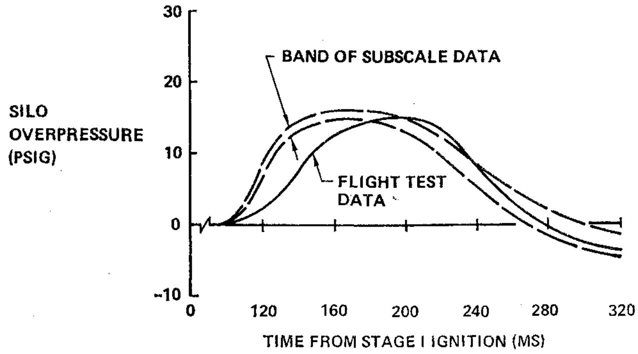

Fig. 4 Silo wall pressure comparisons.

waves originating at the diaphragm station. The balance of the transient is related to motor chamber filling (ignition transient) and in-silo transient gas dynamics. Comparison of a full scale silo wall transient pressure with a faired model pressure transient envelope is shown in Fig. 4. The comparison is considered good. In Fig. 4 (and Fig. 5 below) subscale times were converted to full scale values to allow relevant comparisons of subscale and full scale data.

Missile base pressures obtained with two existing support systems are compared with flight test results in Fig. 5. Since the model ignition transients were steeper than the full scale transients, the subscale pressure were expected to be slightly higher. This was confirmed by the data which shows model pressures to be 2 psig higher than the full scale data for both support systems.

The results demonstrate that the full-scale chamber pressure transient, sound speed and product of silo pressure and gas velocity were closely duplicated in the subscale tests. Thus, it was concluded that the model results formed a valid basis for predicting overpressures required for full scale hardware designs. Actual costs were approximately 20% of estimated costs for either the small rocket grain or shock tube combustion driver techniques.

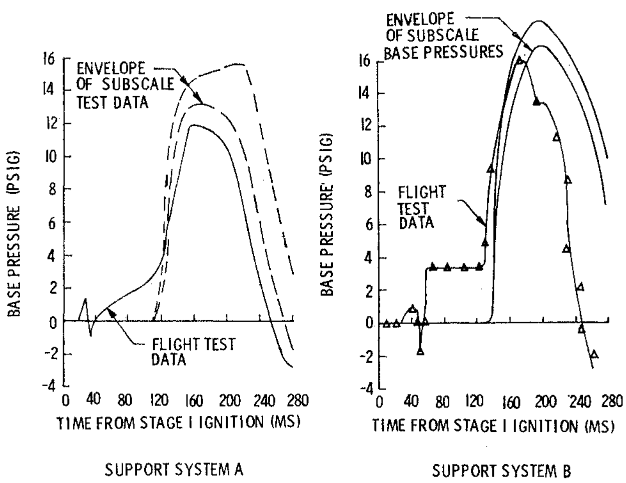

Fig. 5 Base pressures comparisons.

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Missile Liquid Rocket Propulsion Unit VR35 and Some of Its Development Problems

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THE propulsion unit developed for the air-to-ground missile carried by the Swedish strike aircraft Viggen (AJ 37), Fig. 1, is prepacked, hot gas pressurized and has positive expulsion of the storable and hypergolic propellants—inhibited red fuming nitric acid (IRFNA) and Hydyne. Smokeless operation allows the pilot to guide the missile on the line of sight to the target.

The major elements comprising the engine are concentric propellant tanks, a solid propellant gas generator, an electric safe-arm igniter, a pressure relief valve, an ablative combustion chamber, and the injection system.

The oxidizer is stored within a collapsible annular aluminum bladder and the fuel in a central tank equipped with a welded break away piston for the expulsion. Both propellant tanks are placed within a 1.85 mm thick (0.073 in.) maraging steel case with a burst pressure of 2×10^7 N/m^2 (3000 psi) to take the pressure load and compatability with the missile hull. The principal specifications for the propulsion unit (VR35) are given in Table 1.

