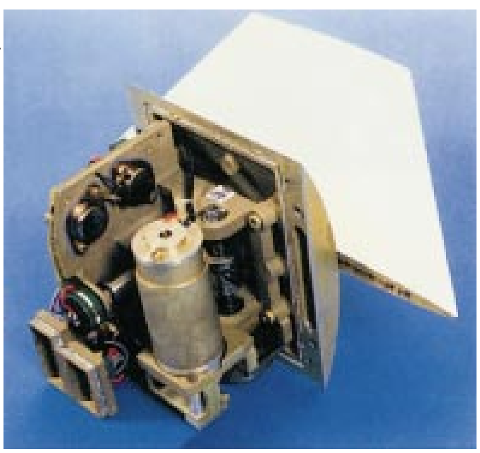


Figure 10-2: An electromechanical flight control actuator for a tail fin of a small missile.

The actuators used to move aerodynamic control surfaces can either be rotary or linear. A rotary actuator can be powered by an electric motor. It responds proportionally to an input command. The actuator is part of a closed-loop control system, which includes an amplifier and a method for sensing the position of the actuator. The mechanical output of the actuator is either a hub that can accept a control surface shaft or a shaft onto which a surface can be mounted. An actuator for thrust vector control (TVC) of a rocket nozzle is shown in Figure 10-1. An electromechanical flight control actuator for a tail fin of a small missile is shown in Figure 10-2. Sometimes this actuator must not only be capable of rotating the control surface into a significant aerodynamic force, but also supporting the entire mass of the surface during high-acceleration launches and maneuvers. Linear actuators are connected to control surfaces through mechanical linkages that convert the linear actuator motion to an angular control surface motion. These actuators are powered by an electric motor, pressurized gas, or hydraulic fluid. A hydraulic TVC actuator for a very large solid rocket motor is shown in Figure 10-3.

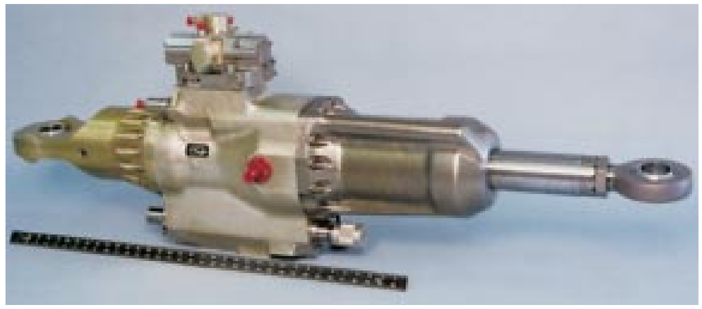


Photo Credit: Moog Inc.

Figure 10-3: Hydraulic TVC actuator.

Appearance (as packaged): Aerodynamic control surfaces and actuators are fairly robust pieces of equipment. Typical packaging includes wooden crates and cardboard or wooden boxes. They are securely attached to the shipping container to avoid movement and probably packed in foam shaped like the part. The sensors used in flight control systems are often more delicate and are normally individually wrapped and secured in a shock-resistant box or crate. They are often wrapped in a moisture-proof bag.

(c) Design technology for integration of air vehicle fuselage, propulsion system and lifting control surfaces to optimize aerodynamic performance throughout the flight regime on an unmanned air vehicle;
(d) Design technology for integration of the flight control, guidance, and propulsion data into a flight management system for optimization of rocket system trajectory.

Nature and Purpose: Stable and controlled air vehicle or missile flight is a very complicated dynamic control problem. Solving it requires in-depth knowledge of all subsystems and their interactions over all flight regimes. This knowledge is normally generated by wind tunnel testing, computer modeling to simulate vehicle performance, and a detailed flight test program. Design integration technology enables missile designers to size, configure, and optimize all the subsystems; to take into account their often-complicated interactions; and thereby to minimize errors. Thus, this technology decreases the time to design, test, and produce a missile or flight vehicle and may also support efforts to improve missile performance.

Method of Operation: Early in a development program, design integration technology is often manifested in a computer program that models the airframe and the propulsion, guidance, and control systems of the vehicle. The software simulates vehicle behavior in all expected flight regimes and predicts theoretical performance. The designer can change the subsystem parameters, rerun the simulation, and choose those parameters that give the best performance. Later in the development program “hardware-in-the-loop” simulations may be used where actual subsystems are connected together on a test bench and the computer simulates the flight environment and any hardware missing from the simulation. Some test equipment, such as wind tunnels, may be used to replicate actual flight conditions as part of the

Produced by companies in

- Australia
- Austria
- Belgium
- Brazil
- Bulgaria
- Canada
- China
- Czech Republic
- Egypt
- France
- Germany
- Greece
- Hungary
- India
- Israel
- Italy
- Japan
- Norway
- Poland
- Portugal
- Romania
- Russia
- South Africa
- South Korea
- Spain
- Sweden
- Switzerland
- Taiwan
- Turkey
- United Kingdom
- United States

simulations. This technique finds real-world effects of hardware interactions, which may be difficult to detect or hard to simulate. For example, the US Space Shuttle was never flight-tested in its final configuration. Although numerous components and subsystems were extensively tested, the shuttle flew with a crew the first time it was launched—an event extremely unlikely without this technology.

Typical Missile-Related Uses: Though not an absolute requirement, modern UAVs, including cruise missiles, and rocket systems use design integration technology to shorten development time, decrease costs, and validate and improve performance.

Other Uses: Similar design integration technology is used to design and integrate commercial and military aircraft.

Appearance (as manufactured): Typically design integration technology takes the form of a computer program stored on printed, magnetic, or other media. Any common media including magnetic tape, floppy disks, removable hard disks, compact disks, and documents can contain this software and data.

Appearance (as packaged): Magnetic tape, floppy disks, removable hard disks, compact disks, and documents containing design integration technology are indistinguishable from any other storage media. Only labeling and accompanying documentation can indicate its use unless the software is run on the appropriate computer. This technology, including the documentation, is capable of being transmitted over a computer network.

ITEM 11
Avionics

Avionics

Avionics equipment, "technology" and components as follows; designed or modified for use in the systems in Item 1, and specially designed software therefor:

(a) Radar and laser radar systems, including altimeters;

Notes to Item 11:

(1) Item 11 equipment may be exported as part of a manned aircraft or satellite or in quantities appropriate for replacement parts for manned aircraft.

(2) Examples of equipment included in this Item:
  - (a) Terrain contour mapping equipment;
  - (b) Scene mapping and correlation (both digital and analogue) equipment;
  - (c) Doppler navigation radar equipment;
  - (d) Passive interferometer equipment;
  - (e) Imaging sensor equipment (both active and passive);

(3) In subitem (a), laser radar systems embody specialized transmission, scanning, receiving and signal processing techniques for utilization of lasers for echo ranging, direction finding and discrimination of targets by location, radial speed and body reflection characteristics.

Produced by companies in

- Australia
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- Norway
- Russia
- South Africa
- South Korea
- Sweden
- Taiwan
- United Kingdom
- United States

Nature and Purpose: Radars, laser radars (LADARs), and infrared (IR) laser radars (LIDARs) are sophisticated active sensor systems that can be used for reconnaissance, target homing, or guidance in unmanned air vehicles (UAVs), especially cruise missiles. Radar scene-matching correlators have been used in UAVs and ballistic missiles. Radar and laser altimeters are somewhat less sophisticated devices used for navigation and terrain avoidance in cruise missiles and weapon fusing in cruise and ballistic missiles. In recent years, significant technological improvements have occurred in transmitters, receivers, antennas, and electronic processing.

Method of Operation: Radar, LADAR, and LIDAR systems operate similarly. They emit a pulse of electromagnetic energy and detect the energy reflected to them from the terrain or target below. Distance is computed as a product of half the elapsed time between signal transmission and reception, and the speed of light. The direction of the target or terrain is given by the angle between the two pulses. The image of the terrain or target thereby created can be compared with stored images, and missile course can be altered as needed.

Radar and laser altimeters operate similarly, but measure only the distance from the missile to the ground. Such altimeters make precise measurements of distance above ground to help low flying missiles avoid terrain and, when compared with elevation maps, can be used as navigation aids. Radar altimeters may also be used in altitude fusing of ballistic missiles.

Doppler navigation systems operate like radar altimeters, but compare the frequencies, not the transit time, of the transmitted beams and the returned energy. The change in frequency is a result of missile movement relative to the ground and can be directly converted to missile velocity. Multiple antennas can measure missile velocity in any direction if they receive enough returned energy. This velocity information can be used to correct for accumulated guidance errors.

Typical Missile-Related Uses: These systems are used in cruise missiles as sensors for target discrimination, homing, and warhead fusing. They are also used as navigation aids for keeping the missile on a prescribed flight path and at certain flight altitudes. Such sensors can also be used for terminal guidance or fusing of ballistic missiles.

Other Uses: Radar and Doppler navigation systems are used on military and commercial aircraft and ships for navigation, weather detection, and collision avoidance. Radar altimeters are commonly used for numerous purposes such as determining height above the terrain on many types of aircraft. LIDARs have been used for atmospheric measurements, oceanographic studies, and smokestack emissions studies.

Appearance (as manufactured): Radar systems for missiles and UAVs (seekers or sensors) are normally designed as a single assembly consisting of an antenna subassembly located at one end of the system and the supporting power, control, and processing subassemblies located in one or more (separate but connected) housings. The antenna subassembly is normally a circular or oblong radiating and receiving, beam-forming element linked to both a power amplifier and waveguides, normally rectangular tubing that couples the signal from the amplifier to the radiating element. Antennas are either flat or parabolic and must be sized to fit within the missile diameter. The antennas are fixed in electronically scanning systems or gimbaled in mechanical scanning systems. The antenna-mounting features and support structure are strong enough to maintain stability and accuracy in the presence of substantial accelerations caused by launch, turbulence, and maneuvering. The shape and weight of the support structure and ancillary equipment housings vary greatly from system to system, but may have some features peculiar to missile applications. For example, to help reduce missile cross-sectional area and improve cooling, the equipment boxes may have one or more cylindrical or conical surfaces and may have mounting features to ensure good contact with the missile skin or provide for coolant flow rather than external fins for air-cooling.

Radar altimeters are generally much smaller than radar seekers or other sensors with fixed, surface-mounted transmitter and receiver antennas. These antennas, which must point toward the ground, are usually flat, rectangular, or circular plates with a mounting surface conforming to the exterior of the missile. The power- and signal-processing requirements are significantly less than those for radar seeker systems. The transmitter and receiver are normally enclosed within one box connected to the antenna by a coaxial cable. This subassembly usually has a volume of less than $0.05 m^3$ and does not require external cooling. A typical Doppler system consisting of a receiver/transmitter/antenna assembly typically occupies $0.007 m^3$, weighs less than 5 kg, and requires about 12 watts of power.

LADAR and LIDAR systems differ from radar systems in that they use the much shorter visible-light and IR wavelengths respectively. They are easily distinguished by the external appearance of an optical lens or window. Systems operating at longer IR wavelengths have an optical port that may appear to be metallic. Like radar antennas, the optical unit of the system is fixed or movable, and it may be mounted separately. Construction is heavy, with rugged mounts. In general, all of these systems have mounting surfaces that are unpainted but coated with a conductive anti-corrosion film. The electrical grounding of all avionics chassis is vital to survival in hostile electromagnetic environments.

Appearance (as packaged): Although these systems are built to survive normal missile handling and storage, and severe flight environments, they must be carefully packaged to ensure that unusual stresses are not imposed by the shipping container and its environments. Because the antenna structure and drive systems are especially sensitive, they are well protected. The systems are sealed in an air-tight enclosure and shipped in cushioned containers. A wide range of outer containers may be used including metal drums, wooden boxes, and composite or metal cases.

Produced by companies in

- Australia
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- Norway
- Russia
- South Africa
- Sweden
- Taiwan
- United Kingdom
- United States

(b) Passive sensors for determining bearings to specific electromagnetic sources (direction finding equipment) or terrain characteristics;

Nature and Purpose: Direction finding systems provide a vehicle with bearing information (angular orientation) to known sources of electromagnetic radiation emanating from ground-based transmitters. Terrain and target characteristics may be determined by imaging systems, typically a visible or infrared (IR) camera. These systems are passive because they receive but do not transmit energy; thus, missiles using them are much less likely to be detected. Both systems are used for UAV guidance and as payload sensors, and in some cases have been used for terminal guidance of ballistic missiles.

Method of Operation: Direction finding equipment uses passive sensors to receive electromagnetic radiation from ground transmitters at various known points. For example, comparing the relative transit times of the signals from two or more sites allows the computer on the missile to determine its location and heading. This information is used by the integrated flight instrumentation system to follow the preprogrammed flight plan. An anti-radiation homing seeker guides the missile to the target by processing the received radar energy from a single emitter.

Imaging sensors may use terrain characteristics to navigate. The optical assembly consists of one or more lenses of fixed or variable focal length, an image intensifier, and a photosensitive array for converting the scene into a digital map. This assembly operates in the visible or IR wavelengths. Visible light systems using a high-intensity flash illuminator at night thus become semi-active sensors. The sensors collect images of ground scenes at predetermined points along a preprogrammed flight path. The images are digitized and compared to stored scenes of the same locations. Differences between the two scenes are converted into a position error used to correct vehicle heading. Alternatively, image sensors can be used in man-in-the-loop guidance where the image of the target area is relayed to a person who actually flies the vehicle. The operator can either guide the UAV to impact or lock the missile on the target after which the missile homes autonomously to impact.

Typical Missile-Related Uses: Inertial guidance systems updated by imaging systems can be used to guide cruise missiles with extraordinary accuracy or for terminal guidance of ballistic missiles. Direction finding equipment can be used to guide UAVs and for ballistic missile terminal guidance.

Other Uses: Interferometer direction finding systems are used in aircraft, ships, and land vehicles. Image sensors are used in many tactical military systems for ordnance delivery, particularly from aircraft. Imaging sensor technology (sensors and algorithms) is also used extensively in robotics and photography. Imaging systems built for cruise missiles, however, usually have no commercial applications.

Appearance (as manufactured): Direction finders consist of three assemblies: an antenna or antenna array, a receiver, and processing equipment. The antenna is a forward-looking parabolic dish, or a flat panel such as a phased array, usually mounted on a gimbaled assembly and sized for installation in the missile structure. The receiver is a small, low power assembly with connectors for power and signal outputs, and one or more coaxial antenna connectors. The signal processing equipment can be integral to other

Figure 11-1: An infrared imaging sensor for an unmanned air vehicle (top) and its associated electronics.

Photo Credit: LFK-Lenkflugkorpersysteme GmbH

Figure 11-2: A gyro stabilized IR camera with its window.

electronics or resident in its own electronics box. The appearance of such signal processing electronics varies greatly and may reflect manufacturer preferences rather than the functional purpose of the equipment. The size of the signal processing equipment ranges from a few centimeters to tens of centimeters on a side.

Imaging sensors consist of a lens and a visible or IR sensor, or camera. They are used with an electronic assembly consisting of a power supply and control and processing electronics, as shown in Figure 11-1. Another IR camera is shown in Figure 11-2. Visible-light sensors are recognizable by the optical lens or window. The optical port of IR light sensors may appear metallic. The flash unit has a large optical window covering a reflector and glass tube.

Imaging sensors may be either fixed or movable, and they may be mounted separately from the rest of the terrain-mapping equipment. The optics mounting features and supporting structure are robust in order to maintain stability and accuracy in the presence of large accelerations during launch, turbulence, and maneuvering. The surface of the unit close to the lens may be shaped to fit the contour of the bottom of the missile because the lens must look at the ground during flight.

Appearance (as packaged): The antennas and optical elements may have special protective packaging because of their sensitivity to shock. These elements are sealed in an airtight, moisture proof enclosures and shipped in cushioned containers. In turn, these packages are shipped in a variety of containers, including metal drums, wooden boxes, or specialized composite or metal cases.

Produced by companies in

- China
- France
- Germany
- Israel
- Japan
- Russia
- South Africa
- United Kingdom
- United States

(c) Global Positioning System (GPS) or similar satellite receivers;
  (1) Capable of providing navigation information under the following operational conditions;
    (i) At speeds in excess of 515 m/sec (1,000 nautical miles/hour); and
    (ii) At altitudes in excess of 18 km (60,000 feet); or
  (2) Designed or modified for use with unmanned air vehicles covered by Item 1.

Nature and Purpose: Global Positioning System (GPS) receivers are small electronic units with power and antenna connections used to provide vehicle position and velocity information. The Global Navigation Satellite System (GLONASS) is a satellite system similar to GPS.

Method of Operation: GPS receivers detect radio signals transmitted from GPS satellites orbiting the earth in precisely known orbits. These radio signals identify the satellite and contain an accurate time reference. The receiver determines its position and velocity by measuring the signal delay among four or more satellites simultaneously and calculating the results on the basis of their locations and other information contained in the signal. GLONASS operates in much the same way as GPS. Combined GPS/GLONASS receivers may also be used.

Typical Missile-Related Uses: Military-grade and commercially available GPS and GLONASS receivers are used in integrated flight instrumentation systems to provide very accurate navigation information to UAVs, including cruise missiles. Specially designed receivers can also be used in ballistic missiles to supplement or update the guidance set and increase missile accuracy.

Photo Credit: Sextant Avionique

Figure 11-3: Global positioning system receiver/processor unit with its patch antenna.

Other Uses: GPS and GLONASS receivers described in Item 11(c) (1) have capabilities required primarily by rocket systems and have few other uses. GPS and GLONASS receivers described in Item 11(c) (2) can be used in airplanes and helicopters.

Appearance (as manufactured): GPS and GLONASS receivers are small, often just a few centimeters on a side, and quite light, often less than a kilogram in weight as shown in Figure 11-3. GPS receivers of MTCR concern cannot always be visually distinguished from uncontrolled GPS receivers because the altitude and velocity limits are implemented in firmware within the microcircuits. Determination of whether a given GPS receiver is MTCR-controlled is best made on the basis of the receiver model, serial number, and associated documentation. GPS receivers are also available as part of a complete guidance package, as shown in Figure 11-4.

Appearance (as packaged): Packaging is typical for small, expensive electronics items. Military-grade items are very well packaged to protect against moisture from prolonged periods of storage.

(d) Electronic assemblies and components specially designed for military use and operation at temperatures in excess of 125 degrees C.

Photo Credit: Litton Guidance & Control Systems

Figure 11-4: A complete guidance package based upon Global Positioning System receivers.

Nature and Purpose: Generally speaking, missile designers try to fit very capable systems into small packages. "Very capable" means that a lot of power is required (such as in a long-range radar or an accurate guidance set), and "small packages" means that power densities are high. If the electronics can be designed to withstand high temperatures, then weight from materials otherwise required for cooling can be avoided. Electronic assemblies and components used in such situations result from extensive design and testing efforts to ensure reliability when used in high-temperature environments. The purpose of rugged, heat-tolerant electronic items is to ensure weapons system performance and reliability while minimizing weight and space.

Method of Operation: These military electronic assemblies and components typically run on batteries and operate much like other electronics. However, a greater margin against failure is designed into them, and their improved reliability has been confirmed by temperature-cycle testing and accelerated-age testing.

Typical Missile-Related Uses: Heat-tolerant electronics are used in guidance computers, inertial navigation systems, and reentry vehicles in ballistic missiles. They are also useful in radars, computers, and seeker systems on UAVs.

Other Uses: Electronic assemblies and components have virtually unlimited uses in all types of military aircraft and other military systems. The same types of assemblies with similar specifications are often used in commercial aircraft and marine vessels, although there may be no confirmation of the claimed reliability through documented exhaustive testing as in the case of military assemblies.

Appearance (as manufactured): Electronic assemblies are usually small and lightweight, measuring a few centimeters in length on a side and a few grams in weight. The components of these assemblies resemble those used in a wide

Figure 11-5: Digital signal processor with the lid removed. The size is 5 to 7.5 cm on each side.

variety of commercial applications. However, electronic assemblies used in military applications are often hermetically sealed in metal or ceramic cases, not in the transparent plastic DIPs used to contain commercial assemblies. Exceptions are high-performance processors such as the quad digital signal processor (DSP) in a multi-chip module package, as shown in Figure 11-5. This DSP includes stacked, high-density memory chips for exceptional speed and memory capacity. The presence of such high cost devices suggests a possible military use; however, some assemblies may look more conventional such as that shown in Figure 11-6.

Photo Credit: AAI Corp.

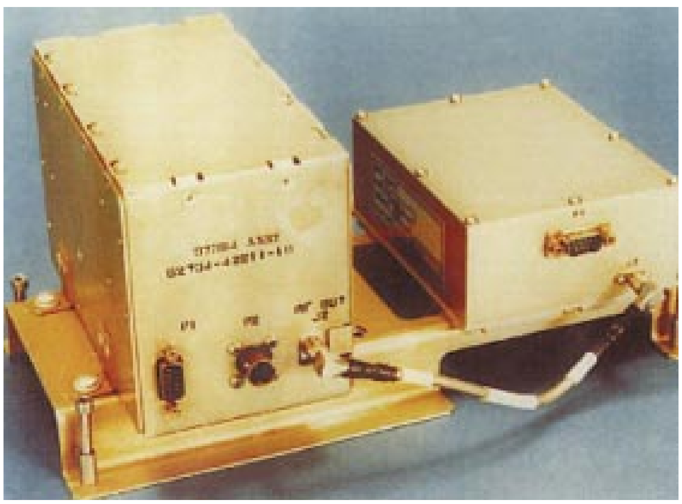


Figure 11-6: Unmanned air vehicle electronics boxes.

Electronic assemblies for military use are often designed to dissipate heat. In some assemblies, the integral heat sinks are supplemented by water cooling. Cable interfaces feature rugged circular connectors or small bolt-on connectors with shielded cables. The electronics are typically mounted within an outer radio frequency (RF) shield (Faraday cage), which may be hermetically sealed or vented to the ambient pressure. Pressurized vessels are sometimes used for missiles and UAVs which must operate at high altitude in order to help conduct heat to the case and the heat sink mounting. Cases are made mainly of aluminum, with exposed metal surfaces painted or treated with corrosion-resistant materials such as nickel plating.

Appearance (as packaged): Electronic assemblies and components are usually shipped in plastic bags marked to designate an electrostatic sensitive device, cushioned in rubber foam or bubble wrap for shock protection, and shipped inside cardboard boxes or, for loads over 20 kg, wooden crates.

Produced by companies in

- China
- France
- Japan
- Russia
- United Kingdom
- United States

(e) Design technology for protection of avionics and electrical subsystems against electromagnetic pulse (EMP) and electromagnetic interference (EMI) hazards from external sources, as follows:
  (1) Design technology for shielding systems;
  (2) Design technology for the configuration of hardened electrical circuits and subsystems;
  (3) Determination of hardening criteria for the above.

Nature and Purpose: Electromagnetic pulse (EMP) and electromagnetic interference (EMI) technology is used to enhance the survival of systems in environments that have intense manmade RF noise, particularly RF noise caused by detonating nuclear weapons. The technology uses at least three approaches, often simultaneously: it configures sensitive circuits in order to minimize interference; it encloses curcuits in conductive boxes; and it protects input/output (I/O) wires by surge suppression devices, commonly just inside the conductive box.

Although the technology used to protect circuits from EMP and EMI is common and unremarkable, determining requirements and implementing them are difficult and sophisticated problems. Circuit topologies, suppression device usage, weapon effects prediction models, and criteria generation can be investigated by interactive computer programs, which input weapon and system parameters and output threat environments such as fields and current levels.

Method of Operation: EMP and EMI protection is generally passive. RF enclosures dissipate RF energy as electrical eddy currents in the conductive outer surface. Care is taken with lids and doors to ensure that fields cannot leak into an enclosure; metal gaskets and screens are typically used to seal such openings. I/O suppression devices simply short electric fields to ground or provide high impedance (i.e., electrical opposition) by using RF chokes and filters. However, some suppression devices like zener diodes, transorbs, spark gaps, and metal oxide varistors change their impedance at certain voltage or current levels.

Typical Missile-Related Uses: EMP and EMI design technology is used in ballistic missiles to protect the guidance set and electronic equipment in the reentry vehicle from the EMP and EMI effects from nearby nuclear detonations. It is also used to protect pyrotechnic devices such as stage-separation systems from premature ignition. This technology can be used in UAVs, but they generally need only be protected against lower levels of EMP and EMI encountered at considerable distance from nuclear blasts or other sources of interference.

