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Design and Development of Propulsion System for Antitank Guided Missile

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ABSTRACT

A propulsion system is designed and developed for the third generation antitank guided missile (ATGM). It consists of a separate booster and sustainer. Booster is ahead of sustainer, having four nozzles canted to the missile axis. Sustainer discharges through a supersonic blast tube. Low smoke, high energy nitramine propellant for this propulsion system developed by the High Energy Materials Research Laboratory (HEMRL), Pune, has been successfully flight-tested. The booster grain is tube-in-tube configuration with end inhibition and the sustainer grain is of end burning configuration. High strength aluminium alloy, HE-15, is used for rocket motor components. Glass-phenolic composite ablative material is used for thermal protection of motors and high density graphite is used for nozzle throats.

The design considerations and approach, including grain configuration, nozzle, and igniters are briefly discussed. The propulsion system has been extensively tested in static tests and in flights, establishing the satisfactory performance of the system.

1. INTRODUCTION

From overall missile system considerations for a third generation antitank guided missile (ATGM), the booster thrust to sustainer thrust ratio is required to be high, more than ten. Because of this high thrust ratio, a dual thrust propulsion system with a single casing and fixed nozzle geometry is not possible as the maximum thrust ratio for optimum design of dual thrust motor with fixed nozzle is about six. Therefore, separate booster and sustainer motors have been configured and designed at Defence Research & Development Laboratory (DRDL) Hyderabad, meeting the performance and geometrical specifications of the system. From aerodynamic and configuration layout requirements it was required to locate the booster ahead of sustainer. The fin control system is configured at the aft section of the missile from considerations of effective control capability. Hence the sustainer exhaust is to be taken to the exit of the missile through a blast tube. Since booster is ahead of sustainer, the exhaust has to be taken through four peripheral nozzles and accordingly the nozzles are canted. Booster and sustainer are connected by an interstage section. Thermal batteries for powering the missile subsystems are located in the space available in the interstage (Fig. 1). Booster burns out after imparting the required velocity to the missile and the sustainer continues for almost the full flight duration.

2. DESIGN CONSIDERATIONS AND SALIENT FEATURES

(a) High energy, low smoke nitramine propellant is used in both booster and sustainer. Same propellant composition is chosen for both booster and sustainer grains to minimise development efforts and from production point of view.

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Figure 1. Schematic of the propulsion system.

[illegible] sig[illegible] for operating over a wide temp[illegible]tu[illegible] [illegible]ng [illegible]xtreme low to high temp[illegible]tu[illegible]

Both booster and sustainer grains are configured as cartridge-loaded type to avoid cyclic thermal stresses due to case bonding and for easy replacement.

Booster is located ahead of sustainer having four nozzles canted to the missile axis. Part of the divergent nozzle protrudes out of the missile and part of it is scarfed.

(e) Sustainer exhausts through a supersonic blast tube.

(f) Both booster and sustainer motors are fabricated using HE-15 aluminium alloy.

(g) The complete inner surface of the motor is lined with glass-phenolic ablative liners. A lap joint is provided between tubular and dished end liners.

(h) Both the motors are ignited simultaneously by means of pyrocartridges.

(i) Booster nozzle end dish is an integral part of the booster casing and sustainer head end dish is an integral part of sustainer casing.

(j) Head end dish of booster and nozzle end dish of sustainer are configured without threads with a retainer ring. This is a unique feature which facilitates easy integration of pyros and other subsystems located inside the interstage and other adjoining sections.

(k) The pyro-flash holes are suitably inclined to the motor axis for effective impingement of flash on the igniter.

3. SYSTEM DESIGN

One of the important requirements of the propulsion system was for smokeless/low smoke exhaust. The propellant selection was made keeping in view this requirement and state-of-art in propellant technology. The propellant should be high energy (high specific impulse) type to keep the system weight minimum and at the same time mechanically strong to withstand pressure loads, lateral and longitudinal accelerations during flight and should have capability to maintain structural integrity for operation from extreme low to high temperature. The conventional double-base propellants have got excellent mechanical properties with very low smoke exhaust. But their specific impulse is about 200 s only. Composite propellants give high specific impulse of about 240 s, but they produce very high smoke. Hence for the present application, it was essential to use a propellant with low smoky exhaust and high energy. Nitramine propellant was chosen which gives high energy and low smoky exhaust. The specific impulse of this class of propellant is about 230 s. The propellant has been developed and successfully tested by HEMRL, Pune.

