ITEM 3

Propulsion Components and Equipment

Propulsion Components and Equipment

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.

Produced by companies in

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

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.

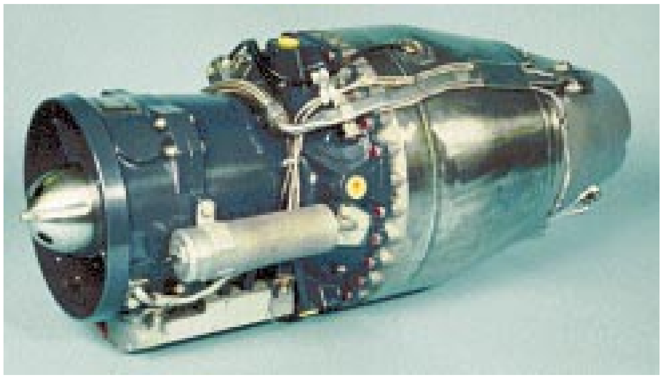

Photo Credit: Teledyne Ryan Aeronautical

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-

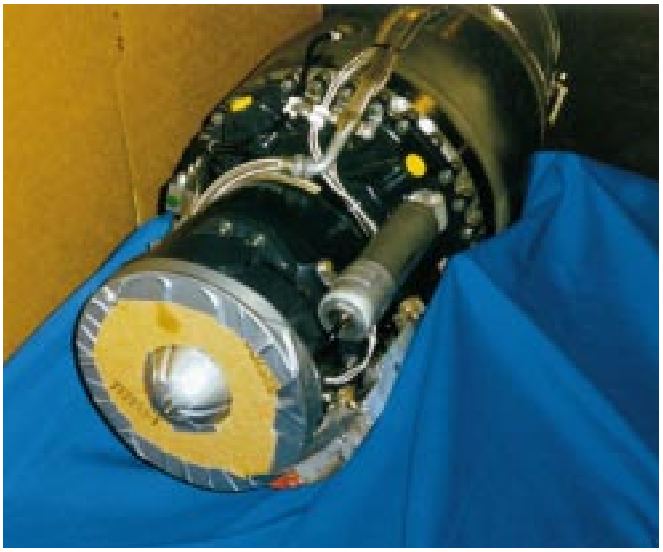

Photo Credit: Teledyne Ryan Aeronatuical

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. Non-metallic 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 bypassed around the compressor and into the afterburner. The engine then operates as a ramjet with the afterburner acting as the ramjet combustor.

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.

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

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: Kaiser Marquardt

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

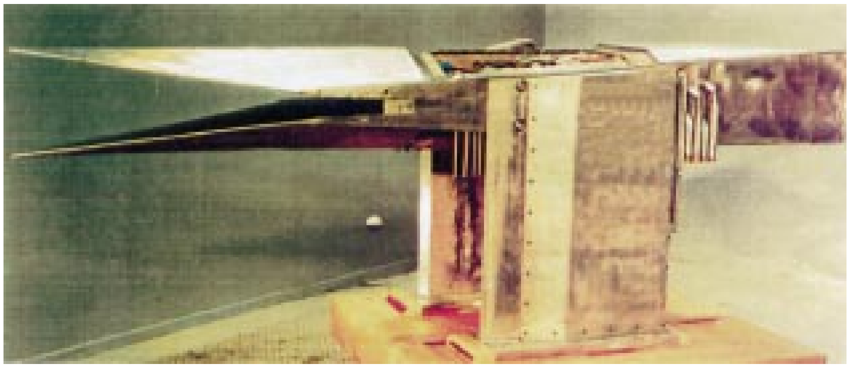

Photo Credit: Kaiser Marquardt

Figure 3-8: A developmental scramjet engine.

Photo Credit: Kaiser Marquardt

Figure 3-9: A developmental scramjet engine.

