Recent Evolution of Carbon-Carbon Nozzles for the Apogee Boost Motor

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Abstract

THE design evolution of carbon-carbon (C-C) nozzles for the Apogee Boost Motor (ABM) during the last five years is presented. The first C-C nozzles featured a small Integral Throat and Entrance (ITE) made of multidirectionally reinforced C-C, and a thin walled C-C exit-cone threaded to it. The small exit-cone diameter led to poor vibration behavior and a difficult manufacturing process. This was solved by using a large free ITE to increase the exit-cone entrance diameter, and by a new joint between the ITE and the exit-cone. The next advance of the ABM nozzle design will be the use of ceramic-ceramic materials, for the nozzle attachment to the chamber.

Contents

Nozzle Apogee Boost Motor Design Criteria

A lightweight nozzle is a primary goal; weight reduction is directly converted into satellite payload. A thin-walled, free-standing carbon-carbon (C-C) exit-cone is the principal technology that results in such a weight saving.

The best compromise between impulse efficiency and nozzle weight must be reached within an imposed envelope. A large exit-cone with a high exit area ratio, as needed for high impulse efficiency, will be fabricated from C-C material with a minimum weight penalty.

The external surface temperature of the exit-cone must remain below 550°C (1022°F). This is usually implemented by a carbon felt blanket. The nozzle must survive vibrations induced by the combustion of launcher lower stages. Lateral vibrations are generally the most critical; they are often amplified at the nozzle level by a motor chamber natural mode. The nozzle exit-cone entrance is a critical point. Typical vibration levels applied at the motor flange are 7*g* between 12.6 and 30 Hz, and 3*g* between 30 and 100 Hz.

Finally, the nozzle must withstand the space environment. The apogee boost motor (ABM) temperature is maintained by the spacecraft between −10°C (14°F) and 40°C (104°F) before ignition, but the exit-cone tip may reach a very low temperature, typically −125°C (−193°F). Hence it is required that the motor can be ignited, the exit-cone being at such a temperature.

First Generation Nozzle

This nozzle, designed for the MAGE 1 ABM (European Space Agency Program), is shown in Fig. 1. The integral throat and entrance (ITE) (point 1) is fabricated from four-directionally reinforced C-C material.[1,2] The reinforcement directions are along the four diagonals of a cube, and the nozzle centerline is perpendicular to a cube face. The exit-cone (point 2) is fabricated from a C-C involute material, the thickness of which tapers from 8 mm (0.31 in.) at the entrance to 2 mm (0.079 in.) near the exit. The exit-cone is connected to the ITE by a threaded joint located at a low area ratio ($A/At = 1.86$) so as to minimize the size and cost of the ITE.

The exit-cone technologies of this nozzle and of a demonstration nozzle tested in 1977 at the Air Force Rocket Propulsion Laboratory (AFRPL) of Edwards AFB are very similar.[3]

The principal problems associated with the MAGE 1 nozzle have been encountered with the exit-cone. The small diameter threaded joint between the exit-cone and the ITE is a critical area, highly stressed by the loads induced by lateral vibrations (see Fig. 2). In one case, the thread has been shorn out. This problem may be solved by an exit-cone lateral support at a larger diameter, but, to avoid thermal radial restraints detrimental to the exit-cone involute structure during the firing, meltable spacers must be used (see Fig. 1).

Also, the small diameter of the exit-cone entrance leads to a difficult manufacturing process. A male mold must be used, resulting in a tricky debulking of the prepeg plies. Moreover, the shape of the exit-cone entrance evolving from a cylinder to a cone in this area is another difficulty, which may also result in defects such as ply wrinkling.

Due to the above-mentioned problems and to schedule difficulties, in spite of some successful tests, the first generation nozzle has not been selected for the MAGE 1 motor. The C-C exit-cone was replaced by a less efficient tape wrapped carbon-phenolic exit-cone.

Second Generation Nozzle

In order to solve the problem of the exit-cone entrance, the diameter has been increased. The attachment area ratio is now 11.5, leading to a reduction of the stresses induced by the lateral vibrations at the joint between the ITE and the exit-cone, and easing the exit-cone manufacturing process (female mold). It results in a large size increase of the ITE downstream of the throat, so that the joint between the ITE and the exit-cone is moved back to the level of the motor chamber aft polar fitting. The ITE was redesigned to reduce weight and became free standing (see Fig. 1).