Other Uses: EMP and EMI design technology is used in satellites, some military aircraft, and some weapons systems. Similar EMI technology is used in the design of some commercial electronic systems such as shortwave radios and stereo equipment to reduce or prevent interference from other electrical devices. Surge suppression devices for lightning strikes on power supplies and cords is another example of EMP/EMI protection.

Appearance (as manufactured): Such design technology can take the form of technical assistance, including training and consulting services. Technology can also take the form of blueprints, plans, diagrams, models, formulae, engineering designs and specifications, and manuals and instructions written or recorded on other media or devices such as disk, tape, and read-only memories.

Photo Credit: Sabritec

Figure 11-7: Some electromagnetic interference suppression devices.

Some design technology is conveyed by the equipment itself. Assemblies are RF-shielded in metal enclosures, usually aluminum. For very lightweight applications, durable composite or rugged plastic boxes are used with a thin coating of metal for RF shielding. The coating is usually aluminum, often on the inside surface of the box. Exposed metal surfaces are often painted or treated with corrosion-resistant materials such as nickel plating. Some EMI suppression devices are shown in Figure 11-7. An EMI / EMP electronics module is shown in Figure 11-8. The electronics are protected by the aluminum perimeter that serves as a RF Faraday cage when hermetically sealed by the mating modules and cover. The aluminum surface beneath the circuit board serves as an RF partition of the internal modules. The bolt pattern for the cover is spaced every few centimeters to prevent gaps in the closure and to maintain even pressure on an RF gasket that may be soft metal, metal-filled gasket, metal spring, or wire mesh. EMI / EMP electronics may take on almost any shape to fit space constraints.

Photo Credit: The Charles Stark Draper Laboratory, Inc.

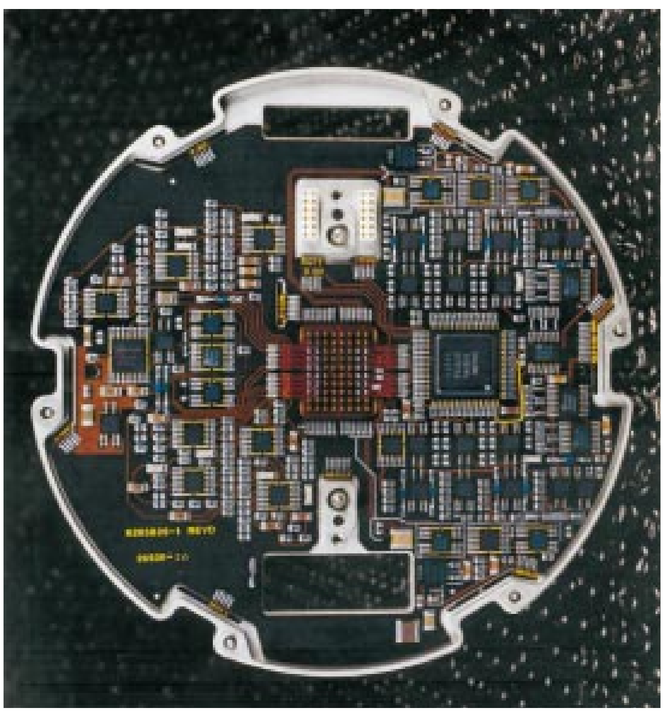


Figure 11-8: Electromagnetic interference / electromagnetic pulse electronics module.

Appearance (as packaged): Technology in forms such as reports, data, and criteria generating programs may be packaged in oversized business envelopes or in ordinary computer electronic media mass distribution packages. Electronic EMP / EMI assemblies are typically shipped with rubber foam or bubble wrap shock protection in cardboard or, if they weigh more than 20 kg, in wooden boxes. They are occasionally shipped in electrostatic-sensitive device (ESD) marked plastic bags even though they are not ESD-sensitive.

ITEM 12
Launch Support

Launch Support

Produced by companies in

- Australia
- China
- France
- Germany
- India
- Iran
- Israel
- Italy
- Japan
- Netherlands
- North Korea
- Russia
- South Korea
- Sweden
- Taiwan
- United Kingdom
- United States

Launch support equipment, facilities and software for the systems in Item 1, as follows:

(a) Apparatus and devices designed or modified for the handling, control, activation and launching of the systems in Item 1;

Nature and Purpose: The launch support equipment covered in Item 12(a) includes all apparatus and devices designed or modified for performing the function specified (handling, control, etc.) of Item 1 systems. Items that provide these functions for mobile or fixed systems are controlled. Examples of such apparatus and devices include, but are not limited to, launch pad facilities, gantries, block houses, underground launch silos, handling equipment, systems test and check-out equipment, and command-and-control equipment. Some of this equipment is relatively simple such as concrete launch pads. Other items are complex such as the sophisticated pad and gantry type launch facilities used for modern space launch vehicles (SLVs). The determining factor is whether the item is designed or modified for an Item 1 system.

Method of Operation: The key operations and equipment used in launching a ballistic missile depend on the nature of the approach. In most approaches, the missile is delivered to the site by a truck, a train, or, at a launch pad, a dolly. The missile is erected into position. The missile is positioned either by special erectors built for the site and the missile or by a crane attached to a permanent gantry. At silos, missiles are positioned by a crane on the transporter, which lowers the missile into the silo; alternatively, missile stages are lowered by crane or winch into the silo and assembled inside it. A liquid-engine missile is fueled by means of pumps, tanks, pipes, and hoses. The guidance system is often aligned and calibrated by compasses and / or surveying equipment. The alignment operation may be performed initially and then regularly updated or updated just before launch. Many guidance systems are capable of self-alignment by sensing earth rotation. Prior to launch, target data and flight profile are loaded into the guidance system. Subsystem performance is verified by electrical and software testing equipment attached to the missile by cables from the control center. Missiles

Figure 12-1: Minimal launch pad with a gantry and connections to a complete rocket system.

maintained on alert are verified continuously. When the status of all responses is verified as satisfactory, the vehicle is ready for launch, and the launch sequence is executed on command. Unmanned air vehicles (UAVs), including cruise missiles, typically are designed for multiple launch platforms with standardized interfaces.

Typical Missile-Related Uses: Launch support equipment is required to prepare and launch missiles. Sometimes these devices continue to monitor and control the missile throughout all or portions of the flight profile.

Other Uses: Hydraulic systems, control electronics, computers, tanks and pipes, and communications equipment required for missile launching are similar, if not identical, to those required for numerous other purposes. Transportation, handling, erection equipment, and targeting and test algorithms are often unique to each missile, with no other uses. Silo-based launch support equipment is often unique to ballistic missiles and has no commercial uses.

Appearance (as manufactured): Launch pad facilities have a concrete apron, a relatively small stand upon which the missile is placed, and a gantry made of steel I-beams. A minimal system including a gantry and connections to a rocket is shown in Figure 12-1. Pads intended for military operations usually lack propellant storage, pumping, or handling facilities; these operations are conducted from tank and pumper trucks. They also lack permanent launch command, control, and system checkout equipment; again, these operations are conducted by equipment in trucks.

Appearance (as packaged): Pads, gantries, and silos are often built in place and rarely shipped assembled. Consistent with their size and weight, the electronic components and consoles are wrapped and sealed in padding to protect them from shock and moisture during transport and storage, and then packed separately in boxes or crates. The electronic equipment used in some small- to medium-sized launch control shelters is often installed in the shelter, and the whole shelter is mounted on a palette for transport. Some launch support electronic equipment is portable and has been reduced to the size of a suitcase.

(b) Vehicles designed or modified for the transport, handling, control, activation, and launching of the systems in Item 1;

Nature and Purpose: Rockets and UAVs covered in Item 1 have been launched from trucks, trains, aircraft, ships, and submarines. Most launches, including launches from fixed sites, require vehicles, most often for transport and handling. Vehicles modified to carry, erect, and launch missiles are distinctive because they generally have no other practical use. Some of these vehicles, referred to as transporter erector launchers (TELs), provide a mobile launch platform independent of permanent launch facilities. Alternatively, some missiles and UAVs are carried and launched from (mobile) erector launchers (ELs or MELs), which are often towed by trucks known as prime movers. Vehicles modified to carry command-and-control equipment needed to activate, target, and control rockets or UAVs are also distinctive. Under subitem 12(b), the MTCR Annex controls the vehicle, including onboard equipment. Some of this onboard equipment (i.e., erector/launcher mechanism) would be controlled by 12(a) if removed from the vehicle.

Method of Operation: TELs and other mobile launchers perform the same preparation and launch functions as do the launch support facilities discussed in the preceding section. A TEL is usually loaded with its rocket(s) or UAV(s) by crane at a staging area. The crane may be part of the TEL. The TEL transports the rocket(s) or UAV(s) to the launch site, where it erects them to launch position. Some missiles are fueled at this point by separate tanker and pumper trucks; others may be transported already fueled. The launch crew makes electrical connections with the vehicle and ensures that all rocket or UAV subsystems are ready for launch. Targeting or flight plan information is loaded, and the guidance system is aligned and calibrated. When everything is ready, the crew launches the rocket(s) or UAV(s), often from a separate command-and-control truck.

Typical Missile-Related Uses: Relevant rocket systems or UAVs require vehicles designed or modified for the system such as TELs and associated command-and-control and support vehicles.

Other Uses: These vehicles, their hydraulic systems, control electronics, and computers and communications equipment are generally derived from a wide variety of commercial and military equipment.

Appearance (as manufactured): The distinguishing feature of TELs designed for ballistic missiles is the presence of an erection mechanism capable of lifting the missile to a vertical position. The vehicle may be tracked, but most are large vehicles about the size of a tractor-trailer or lorry, with 3 to 8 axles and rubber tires. MELs look more like elaborate dollies. Examples

Produced by companies in

- Australia
- Brazil
- China
- Egypt
- France
- Germany
- India
- Iran
- Iraq
- Israel
- Italy
- Japan
- Libya
- North Korea
- Pakistan
- Russia
- South Korea
- Spain
- Syria
- Ukraine
- United Kingdom
- United States

Figure 12-2: Transporter erector launcher with a short-range ballistic missile erected.

Figure 12-3: An ICBM transporter erector launcher with the missile in a launch canister.

of both types of vehicles are shown in Figures 12-2, 12-3, and 12-4. Two versions of vehicles that carry and install ballistic missiles in their silos are shown in Figure 12-5.

TELs or MELs designed for UAVs are characterized by their relative simplicity and the presence of a launch structure (such as a rail or canister), which is sometimes inclined for launch. The launch structure can vary greatly in size and weight, depending on the UAVs to be launched. Launch structures can be as small as 2 to 3 m for hydraulic-assisted or rocket-assisted launchers of UAVs. Similar launch structures may be mounted on a tracked

Figure 12-4: An erector launcher detached from its prime mover.

Figure 12-5: Two different approaches to silo-based missile transporter and installation vehicles.

Figure 12-6: A transporter erector launcher for a large, Category II cruise missile.

Photo Credit: Teledyne Ryan Aeronautical

Figure 12-7: Rocket-assisted unmanned air vehicle erector launcher and its associated command-and-control van.

or wheeled vehicle. Four different approaches for UAV launchers are shown in Figures 12-6, 12-7, 12-8, and 12-9.

Examples of command-and-control trucks that accompany TELs and MELs are shown in Figures 12-10 and 12-11. A UAV command-and-control van is also shown in Figure 12-7. The command-and-control trucks shown in these figures could just as easily support fixed missile operations.

Figure 12-8: A transporter erector launcher used to transport and launch cruise missiles.

Appearance (as packaged): The launch rails and erection mechanisms used on TELs or MELs are generally integrated into the vehicle or trailer chassis. As a result, these devices are placed in their normal stowed position on the mobile vehicle or trailer when packaged for shipment from the production facility. The vehicles are driven, towed, or shipped by rail to the user facility. Other vehicles will be packaged similarly to other military or commercial vehicles.

Figure 12-9: A pneumatic unmanned air vehicle launcher.

Produced by companies in

Relative Gravity Meters

- Canada
- China
- Germany
- Russia
- United States

Gravity Gradiometers

- United States

(c) Gravity meters (gravimeters), gravity gradiometers, and specially designed components therefor, designed or modified for airborne or marine use, and having a static or operational accuracy of 7×10^{-6} m/sec^2 (0.7 milligal) or better, with a time to steady-state registration of two minutes or less;

Nature and Purpose: Gravity meters and gravity gradiometers make very accurate measurements of the magnitude of the force of gravity at various locations. These data are used to create detailed maps of the earth's gravitational field for several kilometers around a ballistic missile launch site because local variations in gravity can cause inaccuracies in inertial guidance unless accounted for in the missile guidance software. Airplanes, helicopters, ships, and submarines outfitted with gravity meters can make gravity maps at sea. Airplanes and helicopters outfitted with gravity meters can make gravity maps over mountainous terrain. Gravity gradiometers can also be used as sensors in guidance systems to improve accuracy.

Figure 12-10: Command-and-control vehicles suitable for launching missiles from fixed or mobile locations.

Method of Operation: The methods of operation vary with the different types of equipment. Some accurately measure the fall time of a dropped mass; others use a set of pendulous electromagnetic force rebalance accelerometers that rotate on a carousel. Some are operated with the airplane, ship, or submarine in motion, and others are lowered to the surface of the land or sea floor to take a measurement. Systems designed to operate on a moving platform such as a ship or airplane need inertial navigation quality gyros and accelerometers for two-axis stabilization of the sensor platform. Systems designed to be lowered to the surface of the land or sea floor need only be self-leveling.

Figure 12-11: A deployed command-and-control truck used for ballistic missile operations.

Gravity gradiometers use a set of very high quality accelerometers on a precision rotating turntable. As the accelerometers rotate in a horizontal plane, they detect the subtle gravity differences about the perimeter of the turntable. The difference between the average readings taken on the east and west sides of the turntable, divided by the diameter of the turntable, yields the longitudinal gravity gradient.

Similarly, the difference between the average readings taken on the north and south sides of the turntable, divided by the diameter of the turntable, yields the latitudinal gravity gradient. Use of multiple accelerometers reduces the effect of individual accelerometer scale factor drift, and rotating the accelerometers about the perimeter virtually eliminates the effect of bias drift.

Photo Credit: La Coste & Romberg

Figure 12-12: Sensor unit for a non-MTCR-controlled air-sea gravity meter.

Typical Missile-Related Uses: Gravity maps for several to hundreds of kilometers in the area of ballistic missile launch sites are required for highly accurate systems. Airborne gravity meters can be used to map a large area of rough terrain or open sea adjacent to mountain roads or other areas where mobile missiles might operate. Ship or submarine-borne gravity meters are used to map the gravitational attraction beneath the sea to facilitate increased accuracy of ballistic missiles launched from submarines or from land installations near the coast. Because the effects of gravity variations in the launch area are rather small, gravity maps are primarily useful for ballistic missile systems that are already very accurate. Gravity gradiometers may be useful for UAV guidance, perhaps over water or other featureless terrain.

Photo Credit: La Coste & Romberg

Figure 12-13: Complete non-MTCR-controlled air-sea gravity meter system with mini-console.

Other Uses: Gravity meters and gravity gradiometers are used in petroleum and mineral resource exploration and in geotechnical and environmental investigations. Gravity gradiometers are used as navigation aids on submarines.

Appearance (as manufactured): Gravity meters (gravimeters) and gravity gradiometers are high quality, sensitive electronic and mechanical instruments. Gravimeter appearance ranges widely because companies build them differently for different purposes. Systems fully integrated into a single case may be as small as 25 × 32 × 32 cm and weigh 14 kg. Systems with separate cases may be as large as a cubic meter and weigh 350 kg; these large systems are modular and may be packaged in more than one container for shipping. The sensor unit of an air-sea gravity meter that is below the performance threshold established by the MTCR and is thus not MTCR controlled is shown in Figure 12-12. A complete, non-MTCR-controlled air-sea gravity meter system with mini-console is shown in Figure 12-13. Systems like the one shown in Figure 12-13 are MTCR controlled if they meet the performance criterion stated above.

Electronic and mechanical components are enclosed in either hard plastic or metal cases. Some systems have the instrument and control panel contained in the same case; other systems have the instruments separated from the control panels. The cases typically have visible electronic or mechanical control panels, pads, rotating control knobs, toggle and push switches, and connections for external electronic and computer cables.

Photo Credit: Scintrex Ltd.

Figure 12-14: A gravity meter that operates suspended from a helicopter. Its associated electronics, shown on the left, are installed in the helicopter.

Photo Credit: La Coste & Romberg

Figure 12-15: A non-MTCR-controlled gravity meter lowered by a ship or submarine.

Some have screens for observing the data collected in either digital or analog form; some have ports for printing hard copies of the data. Most have removable access panels. Batteries may be supplied to operate the system. Some systems have built-in computers and software. Some gravity meters are built to be lowered by a cable to the ground and operated from a helicopter, as shown in Figure 12-14. Others are built to be lowered to the sea floor by a ship or submarine; such a device, which is not MTCR controlled, is shown in Figure 12-15. Similar systems are MTCR controlled if they meet the performance criterion stated above.

Appearance (as packaged): Because the systems are very sensitive and expensive, they are packaged and shipped in rigid containers, which include formed plastic, plastic popcorn, plastic bubble wrap, or other materials designed to protect them from shock. The shipping containers usually have warning labels such as "fragile," "handle with care," or "sensitive instruments."

Produced by companies in

- China
- France
- Germany
- Israel
- Italy
- Japan
- Netherlands
- Russia
- South Africa
- Sweden
- Switzerland
- United Kingdom
- United States

(d) Telemetering and telecontrol equipment usable for unmanned air vehicles or rocket systems;

Nature and Purpose: Telemetering equipment involves sensors, transmitters, and receivers that send in-flight information on rocket or UAV performance to the ground. These devices allow engineers to monitor a vehicle's flight, learn how it performs, or determine what caused any failure. Such equipment is used extensively during rocket and UAV flight testing. During flight tests, telemetry is normally collected throughout the entire flight. Telecontrol equipment that uses different sensors, receivers, and transmitters may be used to remotely control missiles or UAVs during powered flight. However, many operational ballistic missiles and cruise missiles fly autonomously; that is, without any telecontrol.

Method of Operation: Telemetering equipment installed in developmental rockets and UAVs monitor the important flight parameters (acceleration, vibration, control surface settings, etc.) and transmit these data to a ground station. The receiver decodes the data, displays them, and records them for playback later. Most operations are set up inside a building with an external antenna connection. If gimbaled, this antenna can pivot in three axes to track the rocket system or UAV in flight.

Photo Credit: Loral Microcom

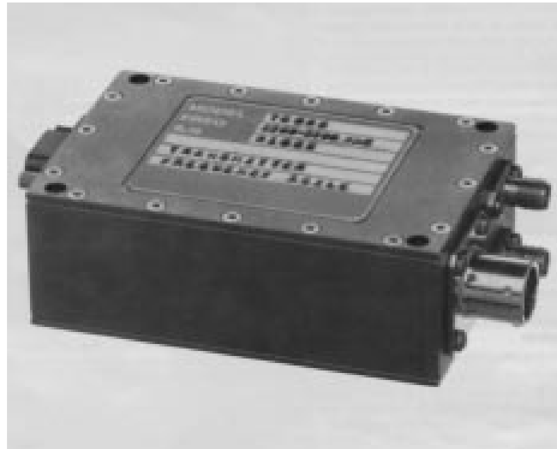


Figure 12-16: Telemetry transmitters for installation in flight vehicles.

Typical telecontrol systems are different for rocket and UAV systems. Rockets using command guidance are usually tracked by a radar near the launch site. Flight path data are processed to compare the actual and desired trajectory. If deviations occur, steering commands are sent from the ground station by radio to a receiver in the rocket system, which implements the commands to bring it on track. This command loop is maintained until the engines are turned off; the rest of the flight is ballistic. Telecontrol for UAVs is often implemented by a "man-in-the-loop" concept. A sensor such as a TV in the UAV transmits a visual image of the local terrain to a control van. A human pilot views this image and sends steering commands to the vehicle over the data link.

Photo Credit: SFIM Industries

Figure 12-17: A typical, but large telemetry reception antenna.

Typical Missile-Related Uses: Telemetering is important in the verification of performance during flight tests for both rockets and UAVs. Without such data, flight testing can be lengthy and expensive. Telecontrol is frequently used for UAV applications. Telecontrol is rarely used in ballistic or cruise missiles that carry weapons because the data link is vulverable to jamming or disruption.

Other Uses: Similar telemetry equipment is used to test commercial and military aircraft. It is also used in industry to collect data from remote sites and from chemical or other plants with a hazardous environment. It is also used in robotic land vehicles that must operate in hazardous environments.

Appearance (as manufactured): Telemetering equipment installed on flight vehicles is contained in small metal boxes with power, cable, and antenna connections. They have few distinctive features, as shown in Figure 12-16. The most notable telemetering equipment at the ground site is the telemetry receiving antenna. They are often large parabolic dishes that can rotate in two dimensions, as shown in Figure 12-17. Electronic equipment used at the ground site to demodulate, read, record, interpret, and

Photo Credit: In-Snec

Figure 12-18: Representative ground-site telemetry receiving and processing equipment.

Photo Credit: AAI Corporation

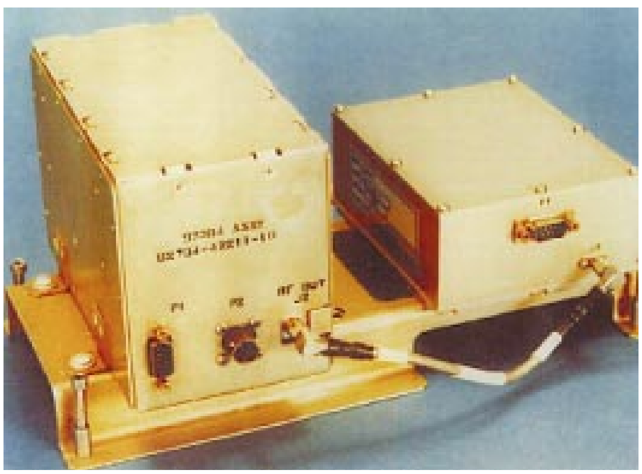


Figure 12-19: Unmanned air vehicle avionics. Left, a C-band transmitter; right, a UHF receiver.

display the telemetry looks like most rack-mounted scientific equipment or computers with few distinguishing features. Representative types of equipment are shown in Figure 12-18.

Telecontrol equipment installed in UAVs permits communication between the UAV and the ground station. Like telemetry equipment, this equipment is housed in metal boxes with power, cabling, and antenna connections, all unremarkable in appearance, as shown in Figures 12-19 and 12-20. Some UAVs communicate to their ground site by way of satellites and require special SATCOM antennas, as shown in Figure 12-21. A commercial satellite transceiver with streamlined antenna is shown in Figure 12-22. Another commercial system with a mechanically steered antenna is shown in Figure 12-23. The equipment for UAVs at the ground station is comprised of a flight control system (usually a joystick console), a video monitor, and recording equipment. A flight control station is shown in Figure 12-24; a portable video monitor is shown in Figure 12-25; and an integrated ground control system for a UAV is shown in Figure 12-26.

Appearance (as packaged): Because of the sensitivity of the electronics, telemetry equipment is usually shipped in cushioned

Photo Credit: AAI Corporation

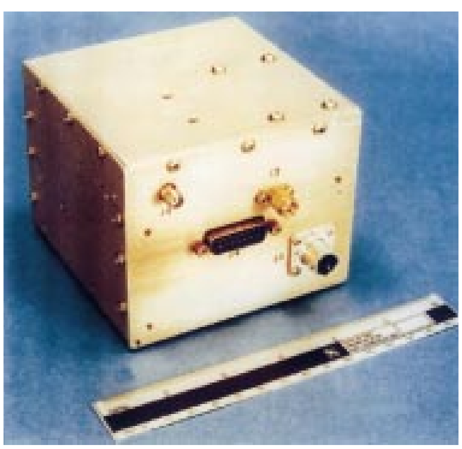


Figure 12-20: Unmanned air vehicle video and telemetry transmitter.

Photo Credit: General Atomics Aeronautical

Figure 12-21: A SATCOM antenna installed in an unmanned air vehicle.