4. CHAMBER PRESSURE AND NOZZLES

Operating chamber pressure was chosen with a view to minimising the total weight of the motor. Higher pressure improves delivered specific impulse, but increases hardware weight. An analysis was carried out to study the effect of chamber pressure on propulsion system and an optimum chamber pressure was chosen. The throat diameter, cant angle and divergent angle of booster nozzle were optimised keeping in view the required mass flow rate and the need to minimise the diameter with the protruded nozzles, motor length and weight.

5. SUSTAINER

The sustainer nozzle was configured to give the required mass flow rate. A supersonic blast tube was designed and used successfully. The blast tube is lined with glass-phenolic ablative material.

6. GRAIN CONFIGURATIONS

With the state-of-art and required burn time, the web fraction for the booster was about 0.2. Different grain configurations were studied for this. The end inhibited tube-in- tube configuration was finally chosen for this web fraction from considerations of maximising cross-sectional loading density (more than 85 per cent) and minimising the sliver (no sliver for the chosen configuration). The port-to-throat area ratio was chosen as 2 in all the three ports to avoid erosive burning. End burning type was chosen for sustainer grain for achieving small mass flow rate. Suitable grooves were provided on the end surface to aid the ignition.

7. IGNITER

Boron potassium nitrate composition is used for both booster and sustainer igniters. Since the quantity of the igniter charge required for the free volume of the booster motor is small, the igniter is configured in ring type aluminium canister with triangular cross-section. The canister is fitted to the head end grid. There are two pyro housings on the head end dish which are perpendicular to the motor axis. The flash hole through which the pyro gases enter into the chamber for initiating the igniter is suitably inclined to the axis of the motor so that the flash of pyrocartridge impinges on the igniter canister (Fig. 2). For sustainer, a disc-type celluloid canister is bonded on to the surface of the propellant grain and the charge is filled through the charging holes. The pyrocartridges are screwed in the pyro housings on nozzle and dish end.

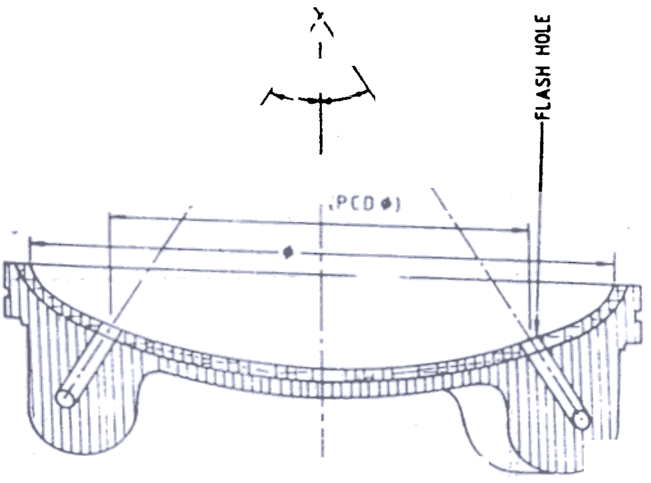


Figure 2. Design showing how the flash of pyrocartridge impinges on the igniter canister.

8. HARDWARE DESIGN

8.1 Material Selection

The material for rocket motors should have high strength-to-weight ratio. Ultra high strength steels, like maraging steel, D6AC, 15CDV6 were not chosen because the thickness required was less than 0.5 mm which was not found suitable from fabrication and integration points of view, since, for threaded joints, 2-3 mm minimum thickness needs to be maintained. Therefore high strength aluminium alloy, HE-15 with a minimum UTS of 45 kg/mm was chosen for both booster and sustainer motor components. Though 7075 aluminium alloy gives UTS higher than 45 kg/mm, it is prone to stress corrosion and so was not considered suitable. A factor of safety of 1.5 and a maximum skin temperature of 100 °C were used for the design.