Photo Credit: Thermojet

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

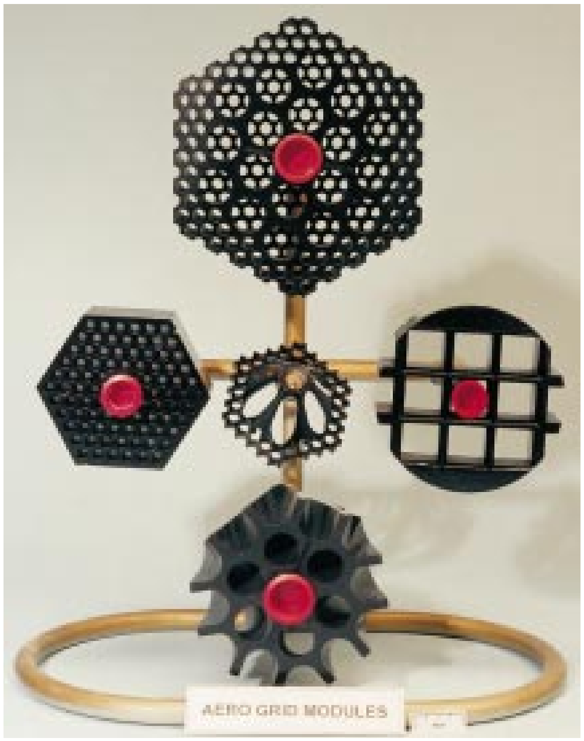

Photo Credit: Kaiser Marquardt

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

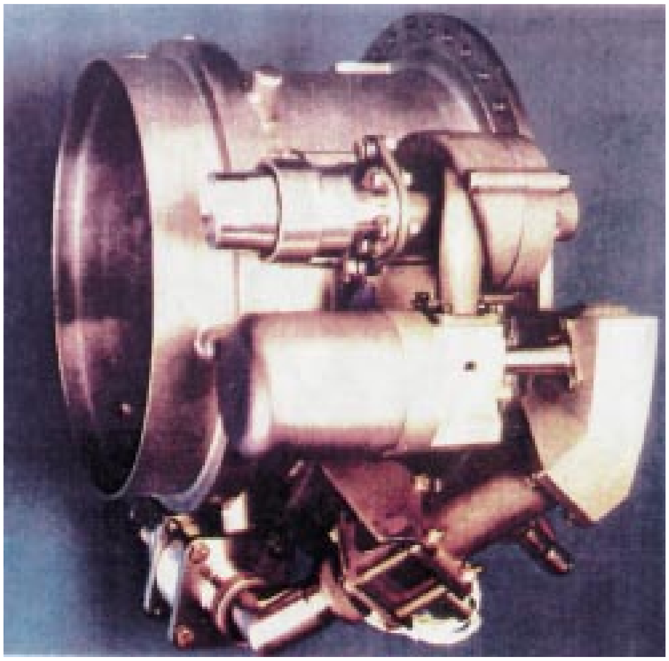
Photo Credit: Kaiser Marquardt

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

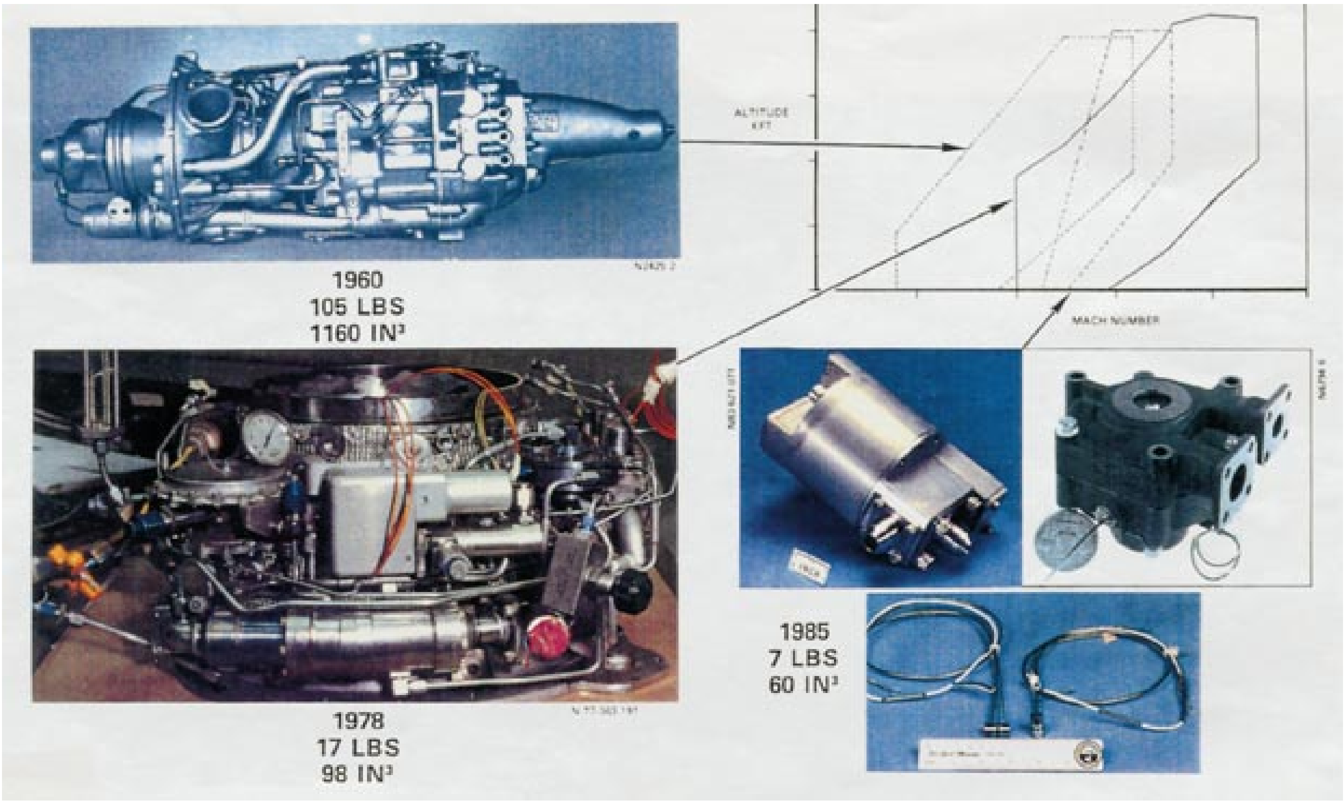

Figure 3-16: Ramjet fuel control technology has progressed significantly since the 1960s.

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.

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: Aerospatiale Espace & Defense

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

