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.

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.

Photo Credit: Thiokol Corp.

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

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.

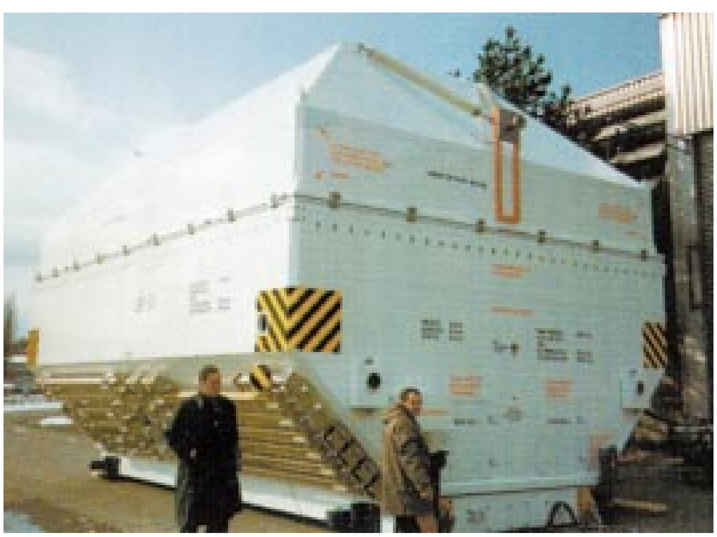

Photo Credit: Zeppelin Technologie GmbH

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

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.

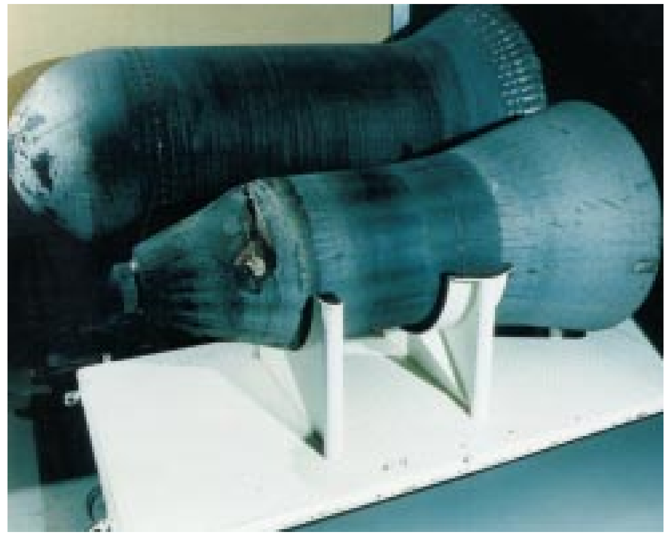

Photo Credit: National Atomic Museum

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

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

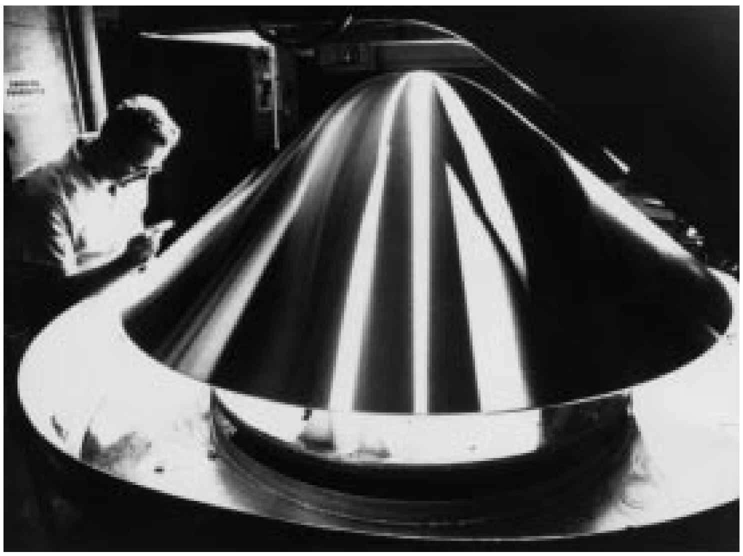

Figure 2-10: Beryllium-copper heat sink.

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.