8.2 Fabrication

8.2.1 Booster

The main components of the booster are casing with integral nozzle end, head end dish and nozzles. The casing and head end dish are fabricated from high strength forgings. The nozzles are fabricated from bar stock. Suitable precision fabrication methods were evolved for the booster casing to meet the required accuracies for nozzle holes from thrust misalignment considerations and the integral lugs for mounting the wings (need to minimise aerodynamic misalignments due to any canting of the wings). Machining of threaded holes to accurately accommodate canted nozzles, internal and external profiles of the nozzle end dish, symmetric machining of the material between the projections for the nozzle housings to reduce the weight are other critical steps. Since it was not possible to achieve the stringent dimensional specifications with conventional machining, CNC turning and milling processes have been employed. The tolerances on the critical parameters, like wall thickness, crown and knuckle radii, cant and skew angles, concentricity, ovality, co-axiality of the lugs, etc. have been achieved, and the fabrication methodology has been established leading to very high yields. Fabrication methodology of the booster is illustrated in Fig. 3 and fabrication and assembly flow charts of the booster are given in Figs 4 and 5, respectively.

Figure 3. Fabrication methodology of the

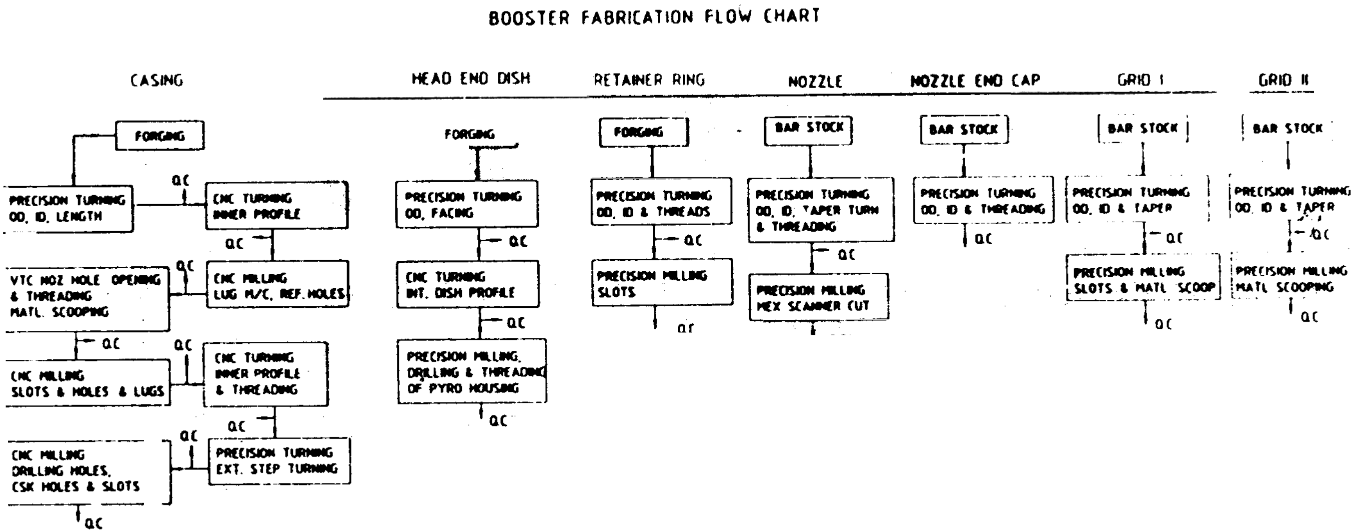


Figure 4. Booster fabrication flow chart

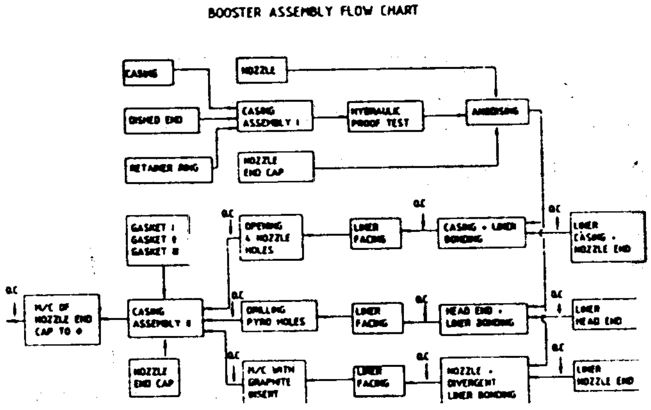


Figure 5. Booster assembly flow chart.