Photo Credit: Racal Avionics

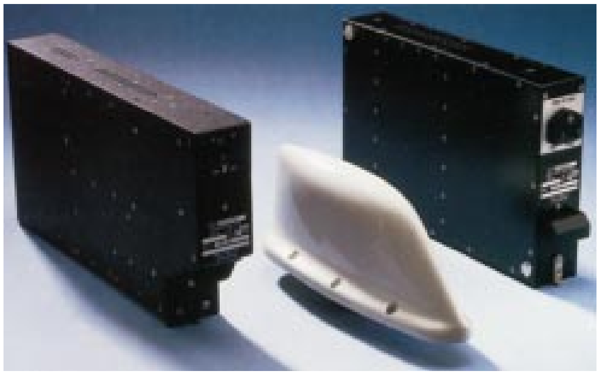


Figure 12-22: A commercial satellite transceiver with streamlined antenna.

Photo Credit: Racal Avionics

Figure 12-23: A commercial system with a mechanically steered antenna (streamlining not shown).

Figure 12-24: A portable flight controller console for an unmanned air vehicle.

Figure 12-25: A portable video monitor for displaying video transmitted from an unmanned air vehicle.

Figure 12-26: An integrated unmanned air vehicle control station.

cardboard or wooden containers. Some containers may have labels indicating the need for careful handling. Usually the equipment is sealed in plastic to protect the electronics from moisture and electrostatic discharges. Large assemblies of equipment such as integrated telecontrol stations will be disassembled and shipped in separate containers.

Produced by companies in

- China
- France
- Germany
- Israel
- Japan
- Russia
- South Africa
- Switzerland
- United Kingdom
- United States

(e) Precision tracking systems:
  (1) Tracking systems which use a code translator installed on the rocket or unmanned air vehicle in conjunction with either surface or airborne references or navigation satellite systems to provide real-time measurements of in-flight position and velocity;
  (2) Range instrumentation radars including associated optical/infrared trackers and the specially designed software therefor with all of the following capabilities:
    (i) an angular resolution better than 3 milli-radians (0.5 mils);
    (ii) a range of 30 km or greater with a range resolution better than 10 metres RMS;
    (iii) a velocity resolution better than 3 metres per second.
  (3) Software which processes post-flight, recorded data, enabling determination of vehicle position throughout its flight path.

Nature and Purpose: Precision tracking systems produce accurate records of rocket system trajectory or UAV flight path. Engineers use these data to help determine vehicle performance and the causes of any vehicle failure. Range safety engineers also use these data to monitor the missile flight path. If the missile veers into an unsafe trajectory, it is destroyed. Precision tracking systems can be used in conjunction with, or as an alternative to, telemetry equipment, which sends back data on vehicle acceleration time history, from which missile trajectory can be reconstructed.

Method of Operation: Code translators installed on a rocket or UAV process signals received from ground or satellite transmitters. Those signals carry timing data that allow the code translator to determine the distance to each transmitter. These data are sent back to the ground site on a different downlink frequency. Because the transmitters are in known locations, the ground site can accurately determine missile position and velocity. These data can be displayed in real time or recorded on magnetic disc or tape.

Range instrumentation radars are also used to determine missile position and velocity. Usually a radar with a wide field-of-view is used to track the approximate vehicle location, which is then used to aim radars with a narrow field-of-view, optical trackers, or infrared trackers capable of determining missile angle, range, and velocity with the required precision. These data are recorded as they occur, along with an ongoing record of the time. A variation on this approach is to install in the flight vehicle a small transmitter that broadcasts or a transponder that receives and re-broadcasts at the radar operating frequency and thereby provides a beacon that allows the radar to track the vehicle more easily.

Figure 12-27: A mobile phased array missile tracking radar.

No matter how the data are collected, to be useful, information on time and position must be interpreted. Post-flight data processing may take place anywhere, but it is often conducted in the telemetry data processing center where real-time data are received and recorded. These recorded data are read, filtered, and processed. The processed tracking data are then re-recorded on disk or tape for further analysis or output plotting.

The post-flight and recorded data processing software typically consist of mathematical filtering software routines that process the previously recorded data in order to provide a smooth estimate of the vehicle trajectory. This processing software is used both to provide the estimated vehicle position data for periods of time when a real-time data outage may have occurred and to perform filtering in order to get the best estimate of the trajectory. Many different types of mathematical filter implementations are used, varying from the simplest such as a straight-line interpolation between data points, to more sophisticated polynomial-based filtering such as spline-fit filtering. Some filtering routines also use Kalman filtering to post-process these data, although the Kalman filtering is normally used for real-time tracking applications because of its ability to use simplified matrix manipulations to arrive at tracking solutions.

Typical Missile-Related Uses: Precision tracking systems and range instrumentation radars are helpful during the testing phase of the flight program to determine whether the missile is traveling along the predicted trajectory and to monitor missile flight for any anomalies. Such information is used to evaluate and improve the performance of numerous subsystems. The software that processes post-flight recorded data and thereby helps determine vehicle position throughout missile flight path is essential to interpretation of those flight data.

Other Uses: These systems can be used to support commercial and military aircraft testing and the development of weapons, including artillery and small rockets. Industry uses post-processing of data to evaluate events after the fact, such as race car performance.

Appearance (as manufactured): Precision tracking systems and range instrumentation radars look like ground-based portions of telemetering and telecontrol equipment. They include familiar dish-type radars as shown in Figure 12-17, as well as phased-array radars, which are characterized by their flat (rather than dish) surface as shown in Figure 12-27. Also used are

Photo Credit: Contraves

Figure 12-28: An optical missile tracking telescope.

Photo Credit: Contraves

Figure 12-29: An optical missile tracking system.

optical devices that look like telescopes as in Figure 12-28; large robotic binoculars as in Figures 12-29 and 12-30; and laser tracking systems that resemble optical instruments as shown in Figure 12-31.

Photo Credit: Contraves

Figure 12-30: An optical missile tracking system.

Photo Credit: Contraves

Figure 12-31: A mobile laser missile tracking system.

The precision tracking system hardware (transponders) carried aboard rockets or UAVs are generally very small electronics enclosures that vary from 800 to 2,500 cm^3. They are generally solid, environmentally sealed enclosures with external power and antenna connectors. The only subelement of these transponders is the antenna element, which is normally located on the external surface of the rocket or UAV.

Appearance (as packaged): Because of its sensitivity to shock, the electronic equipment is usually shipped in cushioned containers. Some may have labels indicating the need for careful handling. This equipment is usually sealed in plastic to protect it from moisture and electrostatic discharge. The larger radars, optical trackers, and laser trackers are shipped disassembled in wooden crates and assembled onsite. All optics are protected with environmental covers.

ITEM 13
Computers

Computers

Analogue computers, digital computers, or digital differential analyzers designed or modified for use in the systems in Item 1, having either of the following characteristics:

(a) Rated for continuous operation at temperatures from below minus 45 degrees C to above plus 55 degrees C; or

(b) Designed as ruggedized or "radiation hardened."

Notes to Item 13:

Item 13 equipment may be exported as part of a manned aircraft or satellite or in quantities appropriate for replacement parts for manned aircraft.

Produced by companies in

- Canada
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- North Korea
- Russia
- South Africa
- South Korea
- Sweden
- Taiwan
- Ukraine
- United Kingdom
- United States

Nature and Purpose: Most missiles use at least one computer, typically in the guidance set or integrated flight instrumentation system. Generally the guidance computer calculates missile velocity and position information from onboard reference sensors. It uses these data for comparison with the prescribed missile flight path and sends steering commands to correct for errors. Computers may also provide time references for the missile and give cutoff commands to the propulsion system and arming commands to the weapons payload at the appropriate flight times. Mission computers may also be used to store and execute preprogrammed flight profiles.

Method of Operation: Onboard analog or digital computers rapidly integrate the equations of motion for missile flight and compute the magnitude and duration of the commands necessary to maintain the missile flight path. The computers receive electrical signals from onboard sensors, perform the appropriate calculations, and send command signals to the various missile systems to try to match the preprogrammed flight path. These computer systems are powered by batteries (typically 28V) and use connecting cables to interface with the sensors and control systems.

Typical Missile-Related Uses: Most complete rocket systems and unmanned air vehicles (UAVs) including cruise missiles, have at least one ruggedized digital computer for navigation and control computations and digital integration of Inertial Measurement Unit (IMU) data. Many also use

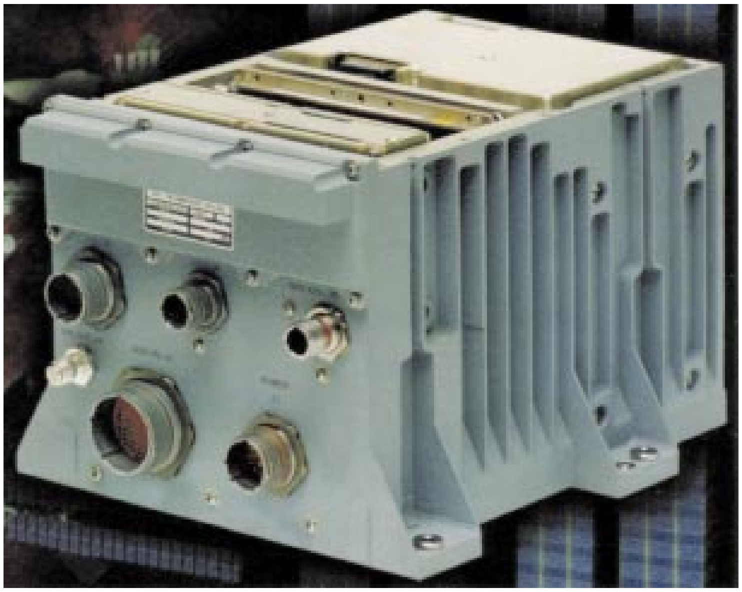


Figure 13-1: A global positioning system (GPS) aided inertial navigation system with integral guidance computer.

analogue computers to provide closed loop control of analogue servos for IMU gimbals and for flight control surface stabilization. The computer must be able to operate at the temperature extremes experienced by ballistic missiles traveling through space, UAVs operating at high altitude, or cruise missiles carried on external pylons at high altitude. Missiles require ruggedized computers to handle the vibrations and shocks of missile flight. Missiles designed to survive and operate in nuclear environments need radiation-hardened computers.

Other Uses: Most military and civilian aircraft, tactical missiles, and spacecraft require ruggedized computers that operate within the temperature extremes defined in the Annex. Long-lifetime spacecraft and satellites stationed in or near the radiation belts also have requirements for radiation hardening, but those requirements may be somewhat lower than the Annex specification.

Photo Credit: LITEF

Figure 13-2: A ruggedized computer for fighters, which is similar to a missile or an UAV computer.

Appearance (as manufactured): Computers configured for missiles and UAVs are usually housed in metal enclosures with integral heat sinks to dissipate power generated by high operating speeds, as shown for the inertial navigation system and guidance computer assembly in Figure 13-1. A ruggedized computer for aircraft, which is similar to rocket and UAV computers, with its printed circuit boards partially removed, is shown in Figure 13-2. A radiation-hardened digital signal processor (DSP), shown in Figure 13-3, is packaged on a single printed circuit board and is ideal for missile use. In these assemblies, the heat sinks are also augmented by water cooling. A radiation-hardened electronics assembly with liquid cooling connections is shown in Figure 13-4. Within such assemblies are a wide variety of ordinary looking electronic parts with wide use in commercial applications. A distinguishing characteristic (not unique to military use) is hermetically sealed metal and

Figure 13-3: A radiation-hardened digital signal processor.

ceramic components as opposed to more common plastic components (chips) found in commercial electronics. The cable interfaces feature rugged, circular connectors or small bolt-on connectors with shielded cables. The electronics are typically within an outer radio frequency (RF) Faraday cage enclosure, which may be hermetically sealed or vented to the ambient pressure. Pressurized vessels are used to help conduct heat to the case and heat-sink mounting of missiles and UAVs, which operate at high altitude. For applications requiring lightweight assemblies, the computers can be packaged in rugged plastic containers with metal coatings inside the plastic covers for RF shielding.

Appearance (as packaged): Electronic computer assemblies and parts typically weigh less than 25 kg. They are packaged in plastic bags, placed inside cardboard boxes, and packed in rubber foam or bubble wrap shock protection; box labels typically indicate the contents as electrostatic sensitive devices. Larger units integrated into a larger system and over 25 kg may be packed in metal or wooden boxes.

Photo Credit: The Charles Stark Draper Laboratory, Inc.

Figure 13-4: A radiation-hardened electronics assembly with liquid cooling.

ITEM 14
Analogue to Digital Converters

Analogue-to-Digital Converters

Produced by companies in

- France
- Germany
- Israel
- Japan
- Russia
- Sweden
- United Kingdom
- United States

Analogue-to-digital converters, usable in the systems in Item 1, having either of the following characteristics:

(a) Designed to meet military specifications for ruggedized equipment; or,

(b) Designed or modified for military use; and being one of the following types:

(1) Analogue-to-digital converter “microcircuits,” which are “radiation-hardened” or have all of the following characteristics:

(i) Having a quantisation corresponding to 8 bits or more when coded in the binary system;

(ii) Rated for operation in the temperature range from below minus 54 degrees C to above plus 125 degrees C; and

(iii) Hermetically sealed.

(2) Electrical input type analogue-to-digital converter printed circuit boards or modules, with all of the following characteristics:

(i) Having a quantisation corresponding to 8 bits or more when coded in the binary system;

(ii) Rated for operation in the temperature range from below minus 45 degrees C to above plus 55 degrees C; and

(iii) Incorporating “microcircuits” listed in (1), above.

Nature and Purpose: Analog-to-digital converters (ADCs) are electronic devices for converting an analog signal, which is a continuously varying voltage, to digital data, which are patterns of “1s” and “0s.” These converters allow the analog outputs of various devices such as sensors, accelerometers, and gyros to be understandable to digital devices, such as digital signal processors (DSPs) and computers.

Method of Operation: In its simplest form, an ADC is a voltmeter with a binary “word” as its output. The longer the word (i.e., the more “bits” per word), the more accurately the input voltage can be represented. For example, an 8-bit word representing a voltage range of zero to one volt provides 256 discrete values. With one word assigned to zero, this results in 255 increments of just over 3.92 millivolts each. Increments of 3.92 millivolts limit the theoretical accuracy to plus or minus 1.96 millivolts or 0.196

percent. Raising the frequency at which an ADC can update the output word to reflect rapid changes in the input voltage allows the ADC to convert input signals with high-frequency content. Manufacturers use one of several different circuit design approaches to make the conversion.

Most ADCs are designed to have a linear input-to-output relationship. However, in more elaborate schemes, input voltages are mapped to digital values according to calibration data previously taken from the analog instrument to which the ADC is mated. This mapping allows the ADC to compensate for nonlinearities in the analog measurement.

Typical Missile-Related Uses: Any missile using a digital computer requires ADCs. The ADCs need to work over the temperature range specified above and be hermetically sealed if, like ballistic missiles, they are flown exo-atmospherically.

Other Uses: ADCs are in widespread use, with ruggedized parts common in all aircraft, automobile electronic ignition systems, and engine sensors. Other commercial applications include a variety of sensor systems, electronic cameras, and radios. Long-duration spacecraft and satellites stationed in or near the radiation belts require radiation-hardened ADCs, which operate over the temperature extremes indicated. Although the space application requirements are about five times lower than the Annex specification, such systems often use MTCR-controlled ADCs.

Photo Credit: Datel, Inc.

Figure 14-1: The military-grade (top) and commercial-grade (bottom) analogue-to-digital converters appear identical except for part numbers; pin styles are optional to both.

Appearance (as manufactured): Military ADC components are hermetically sealed metal packages in order to ensure operation in adverse environment extremes and to dissipate power associated with high data rates from sensors. Aluminum is the primary metal used for ADC board frames, structures, and heat sinks. ADCs can range from a few centimeters to about 0.3 m or more on a side and weigh from 100 g up to 25 kg. Their package density approaches one-third the density of aluminum.

Integrated ADC assemblies consist of a wide variety of electronic parts that are not readily distinguishable from those used in commercial applications. ADCs may be made of discrete electronic components and resemble other military electronics. Similar military and commercial-grade discrete ADCs are shown in Figure 14-1; they differ externally only in part number. Radiation-hardened ADCs are often packaged on a single printed integrated circuit (IC) board ideal for use in ballistic missiles, as shown in Figures 14-2 and 14-3. These devices have special design features to make them rugged and resilient to missile environments. Although ADC circuit boards are similar to those for DSPs, they include linear ICs and discrete circuits for buffer amplifiers, multiplexing, or signal conditioning (filters, voltage limiting, etc.). As a result, a larger portion of the ADC circuit board is made up of discrete components (resistors, capacitors, diodes, operational amplifiers, etc.). Printed circuit boards are fiberglass-epoxy with copper heat sinks and traces. Electronics parts are in special metal cases (mostly copper-nickel) with aluminum or gold bond wires and silicon substrates.

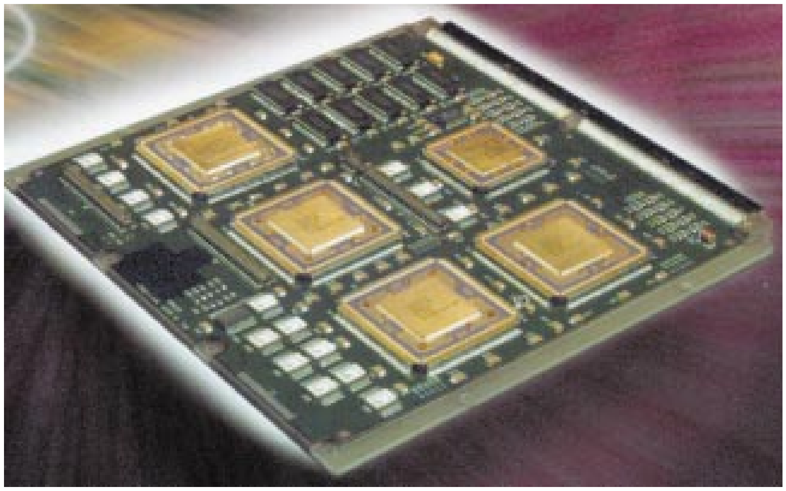


Figure 14-2: Typical analogue-to-digital converter/digital signal processor board.

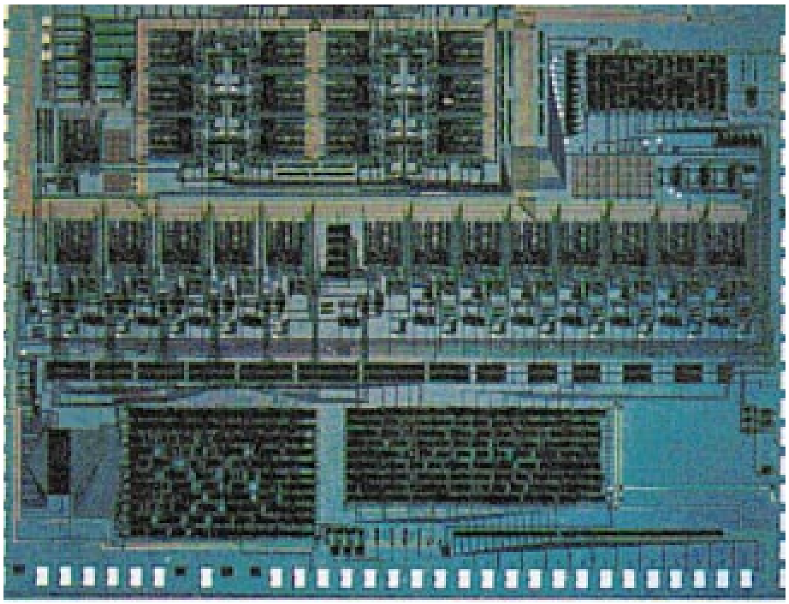


Figure 14-3: A radiation hardened 11-bit analogue-to-digital converter.

Appearance (as packaged): ADC printed circuit board assemblies and modules weigh less than 25 kg. They are encased in plastic bags that are marked to indicate electrostatic sensitive devices, and they are packed in rubber foam or bubble wrap for shock protection inside cardboard boxes.

ITEM 15
Test Equipment

Test Equipment

Produced by companies in

- France
- Germany
- Russia
- United Kingdom
- United States

Test facilities and test equipment usable for the systems in Item 1 and Item 2 as follows; and specially designed software therefor:

(a) Vibration test systems and components therefor, the following:

(1) Vibration test systems employing feedback or closed loop techniques and incorporating a digital controller, capable of vibrating a system at 10g RMS or more over the entire range 20 Hz to 2000 Hz and imparting forces of 50 kN (11,250 lb.), measured "bare table," or greater;

(2) Digital controllers, combined with specially designed vibration test software, with a real-time bandwidth greater than 5 kHz and designed for use with vibration test systems in (1), above;

(3) Vibration thrusters (shaker units), with or without associated amplifiers, capable of imparting a force of 50 kN (11,250 lb.), measured "bare table," or greater, and usable in vibration test systems in (1), above;

(4) Test piece support structures and electronic units designed to combine multiple shaker units into a complete shaker system capable of providing an effective combined force of 50 kN, measured "bare table," or greater, and usable in vibration test systems in (1) above.

<u>Note to Item 15(a):</u>

The term "digital control" refers to equipment, the functions of which are, partly or entirely, automatically controlled by stored and digitally coded electrical signals.

Nature and Purpose: Vibration test systems of this type are large and powerful equipment for simulating the flight vibrations and shocks that rockets and unmanned air vehicles (UAVs) experience during launch, stage separation, and normal flight. Missiles and their subsystems are tested to determine their elastic modes, frequencies, and sensitivities to vibration and shock. This information is used to improve missile design and to qualify systems, subsystems, and components as flight-worthy. Sometimes they are used in quality assurance testing to detect poor connections and loose components.

A typical vibration test system includes a vibration shaker unit, or thruster, to vibrate test articles attached to it; a power amplifier or other source of power to drive the shaker; a controller to command the power amplifier according to the desired vibration frequency and amplitude test profile; and an air- or liquid-cooling system for the shaker and amplifier.

Method of Operation: Vibration test systems use mechanical thrusters that usually operate on an electromagnetic drive principle like that of an audio loudspeaker, except that they are much larger and drive a massive test item rather than a delicate speaker cone. The digital controllers regulate complex vibration patterns with frequency content of controlled amplitude throughout the 20 to 2,000 Hz range. These patterns are designed to simulate the vibration frequencies and amplitudes expected during the mission, including simulation of vibration bursts or shocks. The output from these controllers must be greatly amplified to drive the thrusters. Hydraulic- and pneumatic-based vibration systems, although capable of the vibration testing of items of MTCR concern, are not generally capable of meeting the above performance specifications.

The armatures of two or more thrusters may be joined together with a test equipment support structure to obtain the required vibration levels. These structures must be both strong and light. Electronic units are needed to control multiple thrusters in a synchronous manner. They accept commands from the digital controller and relay them to multiple amplifiers, each driving one of the thrusters.

Typical Missile-Related Uses: All rockets and UAVs are subjected to vibration and shock during transport and flight. If vibration and shock are properly understood, flight vehicles can be made stronger and lighter because safety margins can be reduced. Use of such equipment also helps avoid costly test flight failures.

Other Uses: Vibration test systems are used to test other military and commercial equipment and products such as aircraft parts. Vibration testing is done on numerous other consumer goods, but MTCR-controlled vibration test systems are much more powerful and expensive than those needed for less demanding applications.

Appearance (as manufactured): MTCR-controlled vibration test systems are large devices that occupy a roughly 3 m by 3 m floor area. Details on the components are given below.