Photo Credit: Thiokol Corp.

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

Photo Credit: Fiat Avio

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

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: 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.

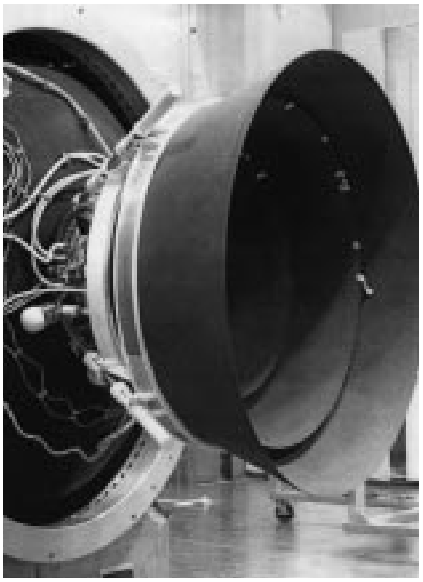

Photo Credit: Alliant TechSystems, Inc.

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.

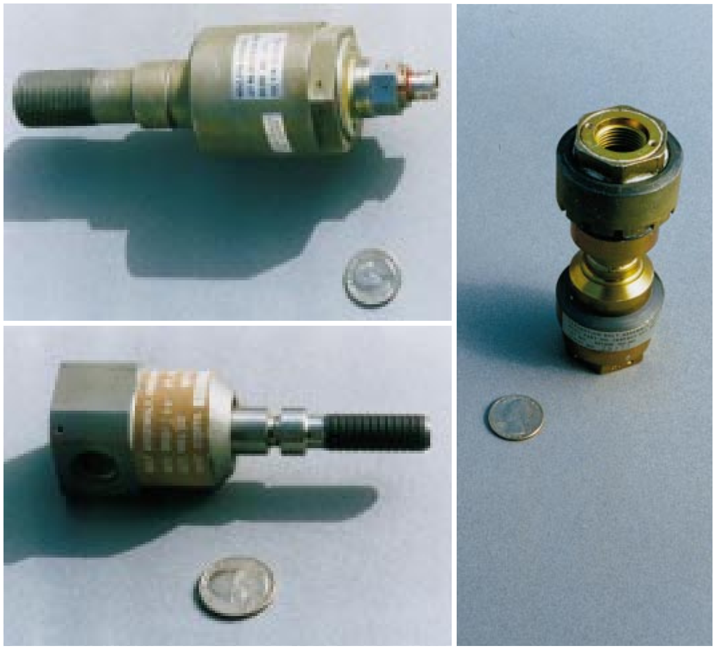

Photo Credit: Hi-Shear Technology Corp.

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.

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

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.