The thrust-time curve is characterized by a boost phase with almost constant thrust as long as the gas generator is burning. After this period, when roughly half of the propellants are expelled, the expulsion proceeds during the sustain phase with a successively decreasing tank pressure and

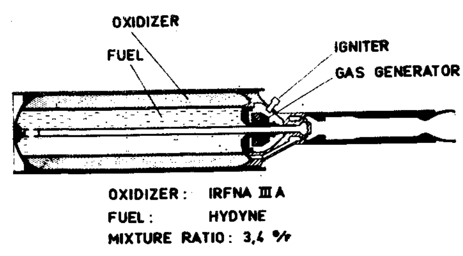

Fig. 1 Schematic view of VR35.

Table 1 Specifications on VR35

Diameter	0.3 m (12 in.)
Length	1.77 m (70 in.)
Total weight	127 kg (280 lb)
Propellant mass fraction	0.59
Operating temperature range	−50°C (−58°F) to +65°C (+149°F)

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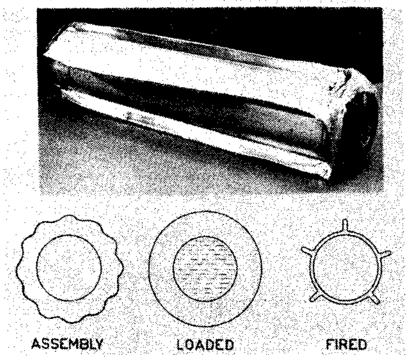

Fig. 2 Oxidizer bladder tank configuration.

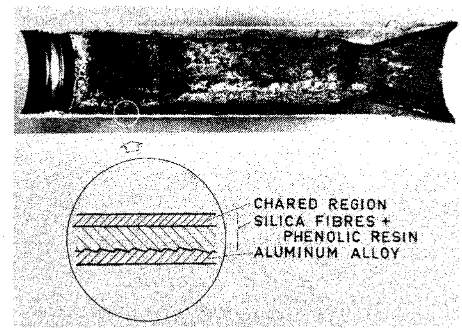

Fig. 4 Sectioned combustion chamber.

thrust—the blow down period. During this program the maximum thrust ratio is approximately 5:1.

Component Description

An interesting detail in this engine is the oxidizer bladder. It is manufactured from a pure aluminum sheet with a thickness of 0.8 mm (0.031 in.) and consists of a cylindrical part spinformed at both ends and TIG welded to machined bulkheads with gradually increasing thickness. The complete bladder is welded to the central aluminium fuel tank in such a way that no penetrating weld exists between oxidizer and fuel.

During the installation of the inner tank assembly into the pressure hull, the diameter of the bladder is decreased by a number of smooth folds, Fig. 2. After the assembly the bladder is blown up with high pressure to contact the supporting structure and is then loaded. When the engine has been fired, the bladder shape is always a five point star with an expulsion efficiency of 99% at a pressure differential of about 5×10^5 N/m^2.

The gas generator, Fig. 3, is a cast double base propellant manufactured at AB Bofors. The propellant has a burning rate of 12 mm/s at the nominal tank pressure of 10^7 N/m^2 at which level there is a rate plateau. The concentric grain is cast into a surrounding liner and is then machined at the rear end. This operation is done to shape the prepressurization part which consists of a number of thin conical flanges. The grain is ignited by a McCormick Selph's Sparrow igniter with a basket filled with B-KNO_3 pellets.

A sectioned combustion chamber is shown in Fig. 4. It has an aluminum alloy outer shell protected from the inside temperature by silica fibers moulded with phenolic resin, keeping the outside wall temperature rise beneath the stipulated 100°C. The insulation is moulded in place along the whole length with the aluminum bar machined on the inside. After moulding, the outer shape is finished and the outlet cone reinforced with glassfiber. The charred region after a firing is around 3 mm thick, and erosion occurs only in the nozzle, where the area increase is between 25 to 30%, acceptable with the specified thrust program.

Vibration and drop tests were run to satisfy enviroment requirements. Vibration tests of 0.05 g^2/Hz for the 20–500 Hz range were passed, as were double drop tests which were followed by successful firings.

