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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Memorandum 33-579*

# *A Brief Survey of Carbon/Carbon Refractory Composites at the Jet Propulsion Laboratory*

*E. Y. Robinson*

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**JET PROPULSION LABORATORY**

**CALIFORNIA INSTITUTE OF TECHNOLOGY**

**PASADENA, CALIFORNIA**

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National Aeronautics and Space Administration

# PREFACE

The work described in this report was performed by the Applied Mechanics Division of the Jet Propulsion Laboratory. This report was presented at the 20th Refractory Composites Working Group Meeting, held in Cleveland, Ohio, Oct. 19-20.

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## ABSTRACT

Refractory composites specifically of carbon-carbon material, are being considered for application in: (a) rocket motor nozzles and skirts, (b) a unique integrated propulsion structure, and (c) planetary atmospheric entry shells.

The first application is intended for radiation-cooled nozzles and skirts which, with presently available materials, can meet operational requirements of deep space missions at substantially lower weights.

The second application requires very high structural performance as well as refractory capability, and is feasible only if high-strength graphite filaments are efficiently incorporated into a carbon-matrix composite.

The third application is comparable in many respects to earth-entry aeroshells and heat shields; however, planetary atmospheres may pose new gas-dynamic and corrosion problems. Furthermore, the entry shell is likely to be an integral structural element which is not jettisoned, and to which critical hard point attachment must be made.

Technical developments and plans in each of these areas are described.

# I. REFRACTORY RADIATION-COOLED ROCKET NOZZLES

The feasibility of using all-carbon composite nozzles was demonstrated at JPL in static firing of 27-kg solid propellant motors (Ref. 1). The configuration of these nozzles is shown in Fig. 1. The significant advancement in long-burning, solid propellant motor technology is reflected in:

(1) Nozzle weights 0.4 to 0.6 that of equivalent flight-weight ablative nozzles,

(2) Reusability with minor, if any, refurbishment (demonstrated by repeated firing of the first nozzle), and

(3) Firing times representative of space mission requirements.

The current nozzle design appears to be acceptable for projected 355-kg motors, based on thermal analysis. The nozzles shown in Fig. 1 were fabricated by the rosette-layup method, illustrated in Fig. 2. This process appeared, at that time, to be preferable to filament-winding techniques and to offer improved accommodation of shrinkage during graphitization and reimpregnation.

During the first firing in air, the nozzle appeared white hot for approximately 35 s of the total 47-s cycle. The nozzle is shown under these conditions in Fig. 3. Calculated thermal profiles, shown in Fig. 4, are consistent with the properties of C/C and are similar to analytical estimates of larger structures.

A summary of tests performed with the subscale nozzles is presented in Table 1.

Large-scale C/C nozzles are currently under evaluation at JPL. Configurations are similar to the subscale specimens shown, with exit bell diameters of 61 cm (24 in.), overall height of 81 cm (32 in.), an 18-deg angle, and a throat diameter of approximately 7.6 cm (3 in.). A total of three such large nozzles will be test-fired under various conditions during the first half of calendar year 1973.

A lower level of interest exists for such nozzles with liquid-propellant motors. Small-scale tests utilizing pyrocarbon nozzles were performed with several propellant combinations, including fluorine-hydrazine, Flox-MMH, and oxygen-fluorine-diborane. At present, only a small C/C insulating insert is used in connection with Flox-MMH motor development, and long-term plans for improved nozzle-bell materials are still in the formative stage.