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

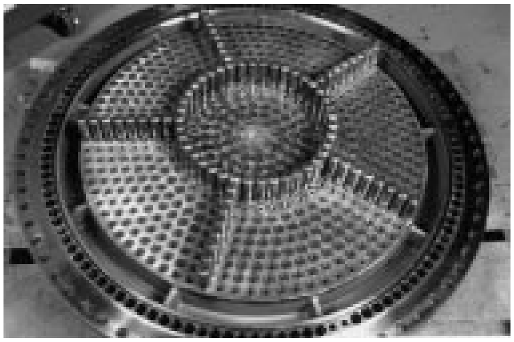

Figure 3-34: Another style of liquid propellant injector plate.

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.

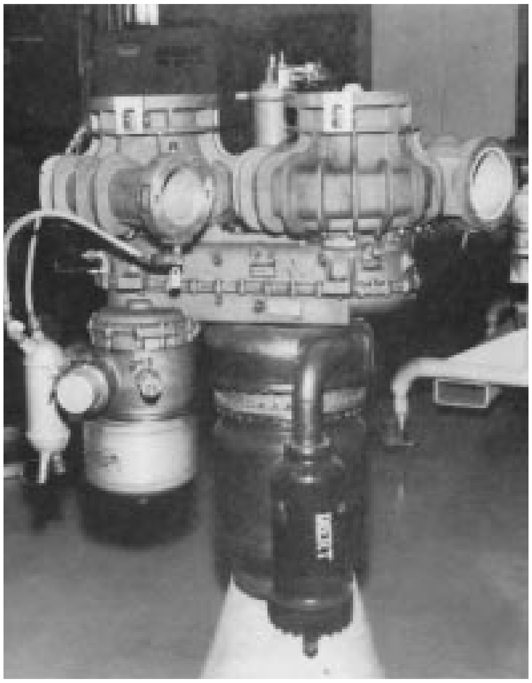
Photo Credit: Aerojet

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

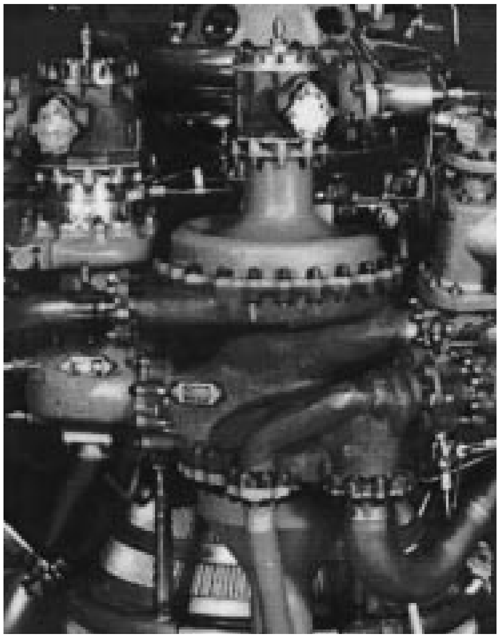
Photo Credit: AlliedSignal Aerospace

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.

Produced by companies in

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

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.

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.

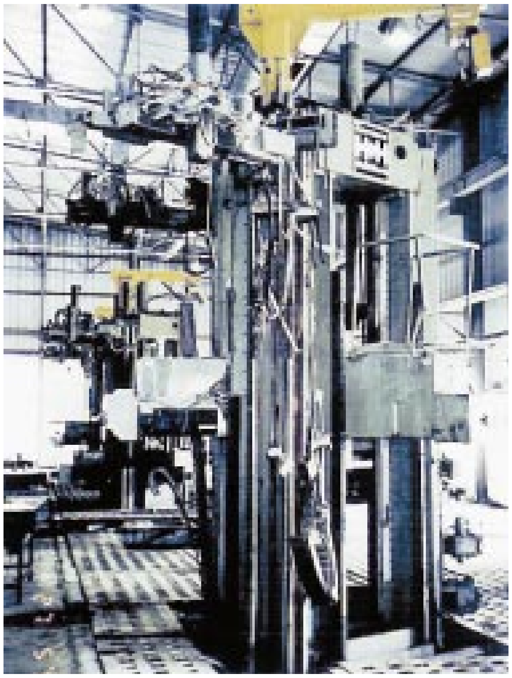

Photo Credit: A Handbook for the Nuclear Suppliers Group Dual-Use Annex, *Report No. LA-13131-M, (April 1996).*

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.