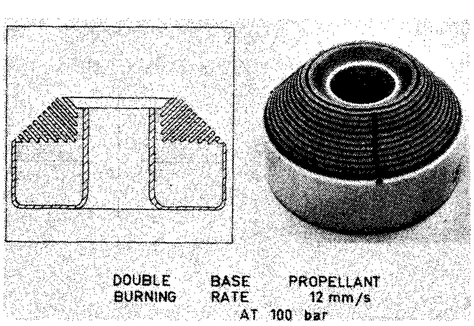

Fig. 3 Solid propellant gas generator grain.

Development Problems

Three interesting problems were solved during the development program.

Burn out smoke

In the basic design, the goal was to have both propellants completely expelled simultaneously at the burn out, both from the performance point of view and, most importantly, for preventing a smoke trail. This was, however, impossible to realize within the whole temperature range and with the manufacturing tolerances used. Many of the flight tests ended with a puff of IRFNA red smoke.

It was then shown that a distinct fuel residual could be handled because the fuel mist, visible as white smoke, was ignited by the tracking flare and burned close to the outlet with a yellow flame. The engine was modified to a fuel residual and flight tested again. This time the pilot could clearly see the missile through burn out, but the microwave attenuation within the hydyne flame was strong enough to disturb the steering connection between transmitter and receiver.

The next and final, successful modification was to equip the engine with a propellant shut-off valve of a rather unique design, Fig. 5. The injector plate is fixed in its normal position by a break away connection, the burst ring, preventing it from moving forward; the pressure drop is also acting in the same manner. The injector plate is furthermore connected to the central fuel pipe. When almost all of the fuel is consumed the piston makes contact with stops on the central pipe, and the fuel pressure falls, thus creating a forward directed high pressure drop over the piston. This pressure force is transmitted through the fuel pipe to the injector and is strong enough to move it forward. The injector plate is equipped with sealing elements of teflon for both propellants and the forward motion closes these elements causing a distinct and simultaneous cut off.

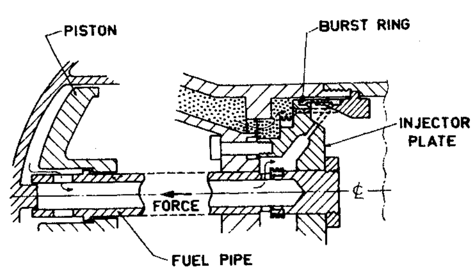

Fig. 5 Schematic propellant shut-off valve.

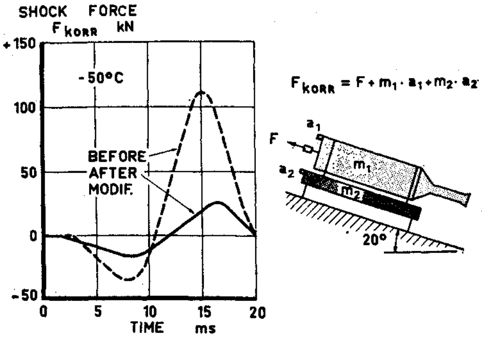

Fig. 6 Ignition shock history.

Ignition shock

The sudden displacement of the fuel to the forward end of the tank when the piston breaks away produced a positive (forward) shock with a magnitude of more than 110 kN, Fig. 6. The shock was calculated from taped measurements with two accelerometers and the ordinary thrust transducer. The engine was then oriented in the most unfavorable firing position with the combustion chamber slightly downward and at the lowest temperature where the ullage is maximum. This magnitude of shock could not be tolerated by the customer due to missile equipment sensitivity. It was, however, impossible to weaken the break away seals on the piston because this could cause an accidental break during the environmental testing.

A computer program was set up for a model of the transient behavior at ignition and this showed that an increase of the initial tank nitrogen pressure and a longer burning time of the ignition pellets would reduce the shock to a tolerable level, but still keep the thrust build up time less than 250 msec. Tests with these modifications showed that the shock dropped to 25 kN and, thus, the specified limit was met with a good margin.