- *Digital controllers and specially designed vibration test software:* The digital controller is approximately the same size as the system unit for a personal computer (PC), 0.5 m wide × 0.5 m deep × 0.25 m high. In some cases, the controller is an electronic device small enough to be rack mounted above the power amplifier. In others, it is a desktop computer complete with monitors and customized interface cards for connection to the power

Photo Credit: Unholtz-Dickie

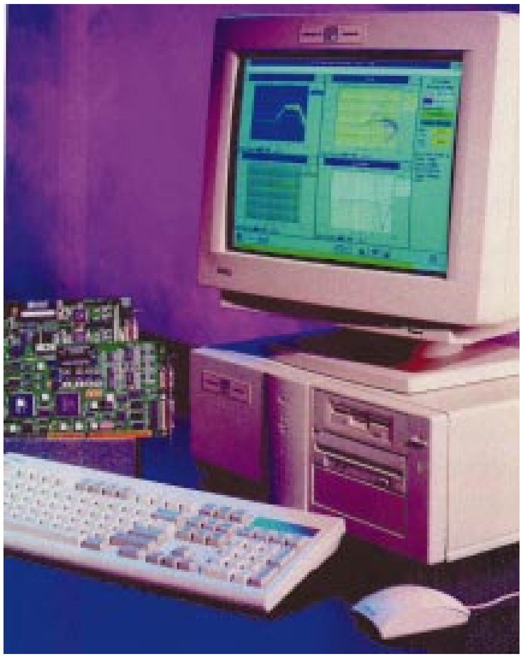


Figure 15-1: A desktop computer with customized interface cards and software.

Photo Credit: Unholtz-Dickie

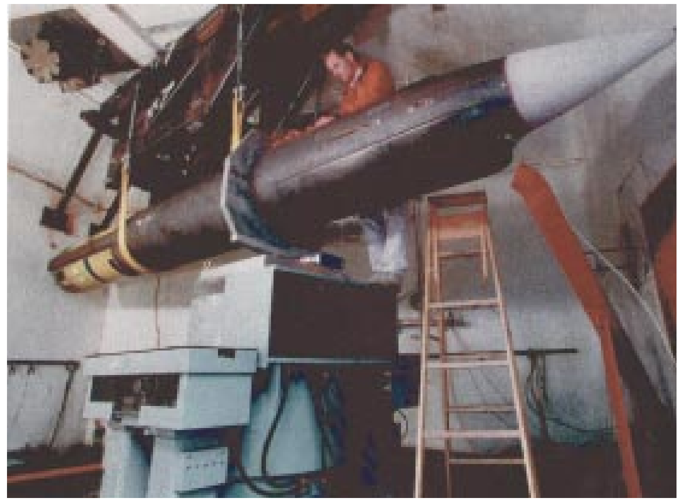


Figure 15-2: A thruster being prepared to vibration-test a missile.

Photo Credit: Unholtz-Dickie

Figure 15-3: A missile vibration test facility and thruster.

amplifier, as shown in Figure 15-1. Controllers require special purpose vibration control software. Manufacturers of vibration test systems are now offering PC-based software that integrates the functions for test system control, data recording, and data analysis.

- *Thrusters (shaker units):* An MTCR-controlled thruster usually has a very heavy, U-shaped, cast-steel base with thick flanges for securely attaching it to the floor. It measures about 1.3 m on a side and weighs several metric tons. The cylindrical or drum-like steel shaker housing, about 1 m in length and diameter, is hung between the vertical sides of the base. These vertical sides usually have trunnions (pivots) that allow the shaker housing to be rotated to change the thrust direction. A thruster in the vertical position in preparation for vibration testing a cruise missile is shown in Figure 15-2; another thruster preparing to test a sounding rocket is shown in Figure 15-3.

The part of the thruster that shakes the test item is a round metal armature emerging from one end of the shaker housing. The armature is drilled in a pattern of holes for bolts used to attach the test item. A rubber diaphragm between the armature plate and the thruster housing body is often used to seal the inner workings. Figure 15-4 shows a thruster with an expanded head for mounting larger test items.

Photo Credit: Unholtz-Dickie

Figure 15-4: A thruster with an expanded head.

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M (April 1996).*

Figure 15-5: Thruster (in rear) connected to a slip table on common base.

Photo Credit: Unholtz-Dickie

Figure 15-6: A power amplifier and its associated thruster.

The thruster system may include an accessory slip table, which is often made of magnesium to minimize weight. It supports the weight of the test article on an oil film or air bearing above the slip table base, which is often made of granite. To use the slip table, the thruster itself is pivoted on its trunnions until the axis of motion of its armature is horizontal. The armature is then attached to the side edge of the slip table in order to vibrate the unit under test in either horizontal axis. Such a slip table assembly has the same size and weight as the thruster assembly itself, and both may be mounted on a common base, as shown in Figure 15-5.

- *Power amplifier:* The power amplifier for an MTCR-controlled electrodynamic vibration test system occupies one or more full racks (each 0.5 m wide × .75 m deep × 2 m high) of electronic power control equipment, as shown in Figure 15-6. The electric input power required to drive such a system is about 60 to 80 kW. The power draw is so large that it must be hard-wired to the building electrical supply; it cannot use a standard electrical cord and plug.

- *Cooling:* Because the thruster and amplifier give off about one-half of their input electrical power as heat, cooling by forced air or circulating liquid coolant is required. The fan for air-cooling a typical installation measures 1.5 m × 0.5 m × 0.8m and weighs 200 to 250 kg. Liquid cooling circulates cooling water through the test system and into a cooling tower or a radiator equipped with electric fans. Either liquid-cooling system is at least as large as the air-cooling fan. Alternatively, a continuous supply of site water can be simply run through the cooling system and drained away.

- *Support structures:* Test equipment support structures used with such vibration test equipment are custom-made assemblies, which measure as much as 3 m × 3 m × 3 m or more, depending upon the test unit, and weigh as much as 5 to 10 tons. Electronic units designed to combine multiple thruster units into a complete thruster system range from an ordinary PC equipped with multiple, special internal interface cards, each controlling a single thruster unit, to one or more racks of custom-built electronic equipment. Recent trends in vibration testing increasingly use PC-based systems because they provide flexibility at low cost. Because specialized vibration system control interface cards are installed within the PCs, it may not be evident from external examination that the PCs are MTCR controlled.

Appearance (as packaged): With the exception of the system controller, which is typically the same size as a personal computer and can be packaged for shipping in typical PC packaging, the components of a vibration test system of MTCR concern are so large and heavy that they must be packaged in custom-built wooden crates of extremely robust construction.

(b) Wind-tunnels for speeds of Mach 0.9 or more;

Produced by companies in

- Canada
- China
- France
- Germany
- Japan
- Netherlands
- Russia
- Switzerland
- United Kingdom
- United States

Nature and Purpose: Wind tunnels are large enclosures in which air is circulated or blown through a test section containing a replica of the rocket or UAV. They are used to measure the aerodynamic performance of the airframe design during a simulated flight through the atmosphere. Instrumentation in the test section gathers data on vehicle lift and drag, stability and control, engine inlet and exhaust configuration, thermal effects, and infrared signature. Wind tunnels are of either the continuous-flow (e.g., closed-circuit) or the blow-down (e.g., shock tube) type and measure aerodynamic parameters for long or short duration, respectively.

Method of Operation: A continuous-flow wind tunnel uses a large, electrically driven fan compressor to move air through the tunnel entrance cone to achieve the desired Mach number in the throat, or test, section. After it leaves the test section, this air moves through a diffuser and then circulates back through the fan to create a continuous flow of air past the test object. A blow-down wind tunnel stores air or other gas in a large reservoir under high pressure, releases it through a control valve into the tunnel entrance cone and on to the test section, and then exhausts it through a diffuser into the atmosphere.

Typical Missile-Related Uses: Wind tunnels capable of exceeding Mach 0.9 are used to test rockets, supersonic UAVs, and reentry vehicles. For high-speed flight, generally above Mach 3, heat transfer tests may be conducted. High-enthalpy, continuous-flow tunnels, or shock tubes, are needed to produce wind speeds beyond Mach 5 for testing long-range ballistic missiles.

Figure 15-7: The exterior of a large wind tunnel showing the closed-loop circuit for continuous airflow.

Figure 15-8: Exposed adjustable nozzle section of wind tunnel.

Other Uses: Wind tunnels are used in designing supersonic aircraft.

Appearance (as manufactured): Wind tunnels are usually large facilities with several buildings housing the test section, compressors, data acquisition systems, and power supplies. A continuous-flow wind tunnel suitable for testing full size missiles is usually 50 to 100 m in length and 25 to 50m in width, with diffusers 10 to 15 m in diameter. The large closed-loop circuit for airflow can be seen in Figure 15-7. A tunnel to test small-scale models may be much smaller in diameter. The larger-size wind tunnel is generally laid out in a horizontal oval 10 to 20 times the length of the test section length and 5 to 10 times its width. The tubular sections of the tunnel are generally made of steel plates welded together to form the circuit, which is supported from the outside by steel I-beams. Some wind tunnels use adjustable nozzle sections, as shown in Figure 15-8, to vary the characteristics of the airflow.

The test section, located on one side of the tunnel, often has large access doors so that test objects can be moved into and out of the wind tunnel and mounted on the test support. The test section may have windows for observing supersonic air flow around the missile with special Schlieren photographic recording devices (or other flow visualization devices). Test objects in typical wind tunnel test sections are shown in Figures 15-9 and 15-10. The test section usually has an associated operations building that houses the controls and data collection instrumentation, and may handle the insertion, positioning, or removal of test objects. Testing of full size missiles in continuous-flow wind tunnels produces the most accurate results but requires high power (on the order of 200,000 hp) to move the large volumes of air at flight speeds.

The blow-down tunnel stores air or other gases under high pressure in large tanks or cylinders. An air duct sealed by a large valve or diaphragm connects the tanks to the tunnel entrance cone and test section. The tunnel walls are

Figure 15-9: Test objects in test section of a hypersonic wind tunnel.

Figure 15-10: Test object under inspection in test section of a 5-meter transonic wind tunnel.

generally made of relatively thick steel and are sometimes coated with insulation because of the high temperatures generated by very high wind speeds. A large compressor is used to pump air under pressure into the tanks before each test.

Appearance (as packaged): Because wind tunnels and their associated operations buildings are very large structures, they are seldom, if ever, shipped in their assembled state. Individual components like the compressor motor, fan blades, corner turning vanes, complete test section or test section walls, viewing windows, and control and instrumentation panels are crated or mounted on heavy pallets for shipping. The main tunnel walls are generally shipped as structural components to be assembled together at the facility location.

(c) Test benches / stands which have the capacity to handle solid or liquid propellant rockets or rocket motors of more than 90 kN (20,000 lbs) of thrust, or which are capable of simultaneously measuring the three axial thrust components;

Produced by companies in

- China
- Germany
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: Test benches and test stands for testing rocket systems, solid rocket motors, and liquid rocket engines of more than 90 kN of thrust are large rigid structures. They securely hold test items being operated at full power in order to collect performance data on critical parameters. These data support design development and confirm design integrity and performance. Liquid rocket engines are sometimes tested in test stands to verify performance before delivery.

Method of Operation: The test item is mounted on the test bench or test stand. Sensors are positioned and checked. Personnel are cleared from the test area, and data are collected while the rocket is operated at full power.

Photo Credit: Fiat Avio Sp.A.

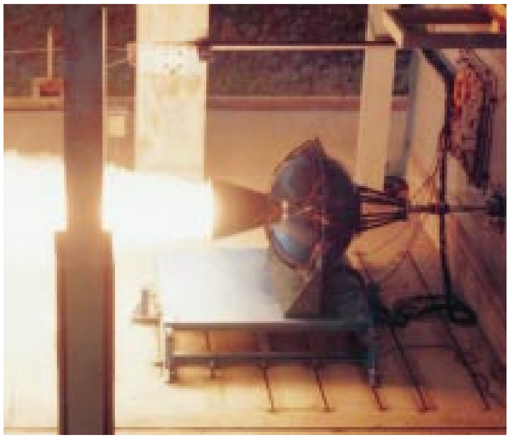


Figure 15-11: A small rocket motor test stand.

Photo Credit: Aerojet

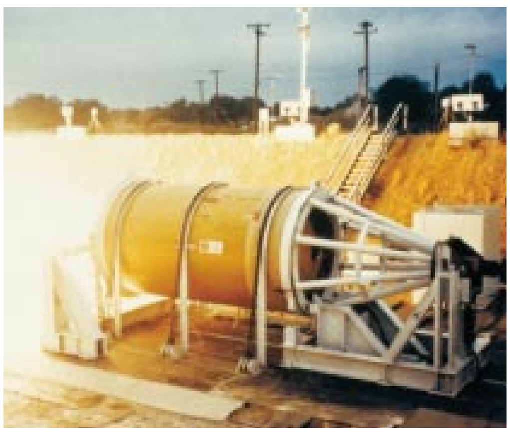


Figure 15-12: An outdoor, horizontal solid rocket motor test stand showing the dolly and frame holding the motor

Photo Credit: Rockwell International

Figure 15-13: A single liquid rocket engine vertical test stand.

Solid rocket motors are usually tested horizontally, and liquid rocket engines are usually tested vertically. Sensors measure pressures, propellant flow rates, forces, event timing, vibrations, displacements, and temperatures. Solid propellant rocket motors run to exhaustion; by contrast, liquid rocket engines and hybrid rocket motors can be throttled or shut down. Post-test inspections are conducted, and data are analyzed.

Typical Missile-Related Uses: Test benches and stands are essential equipment in the development phase of a missile program. Liquid rocket engine test stands are also used for full-scale testing of engine components such as turbopumps.

Other Uses: Similar, though often smaller, horizontal test benches and stands are used to test jet engines, including for use in UAVs.

Appearance (as manufactured): A horizontal solid rocket motor test stand generally consists of a dolly, thrust cup, load cell, thrust block, and instrumentation. The solid rocket motor is first secured horizontally on a movable dolly and locked down. Larger motors are often connected to a frame, which is then inserted into the thrust-cup; smaller motors are often inserted directly into the thrust-cup. The thrust-cup is mated to a load cell, which measures the three axial thrust components, and the load-cell is mounted on a large concrete vertical block or metal frame called the thrust block, which absorbs the forward force as the motor is being fired. Instrumentation connected to the load cell sends data to a blockhouse containing recording equipment. The entire assembly is usually outdoors but may be either partially or totally enclosed in a concrete building or a trench, as shown in Figures 15-11 and 15-12.

Most liquid rocket engines use a vertical test stand, a large gantry-type structure made of steel beams and girders. The liquid rocket engine is attached to load cells, which measure the three axial thrust components; these data are sent to a block house for recording. Run tanks carrying the propellants, the flame bucket, and usually a concrete apron that directs the exhaust away from the test stand are also parts of the installation. Two different test stand configurations are shown in Figures 15-13 and 15-14; a close up of the middle test bay of the latter stand is shown in Figure 15-15.

Photo Credit: Aerojet

Figure 15-14: A liquid rocket engine test stand with three testing bays. The bay on the right is for testing turbopumps.

Photo Credit: Aerojet

Figure 15-15: Close-up of the missile testing bay in Figure 15-14 showing the engine, feed lines, and run tanks.

Appearance (as packaged): Rocket test benches and stands are seldom shipped as assembled structures. Instead, their materials and components are shipped separately and assembled at the test site. A review of the design drawings and fabrication or assembly instructions can identify the intended use of the construction materials and components.

(d) Environmental chambers and anechoic chambers capable of simulating the following flight conditions:
  (1) Altitude of 15,000 meters or greater; or
  (2) Temperature of at least minus 50 degrees C to plus 125 degrees C; and either
  (3) Vibration environments of 10 g RMS or greater between 20 Hz and 2,000 Hz imparting forces of 5 kN or greater, for environmental chambers; or
  (4) Acoustic environments at an overall sound pressure level of 140 dB or greater (referenced to 2×10^{-5} N per square metre) or with a rated power output of 4 kiloWatts or greater, for anechoic chambers.

Produced by companies in

- Canada
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: Environmental testing in ground facilities exposes components, subsystems, and entire vehicles to the low pressures, high and low temperatures, vibrations, and acoustics of powered flight in order to measure the responses. The data generated are used to confirm or correct designs and thereby ensure flight worthiness.

Method of Operation: High altitude is simulated by sealing test objects into rugged pressure chambers that are then evacuated with vacuum pumps. Flight temperatures are simulated inside thermally insulated chambers equipped with heaters and refrigeration equipment. MTCR-controlled temperature chambers must also be equipped to replicate specific vibration or acoustic environments. Vibration equipment are motor-driven tables capable of providing amplitude-frequency spectra to the levels stated above and replicating the range of vibrations experienced by a component, subsystem, or system during powered flight. Acoustic chambers use a combination of electrostatically or electromagnetically driven horns, like loudspeakers, to provide a spectrum of sound pressures like those generated by rocket motor exhaust and very high-speed aerodynamic flight.

Typical Missile-Related Uses: Altitude tests are used to investigate engine performance, heat transfer, altitude ignition, nozzle development, and propellant dynamics phenomena. Simultaneous temperature-vibration and temperature-acoustic tests are used to subject missile hardware to high-fidelity flight environments to develop technology and qualify missiles for flight. Such testing is not required for basic missile programs, but is necessary for advanced development. This equipment can also decrease the cost of a flight test program, but some of this equipment, particularly the large environmental chambers, can be quite expensive.

Other Uses: High-altitude and simultaneous temperature-vibration and temperature-acoustic testing is routinely done on satellites, tactical missiles, and aircraft components.

Appearance (as manufactured): Environmental pressure chambers are rugged, usually metal, airtight, cylindrical chambers with bulged or hemispherical ends to withstand the external pressure of one atmosphere (plus safety margin). They often have thick glass or acrylic viewing ports. An access panel or door at one end is used to insert and remove test items. They are often linked to large vacuum pumps that evacuate the chamber. Their size is a function of the items to be tested; thus, they can range from less than a meter to tens of meters on a side. They are usually supported by numerous buildings housing pumps, power, data collection, and operations. Two different approaches to pressure chambers suitable for rocket motor testing are shown in Figures 15-16 and 15-18; Figure 15-17 shows an interior view of a solid rocket motor being tested at simulated altitude in a facility similar to that shown in Figure 15-16. A large facility capable of testing large solid rocket motors at simulated altitudes of up to 33,000 m is shown in Figure 15-19, and a view of the inside of the test cell of that facility is shown in Figure 15-20.

Temperature chambers are thermally insulated chambers or rooms with heating and cooling equipment. MTCR-controlled temperature chambers have provisions for vibration or acoustic testing at various temperatures encountered in flight.

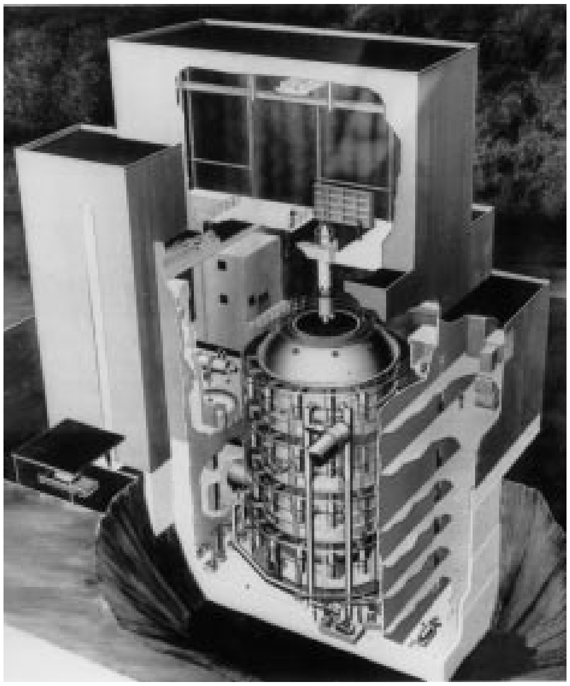


Figure 15-16: A large environmental chamber for simulating high altitude.

Figure 15-17: A solid rocket motor being tested at simulated altitude.

Figure 15-18: A different approach to an altitude test stand. The test object is shown in red inside the pressure vessel.

Figure 15-19: A large rocket test facility capable of simultated altitudes of up to 33,000 m.

Figure 15-20: The test cell of the facility shown in Figure 15-19.

Photo Credit: RMS Dynamic Test Systems

Figure 15-21: A thruster table and its power supply.

Photo Credit: RMS Dynamic Test Systems

Figure 15-22: A controlled environmental chamber with vibration capability.

Photo Credit: Unholtz-Dickie

Figure 15-23: Another vibration and environmental test apparatus configuration.

Temperature chambers for vibration testing contain a powerful device to shake test items. This device, known as a thruster or shaker, usually has a round, flat, steel table, which may have predrilled / tapped mounting locations for attaching test articles. Table motion is often driven by a cylindrical, variable-speed linear electric motor. Depending on the size of the items tested, these tables range from tens to thousands of kilograms in weight. A table capable of imparting 5 kN or greater is shown in Figure 15-21. Environmental chambers controlled under this item can simulate flight conditions of 10 or more g rms from 20 Hz to 2,000 Hz, impart forces of 5 kN or greater, and have operating temperatures of at least –50° C to +125° C, as shown in Figure 15-22. Figure 15-23 shows a different combined environmental test apparatus.

Temperature chambers for acoustic testing are large rooms with acoustic horns mounted in the walls. The horns themselves are monotonic (operate at one frequency) and range in length from several centimeters for high-frequency horns to 1 m for low-frequency horns, with corresponding exit area, or mouth, sizes. Acoustic testing usually requires that the chamber be lined with very coarsely corrugated (often conic-shaped), soft, porous, sound-absorbing material.

Appearance (as packaged): External pressure chambers vary in size, but they are usually very large and constructed onsite. Large MTCR-controlled temperature chambers may be shipped as prefabricated panels of construction materials. The assembly instructions or construction plans can help identify intended use. Smaller temperature chambers are shipped much like a common refrigerator. Dynamic test tables in a partially assembled state are shipped in simple wooden crates, usually with some internal contouring and cushioning for the parts. The shipping containers of these rugged pieces of equipment are not likely to have any special handling markings. Acoustic horns are shipped in metal canisters or wooden crates. Because the driver diaphragms in these horns are sensitive components, shipping containers may have special handling markings.

(e) Accelerators capable of delivering electromagnetic radiation produced by "bremsstrahlung" from accelerated electrons of 2 MeV or greater and systems containing those accelerators.

Note: The above equipment does not include that specially designed for medical purposes.

Produced by companies in

- China
- Germany
- India
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: MTCR-controlled accelerators are of three basic types: linear radio frequency (RF) accelerators (linac), flash X-ray machines, and mechanically charged, high-voltage electrostatic accelerators (Van de Graaff type). Their primary use is to create X-rays capable of penetrating missile parts (such as solid rocket motors) so that X-ray photographs can be made of their interiors. Other uses for energetic X-rays include simulating nuclear weapon effects and stop-action X-ray photography of very high-speed events like explosions and impacts.

Method of Operation: The accelerators of most interest are the linac type. They accelerate a beam or cluster of electrons to speeds approaching the speed of light by passing them through cavities charged with an electric potential (voltage) supplied by an RF generator. Because the effect of these cavities is additive, total electron energies of millions of electron volts (MeV) can be obtained from relatively small devices. This energetic beam of electrons exits the linac and strikes a target (usually a dense metal such as tungsten). The electrons give off X-ray radiation as they are decelerated inside the target; this phenomenon is called "bremsstrahlung," German for braking radiation. The X-rays pass through the object and are recorded on film or, increasingly, in electronic sensors that immediately display the picture on a computer screen. A Van de Graaff accelerator normally creates a large electrostatic potential by mechanically driving a vulcanized rubber belt or insulating string of polished metallic beads on an insulating surface. The targets used to stop the electrons in the electrostatic generators are metal foil like that used in linear accelerators. Most flash X-ray machines operate by charging a very large bank of capacitors to high voltage and then suddenly discharging them. Like the linac, the resulting electron current strikes a heavy metal target and creates X-rays.

Typical Missile-Related Uses: One of the most important uses of linacs is to produce X-rays for non-destructive testing of solid rocket motors. They are

Photo Credit: Titan Beta

Figure 15-24: A 10 MeV X-ray machine used for sterilization (not MTCR-controlled).

Photo Credit: Varian Associates, Inc.

Figure 15-25: Typical linac X-ray system.

used to find cracks and voids in the propellant grain, cracks and incomplete welds in the case, or incomplete bonds to the insulation or interior lining. Such X-ray equipment can be used to inspect most missile components such as structural members, welds, nozzles, and turbopump parts. Linacs are also used to investigate nuclear radiation effects of missile electronics and to test equipment and parts for radiation hardness. These are also the primary uses of large flash X-ray machines. Van de Graaff accelerators are not usually used for these purposes because of their size and low beam current (and thus low X-ray) output.

Photo Credit: Varian Associates, Inc.

Figure 15-26: A linac control console.