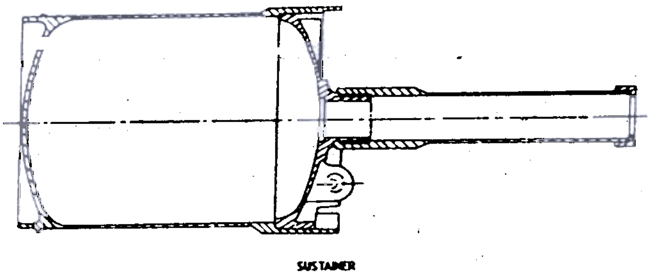


Figure 6. Fabrication methodology of the sustainer.

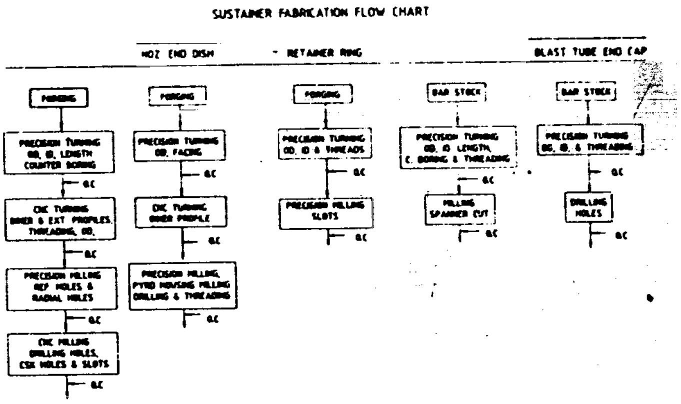


Figure 7. Sustainer fabrication flow chart.

8.2.2 *Sustainer*

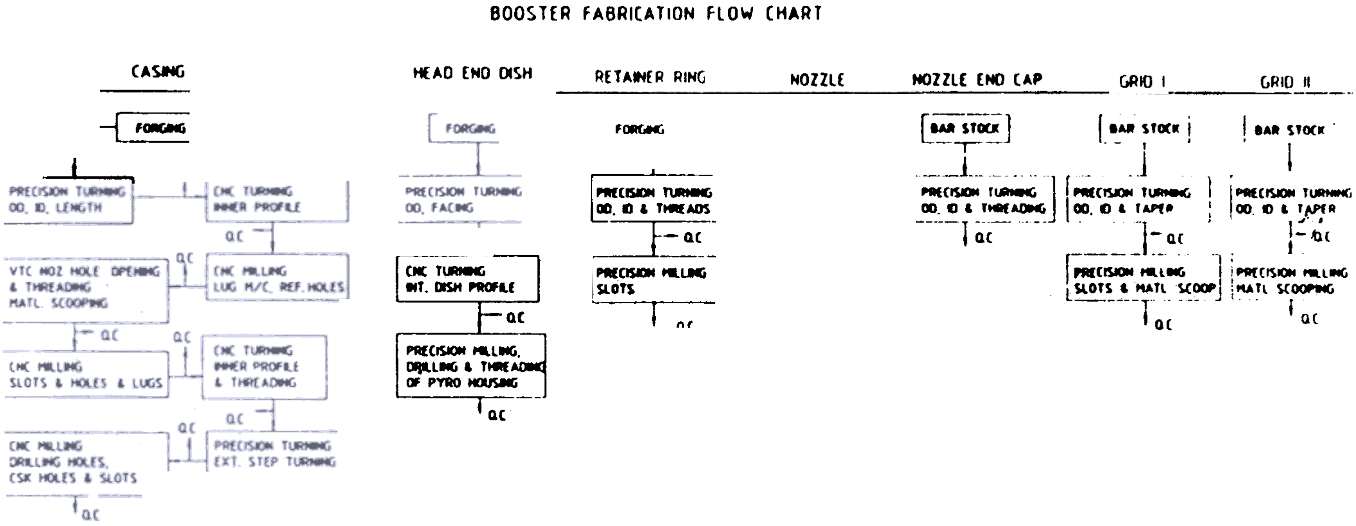
The main components of sustainer are casing with integral head end dish, nozzle end dish and blast tube. The casing and nozzle end dish are fabricated from high strength forgings and the blast tube is fabricated from bar stock. CNC turning and precision milling processes have been employed for fabricating sustainer casing and nozzle end dish also. Fabrication methodology of the sustainer is illustrated in Fig. 6 and assembly flow charts of the sustainer are given in Figs 7 and 8. Precision turning and milling processes have been employed for fabricating the interstage also.