## II. INTEGRATED PROPULSION STRUCTURE

High-energy missions place a strong incentive on the weight-efficiency (mass fraction) of upper propulsion stages (Ref. 2). A four-stage system, shown schematically in Fig. 5a, contains weight contributions from interstage thrust structure, surrounding fairings, as well as from motor cases and accessories. Using the nozzles as thrust structure reduces the envelope (and firing weight) and eliminates preexisting thrust structure as shown in Fig. 5b. Reshaping the motor case allows each stage motor case to be nested within the nozzles of the next stage, further reducing envelope dimension as shown in Fig. 5c. The double wall of nozzle and motor case may be replaced by a single dual-purpose shell, shown in Fig. 5d. This configuration has been termed the "conesphere" concept, and is shown in Fig. 6. The principle of operation is to separate, by a shaped explosive charge, the spent stage at the point indicated on Fig. 6. The remaining portion of the motor case becomes the nozzle skirt of the next stage, and so on.

The structural material must provide very high efficiency as a relatively cool pressure-case and, subsequently, must resist high thermal stress as well as temperatures on the order of 3238 K (5000°F). The most obvious candidate material is a C/C composite. The pressure-vessel mode, as well as the requirement to transmit thrust loading and resist launch forces, demands good biaxial strength of the material. Preliminary review indicates that a 0/90 laminate is preferable to ±θ orientations; however, a radically different fabrication approach becomes necessary. In addition, the residual stress states of 0/90 systems are more extreme.

Industry sources of C/C technology have been, and are being, canvassed to determine the prospects of achieving reliable high-performance C/C structure for this application, using various material/process alternatives and orientation patterns. This survey activity is expected to continue at a moderate pace.

One of the critical feasibility questions associated with the concept is that of reliable explosive separation. Some very preliminary evaluations of shaped-charge separation were made at JPL. Effective cutting by a shaped charge depends on explosive loading, sheath material, and standoff from the target surface. These parameters must be optimized for each material and plate thickness. While metal cutting by shaped charge depends to a great extent on melting and vaporization processes, neither of these phenomena is likely to be present with C/C composites. It is necessary to develop methods which make effective use of shock and abrasive action to achieve a reasonably clean cut of C/C composites. Results of preliminary trials of shaped-charge cutting of low-density ($\sim$1.3 g/cm$^3$) C/C are shown in Fig. 7. A slight restraint, characteristic of a real structure, appears to be sufficient to prevent extended delamination. Higher density material ($\sim$1.7 g/cm$^3$) is shown in Figs. 8 and 9. Higher charge densities were used at two standoff locations. These preliminary trials suggest that shaped-charge cutting of C/C is feasible, and that fairly good control of the cut edge could be achieved for low-density material. Further experimental development is needed, but prospects for achieving useful separation techniques appear good.

## III. ATMOSPHERIC ENTRY SHELLS

Planetary probes involve high-velocity atmospheric entry and the requirement for thermal protection of the payload, as well as maintenance of structural integrity and predictability of flight path. The type of entry shell considered at JPL is depicted schematically in Fig. 10. General structural features shown are the optionally separate nose piece, skirt-stiffener at the outer periphery, and an intermediate ring for hard-point attachment.

Figure 11 shows structural detail of developmental concepts based on light-core sandwich structure to optimize shell flexural stiffness and buckling resistance. Figure 11 also indicates a heat shield material which may be up to 1.25 cm (0.5-in.) thick. There is interest in the potential of C/C integral sandwich for a multipurpose structure which combines adequate strength and thermal stress resistance with payload insulation capability and resistance to atmospheric corrosion.

There are, at present, no specific structure development or data generation programs for this application at JPL. The state-of-the-art in complex C/C structure, and mofidied C/C for corrosion protection, is being monitored.

## REFERENCES


1. Bailey, R. L., and Shafer, J. I., "An All-Carbon Radiating Nozzle for Long-Burning Solid Propellant Motors," JPL Quarterly Technical Review, Vol. 1, No. 2, p. 36, Jet Propulsion Laboratory, Pasadena, Calif., July 1971.

2. Nakamura, Y., and Shafer, J. I., Solid Propulsion Advanced Concepts, Technical Memorandum 33-534, Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1972.