Other Uses: Industrial microwave, accelerator-based, high-energy X-ray machines have been routinely used for a wide variety of industrial applications for more than 30 years. These applications include defect-detection large casting and welded assemblies used in automotive, shipbuilding, aerospace, and power production component manufacturing. A high-energy X-ray machine used for sterilization is shown in Figure 15-24. These machines also are used in large security systems for detection of contraband or explosives in container shipments. Similar technology is employed in the production of machines used to treat cancer.

Photo Credit: Varian Associates, Inc.

Figure 15-27: A linac RF amplifier on the left with the water pump cabinet on the right.

Appearance (as manufactured): The most commonly used 2 MeV + accelerator is the linac, as shown in Figure 15-25, because of its small size and ruggedness. These X-ray machines consist of five major parts: the accelerator, the X-ray head, the RF amplifiers or modulators, a control console, and a water pump cabinet. The box-like structure of Figure 15-25 contains the accelerator and the X-ray head. Figure 15-26 shows the control console. Figure 15-27 shows the RF amplifier on the left and the water pump cabinet on the right.

The source of the X-rays is the X-ray head. It is connected to the RF modulator by means of a waveguide, which is a rectangular rigid or semi-rigid conduit or cable. The accelerator portion of the X-ray head is a tube or pipe with semi-circular disks on alternating sides along its length. This assembly may be in the center of a larger diameter electromagnet. The modulator or RF amplifier, which supplies RF energy to the acceleration tube, is often in a separate cabinet. This energy is normally coupled through a rectangular waveguide or, less frequently, a coaxial cable. The modulator operates at a frequency corresponding to the accelerating structure, normally in the 1 to 3 GHz range. The other supporting components are the control system and the water-cooling system. These systems control and cool the accelerator to keep it within a narrow range of operating temperatures. Typical dimensions for the X-ray head, modulator cabinet, and control console are shown in Table 15-1.

Table 15-1: Typical linac dimensions.

	X-ray Head	Modulator Cabinet	Control Console
Height:	0.5 m	1.0 m	0.2 m
Width:	0.5 m	0.5 m	0.3 m
Depth:	1.0 m	1.0 m	0.3 m
Weight:	200 kg	300 kg	2 kg

X-rays produced by MTCR-controlled accelerators are energetic enough to require lead shielding several centimeters thick. These accelerators are often shipped without shielding since the shielding can be readily manufactured and installed by the recipient. Often an unshielded system is placed inside a shielded building.

The other type of accelerator for use in high-energy X-ray generation is a mechanically driven Van de Graaff type generator. These systems are much larger than linear accelerators and more difficult to position, and thus are not normally used for radiography. They consist of a high-voltage power supply capable of generating electrostatic potentials of 2 MV or more, an acceleration tube made of highly polished nickel, and a control console. The power supply and the acceleration tube are usually integral parts. They are contained within a high-pressure tank made of thick-walled steel, which when operational, contains a high dielectric gas such as sulfur hexafloride or pure nitrogen at a pressure of several atmospheres. Unlike the linear accelerators, which are small enough to be rotated around the piece being X-rayed, the very large electrostatic accelerators remain stationary, and the test piece is moved as needed to achieve the desired relative positioning. Typical dimensions of a Van de Graaff system are given in Table 15-2.

Table 15-2: Typical dimensions for a Van de Graaff system.

	Pressure Vessell	Control Console
Length:	2.5 m	0.2 m
Diameter:	1.0 m	
Width:		0.2 m
Weight:	1,200 kg	2 kg

Figure 15-28:
A 2.3MeV flash X-ray unit used for inspecting solid rocket motors.

Flash X-ray equipment varies in size from a desktop unit to huge systems that require special buildings. A typical unit used for inspection of solid rocket motor grains is shown in Figure 15-28.

Appearance (as packaged): Linear accelerators are packaged for shipment in crates or boxes. They may appear as three separate cabinets. The X-ray head and modulator normally come from the same vendor. The cooling system and the control system can be purchased separately. The packaging uses foam, Styrofoam, or other shock-attenuating fill to protect the modulator from excessive vibration and shock. The equipment may be labeled with X-ray caution labels, RF field signs, and possibly labels indicating high-voltage. The system may be heavier than lower-energy systems because of the amount of lead shielding, if shipped with shielding installed, required to shield personnel from penetrating X-rays.

The electrostatic accelerators are much larger. The high-voltage supply and the acceleration tube are shipped together inside the pressure vessel. Because of its weight, the pressure vessel is most likely shipped in a crate made for fork-lift handling. The unit is not likely to be shipped in operational condition and usually has additional packing material inside the pressure vessel to support the high-voltage supply and acceleration column.

ITEM 16
Modeling and Design Software

Modeling and Design Software

Specially designed software, or specially designed software with related specially designed hybrid (combined analogue / digital) computers, for modelling, simulation, or design integration of the systems in Item 1 and Item 2.

Note to Item 16:
The modeling includes in particular the aerodynamic and thermodynamic analysis of the systems.

Produced by companies in

- Australia
- Brazil
- Canada
- China
- France
- Germany
- India
- Israel
- Italy
- Japan
- Norway
- Russia
- South Africa
- South Korea
- Sweden
- Ukraine
- United Kingdom
- United States

Nature and Purpose: Modeling, simulation, and design integration software tools permit the designer to build and fly a missile using a computer. Numerous design changes and flight environments can be investigated by using these tools and thereby avoiding the expense of building, testing, and redesigning actual hardware. This modeling capability dramatically decreases the cost and time required to develop a rocket or an unmanned air vehicle (UAV). Various computer-generated codes have a critical role in designing a missile with desired performance capability, especially for longer range missiles. Using a full library of software models to validate performance in the design stage leads to missiles with the most appropriate, mission related trade-offs, including range and payload capabilities.

Hybrid computers combine analog and digital components to exploit the advantages of each. They are useful in situations in which data rates are extremely high and the signal-to-noise ratio is low, such as focal plane arrays in advanced sensors. These conditions may be stressing to purely digital computers because such computers cannot always keep up with the data stream, and the low signal strength sometimes does not create the clear “1” or “0” required by a digital device. Thus, analog circuitry is sometimes used to collect and process the output of the sensor before digitizing the data.

Method of Operation: Most missile design software models represent the physics of missile operation. Modern aerodynamic models may offer a highly accurate treatment of flows internal and external to the missile and can be tailored to the specific missile geometry under evaluation.

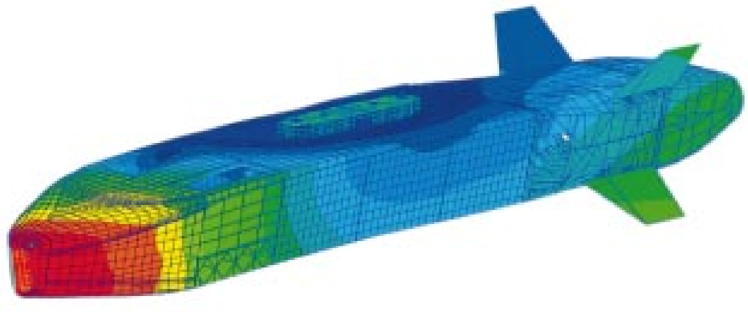


Figure 16-1: The output of a finite-element missile structures code showing relative deformation across a missile body.

Thermodynamic models predict both the frictional heating and chemical reactions involved in missile propulsion and thermal protection, and the resulting flow of heat into critical missile components. Applications of finite element models in designing missile structures are now common, as are applications of models combining guidance hardware and missile controls to test performance. An example of the output of a structures code is shown in Figure 16-1. Once designed, subsystem hardware is frequently tested by means of hardware-in-the-loop simulators. These simulators may range from straightforward actuation of mechanical linkages on a rocket nozzle during simulated test firing to highly sophisticated laboratory assemblies involving the measurement of the responses of complex subsystems such as guidance and control.

Typical Missile-Related Uses: Missile design software may be applied early in the design process to define overall configurations, thrust capabilities, aerodynamic flight loads, structural requirements, thermal insulation requirements, and the guidance or control requirements of candidate design concepts, or models. Subsystem hardware designs based on these models are performance tested, often with simulation software in-the-loop, to validate their capabilities and to refine the models to make them more design specific. The computer then combines these design-specific models in order to represent an integrated rocket or UAV system in flight and to confirm its design capabilities before actual flight testing. This modeling approach eliminates much of the need for expensive iterative flight testing.

Other Uses: Many of the more fundamental software models used in rocket systems or UAV design are commonly used commercially. A popular structural model, NASTRAN, is used in designing trucks and building bridges. Thermodynamic codes such as SINDA are used in satellite and power plant design. Flight motion computers have wide applications for pilot training and other flight simulators.

Appearance (as manufactured): Software for missile design is physically indistinguishable from commercial software. It is contained on the same computer disks or CD-ROMs, etc. Missile analog / hybrid computers are custom electronics generally smaller than a breadbox. Flight motion computers are cabinets with commercial standard electronics racks. A hardware-in-the-loop missile simulator testbed for a missile with high accuracy requirements is shown in Figure 16-2. Alternatively, missile software and specialized flight dynamics models can be loaded on a pure digital, real-time computer (flight emulator), as shown in the lower portion of Figure 16-2. Real-time models can be used to replace the test article hardware in the loop.

Appearance (as packaged): Typical packaging schemes for missile simulation and software test equipment are shown in Figure 16-3. Custom electronics like the analog / hybrid computers may be packaged in a variety of ways, including trunk containers used for shipping sensitive instruments and computer monitors. Flight motion computers are generally shipped like other electronic equipment. Other flight simulator hardware, including flight motion tables, may be packed in wooden crates for shipment. Models and real-time software look like any other software product and are packaged in cardboard boxes, possibly in shrink wrap (if commercial / new) or on unmarked standard transfer media, such as floppy disks, CD-ROMs, or 1 / 4″ magnetic tape cartridges.

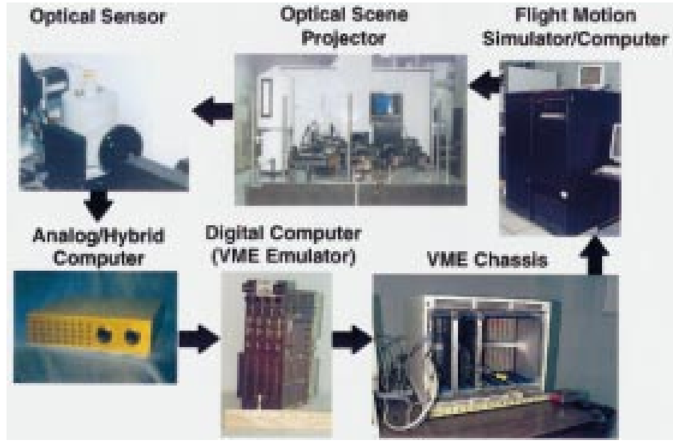


Figure 16-2: Hardware-in-the-loop missile hardware simulation.

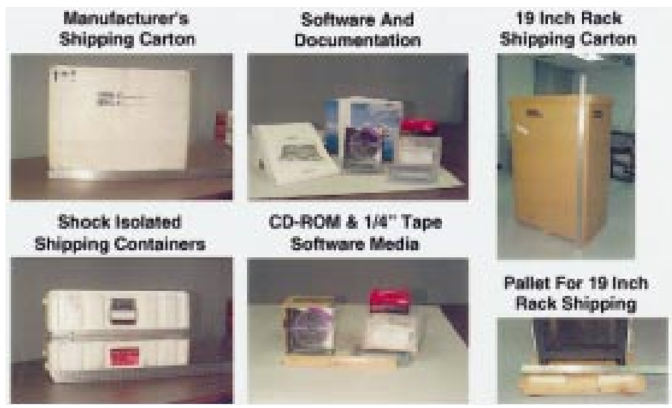


Figure 16-3: Packaged missile simulator equipment and software appearance.

Additional Information: High speed digital computers based on industry bus standard definitions such as Virtual Machine Europa, Multibus, and Futurebus+, provide considerable leverage for developing real-time missile flight software. These commercial standards are fast enough to support real-time missile performance simulations. The flight motion computer is the essential integrator that makes these commercial computers useful as emulators for missile software development and testing. Flight motion computers have specialized operating systems that enable them to act as simulation controllers and flight performance data loggers.

ITEM 17
Stealth

Stealth

Materials, devices, and specially designed software for reduced observables such as radar reflectivity, ultraviolet / infrared signatures and acoustic signatures (i.e., stealth technology), for applications usable for the systems in Item 1 or Item 2, for example:

(a) Structural materials and coatings specially designed for reduced radar reflectivity;

(b) Coatings, including paints, specially designed for reduced or tailored reflectivity or emissivity in the microwave, infrared or ultraviolet spectra, except when specially used for thermal control of satellites;

Produced by companies in

- Brazil
- China
- France
- Germany
- Israel
- Italy
- Japan
- Netherlands
- Russia
- South Africa
- Sweden
- Taiwan
- United Kingdom
- United States

Nature and Purpose: The need to protect missiles from detection and destruction has led to the development of technologies to reduce their observables; when reduced observables are a primary design goal for a new vehicle, they are often referred to generically as "stealth" technology. Reflections and emissions are reduced or tailored through the use of carefully designed shapes and special materials. Other devices such as low probability intercept radar may be used. The objective is to make the object difficult to detect.

Method of Operation: Emissions and reflections are acoustic or electromagnetic in nature. Emissions are held to a minimum by any of a wide range of techniques such as frequency staggering, vibration isolation, shielding, masking, directing, and dampening.

Electromagnetic emissions and reflections occur in numerous frequency bands, including microwave (radar), infrared (IR), visible, and ultraviolet bands. Because radiation behavior varies significantly between and even within frequency bands, different methods must be applied across the spectrum. Emissions and reflections can be directed away from the observer and / or reduced in amplitude or altered in frequency response with the aid of carefully selected shapes and materials. This reduction is achieved by shaping, material, or devices for controlled emissions, reflectance, absorption, and second surfaces (added insulators and reflectors). These techniques or devices either conceal or disguise the true nature of the object from the observer or allow the vehicle to be detectable only at certain angles and for brief intervals, thereby delaying or avoiding detection and engagement.

Typical Missile-Related Uses: Stealth technology is used to make ballistic missiles, unmanned air vehicles (UAVs), including cruise missiles, and their payloads more difficult to detect, track, identify, and engage by defensive weapon systems. Most design elements of a missile are subject to treatment with stealth technology, including its basic shape, its structural components, its surfaces and leading edges, and its inlets and openings.

Other Uses: Most of the materials used for signature control were originally developed for military aircraft and are found on both fixed- and rotary-wing systems. Modified versions of the materials and treatment techniques are found on some ships, submarines, and ground combat and tactical vehicles. Emission control materials technology also is used to control temperatures in satellites. Several devices can be used with communication gear to reduce detectability. There are commercial uses for some of the low cost, low performance materials for reducing electromagnetic interference and for reducing solar loading.

Appearance (as manufactured): Typical materials for reduced-observable treatments include, but are not limited to, the following categories:

- There are two kinds of conductive fillers: conductive fibers, which look like very light whiskers 2 to 6 mm long, are made of carbon, metals, or conductive-material coated glass fibers; and conductive-material coated particles, which may look like colored sand.

- Sprays include conductive inks or paints, which normally contain silver, copper, zinc, bronze, or gold as the base ingredient. They appear black, metallic gray, copper, bronze, or gold in color.

- Small cell foams, both open and closed, are painted, or loaded, with absorbing inks and paints. These foams resemble flexible foam rubber sheets or air conditioning filters. They can be single-layered or noticeably multilayered, with glue lines separating the strata. A ground plane, if applied, can consist of a metallic paint, a metallic sheet (aluminum foil or metalized thin plastic), or undetectable sprayed inks. Some manufacturers may mark the front of these foams with lettering saying “front” or with serial numbers if the ground plane is not obvious. Some foams may contain composite fiber to make them more rigid or even structural. Four such foams are shown in Figure 17-1.

- Magnetic Radar Absorbing Material (MAGRAM), as applied to vehicles, may appear in forms such as surface coverings, molded edges, or gap fillers. It consists of very fine grained ferromagnetic or ferrite particles suspended in a variety of rubber, paint, or plastic resin binders. At least one commercially available version uses a silicon-based binder, as shown in Figure 17-2. It may be applied as sprays, sheets, molded or machined parts, or putties. Because of the general colors of typical binders and ferromagnetic particles, the natural colors of MAGRAM range from light gray to nearly black; however, with additional pigments added for other reasons (e.g., visual camouflage or manufacturing/maintenance-aid coding), almost any color is possible. Thin films of plastic or paper material may cover one or both sides of sheets for identification coding or maintaining preapplication surface cleanliness. Sheet thickness may range from less than a millimeter to several centimeters. The density of the material is likely to range from 50 to 75 percent of solid iron.

Figure 17-1: Four radar absorbing material foams, clockwise from upper left: low-dielectric foam (epoxy); lightweight lossy foam (urethane); thermoplastic foam (polytherimide); and sprayable lightweight foam (urethane).

- Resistive Cards (R-Cards) consist of a sheet of fiber paper or very thin plastic covered with a continuous coat of a conductive ink, paint, or extremely thin metallic film. The surface electrical resistivity of the coating may be constant or may vary continuously in one or two directions. The conductive ink versions are likely to be dark gray to black. The metallic coated versions may vary in color depending on both the specific metals used and the thicknesses involved, but black, yellow, green, and gold tints are common. A Kapton R-card is shown in Figure 17-3.

Figure 17-2: A sample of a thin MAGRAM silicone resin sheet.

- Loaded ceramic spray tiles are sprayed-on and fired ceramic coatings heavily loaded with electrically conductive fillers or ferromagnetic particles. They are likely to range from dark gray to black in color. Depending on the specific filler and surface-sealing glaze used, they may range from smooth to abrasive in surface texture. Sprayed-on coatings may range from a few millimeters to tens of centimeters in thickness.

Figure 17-3: A sample of resistive card (R-card) made of metallized Kapton.

Figure 17-4: A sample of radar absorbing honeycomb material.

- Absorbing honeycomb is a lightweight composite with open cells normally 3 to 12 mm in diameter and 25 to 150 mm maximum thickness. It is treated with partially conductive inks, paints, or fibers. The honeycomb core may be shipped without being loaded, in which case it might be indistinguishable from materials used solely for structural purposes. The conductive inks and paints for subsequent loading are likely to come from an entirely different source than the core itself. Absorbing honeycomb is shown in Figure 17-4.

- Transparent RAM (T-RAM) looks like sheet polycarbonate. It is normally 75 to 85 percent transparent in the visible spectrum. Absorbing materials can vary from fibers or spheres spread throughout the material to thin coatings, which look like yellow / green metallic window tinting. A clear sample is shown in Figure 17-5.

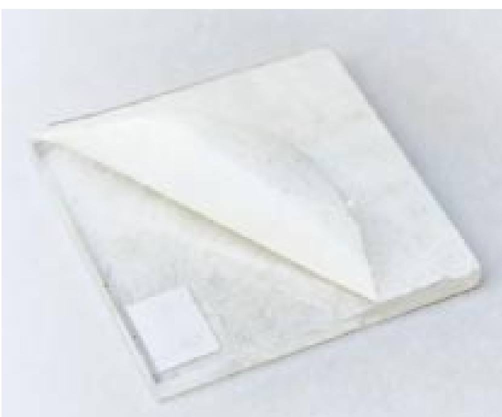


Figure 17-5: A small sample of transparent RAM. Notice the protective covering adhered to the surface.

- Infrared (IR) Treatments usually consist of paints and coatings. Often these coatings are customized to tailor reflectance and / or radiation of IR energy. Because of the wide spectrum (0.8 to 14 microns wavelength) of IR energy and the variety of applications, IR coatings may either be reflective (low emissivity) or designed to absorb (high emissivity). Coatings used for IR treatment include specially designed military paints in camouflage colors or commercial paints designed to reflect solar heat. Some of these products have a noticeable metal content in the paint / binder due to the IR pigments used. Others are designed to have high emissivity and as such, contain pigments that absorb IR. These high emissivity coatings contain carbon-based or other highly emissive particle-based pigments (normally nearly black). In either case, these IR pigments are sometimes shipped separately from the paint / binder.

Appearance (as packaged):

- Absorbing fibers vary from 2 to 6 mm in length and are usually packaged in plastic bags, vials, or jars. Their weight depends on the materials used. Fibers shipped before being chopped to their functional length may be in the form of conventional spools of textile fibers or in bundles 1 to 2 m in length and 2 to 10 cm in diameter.

- Spray paints and inks are generally shipped in standard size cans. The cans may be in boxes containing desiccants, or the pigments and binders may be shipped separately. Pigments are shipped in jars, plastic bags, or cans, and the binders are shipped in cans or drums. Most are highly toxic or caustic materials until applied and cured.

- Foams come in sheets usually no larger than 1 × 1 m, ranging from 6 to 200 mm in thickness, and weighing less than 40 g per square meter. They are packaged in cardboard boxes.

- MAGRAM may be shipped in sheets, uncured slurries, and finished parts, or in raw material form (particles, binder, and polymerization-activator all shipped separately). The particles would most likely be shipped in a very fine powder or short fiber form, but possibly also immersed in a hydrophobic fluid to prevent rusting. It may be shipped in sheets up to a few meters in length and width. Sheet thickness may range from less than a millimeter up to tens of centimeters. It may be shipped several layers deep on flat pallets or as a rolled sheet inside a cardboard tube. If shipped as formed parts, it may be in rectangular cardboard or wooden boxes as large as 0.1 × 0.1 × 2 m or as small as 20 × 20 × 20 cm.

- R-Cards are packaged in an envelope or box with a nonabrasive paper sheet between each card. Larger quantities may be shipped in rolls from 0.2 to 1 m in length and 15 cm in diameter, inside desiccated tubes, or in cardboard boxes.

- Loaded ceramic spay tiles are usually bubble wrapped and packaged in cardboard boxes.

- Absorbing honeycomb is shipped in cardboard boxes.

- T-RAM is packaged like sheet polycarbonate or like a window or canopy part. It can have an adhesive protective paper applied to the outside. If shipped in smaller pieces, it can be boxed.

- IR thermal paints and coatings are usually packaged in cans like any paint product. IR paint pigments can be packaged in cans, vials, or plastic bags.

(c) Specially designed software or databases for analysis of signature reduction;

Nature and Purpose: Designing and producing materials for, and systems with, signature reduction normally requires software and databases for analyzing these materials and systems. Software and databases specially designed for analysis of signature reduction are controlled. These databases and software will include data or functions essential to analysis of the signature reduction capability of systems and materials.

Produced by companies in

- France
- Germany
- Israel
- Japan
- Russia
- South Korea
- Sweden
- United Kingdom
- United States

Method of Operation: Because emissions and reflections may take many forms such as acoustic, radio frequency, or infrared energy, software and / or databases containing information or methodologies specially designed for analysis of emissions and reflectance (signatures) are used to evaluate materials for their signature reducing properties. Similarly, software and databases may be used to analyze systems in order to determine effectiveness of the materials and devices already incorporated as well as to determine what areas need improvement.

Typical Missile-Related Uses: These items are used to analyze airframe shape and materials for ballistic missile and UAV, including cruise missiles, applications in order to select signature reducing treatments or identify hot spots (potential areas for improvement). Similarly, these items may be used to evaluate the signature of systems, quantify performance of designs and material choices in systems, and evaluate areas for improvement.

Other Uses: Similar items may be used to analyze signature reduction on many military articles including ground vehicles, manned aircraft, and ships, as well as analysis of effectiveness of energy management systems for satellites and homes. Additionally, passive and active detectors used for security alarm systems also may require analysis using similar technologies.

Figure 17-6: Software in the form of a computer disc, a cassette tape, and written media.

Appearance (as manufactured): Software for signature reduction design tools may be packaged on floppy discs, tapes, and compact discs. A few examples are shown in Figure 17-6. Alternatively, a computer network can be used to distribute software and its documentation electronically.

Additional Information: Each spectrum has its own specific design software. Most countries and defense contractors have developed one-, two-, or three-dimensional computer codes for analysis and design optimization. In the radio frequency (RF) / radar spectrum, any code that can model antennas or radomes can be modified and used as a radar cross-section (RCS) tool. As a rule of thumb, any software code name that includes the letters SIG, RF, or RCS should be regarded as suspect RCS code. Basic codes that run on personal computers can give good fundamental design guidance. When exotic materials and complex shapes come into play, supercomputers and specially designed codes are required.