8.2.3 *Hydraulic Proof Testing*

Both booster and sustainer motors after fabrication were hydraulically proof-tested up to proof pressure which is about 25 per cent higher than the maximum operating pressure. Strains were monitored at critical locations using strain gauges. Two booster and sustainer motors each were burst-tested. The burst pressure and the pattern of failure were as per the design predictions.

8.2.4 *Anodising*

After hydraulic proof-testing, all the components are being anodised as per the specification DIN-IN-9368-2001.6.



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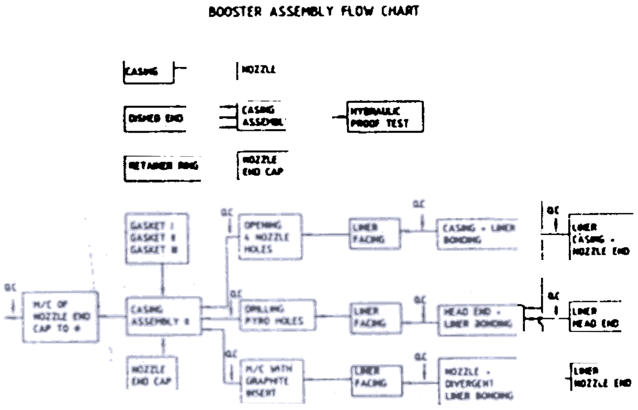

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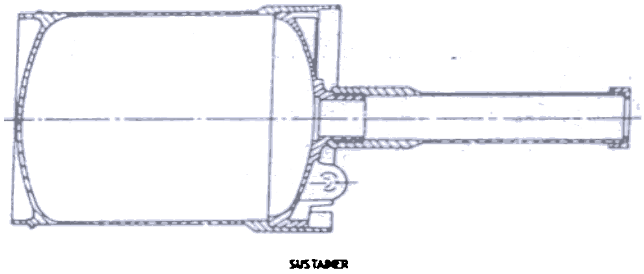

Figure 6. Fabrication methodology of the sustainer.

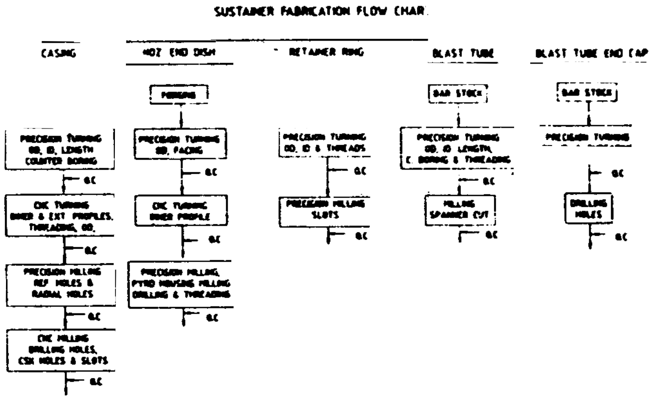

Figure 7. Sustainer fabrication flow chart.

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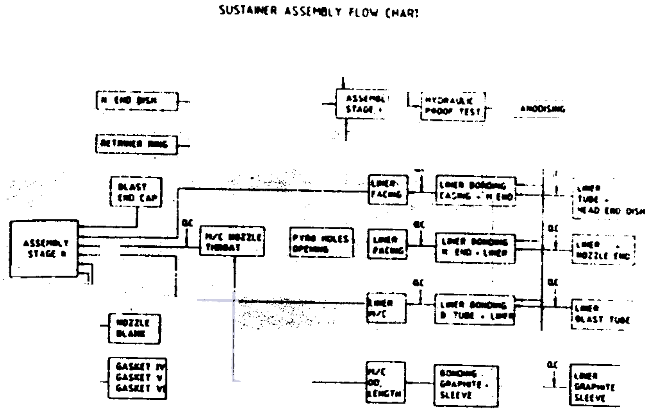

Figure 8. Sustainer assembly flow chart.

8.2.5 Lining

Booster head end dish, sustainer nozzle end dish and booster nozzle divergent liners are made with glass-phenolic formaldehyde by compression moulding technique. The tubular liner is made of glass-phenolic and is wound on mandrel and cured in autoclave. A lap joint is provided between the tubular and dished end liners and these are bonded to the motors. High density and high strength graphite is used for nozzle throat inserts of booster and sustainer. At present the grids for booster are fabricated with M.S. material and they will be replaced by composite material.