Combustion instability

The injector is based on a design developed by the Swedish Research Institute of National Defense and has 20 unlike doublets impinging on a splashplate, Fig. 7. It had shown excellent performance during the component testing, but installed in the complete propulsion system the fuel pressure drop across the injector had to be decreased in order to get a sufficient combustion efficiency. An instability at 1000 Hz was introduced by this change.

It was shown analytically that this instability was due to a coupling between the feed system and the injector where the liquid freestream time was of significant importance. By intensive component testing of the injector parameters, and by comparing the results with those obtained at actual engine firings, the injector characteristics could be plotted very clearly, Fig. 8. The figure shows that the way to get a stable combustion with a high c^* efficiency was to decrease the freestream time, either by increasing the velocity, increasing the pressure drop, or by decreasing the freestream length. The stable part of the diagram becomes more narrow with higher performance and to allow for the manufacturing tolerances, the requirements were restricted to around 97% c^* efficiency.

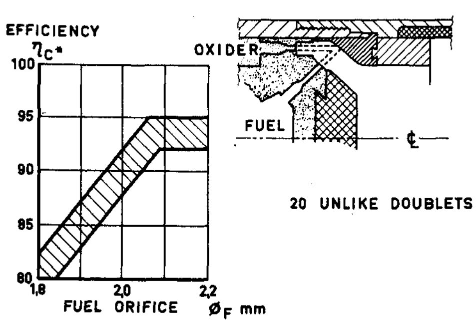

Fig. 7 Injector principle.

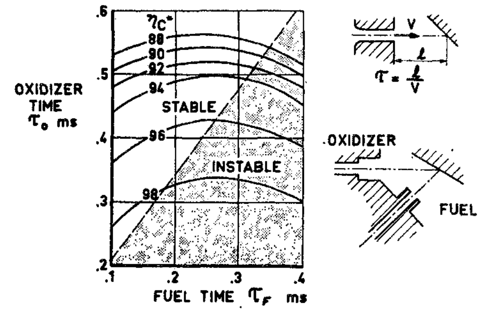

Fig. 8 Injector characteristic.

Transverse Deflection of Guided Projectile Tail Fins during Deployment

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Introduction

AN important problem in the development of guided projectiles is the design of suitable high aspect ratio tail fins which deploy automatically under the influence of low spin as the projectile leaves the gun. In order to accommodate the fins in the gun barrel and to achieve the most rearward possible fin location (to maximize airframe stability) attention has been directed mainly at tail fins which deploy rearwards from their stowed position in the projectile afterbody (Fig. 1). Deployment tests at the Naval Weapons Lab.

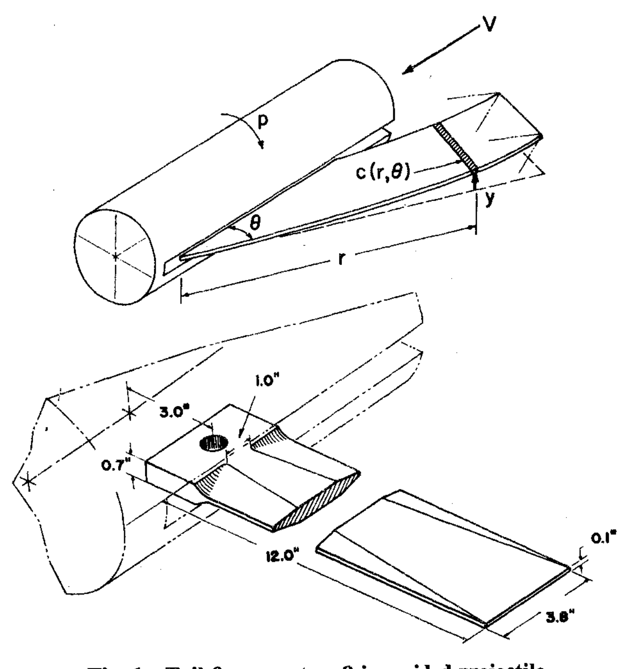

Fig. 1 Tail-fin geometry; 8-in. guided projectile.

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