The key elements of RCS design codes involve the ability to define a vehicle surface profile within an adequate margin (which can be as small as 1 / 20 of a wavelength of the highest frequency of interest); the ability to represent very small elements of the surface as vectors; and the ability to handle the four real and complex terms associated with magnetic permeability and electrical permittivity. These items indicate the value of general purpose codes and machines capable of rapidly inverting and manipulating very large matrices of numbers.

IR thermal codes are less readily available or mature, but there are commercial codes available that can be used or modified for military applications. These codes include those used for thermal quality control. As in RF, a code capable of vector representation of the size and orientation of surface elements is a critical starting point. Codes estimating the atmospheric transmission of IR radiation at different altitudes, seasons, and types of gaseous environments are used in the design process. Codes for determining heat transfer in aircraft are essential. Codes for determining plume temperature from the volume of combustion products passing through the tailpipe and expanding and dissipating in the atmosphere are typically involved. (This plume modeling often involves engine deck codes but goes beyond their use for determining propulsion performance.) Codes that use material emissivity and bidirectional reflection coefficients of materials as inputs may indicate their potential use in IR signature control design.

Appearance (as packaged): Software on floppy discs, tapes, and compact discs will be packaged in any of a wide variety of packets, pouches, mailers, or boxes. Software may also be packed with related hardware.

(d) Specially designed radar cross section measurement systems.

Produced by companies in

- France
- Germany
- Israel
- Japan
- Russia
- South Korea
- Sweden
- United Kingdom
- United States

Nature and Purpose: RCS measurement equipment has been developed to evaluate, tailor, and reduce the RCS of missile systems in order to reduce detectability by air defense radars. RCS measurement equipment can be used in either indoor or outdoor ranges. Many of the ranges are usable for both military and commercial purposes. RCS measurement equipment can be used for evaluating material samples, missile components, scale models of missiles, and actual rocket systems or UAVs.

Method of Operation: An object under test, often called the target, is positioned or suspended in a test area with a few or no other objects in order to minimize sources of extraneous radar scattering. The target is then illuminated repeatedly by a radar over a select range of radar frequencies of known amplitude, and the reflections are measured. The resulting data are evaluated, and radar reflectivity of the target as a function of frequency and viewing angle is determined.

Typical Missile-Related Uses: This equipment is necessary to determine, tailor, and reduce the radar signature of a rocket, UAV, or payload. These measurement systems also assess computer-modeled performance and ascertain whether the missiles have the desired reduced and tailored observables. Certain RCS equipment is used to characterize radar-absorbing materials.

Other Uses: RCS measurement systems can be used to determine the radar signature of any military vehicle such as land vehicles aircraft, and ships. The

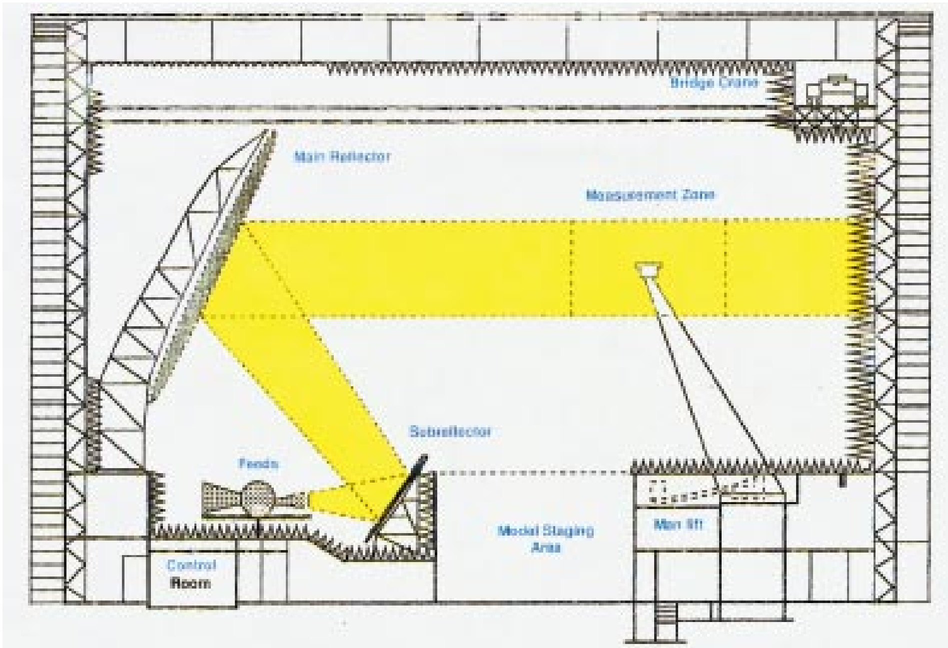


Figure 17-7: Schematic of a typical Cassegrain indoor RCS measurement range.

measurements provide information that aids in tailoring or reducing the RCS. Indoor RCS measurement ranges can be adapted to measure antenna performance patterns for various commercial applications such as cell phones, automobile antennas, and satellite dishes.

Appearance (as manufactured): The basic elements of an indoor RCS test range are explained below and shown in Figure 17-7.

- *Radar Source Equipment:* RF equipment is a rack-mounted collection of electronic equipment that, when assembled, occupies the space of a filing cabinet and is used in all types of RCS measurement systems. Up / down converters with feed horns provide radar illumination. To provide a wide range of frequencies, the conical feed horns vary in diameter from 1 to 100 cm in internal width. The feed horn length is generally two and a half times the internal width. They are metal lined and have provisions for attaching a coaxial cable or waveguide on the rear end. In RCS measurement systems, radar feed sources can be replaced by a radar source from a commercial radar system (e.g., marine radar). Network analyzers can measure absorption and reflection, and are commonly used commercially to develop antennas and electromagnetic interference shielding materials. RF cabling is low-loss coaxial cabling and is required for connecting the components. These cables vary in length but are normally 1 to 2 cm in diameter and have a metal mesh outer surface.

- *Dual Reflectors:* Cassegrain measurement systems use two large plates or dishes of different dimensions as reflectors; they can be circular, elliptical, or rectangular. The plates may have calibration marks on several portions of the surfaces and may be painted. Reflectors may be assembled from pieces and may have rolled or serrated edges. For measuring the RCS of a typical cruise missile, the two reflectors are 2 to 5 cm in thickness, and their major axes are 4 m and 5 m in length. These reflectors create a measurement “sweet spot” 2 m in diameter. A typical RCS dual-reflector measurement system is shown in Figure 17-8. This type of system is almost invariably used for indoor measurements. It should be noted that a measurement system could be devised using a single reflector.

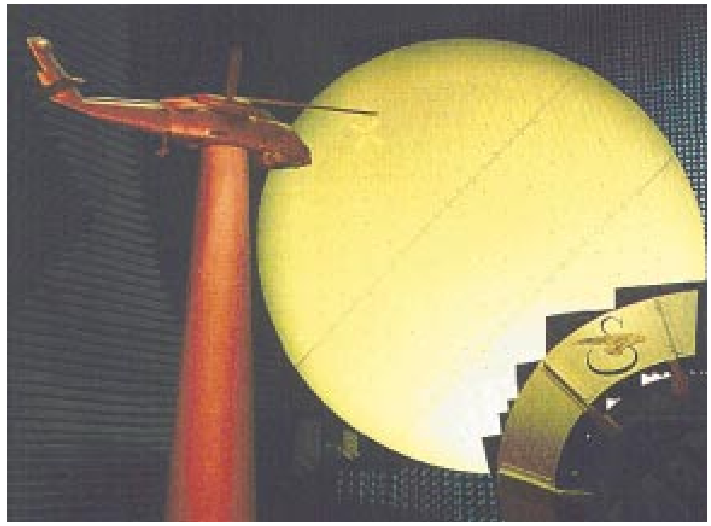


Figure 17-8: RCS measurement equipment using a dual reflector system.

- *Target Support Devices:* These devices hold the target off the floor or ground and in the radar illumination; they need to be as imperceptible to radar as possible. Styrofoam columns, metal blades coated with radar absorbing material (RAM), and puppet strings from overhead mounts are common methods of supporting and suspending targets to be measured. The Styrofoam columns may range from 2 m in height and 0.5 m in diameter to 5 m in height and 2 m in diameter. Their horizontal cross-section may be round (with or without taper), square, triangular, or diamond-shaped; Figure 17-8 shows a truncated-cone column. The metal blades, or pylons, may range from 2 to 40 m in length and be 5 × 30 cm at the top; short pylons are 50 × 90 cm at the bottom, and tall pylons are 2 × 8 m at the bottom. Both Styrofoam columns and pylons can be mounted on a mechanism that tilts them forward. Rotating interfaces can also turn the Styrofoam column and target. Sets of three to five Styrofoam columns mounted on a common turntable can be used to support and rotate a target. Some pylons also have a rotating interface with the target at the top.

- *Bidirectional Arches:* Another approach to measuring missile RCS is to use a bidirectional arch, which can be made out of plywood, fiberglass, or metal. An electric motor drive system is used to relocate the feed horns along the arch, as shown in Figure 17-9. Custom cabling links the arch to a control computer (normally a PC with a keyboard and monitor) and the feed controls. A test article, with its surface perpendicular to the plane defined by the arch, is placed at the center of the arch. The articles are typically 0.3 to 1.0 m on a side. The calibration reference is a flat, smooth metal plate the same size as the test article.

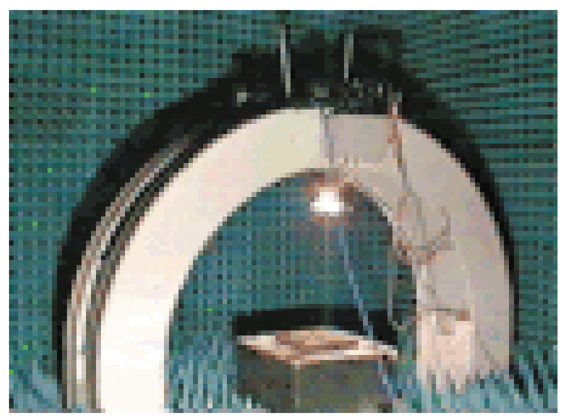


Figure 7-9: Bidirectional reflectance arch.

Appearance (as manufactured): Transmission / reflection tunnel RCS measurement systems look like large, sheet metal, air vent ducting. They have two matching metal feed horns with coaxial cabling or waveguides leading to the radar source and detector measurement electronics. They are controlled by a computer that looks like any PC with a keyboard and a monitor. There may be radar-absorbing foam (normally medium blue or black in color and spiked on the surface) inserted in portions of the ducting. Direct illumination indoor systems and bounce range outdoor systems use conventionally shaped, parabolic radar reflectors ranging in size from a few centimeters up to 10 m in diameter.

Appearance (as packaged): Radar ranges are seldom shipped as one piece; rather, they are assembled onsite from many components. There are no unique packaging requirements for this equipment beyond those of the industry standard for rack-mounted electronics and commercial computer components. Some of the components (such as the Cassegrain reflectors) can be fairly large and require special crates. Styrofoam target supports are delicate and must be packaged to prevent denting.

ITEM 18
Nuclear Effects Protection

Nuclear Effects Protection

Devices for use in protecting rocket systems and unmanned air vehicles against nuclear effects (e.g. Electromagnetic Pulse (EMP), X-rays, combined blast and thermal effects), and usable for the systems in Item 1, as follows:
(a) "Radiation hardened" "microcircuits" and detectors.

Note to Item 18 (a):
A detector is defined as a mechanical, electrical, optical or chemical device that automatically identifies and records, or registers a stimulus such as an environmental change in pressure or temperature, an electrical or electromagnetic signal or radiation from a radioactive material.

Produced by companies in

- France
- Israel
- Japan
- Russia
- Sweden
- United Kingdom
- United States

Nature and Purpose: Microcircuits require protection from ionizing radiation in the form of gamma and X-rays from detonated nuclear weapons. Ionizing radiation causes two problems in microcircuits. The first problem is the build-up of a permanent electrical charge in a circuit, which disrupts its ability to respond or causes it to fail completely (latch-up). This effect depends on the total dose of radiation delivered to the circuit. The second problem is excess flow of electrical current in a circuit, which disrupts or destroys it. This effect depends on how quickly the radiation is delivered to the circuit (dose rate). Of the several ways to protect circuits from such effects, the two covered by the MTCR Annex are to make microcircuits intrinsically resistant to the total dose of ionizing radiation (hardening) or to use a radiation detector to sense the dose rate from a nuclear event and turn the circuit power off or trigger protection devices until the event is over.

Method of Operation: Hardened microcircuits are similar in operation and appearance to regular microcircuits, but they are made of materials and by processes that resist accumulating excess charge. Improved oxide insulating layers, increased material purity, decreased porosity, and sometimes polishing of the insulating layers are all used to reduce the charge-holding tendencies of the oxide. These techniques greatly increase the cost of a hardened microcircuit, and they tend to lower digital operating rates. Radiation detectors are relatively simple devices that sense an increase in current caused by incident radiation. After the radiation passes a threshold, the detectors issue a

Photo Credit: The Charles Stark Draper Laboratory, Inc.

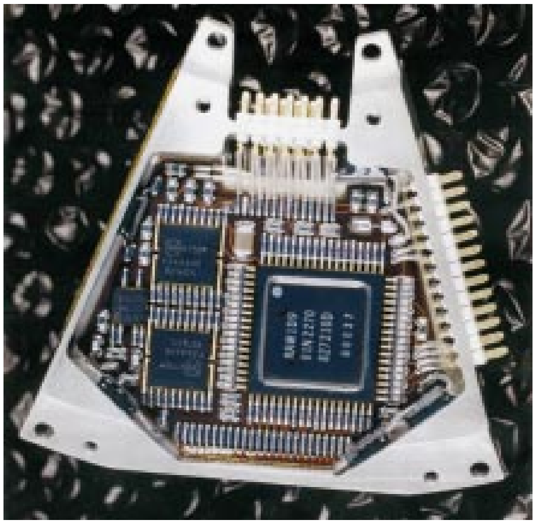


Figure 18-1: A circuit board populated with microcircuits hardened against nuclear effects.

Photo Credit: The Charles Stark Draper Laboratory, Inc.

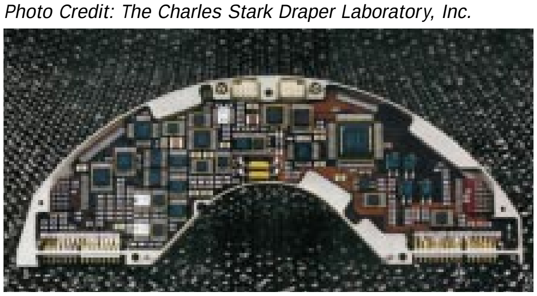


Figure 18-2: Another circuit board populated with microcircuits hardened against nuclear effects.

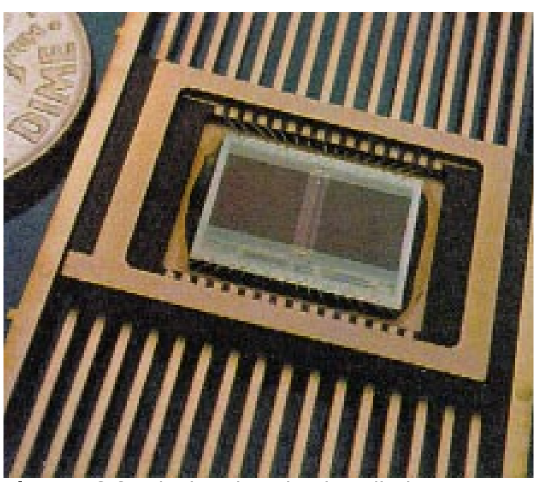


Figure 18-3: Single microcircuit radiation detector.

control signal to protection circuitry, which either shunts currents away from sensitive devices or turns off the equipment to avoid burn out. The detectors usually have a test input to activate the detector during construction or maintenance activities to verify operation. They must usually resist radiation effects (e.g., they must work again), and they must be fast in issuing protection commands before damage occurs in the microcircuits.

Typical Missile-Related Uses: Radiation-hardened microcircuits and detectors are used in ballistic missiles intended to operate in a nuclear environment. Protecting unmanned air vehicles (UAVs) from ionizing radiation is generally not required because they are usually more vulnerable to blast overpressure, which would impact a UAV at greater distances from a nuclear explosion than radiation.

Other Uses: Radiation-hardened devices are used in spacecraft for long-duration missions, including military, telecommunications, scientific, and meteorological satellites, space stations, and planetary probes. However, the total dose that these applications are required to withstand is generally significantly lower than that specified by the MTCR Annex (5×10^5 rads (Si)), but MTCR-controlled items are often used. Hardened microcircuits are also used in high-radiation environments such as nuclear reactor safety; instrumentation, control, and robotics systems; and high-energy physics accelerator instrumentation, detectors, control, and safety systems.

Appearance (as manufactured): Hardened electronic component devices and their assemblies are typically mounted in hermetically sealed metal or ceramic packages with surface-mounted devices common in high-density assemblies. They look like commercial devices, but they may have part numbers identifying them as hardened. Two circuit boards populated with hardened microcircuits are shown in Figures 18-1 and 18-2.

Radiation detector circuits can be a dozen or so square centimeters of circuit board space or a single microcircuit with a few external select components as shown in Figure 18-3.

Appearance (as packaged): Electronic assemblies and components are typically shipped in plastic bags marked to designate an electrostatic sensitive device. They are cushioned in rubber foam or bubble wrap for shock protection and packed inside cardboard boxes.

(b) Radomes designed to withstand a combined thermal shock greater than 100 cal / sq cm accompanied by a peak over pressure of greater than 50 kPa (7 pounds per square inch).

Produced by companies in

- Russia
- United States

Nature and Purpose: Radomes are non-metallic structures that protect antennas from the environment while allowing transmission of radio frequency signals with minimal signal loss and distortion. They are usually made of an insulating material such as ceramics or silicon phenolic. The indicated specifications limit concern to radomes intended to survive a severe heat and pressure environment.

Method of Operation: Radome materials are selected for their strength and signal transparency in the frequency bands of interest throughout the expected temperature range. They are usually shaped to enhance the aerodynamic performance of the vehicle and to avoid undue perturbations of the signal from prismatic, or lens, effects. Properly designed radomes allow the enclosed antenna to transmit and receive signals through the radome with minimal distortions.

Typical Missile-Related Uses: The severe environments specified in this Item typically limit the missile-related uses of these radomes to some cruise missiles and to the reentry vehicles (RVs) carried by short- to intermediate-range ballistic missiles. One use of such radomes is to protect active radar seekers installed in the nose of RVs as they guide the RVs to their targets. Longer-range missiles reenter the atmosphere too fast for nose mounted radomes to survive. For these RVs, radomes (windows) may be located further back on the RV body. These radomes are not generally needed for UAVs because most UAVs cannot survive the specified nuclear effects. In any case, radomes also can be hardened to the specified nuclear effects to protect antennas at missile silos or command posts designed to survive nuclear attack.

Other Uses: These radomes have few if any commercial uses.

Appearance (as manufactured): Radomes used to protect nose-mounted sensors in RVs are conical, as shown in Figures 18-4 and 18-5. They range in size from 30 cm to 1 m or more in diameter and length, depending on the size of the RVs to which they are

Photo Credit: British Aerospace Defense Limited

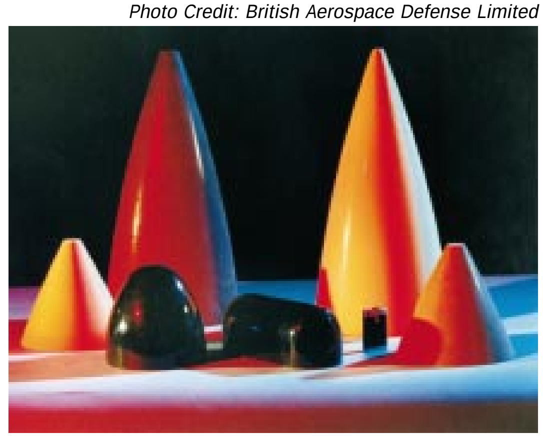


Figure 18-4: Aerodynamic radomes.

Photo Credit: American Technology & Research Industries, Inc.

Figure 18-5:
Radomes similar to those that might be used to protect RV seekers on reentry.

attached. The materials are basically dielectrics in solid laminates or sandwiched foam formed as a single, one-piece molded radome. A thin wall, dielectric space frame (DSF) radome, usually 0.1 cm or less in thickness, may be used for small antennas. A solid laminate-wall DSF radome typically is 0.25 cm in thickness. For two-layer, sandwich DSF radomes, a foam layer is added to the inside of the thin wall radome. The foam thickness is chosen primarily for thermal insulation and resistance to thermal shock loads of 100 cal / sq cm. A composite sandwich, foam-core wall radome is the most expensive design and provides the strength to withstand peak over-pressure loads greater than 50 kPa. A sandwiched foam-core wall is one-quarter wavelength thick for the highest radio frequency signal.

Appearance (as packaged): Radomes are shipped in wooden crates that have contour braces within them to support their thin wall structure. Radomes have closure frames mounted on their aft flanges to maintain structural rigidity in transit and are wrapped in polyethylene bags. Crates can use either formed wooden bulkheads for contour bracing or polyurethane, foamed in place, to support the radome.

ITEM 19
Other Rocket and UAV Systems

Other Rocket and UAV Systems

Complete rocket systems (including ballistic missile systems, space launch vehicles and sounding rockets) and unmanned air vehicles (including cruise missile systems, target drones and reconnaissance drones), not covered in Item 1, capable of a maximum range equal or superior to 300 km.

Produced by companies in

- Australia
- Brazil
- Bulgaria
- China
- Czech Republic
- Egypt
- France
- Germany
- India
- Iran
- Iraq
- Israel
- Italy
- Japan
- Libya
- North Korea
- Pakistan
- Russia
- South Africa
- South Korea
- Spain
- United Kingdom
- United States

Nature and Purpose: This item covers missiles that can reach a range of at least 300 km, but only with payloads less than 500 kg. (Otherwise, the missiles would be controlled under Item 1.) Evaluations of missiles covered under this item must take into account the ability to trade payload for range. This inherent capability may differ significantly from manufacturers specifications or intended operational concept. The determination of an unmanned air vehicle's (UAV) inherent capability may be more complex than that for a ballistic missile. These systems are MTCR controlled because of their suitability for delivering chemical and biological weapons, which are not constrained to substantial minimal weights as nuclear weapons are by critical mass.

Figure 19-1: A jet-powered Category II unmanned air vehicle in front of its transporter erector launcher.

Rockets and UAVs captured under this Item are identical in most respects to, but smaller than, the missiles and UAVs described in Item 1. They operate in the same manner, have similar uses, look almost the same (except possibly for size), and are similarly packaged for shipment. Some representative Category II systems are shown in Figures 19-1, 19-2, and 19-3.

Photo Credit: General Atomics Aeronautical

Figure 19-2: A typical unmanned air vehicle design normally used for reconnaissance missions.

Photo Credit: STN ATLAS Electronik GmbH

Figure 19-3: A propeller-driven UAV launched from a rocket booster.

ITEM 20
Other Complete Subsystems

Other Complete Subsystems

Complete subsystems as follows, usable in systems in Item 19, but not in systems in Item 1, as well as specially designed "production facilities" and "production equipment" therefor:

(a) Individual rocket stages

(b) Solid or liquid propellant rocket engines, having a total impulse capacity of 8.41×10^5 Ns (1.91×10^5 lb-s) or greater, but less than 1.1×10^6 Ns (2.5×10^5 lb-s).

Produced by companies in

- Brazil
- China
- France
- Germany
- India
- Iran
- Iraq
- Israel
- Italy
- Japan
- North Korea
- Pakistan
- Russia
- South Korea
- Spain
- Ukraine
- United Kingdom
- United States

Nature and Purpose: Solid rocket stages and rocket motors used in systems falling under Item 19 are similar in every respect except perhaps size to those described in Item 2. They operate identically to larger motors; they look the same except for their smaller size, and they use the same packaging methods. Some Category I and II solid rocket motors are shown in Figure 20-1. A wooden shipping crate for four Category II solid rocket motors from the side and end views, respectively, is shown in Figures 20-2 and 20-3.