9. STATIC TESTS

The performance of the propellant was evaluated extensively in proof motor. Subsequently static tests were also conducted in flight motors for both booster and sustainer and in integrated mode. One ton capacity, horizontal, swing-type static test stand was designed, fabricated and commissioned exclusively for static testing of this propulsion system. The typical pressure-time curves of booster and sustainer and thrust-time curve for the integrated booster-sustainer tests obtained are shown in Figs 9, 10 and 11 respectively. About 3 per cent loss of specific impulse in booster due to scarfing of nozzles and 5 per cent loss of specific impulse in sustainer due to supersonic blast tube were observed during static tests. The propulsion system has been successfully flight-tested in a number of trials realising the specified performance requirements.

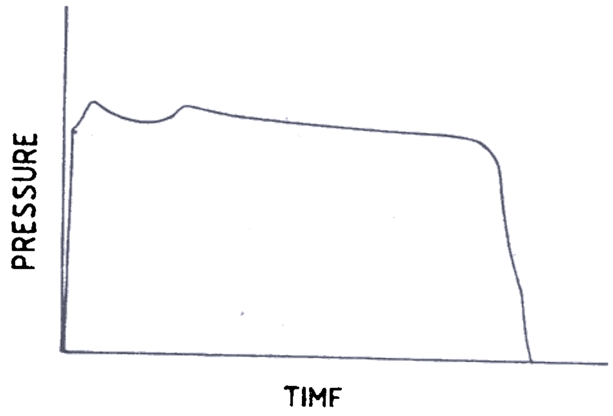

Figure 9. Typical pressure vs time for booster.

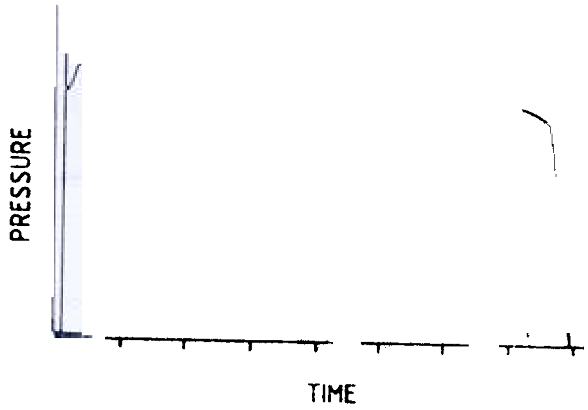

Figure 10. Typical pressure vs time for sustainer.

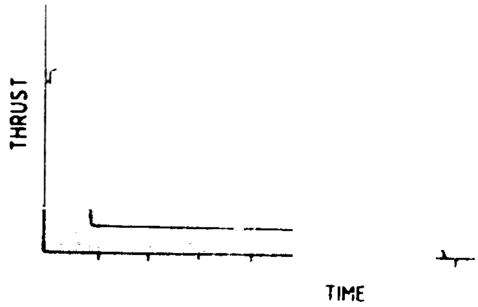

Figure 11. Typical thrust vs time for propulsion system

10. PROBLEMS FACED DURING DEVELOPMENT

This section outlines some of the typical problems faced during development of the propulsion system and the steps taken to overcome these problems.

10. Irregularities in Pressure-Time Curve

During static tests of booster proof motor, some irregularities in pressure-time curves, like hump and spikes were observed. Few of the parameters given in the following were varied in static tests with a view to studying their effects and possible contributions to the irregular pressure-time profiles.

(a) Location of inhibited end face of propellant grain at head/ nozzle end.

(b) Complete removal of inhibition.

(c) Performance studies with equivalent single-nozzle and four- nozzle configurations.

(d) Drilling radial holes in the propellant grains.

(e) Local widening of ports at head end side for smooth entry of ignition gases.

(f) Changes in igniter charge quantities.

It was seen that none of the above parameters contributed to irregular pressure-time curves; also it was observed that the performance of propellant grain from a batch is repeatable and consistent. It was felt during this initial development phase that the irregular pressure-time records could be due to low mechanical properties of the propellant, since grain could deform under pressure because of low mechanical properties, resulting in non-uniform ports. Later the mechanical properties of propellant grain were improved and static tests were carried out. All the anomalies were eliminated with the use of propellant grains with improved mechanical properties.