The nozzle is attached to the chamber by a small titanium ring (point 5) insulated by two carbon-phenolic parts (point 3). The nozzle blowoff load is transmitted to the titanium ring through a C-C nut (point 4). For the ITE to withstand the external pressure, the deformations induced by this pressure field must remain small and axisymmetric. A four-directionally reinforced C-C material with a rod direction along the nozzle centerline was selected to meet these requirements.[4] Such a nozzle was successfully tested in November 1979 at the AFRPL.[5]

Third Generation Nozzle

This third generation nozzle is now state-of-the-art. The second generation nozzle threaded joint between the exit-cone and the ITE remains difficult to manufacture due to the transition from a cylindrical to a conical shape. The third generation nozzle exit-cone attachment with the ITE is made through a conical trapped joint, so as to have a continuous

Submitted June 7, 1982; presented as Paper 82-1187 at the AIAA/SAE/ASME 18th Joint Propulsion Conference, Cleveland, Ohio, June 21-23, 1982; synoptic received May 11, 1983. Full paper available from the AIAA Library, 555 West 57th St., New York, N.Y. 10019; micro-fiche—$4.00, hard copy—$8.00. **Remittance must accompany order.**

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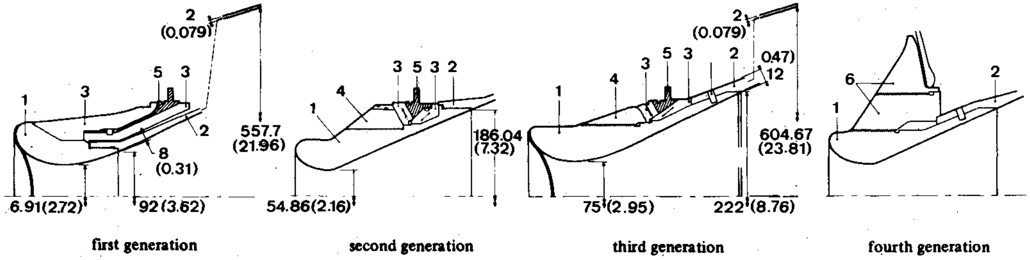

Fig. 1 C-C nozzles evolution.

1 : C-C 4D *I.T.E* - 2: C-C *Exit - cone* - 3 : Carbon phenolic *Insulation* - 4 : C-C *Nut* - 5 : Titanium *Attach ring* - 6 : T.L.C

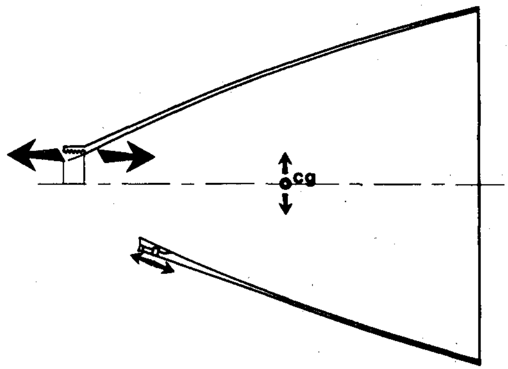

Fig. 2 Loads induced by lateral vibrations (first and third generation nozzles).

conical shape for the exit-cone, leading to an easy manufacturing process (see Fig. 1). The conical trapped joint features a good response to the loads induced by lateral vibrations before the firing (see Fig. 2). C-C pins link the exit-cone to the ITE and avoid any relative displacements during the firing, in spite of different thermal expansions, which may debond the exit-cone from the carbon-phenolic insulation (point 3).

The ITE increased cost is overcome by the ease of exit-cone manufacturing, the number of rejected exit-cones in production becoming nearly zero. Such a nozzle has been selected for the MAGE 2 ABM qualified early in 1982, which will be used with the ECS and Telecom European satellites. Six successful firing tests have been performed, five in altitude simulation. Two altitude simulation firing tests were performed at the AFRPL in July and September 1981. The last firing test was made with the exit-cone cooled at $-125°C$ by liquid nitrogen sprayed on it just before ignition.

Fourth Generation Nozzle

The nozzle attachment with the chamber will be simplified by the use of new insulative ceramic/ceramic materials. This new attachment concept is called Thermostructural Liaison Composite, or TLC (patent pending). The design of this fourth generation nozzle is depicted by Fig. 1. The two TLC parts supersede the C-C nut (point 4), the carbon-phenolic insulations (point 3), the titanium attach ring (point 5), the chamber aft polar fitting, the seals, and the fasteners of the third generation nozzle.

Concluding Remarks

The principal features and the most critical part of an ABM nozzle is the large thin-walled C-C exit-cone. The manufacturing process of multidirectionally reinforced C-C materials being now well controlled, the ITE was enlarged and became free standing, resulting in easier exit-cone manufacturing and better attachment behavior. In the future, the linking with the chamber will be improved and simplified by the new TLC concept.

References

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