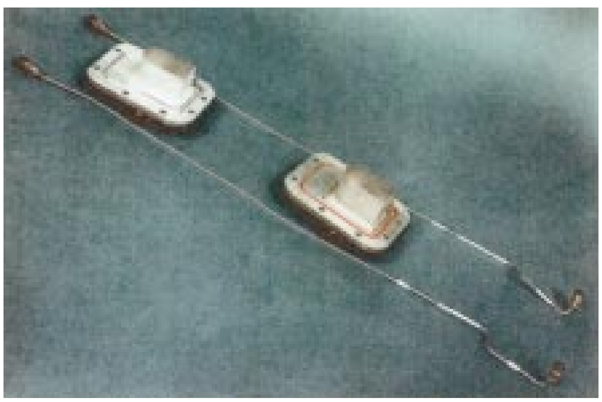
Figure 2-13: An RV radar antenna set.

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.

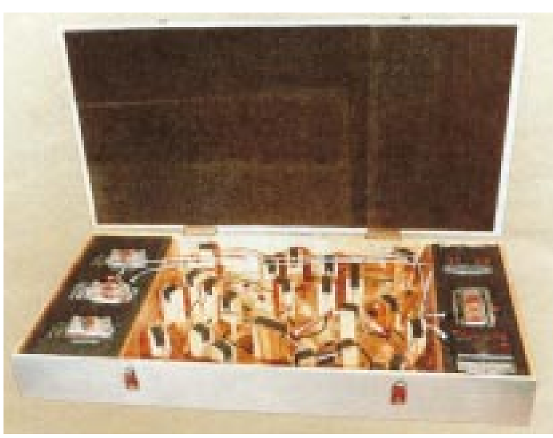
Figure 2-14: An RV radar antenna set packaged for shipment.

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

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

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.

Produced by companies in

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

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.

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.