10.2 Sustainer Blast Tube

Initially subsonic blast tube was designed, fabricated and used in the static tests of sustainer proof motor. This blast tube was chosen in view of smaller performance loss due to blast tube. The sketch of subsonic blast tube is given in Fig. 12. The propellant processed by Slurry-Cast route contained a small percentage of aluminium powder. The aluminium oxide present in the exhaust gases was getting deposited on the nozzle throat. The consequent reduction in the throat diameter caused the rise in pressure. This type of rise in the chamber pressure was not permissible for the system. To avoid this, supersonic blast tube was configured. The sketch of the supersonic blast tube is shown in Fig. 13. About 5 per cent loss in delivered specific impulse was observed with supersonic blast tube, but without any pressure rise in the chamber. With non-aluminised propellant, use of subsonic blast tube is considered feasible so that the performance loss due to blast tube can be minimised.

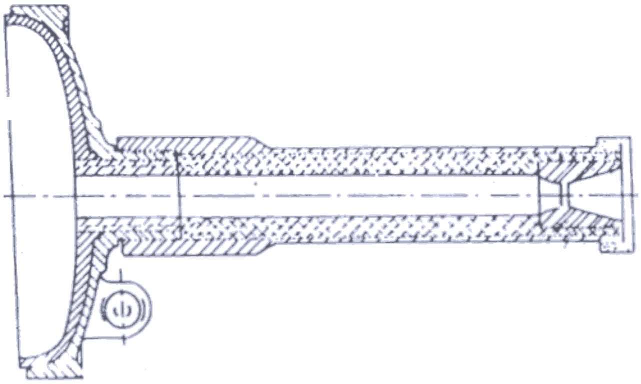

Figure 12. Sustainer nozzle end with subsonic blast tube.

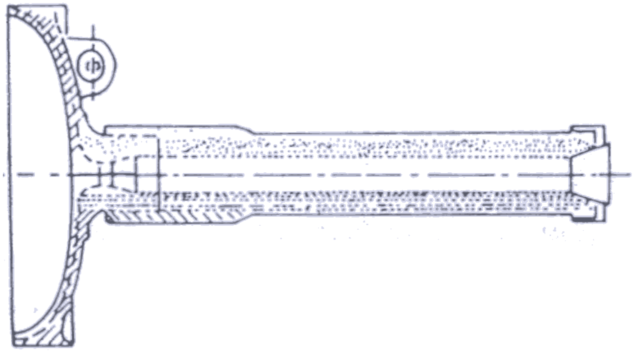

Figure 13. Sustainer nozzle end with supersonic blast tube

10.3 Reconfiguration of Booster Nozzle End

Efforts were made to improve the booster performance by reducing nozzle canting losses. The booster nozzle end was reconfigured and the cant angle was reduced by 5 degree without altering the nozzle exit conditions. Static tests were conducted using the modified nozzle end and about 4 per cent performance enhancement was obtained. This was achieved without any dimensional or weight penalties.

10.4 Reconfiguration of Booster Head End Dish and Sustainer Nozzle End Dish

Initially the booster head end dish and sustainer nozzle end dish were designed for threaded joints. The pyro housings on the dishes are required to be oriented in a particular direction during the missile integration. With threaded joints, it was not possible to orient in the desired direction. Therefore the dished ends were reconfigured without threads and a retainer ring was introduced in the place of threaded dished ends. This enabled orientation of the pyro housings on the dished ends in any desired direction.

11. CONCLUSIONS

With the high energy, mini smoke, nitramine propellant developed by HEMRL, the performance of the propulsion system of the third generation ATGM has been established through extensive static and flight tests. The motor casings are designed with high strength HE-15 aluminium alloy and fabrication has been established on CNC machining centre to maintain accuracies in respect of nozzle skew and cant angles, thickness, radii, orientation of wing lugs, concentricity, ovality, etc., for meeting the stringent requirements of booster thrust misalignments with canted nozzles. Glass-phenolic tubular liner and glass-filled phenol formaldehyde moulded components were developed and NDT methods have been established for quality control. The total propulsion system was extensively static-tested and its satisfactory performance was demonstrated in flights.

ACKNOWLEDGEMENTS

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