Figure 20-1: On the right, solid rocket motors controlled under Category II. Motors on the left are large enough to be controlled under Item 2, Category I.

Figure 20-2: Side view of a shipping container containing four Category II solid rocket motors.

Figure 20-3: End view of a shipping container containing four Category II solid rocket motors.

Liquid engines meeting the requirements of Item 20 are relatively rare. They tend to be either large propulsion engines or small reaction control engines designed to adjust a spacecraft's trajectory outside the atmosphere. An example of a relatively small propulsion engine for a sounding rocket sustainer is shown schematically in Figure 20-4. Reaction control engines are not really suitable for rocket propulsion because they operate at low levels of thrust. But since they can typically operate for several minutes, they can exceed the impulse allowed under Item 20. An example of such an engine is shown in Figure 20-5, a reaction control engine used in a space launch program. It can generate 440 N of thrust for up to 2,000 seconds. Furthermore, all liquid rocket engines can produce greater impulse simply by increasing the size of the propellant tanks.

Production facilities and equipment here are similar to those discussed in Item 2. These facilities and equipment may be indistinguishable from those for larger items but may be smaller in size.

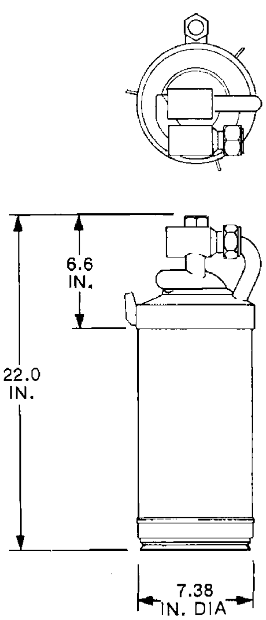


Figure 20-4: A sounding rocket sustainer engine that develops 1.8×10^4 N of thrust for approximately 51 seconds.

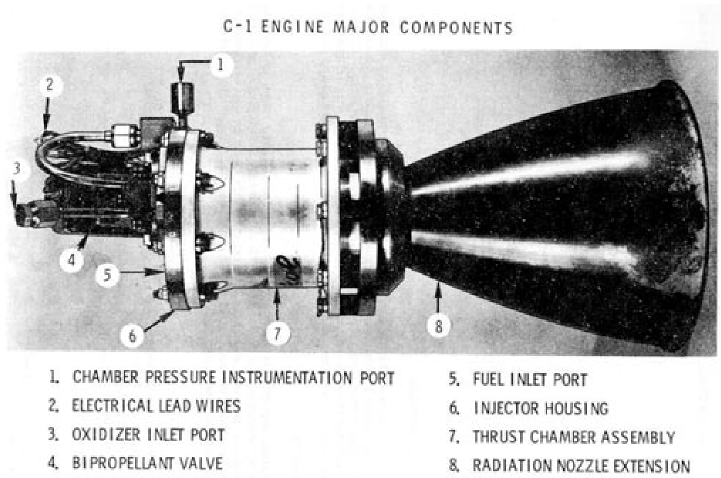


Figure 20-5: A reaction control engine that can generate 100 lbs. of thrust for up to 2,000 seconds.

Overview of Composites

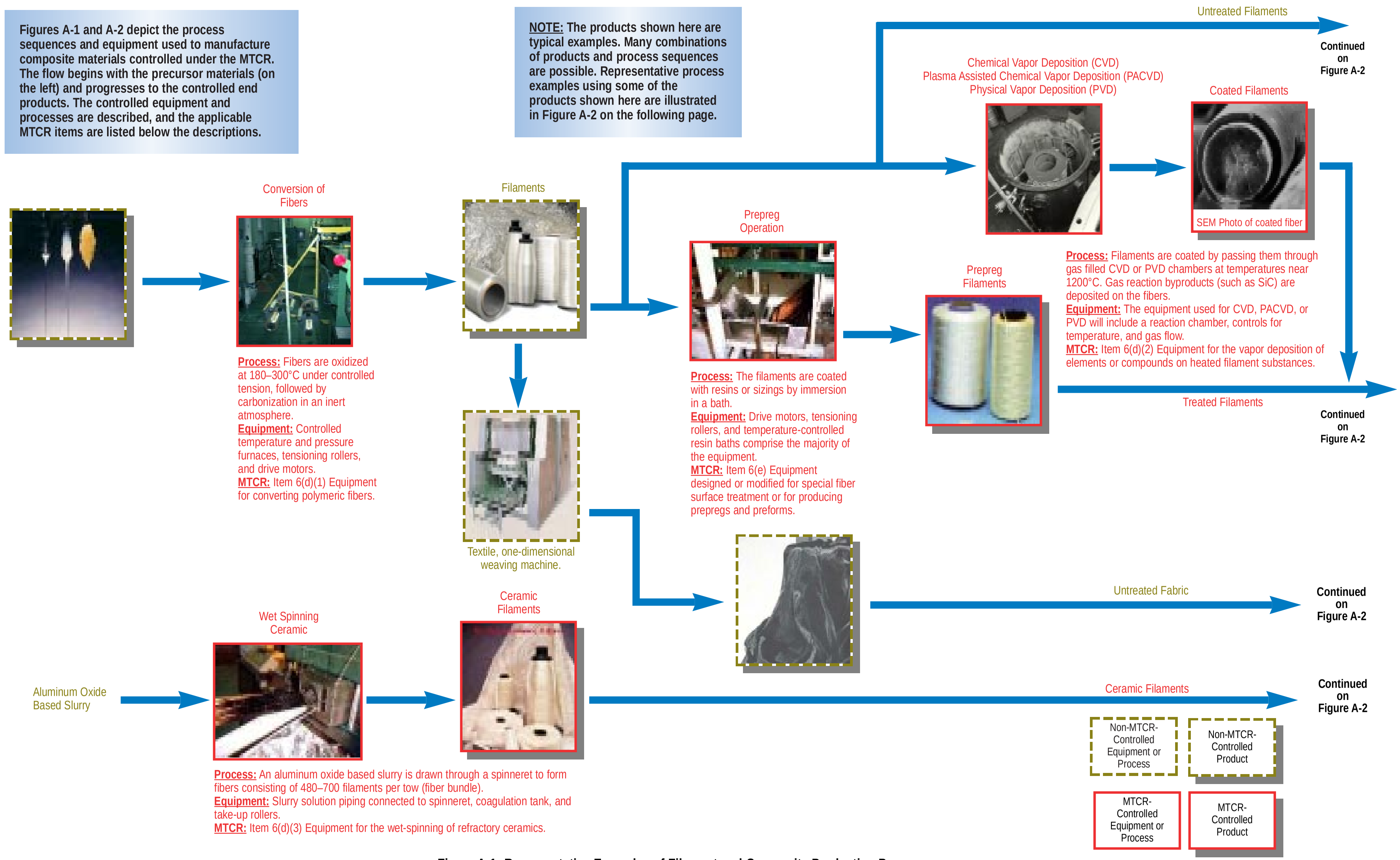


Figure A-1: Representative Examples of Filament and Composite Production Processes

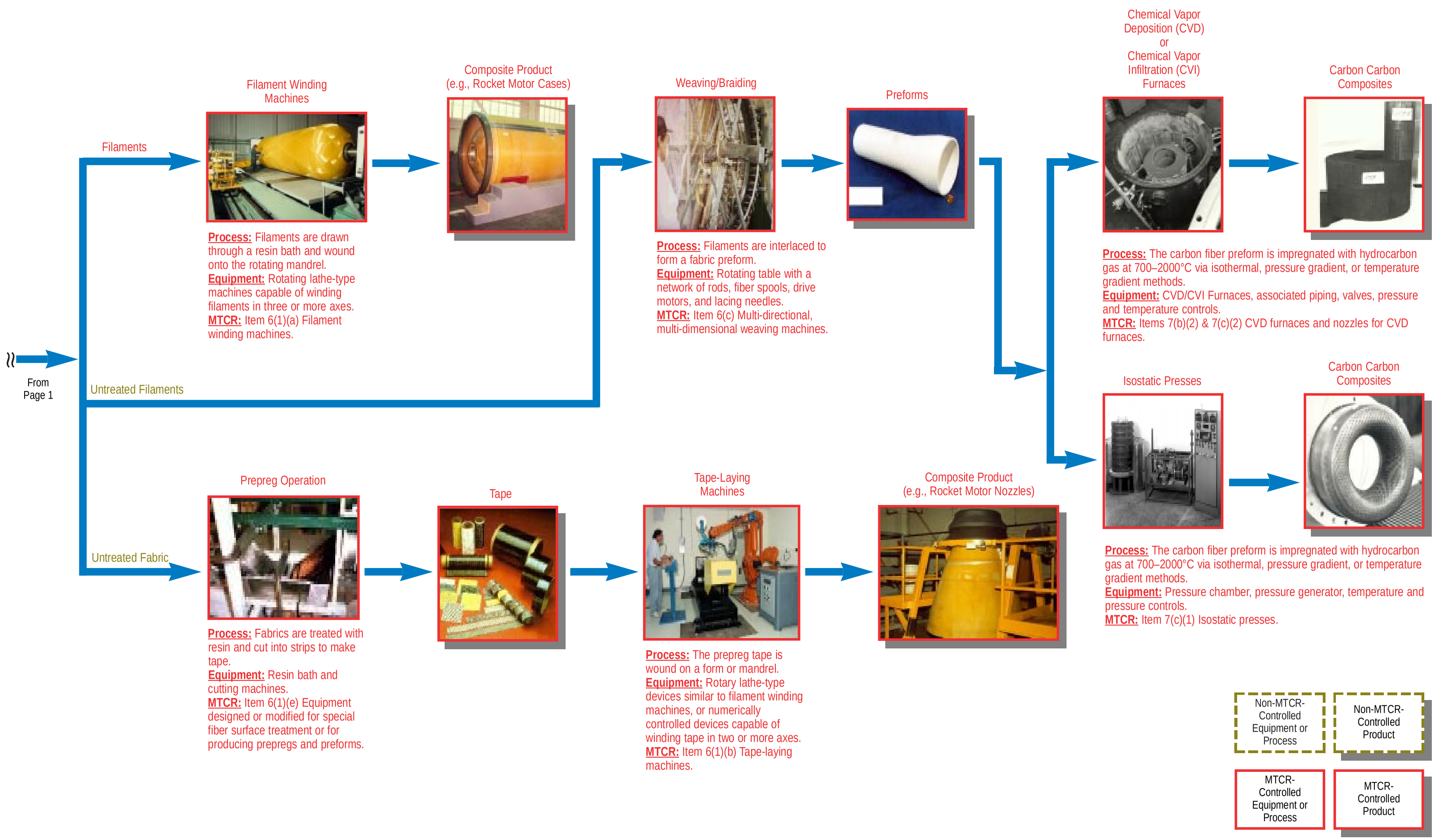


Figure A-2: Representative Examples of Filament and Composite Production Processes

MTCR Guidelines and Annex

APPENDIX

Missile Technology Control Regime (MTCR) Guidelines

Guidelines for Sensitive Missile-Relevant Transfers

1. The purpose of these Guidelines is to limit the risks of proliferation of weapons of mass destruction (i.e. nuclear, chemical and biological weapons), by controlling transfers that could make a contribution to delivery systems (other than manned aircraft) for such weapons. The Guidelines are not designed to impede national space programs or international cooperation in such programs as long as such programs could not contribute to delivery systems for weapons of mass destruction. These Guidelines, including the attached Annex, form the basis for controlling transfers to any destination beyond the Government's jurisdiction or control of all delivery systems (other than manned aircraft) capable of delivering weapons of mass destruction, and of equipment and technology relevant to missiles whose performance in terms of payload and range exceeds stated parameters. Restraint will be exercised in the consideration of all transfers of items contained within the Annex and all such transfers will be considered on a case-by-case basis. The Government will implement the Guidelines in accordance with national legislation.

2. The Annex consists of two categories of items, which term includes equipment and technology. Category I items, all of which are in Annex Items 1 and 2, are those items of greatest sensitivity. If a Category I item is included in a system, that system will also be considered as Category I, except when the incorporated item cannot be separated, removed or duplicated. Particular restraint will be exercised in the consideration of Category I transfers regardless of their purpose, and there will be a strong presumption to deny such transfers. Particular restraint will also be exercised in the consideration of transfers of any items in the Annex, or of any missiles (whether or not in the Annex), if the Government judges, on the basis of all available, persuasive information, evaluated according to factors including those in paragraph 3, that they are intended to be used for the delivery of weapons of mass destruction, and there will be a strong presumption to deny such transfers. Until further notice, the transfer of Category I production facilities will not be authorized. The transfer of other Category I items will be authorized only on rare occasions and where the Government (A)

obtains binding government-to-government undertakings embodying the assurances from the recipient government called for in paragraph 5 of these Guidelines and (B) assumes responsibility for taking all steps necessary to ensure that the item is put only to its stated end-use. It is understood that the decision to transfer remains the sole and sovereign judgment of the Government.

3. In the evaluation of transfer applications for Annex items, the following factors will be taken into account:

    A. Concerns about the proliferation of weapons of mass destruction;

    B. The capabilities and objectives of the missile and space programs of the recipient state;

    C. The significance of the transfer in terms of the potential development of delivery systems (other than manned aircraft) for weapons of mass destruction;

    D. The assessment of the end-use of the transfers, including the relevant assurances of the recipient states referred to in subparagraphs 5.A and 5.B below;

    E. The applicability of relevant multilateral agreements.

4. The transfer of design and production technology directly associated with any items in the Annex will be subject to as great a degree of scrutiny and control as will the equipment itself, to the extent permitted by national legislation.

5. Where the transfer could contribute to a delivery system for weapons of mass destruction, the Government will authorize transfers of items in the Annex only on receipt of appropriate assurances from the government of the recipient state that:

    A. The items will be used only for the purpose stated and that such use will not be modified nor the items modified or replicated without the prior consent of the Government;

    B. Neither the items nor replicas nor derivatives thereof will be retransferred without the consent of the Government.

6. In furtherance of the effective operation of the Guidelines, the Government will, as necessary and appropriate, exchange relevant information with other governments applying the same Guidelines.

7. The adherence of all States to these Guidelines in the interest of international peace and security would be welcome.

APPENDIX

Missile Technology Control Regime (MTCR) Equipment and Technology Annex

1. INTRODUCTION

(a) This Annex consists of two categories of items, which term includes equipment and "technology." Category I items, all of which are in Annex items 1 and 2, are those items of greatest sensitivity. If a Category I item is included in a system, that system will also be considered as Category I, except when the incorporated item cannot be separated, removed or duplicated. Category II items are those items in the Annex not designated Category I.

(b) The transfer of "technology" directly associated with any items in the Annex will be subject to as great a degree of scrutiny and control as will the equipment itself, to the extent permitted by national legislation. The approval of any Annex item for export also authorizes the export to the same end user of the minimum technology required for the installation, operation, maintenance, and repair of the item.

(c) In reviewing the proposed applications for transfers of complete rocket and unmanned air vehicle systems described in Items 1 and 19, and of equipment or technology which is listed in the Technical Annex, for potential use in such systems, the Government will take account of the ability to trade off range and payload.

2. DEFINITIONS

For the purpose of this Annex, the following definitions apply:

(a) "Development" is related to all phases prior to "production" such as:

—design
—design research
—design analysis
—design concepts
—assembly and testing of prototypes
—pilot production schemes

—design data
—process of transforming design data into a product
—configuration design
—integration design
—layouts

(b) A “microcircuit” is defined as a device in which a number of passive and / or active elements are considered as indivisibly associated on or within a continuous structure to perform the function of a circuit.

(c) “Production” means all production phases such as:

—production engineering
—manufacture
—integration
—assembly (mounting)
—inspection
—testing
—quality assurance

(d) “Production equipment” means tooling, templates, jigs, mandrels, moulds, dies, fixtures, alignment mechanisms, test equipment, other machinery and components therefor, limited to those specially designed or modified for “development” or for one or more phases of “production.”

(e) “Production facilities” means equipment and specially designed software therefor integrated into installations for “development” or for one or more phases of “production.”

(f) “Radiation Hardened” means that the component or equipment is designed or rated to withstand radiation levels which meet or exceed a total irradiation dose of 5×10^5 rads (Si).

(g) “Technology” means specific information which is required for the “development,” “production” or “use” of a product. The information may take the form of “technical data” or “technical assistance.”

(1) “Technical assistance” may take the forms such as:

—instruction
—skills
—training
—working knowledge
—consulting services

(2) "Technical data" may take forms such as:

—blueprints
—plans
—diagrams
—models
—formulae
—engineering designs and specifications
—manuals and instructions written or recorded on other media or devices such as:

–disk
–tape
–read-only memories

NOTE:

This definition of technology does not include technology "in the public domain" nor "basic scientific research."

(i) "In the public domain" as it applies to this Annex means technology which has been made available without restrictions upon its further dissemination. (Copyright restrictions do not remove technology from being "in the public domain.")

(ii) "Basic scientific research" means experimental or theoretical work undertaken principally to acquire new knowledge of the fundamental principles of phenomena and observable facts, not primarily directed towards a specific practical aim or objective.

(h) "Use" means:

—operation
—installation (including on-site installation)
—maintenance
—repair
—overhaul
—refurbishing

3. TERMINOLOGY

Where the following terms appear in the text, they are to be understood according to the explanations below:

(a) "Specially Designed" describes equipment, parts, components or software which, as a result of "development," have unique properties that distinguish them for certain predetermined purposes. For example, a piece of equipment that is "specially designed" for use in a missile will only be considered so if it has no other function or use. Similarly, a piece of manufacturing equipment that is "specially designed" to produce a certain type of component will only be considered such if it is not capable of producing other types of components.

(b) "Designed or Modified" describes equipment, parts, components or software which, as a result of "development," or modification, have specified properties that make them fit for a particular application. "Designed or Modified" equipment, parts, components or software can be used for other applications. For example, a titanium coated pump designed for a missile may be used with corrosive fluids other than propellants.

(c) "Usable In" or "Capable Of" describes equipment, parts, components or software which are suitable for a particular purpose. There is no need for the equipment, parts, components or software to have been configured, modified or specified for the particular purpose. For example, any military specification memory circuit would be "capable of" operation in a guidance system.

ITEM 1—CATEGORY I

Complete rocket systems (including ballistic missile systems, space launch vehicles and sounding rockets) and unmanned air vehicle systems (including cruise missile systems, target drones and reconnaissance drones) capable of delivering at least a 500 kg payload to a range of at least 300 km as well as the specially designed "production facilities" for these systems.

ITEM 2—CATEGORY I

Complete subsystems usable in the systems in Item 1, as follows, as well as the specially designed "production facilities" and "production equipment" therefor:

(a) Individual rocket stages;

(b) Reentry vehicles, and equipment designed or modified therefor, as follows, except as provided in Note (1) below for those designed for non-weapon payloads:

(1) Heat shields and components thereof fabricated of ceramic or ablative materials;

(2) Heat sinks and components thereof fabricated of lightweight, high heat capacity materials;

(3) Electronic equipment specially designed for reentry vehicles;

(c) Solid or liquid propellant rocket engines, having a total impulse capacity of 1.1×10^6 N-sec (2.5×10^5 lb-sec) or greater;

(d) "Guidance sets" capable of achieving system accuracy of 3.33 percent or less of the range (e.g. a CEP of 10 km or less at a range of 300 km), except as provided in Note (1) below for those designed for missiles with a range under 300 km or manned aircraft;

(e) Thrust vector control sub-systems, except as provided in Note (1) below for those designed for rocket systems that do not exceed the range / payload capability of Item 1;

(f) Weapon or warhead safing, arming, fusing, and firing mechanisms, except as provided in Note (1) below for those designed for systems other than those in Item 1.

Notes to Item 2:

(1) The exceptions in (b), (d), (e) and (f) above may be treated as Category II if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above.

(2) CEP (circle of equal probability) is a measure of accuracy; and defined as the radius of the circle centered at the target, at a specific range, in which 50 percent of the payloads impact.

(3) A "guidance set" integrates the process of measuring and computing a vehicle's position and velocity (i.e. navigation) with that of computing and sending commands to the vehicle's flight control systems to correct the trajectory.

(4) Examples of methods of achieving thrust vector control covered by (e) include:

(a) Flexible nozzle;

(b) Fluid or secondary gas injection;

(c) Movable engine or nozzle;

(d) Deflection of exhaust gas stream (jet vanes or probes); or

(e) Use of thrust tabs.

(5) Liquid propellant apogee engines specified in Item 2(c), designed or modified for satellite applications, may be treated as Category II, if the subsystem is exported subject to end use statements and quantity limits appropriate for the excepted end use stated above, when having all of the following parameters:

(a) Nozzle throat diameter of 20 mm or less, and

(b) Combustion chamber pressure of 15 bar or less.

ITEM 3—CATEGORY II

Propulsion components and equipment usable in the systems in Item 1, as follows, as well as the specially designed "production facilities" and "production equipment" therefor, and flow-forming machines specified in Note (1):

(a) Lightweight turbojet and turbofan engines (including turbo-compound engines) that are small and fuel efficient;

(b) Ramjet / scramjet / pulsejet / combined cycle engines, including devices to regulate combustion, and specially designed components therefor;

(c) Rocket motor cases, "interior lining," "insulation" and nozzles therefor;

(d) Staging mechanisms, separation mechanisms, and interstages therefor;

(e) Liquid and slurry propellant (including oxidizers) control systems, and specially designed components therefor, designed or modified to operate in vibration environments of more than 10 g RMS between 20 Hz and 2,000 Hz.

(f) Hybrid rocket motors and specially designed components therefor.

Notes to Item 3:

(1) Flow-forming machines, and specially designed components and specially designed software therefor, which:

(a) According to the manufacturer's technical specification, can be equipped with numerical control units or a computer control, even when not equipped with such units at delivery, and

(b) With more than two axes which can be coordinated simultaneously for contouring control.

Technical Note:

Machines combining the functions of spin-forming and flow-forming are for the purpose of this item regarded as flow-forming machines.

This item does not include machines that are not usable in the production of propulsion components and equipment (e.g. motor cases) for systems in Item 1.

(2) (a) The only engines covered in subitem (a) above, are the following:

(1) Engines having both of the following characteristics:

(a) Maximum thrust value greater than 1000 N (achieved un-installed) excluding civil certified engines with a maximum thrust value greater than 8,890 N (achieved un-installed), and

(b) Specific fuel consumption of 0.13kg / N / hr or less (at sea level static and standard conditions); or

(2) Engines designed or modified for systems in Item 1, regardless of thrust or specific fuel consumption.

(b) Item 3 (a) engines may be exported as part of a manned aircraft or in quantities appropriate for replacement parts for manned aircraft.

(3) In Item 3(c), “interior lining” suited for the bond interface between the solid propellant and the case or insulating liner is usually a liquid polymer based dispersion of refractory or insulating materials, e.g., carbon filled HTPB or other polymer with added curing agents to be sprayed or screeded over a case interior.

(4) In Item 3(c), “insulation” intended to be applied to the components of a rocket motor, i.e., the case, nozzle inlets, and case closures, includes cured or semi-cured compounded rubber sheet stock containing an insulating or refractory material. It may also be incorporated as stress relief boots or flaps.

(5) The only servo valves and pumps covered in (e) above, are the following:

(a) Servo valves designed for flow rates of 24 liters per minute or greater, at an absolute pressure of 7,000 kPa (1,000 psi) or greater, that have an actuator response time of less than 100 msec.

(b) Pumps, for liquid propellants, with shaft speeds equal to or greater than 8,000 RPM or with discharge pressures equal to or greater than 7,000 kPa (1,000 psi).

(6) Item 3(e) systems and components may be exported as part of a satellite.

ITEM 4—CATEGORY II

Propellants and constituent chemicals for propellants as follows:

(a) Composite Propellants

(1) Composite and composite modified double base propellants;

(b) Fuel Substances

(1) Hydrazine with concentration of more than 70 percent and its derivatives including monomethylhydrazine (MMH);

(2) Unsymmetric dimethylhydrazine (UDMH);

(3) Spherical aluminum powder with particles of uniform diameter of less than 500×10^{-6} m (500 micrometers) and an aluminum content of 97 percent by weight or greater;

(4) Zirconium, beryllium, boron, magnesium and alloys of these in particle size less than 500×10^{-6} m (500 micrometers), whether spherical, atomized, spheroidal, flaked or ground, consisting of 97 percent by weight or more of any of the above mentioned metals;

(5) High energy density materials such as boron slurry, having an energy density of 40×10^{6} J / kg or greater.