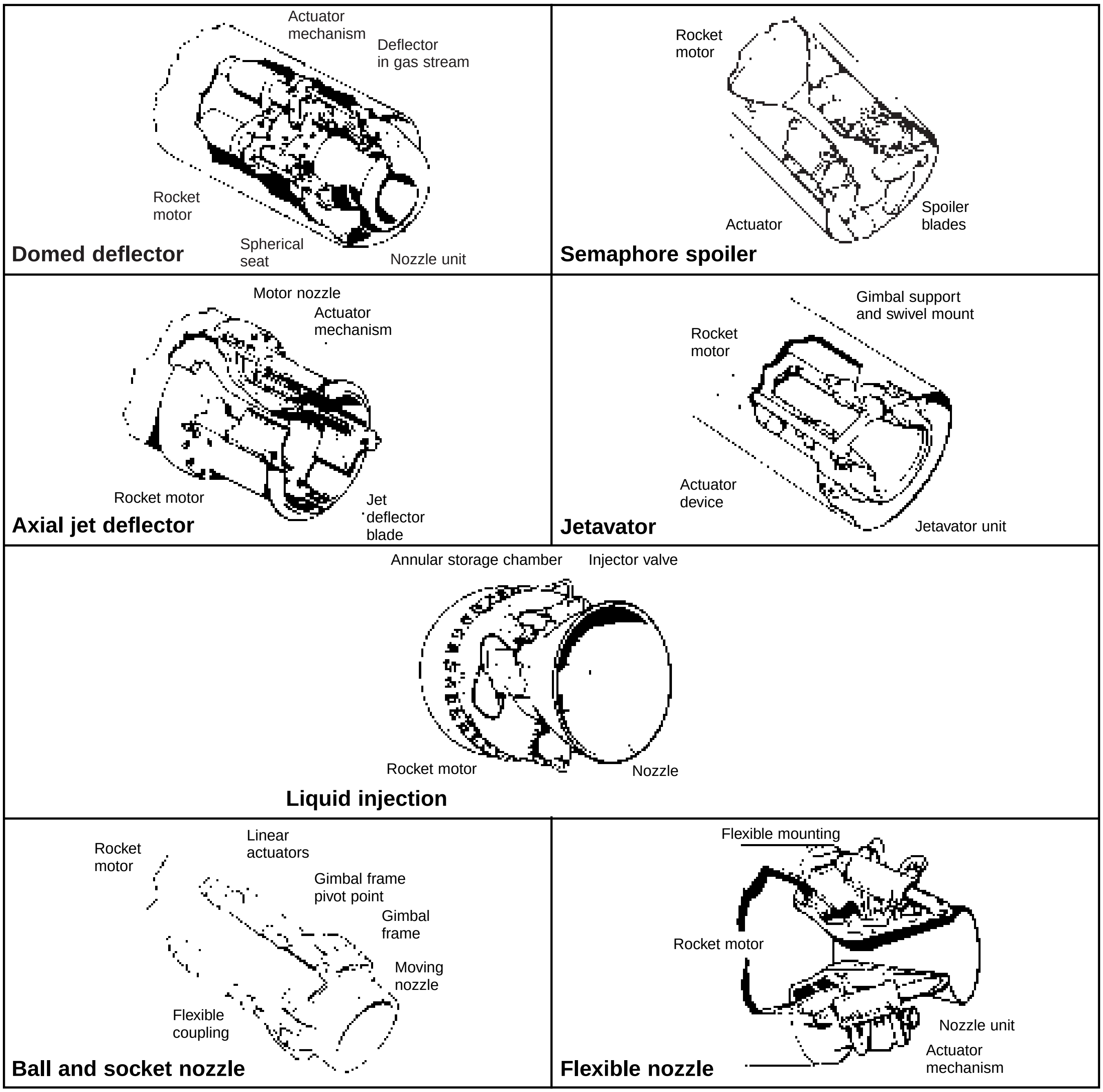

Photo Credit: British Aerospace Defense Limited

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.

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: Moog, Inc.

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

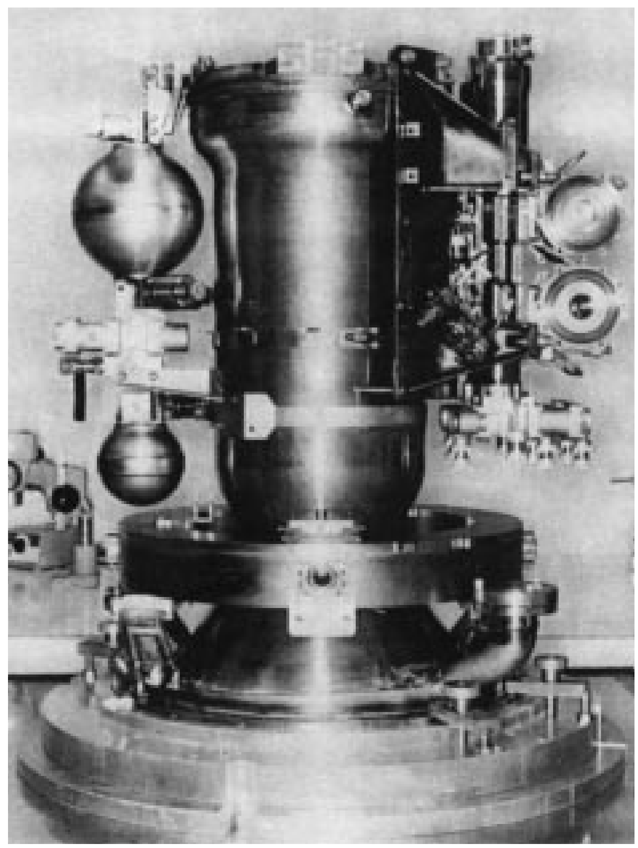

Photo Credit: Aerojet-General Corp.

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

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.

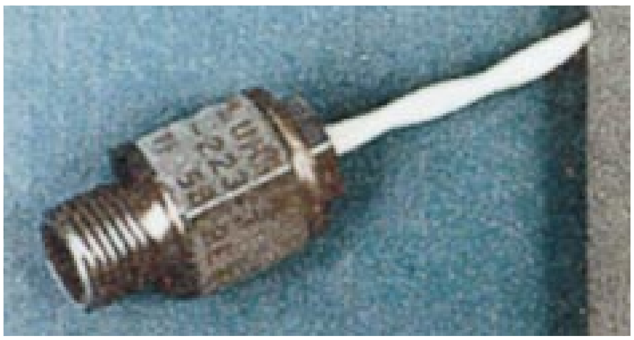

Figure 2-35: A small firing device for an RV that generates a voltage upon impact.

Figure 2-37: An RV launch safety device.

Photo Credit: Kaman Aerospace Corp.

Figure 2-34: Another style of missile fuse.

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

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.

Photo Credit: Kaman Aerospace Corp.

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