(c) Oxidizers / Fuels

(1) Perchlorates, chlorates or chromates mixed with powdered metals or other high energy fuel components.

(d) Oxidizer Substances

(1) Liquid

(a) Dinitrogen trioxide;

(b) Nitrogen dioxide / dinitrogen tetroxide;

(c) Dinitrogen pentoxide;

(d) Inhibited Red Fuming Nitric Acid (IRFNA);

(e) Compounds composed of flourine and one or more of other halogens, oxygen or nitrogen.

(2) Solid

(a) Ammonium perchlorate;

(b) Ammonium Dinitramide (ADN);

(c) Nitro-amines (cyclotetramethylene-tetranitramine (HMX), cyclotetrimethylene-trinitramine (RDX)).

(e) Polymeric Substances

(1) Carboxyl-terminated polybutadiene (CTPB);

(2) Hydroxyl-terminated polybutadiene (HTPB);

(3) Glycidyl azide polymer (GAP);

(4) Polybutadiene-acrylic acid (PBAA);

(5) Polybutadiene-acrylic acid-acrylonitrile (PBAN).

(f) Other Propellant Additives and Agents

(1) Bonding Agents

(a) Tris (1-(2-methyl)) aziridinyl phosphine oxide (MAPO);

(b) Trimesoyl-1-(2-ethyl) aziridene (HX-868, BITA);

(c) "Tepanol" (HX-878), reaction product of tetraethylene-pentamine, acrylonitrile and glycidol;

(d) "Tepan" (HX-879), reaction product of tetraethylene-pentamine and acrylonitrile;

(e) Polyfunctional aziridene amides with isophthalic, trimesic, isocyanuric, or trimethyladipic backbone and also having a 2-methyl or 2-ethyl aziridene group (HX-752, HX-874 and HX-877).

(2) Curing Agents and Catalysts

(a) Triphenyl Bismuth (TPB);

(3) Burning Rate Modifiers

(a) Catocene;

(b) N-butyl-ferrocene;

(c) Butacene;

(d) Other ferrocene derivatives;

(e) Carboranes, decarboranes, pentaboranes and derivatives thereof;

(4) Nitrate Esters and Nitrated Plasticizers

(a) Triethylene glycol dinitrate (TEGDN);

(b) Trimethylolethane trinitrate (TMETN);

(c) 1,2,4-Butanetriol trinitrate (BTTN);

(d) Diethylene glycol dinitrate (DEGDN);

(5) Stabilizers, as follows

(a) 2-Nitrodiphenylamine;

(b) N-methyl-p-nitroaniline

ITEM 5—CATEGORY II

Production technology, or “production equipment” (including its specially designed components) for:

(a) Production, handling or acceptance testing of liquid propellants or propellant constituents described in Item 4.

(b) Production, handling, mixing, curing, casting, pressing, machining, extruding or acceptance testing of solid propellants or propellant constituents described in Item 4 other than those described in 5(c).

(c) Equipment as follows:

(1) Batch mixers with the provision for mixing under vacuum in the range of zero to 13.326 kPa and with temperature control capability of the mixing chamber and having;

(i) A total volumetric capacity of 110 litres or more; and

(ii) At least one mixing / kneading shaft mounted off centre;

(2) Continuous mixers with provision for mixing under vacuum in the range of zero to 13.326 kPa and with temperature control capability of the mixing chamber and having;

(i) Two or more mixing / kneading shafts; and

(ii) Capability to open the mixing chamber;

(3) Fluid energy mills usable for grinding or milling substances specified in Item 4;

(4) Metal powder "production equipment" usable for the "production," in a controlled environment, of spherical or atomised materials specified in 4(b) (3) or 4(b) (4) including:

(i) Plasma generators (high frequency arc-jet) usable for obtaining sputtered or spherical metallic powders with organization of the process in an argon-water environment;

(ii) Electroburst equipment usable for obtaining sputtered or spherical metallic powders with organization of the process in an argon-water environment;

(iii) Equipment usable for the "production" of spherical aluminum powders by powdering a melt in an inert medium (e.g., nitrogen).

Notes to Item 5:

(1) The only batch mixers, continuous mixers usable for solid propellants or propellants constituents specified in Item 4, and fluid energy mills specified in Item 5, are those specified in 5(c).

(2) Forms of metal powder "production equipment" not specified in 5(c) (4) are to be evaluated in accordance with 5(b).

ITEM 6—CATEGORY II

Equipment, "technical-data" and procedures for the production of structural composites usable in the systems in Item 1 as follows and specially designed components, and accessories and specially designed software therefor:

(a) Filament winding machines of which the motions for positioning, wrapping and winding fibres can be coordinated and programmed in three or more axes, designed to fabricate composite structures or laminates from fibrous or filamentary materials, and coordinating and programming controls;

(b) Tape-laying machines of which the motions for positioning and laying tape and sheets can be coordinated and programmed in two or more axes, designed for the manufacture of composite airframes and missile structures;

(c) Multi-directional, multi-dimensional weaving machines or interlacing machines, including adapters and modification kits for weaving, interlacing or braiding fibres to manufacture composite structures, except textile machinery not modified for the above end uses;

(d) Equipment designed or modified for the production of fibrous or filamentary materials as follows:

  (1) Equipment for converting polymeric fibres (such as polyacrylonitrile, rayon or polycarbosilane) including special provisions to strain the fibre during heating;

  (2) Equipment for the vapor deposition of elements or compounds on heated filament substrates; and

  (3) Equipment for the wet-spinning of refractory ceramics (such as aluminum oxide);

(e) Equipment designed or modified for special fibre surface treatment or for producing prepregs and preforms.

(f) "Technical data" (including processing conditions) and procedures for the regulation of temperature, pressures or atmosphere in autoclaves or hydroclaves when used for the production of composites or partially processed composites.

<u>Notes to Item 6:</u>

(1) Examples of components and accessories for the machines covered by this entry are: moulds, mandrels, dies, fixtures and tooling for the preform pressing, curing, casting, sintering or bonding of composite structures, laminates and manufactures thereof.

(2) Equipment covered by subitem (e) includes but is not limited to rollers, tension stretchers, coating equipment, cutting equipment and clicker dies.

ITEM 7—CATEGORY II

Pyrolytic deposition and densification equipment and "technology" as follows:

(a) "Technology" for producing pyrolytically derived materials formed on a mould, mandrel or other substrate from precursor gases which decompose in the 1,300 degrees C to 2,900 degrees C temperature range at pressures of 130 Pa (1 mm Hg) to 20 kPa (150 mm Hg) including technology for the composition of precursor gases, flow-rates and process control schedules and parameters;

(b) Specially designed nozzles for the above processes;

(c) Equipment and process controls, and specially designed software therefor, designed or modified for densification and pyrolysis of structural composite rocket nozzles and reentry vehicle nose tips.

Notes to Item 7:

(1) Equipment included under (c) above are isostatic presses having all of the following characteristics:

(a) Maximum working pressure of 69 MPa (10,000 psi) or greater;

(b) Designed to achieve and maintain a controlled thermal environment of 600 degrees C or greater; and

(c) Possessing a chamber cavity with an inside diameter of 254 mm (10 inches) or greater.

(2) Equipment included under (c) above are chemical vapour deposition furnaces designed or modified for the densification of carbon-carbon composites.

ITEM 8—CATEGORY II

Structural materials usable in the system in Item 1, as follows:

(a) Composite structures, laminates, and manufactures thereof, specially designed for use in the systems in Item 1 and the subsystems in Item 2, and resin impregnated fibre prepregs and metal coated fibre preforms therefor, made either with organic matrix or metal matrix utilizing fibrous or filamentary reinforcements having a specific tensile strength greater than 7.62×10^4 m (3×10^6 inches) and a specific modulus greater than 3.18×10^6 m (1.25×10^8 inches);

(b) Resaturated pyrolyzed (i.e., carbon-carbon) materials designed for rocket systems;

(c) Fine grain recrystallized bulk graphites (with a bulk density of at least 1.72 g/cc measured at 15 degrees C and having a particle size of 100×10^{-6} m (100 microns) or less), pyrolytic, or fibrous reinforced graphites usable for rocket nozzles and reentry vehicle nose tips;

(d) Ceramic composite materials (dielectric constant less than 6 at frequencies from 100 Hz to 10,000 MHz) for use in missile radomes and bulk machinable silicon-carbide reinforced unfired ceramic usable for nose tips;

(e) Tungsten, molybdenum and alloys of these metals in the form of uniform spherical or atomized particles of 500 micrometer diameter or less with a purity of 97 percent or higher for fabrication of rocket motor components; i.e. heat shields, nozzle substrates, nozzle throats and thrust vector control surfaces;

(f) Maraging steels (steels generally characterized by high nickel, very low carbon content and the use of substitutional elements or precipitates to produce age-hardening) having an Ultimate Tensile Strength of 1.5×10^{9} Pa or greater, measured at 20 degrees C.

(g) Titanium-stabilized duplex stainless steel (Ti-DSS) having:

(1) All the following characteristics:

(a) Containing 17.0 to 23.0 weight percent chromium and 4.5 to 7.0 weight percent nickel, and

(b) A ferritic-austenitic microstructure (also referred to as a two-phase microstructure) of which at least 10 percent is austenite by volume (according to ASTM E-1181-87 or national equivalents), and

(2) Any of the following forms:

(a) Ingots or bars having a size of 100 mm or more in each dimension,

(b) Sheets having a width of 600 mm or more and a thickness of 3 mm or less, or

(c) Tubes having an outer diameter of 600 mm or more and a wall thickness of 3 mm or less.

Notes to Item 8:

(1) Maraging steels are only covered by 8(f) above for the purpose of this Annex in the form of sheet, plate or tubing with a wall or plate thickness equal to or less than 5.0 mm (0.2 inch).

(2) The only resin impregnated fibre prepregs specified in (a) above are those using resins with a glass transition temperature (Tg), after cure, exceeding 145 degrees C as determined by ASTM D4065 or national equivalents.

ITEM 9—CATEGORY II

Instrumentation, navigation and direction finding equipment and systems, and associated production and test equipment as follows; and specially designed components and software therefor:

(a) Integrated flight instrument systems, which include gyrostabilizers or automatic pilots and integration software therefor, designed or modified for use in the systems in Item 1;

(b) Gyro-astro compasses and other devices which derive position or orientation by means of automatically tracking celestial bodies or satellites;

(c) Accelerometers with a threshold of 0.05 g or less, or a linearity error within 0.25 percent of full scale output, or both, which are designed for use in inertial navigation systems or in guidance systems of all types;

(d) All types of gyros usable in the systems in Item 1, with a rated drift rate stability of less than 0.5 degree (1 sigma or rms) per hour in a 1 g environment;

(e) Continuous output accelerometers or gyros of any type, specified to function at acceleration levels greater than 100 g;

(f) Inertial or other equipment using accelerometers described by subitems (c) or (e) above or gyros described by subitems (d) or (e) above, and systems incorporating such equipment, and specially designed integration software therefor;

(g) Production equipment and other test, calibration, and alignment equipment, other than that described in 9(h), designed or modified to be used with equipment specified in a–f above, including the following:

(1) For laser gyro equipment, the following equipment used to characterize mirrors, having the threshold accuracy shown or better:

(i) Scatterometer (10 ppm);

(ii) Reflectometer (50 ppm);

(iii) Profilometer (5 Angstroms).

(2) For other inertial equipment:

(i) Inertial Measurement Unit (IMU Module) Tester;

(ii) IMU Platform Tester;

(iii) IMU Stable Element Handling Fixture;

(iv) IMU Platform Balance fixture;

(v) Gyro Tuning Test Station;

(vi) Gyro Dynamic Balance Station;

(vii) Gyro Run-In / Motor Test Station;

(viii) Gyro Evacuation and Filling Test Station;

(ix) Centrifuge Fixture for Gyro Bearings;

(x) Accelerometer Axis Align Station;

(xi) Accelerometer Test Station.

(h) Equipment as follows:

(1) Balancing machines having all the following characteristics:

(i) Not capable of balancing rotors / assemblies having a mass greater than 3 kg;

(ii) Capable of balancing rotors / assemblies at speeds greater than 12,500 rpm;

(iii) Capable of correcting unbalance in two planes or more; and

(iv) Capable of balancing to a residual specific unbalance of 0.2 gram mm per kg of rotor mass;

(2) Indicator heads (sometimes known as balancing instrumentation) designed or modified for use with machines specified in 9 (h) 1;

(3) Motion simulators / rate tables (equipment capable of simulating motion) having all the following characteristics:

(i) Two axis or more;

(ii) Slip rings capable of transmitting electrical power and / or signal information; and

(iii) Having any of the following characteristics:

(a) For any single axis:

(1) Capable of rates of 400 degrees / sec or more; or 30 degrees / sec or less; and

(2) A rate resolution equal to or less than 6 degrees / sec and an accuracy equal to or less than 0.6 degrees / sec;

(b) Having a worst-case rate stability equal to or better (less) than plus or minus 0.05 percent averaged over 10 degrees or more; or

(c) A position accuracy equal or better than 5 arc second;

(4) Positioning tables (equipment capable of precise rotary positioning in any axes) having the following characteristics:

(i) Two axes or more; and

(ii) A positioning accuracy equal to or better than 5 arc second;

(5) Centrifuges capable of imparting accelerations above 100 g and having slip rings capable of transmitting electrical power and signal information.

<u>Notes to Item 9:</u>

(1) Items (a) through (f) may be exported as part of a manned aircraft, satellite, land vehicle or marine vessel or in quantities appropriate for replacement parts for such applications.

(2) In subitem (d):

(a) Drift rate is defined as the time rate of output deviation from the desired output. It consists of random and systematic components and is expressed as an equivalent angular displacement per unit time with respect to inertial space.

(b) Stability is defined as standard deviation (1 sigma) of the variation of a particular parameter from its calibrated value measured under stable temperature conditions. This can be expressed as a function of time.

(3) Accelerometers which are specially designed and developed as MWD (Measurement While Drilling) Sensors for use in downhole well service operations are not specified in Item 9 (c).

(4) The only balancing machines, indicator heads, motion simulators, rate tables, positioning tables, and centrifuges specified in Item 9 are those specified in 9(h).

(5) 9(h) (1) does not control balancing machines designed or modified for dental or other medical equipment.

(6) 9(h) (3) and (4) do not control rotary tables designed or modified for machine tools or for medical equipment.

(7) Rate tables not controlled by 9(h) (3) and providing the characteristics of a positioning table are to be evaluated according to 9(h) (4).

(8) Equipment that has the characteristics specified in 9(h) (4) which also meets the characteristics of 9(h) (3) will be treated as equipment specified in 9 (h) (3).

ITEM 10—CATEGORY II

Flight control systems and "technology" as follows; designed or modified for the systems in Item 1 as well as the specially designed test, calibration, and alignment equipment therefor:

(a) Hydraulic, mechanical, electro-optical, or electro-mechanical flight control systems (including fly-by-wire systems);

(b) Attitude control equipment;

(c) Design technology for integration of air vehicle fuselage, propulsion system and lifting control surfaces to optimize aerodynamic performance throughout the flight regime on an unmanned air vehicle;

(d) Design technology for integration of the flight control, guidance, and propulsion data into a flight management system for optimization of rocket system trajectory.

Note to Item 10:

Items (a) and (b) may be exported as part of a manned aircraft or satellite or in quantities appropriate for replacement parts for manned aircraft.

ITEM 11—CATEGORY II

Avionics equipment, “technology” and components as follows; designed or modified for use in the systems in Item 1, and specially designed software therefor:

(a) Radar and laser radar systems, including altimeters;

(b) Passive sensors for determining bearings to specific electromagnetic sources (direction finding equipment) or terrain characteristics;

(c) Global Positioning System (GPS) or similar satellite receivers;

(1) Capable of providing navigation information under the following operational conditions;

(i) At speeds in excess of 515 m / sec (1,000 nautical miles / hour); and

(ii) At altitudes in excess of 18 km (60,000 feet); or

(2) Designed or modified for use with unmanned air vehicles covered by Item 1.

(d) Electronic assemblies and components specially designed for military use and operation at temperatures in excess of 125 degrees C.

(e) Design technology for protection of avionics and electrical subsystems against electromagnetic pulse (EMP) and electromagnetic interference (EMI) hazards from external sources, as follows:

(1) Design technology for shielding systems;

(2) Design technology for the configuration of hardened electrical circuits and subsystems;

(3) Determination of hardening criteria for the above.

Notes to Item 11:

(1) Item 11 equipment may be exported as part of a manned aircraft or satellite or in quantities appropriate for replacement parts for manned aircraft.

(2) Examples of equipment included in this Item:

(a) Terrain contour mapping equipment;

(b) Scene mapping and correlation (both digital and analogue) equipment;

(c) Doppler navigation radar equipment;

(d) Passive interferometer equipment;

(e) Imaging sensor equipment (both active and passive);

(3) In subitem (a), laser radar systems embody specialized transmission, scanning, receiving and signal processing techniques for utilization of lasers for echo ranging, direction finding and discrimination of targets by location, radial speed and body reflection characteristics.

ITEM 12—CATEGORY II

Launch support equipment, facilities and software for the systems in Item 1, as follows:

(a) Apparatus and devices designed or modified for the handling, control, activation and launching of the systems in Item 1;

(b) Vehicles designed or modified for the transport, handling, control, activation, and launching of the systems in Item 1;

(c) Gravity meters (gravimeters), gravity gradiometers, and specially designed components therefor, designed or modified for airborne or marine use, and having a static or operational accuracy of 7×10^{-6} m / sec^2 (0.7 milligal) or better, with a time to steady-state registration of two minutes or less;

(d) Telemetering and telecontrol equipment usable for unmanned air vehicles or rocket systems;

(e) Precision tracking systems:

(1) Tracking systems which use a code translator installed on the rocket or unmanned air vehicle in conjunction with either surface or airborne references or navigation satellite systems to provide real-time measurements of in-flight position and velocity;

(2) Range instrumentation radars including associated optical / infrared trackers and the specially designed software therefor with all of the following capabilities:

(i) an angular resolution better than 3 milli-radians (0.5 mils);

(ii) a range of 30 km or greater with a range resolution better than 10 metres RMS;

(iii) a velocity resolution better than 3 metres per second.

(3) Software which processes post-flight, recorded data, enabling determination of vehicle position throughout its flight path.

ITEM 13—CATEGORY II

Analogue computers, digital computers, or digital differential analyzers designed or modified for use in the systems in Item 1, having either of the following characteristics:

(a) Rated for continuous operation at temperatures from below minus 45 degrees C to above plus 55 degrees C; or

(b) Designed as ruggedized or “radiation hardened.”

Note to Item 13:

Item 13 equipment may be exported as part of a manned aircraft or satellite or in quantities appropriate for replacement parts for manned aircraft.

ITEM 14—CATEGORY II

Analogue-to-digital converters, usable in the systems in Item 1, having either of the following characteristics:

(a) Designed to meet military specifications for ruggedized equipment; or,

(b) Designed or modified for military use; and being one of the following types:

(1) Analogue-to-digital converter “microcircuits,” which are “radiation-hardened” or have all of the following characteristics:

(i) Having a quantisation corresponding to 8 bits or more when coded in the binary system;

(ii) Rated for operation in the temperature range from below minus 54 degrees C to above plus 125 degrees C; and

(iii) Hermetically sealed.

(2) Electrical input type analogue-to-digital converter printed circuit boards or modules, with all of the following characteristics:

(i) Having a quantisation corresponding to 8 bits or more when coded in the binary system;

(ii) Rated for operation in the temperature range from below minus 45 degrees C to above plus 55 degrees C; and

(iii) Incorporating "microcircuits" listed in (1), above.

ITEM 15—CATEGORY II

Test facilities and test equipment usable for the systems in Item 1 and Item 2 as follows; and specially designed software therefor:

(a) Vibration test systems and components therefor, the following:

(1) Vibration test systems employing feedback or closed loop techniques and incorporating a digital controller, capable of vibrating a system at 10g RMS or more over the entire range 20 Hz to 2000 Hz and imparting forces of 50 kN (11,250 lb.), measured "bare table," or greater;

(2) Digital controllers, combined with specially designed vibration test software, with a real-time bandwidth greater than 5 kHz and designed for use with vibration test systems in (1), above;

(3) Vibration thrusters (shaker units), with or without associated amplifiers, capable of imparting a force of 50 kN (11,250 lb.), measured "bare table," or greater, and usable in vibration test systems in (1), above;

(4) Test piece support structures and electronic units designed to combine multiple shaker units into a complete shaker system capable of providing an effective combined force of 50 kN, measured "bare table," or greater, and usable in vibration test systems in (1) above.

(b) Wind-tunnels for speeds of Mach 0.9 or more;

(c) Test benches/stands which have the capacity to handle solid or liquid propellant rockets or rocket motors of more than 90 kN

(20,000 lbs) of thrust, or which are capable of simultaneously measuring the three axial thrust components;

(d) Environmental chambers and anechoic chambers capable of simulating the following flight conditions:

(1) Altitude of 15,000 meters or greater; or

(2) Temperature of at least minus 50 degrees C to plus 125 degrees C; and either

(3) Vibration environments of 10 g RMS or greater between 20 Hz and 2,000 Hz imparting forces of 5 kN or greater, for environmental chambers; or

(4) Acoustic environments at an overall sound pressure level of 140 dB or greater (referenced to 2×10^{-5} N per square metre) or with a rated power output of 4 kiloWatts or greater, for anechoic chambers.

(e) Accelerators capable of delivering electromagnetic radiation produced by "bremsstrahlung" from accelerated electrons of 2 MeV or greater and systems containing those accelerators.

Note: The above equipment does not include that specially designed for medical purposes.

Note to Item 15(a):

The term "digital control" refers to equipment, the functions of which are, partly or entirely, automatically controlled by stored and digitally coded electrical signals.

ITEM 16—CATEGORY II

Specially designed software, or specially designed software with related specially designed hybrid (combined analogue / digital) computers, for modelling, simulation, or design integration of the systems in Item 1 and Item 2.

Note to Item 16:

The modeling includes in particular the aerodynamic and thermodynamic analysis of the systems.

ITEM 17—CATEGORY II

Materials, devices, and specially designed software for reduced observables such as radar reflectivity, ultraviolet / infrared signatures and acoustic signatures (i.e., stealth technology), for applications usable for the systems in Item 1 or Item 2, for example:

(a) Structural materials and coatings specially designed for reduced radar reflectivity;

(b) Coatings, including paints, specially designed for reduced or tailored reflectivity or emissivity in the microwave, infrared or ultraviolet spectra, except when specially used for thermal control of satellites;

(c) Specially designed software or databases for analysis of signature reduction;

(d) Specially designed radar cross section measurement systems.

ITEM 18—CATEGORY II

Devices for use in protecting rocket systems and unmanned air vehicles against nuclear effects (e.g. Electromagnetic Pulse (EMP), X-rays, combined blast and thermal effects), and usable for the systems in Item 1, as follows:

(a) “Radiation Hardened” “microcircuits” and detectors.

(b) Radomes designed to withstand a combined thermal shock greater than 100 cal / sq cm accompanied by a peak over pressure of greater than 50 kPa (7 pounds per square inch).

Note to Item 18 (a):

A detector is defined as a mechanical, electrical, optical or chemical device that automatically identifies and records, or registers a stimulus such as an environmental change in pressure or temperature, an electrical or electromagnetic signal or radiation from a radioactive material.

ITEM 19—CATEGORY II

Complete rocket systems (including ballistic missile systems, space launch vehicles and sounding rockets) and unmanned air vehicles (including cruise missile systems, target drones and reconnaissance drones), not covered in Item 1, capable of a maximum range equal or superior to 300 km.

ITEM 20—CATEGORY II

Complete subsystems as follows, usable in systems in Item 19, but not in systems in Item 1, as well as specially designed “production facilities” and “production equipment” therefor:

(a) Individual rocket stages

(b) Solid or liquid propellant rocket engines, having a total impulse capacity of 8.41×10^5 Ns (1.91×10^5 lb-s) or greater, but less than 1.1×10^6 Ns (2.5×10^5 lb-s).

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