Table 1. Static-firing test conditions and results

| Item | All-carbon nozzles Test 1 (SN-1) | Test 2 (SN-1) | Test 3 (SN-2) | Ablative nozzle |
|---|---|---|---|---|
| Propellant weight, kg | 26.65 | 25.42 | 26.65 | 27.57 |
| Simulated altitude, km | Sea level | Sea level | 15.90 | 15.90 |
| Motor burning time, s | 47 | 45 | 48 | 20 |
| Nozzle expansion ratio $\epsilon$ | 53.5 | 40.3 | 40.4 | 35 |
| Maximum chamber pressure, $N/cm^2$ | 196.6 | 146.3 | 157.4 | 172.5 |
| Nozzle weight, kg | | | | |
| Initial | 1.069 | 0.909 | 0.987 | 1.981 |
| Final | 0.928 | 0.869 | 0.924 | 1.776 |
| Throat diameter, cm | | | | |
| Initial | 2.533 | 2.920 | 2.916 | 4.445 |
| Final | 2.635 | 2.998 | 2.954 | 4.465 |

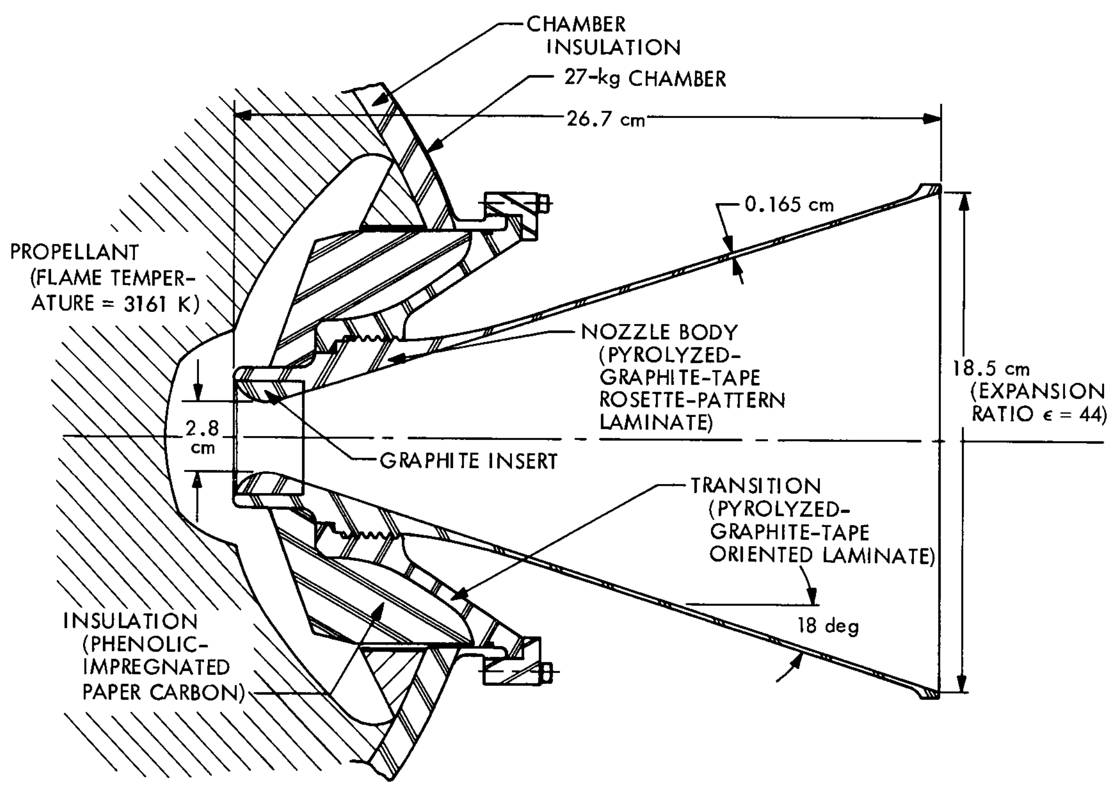


Fig. 1. Configuration of all-carbon nozzle for feasibility testing

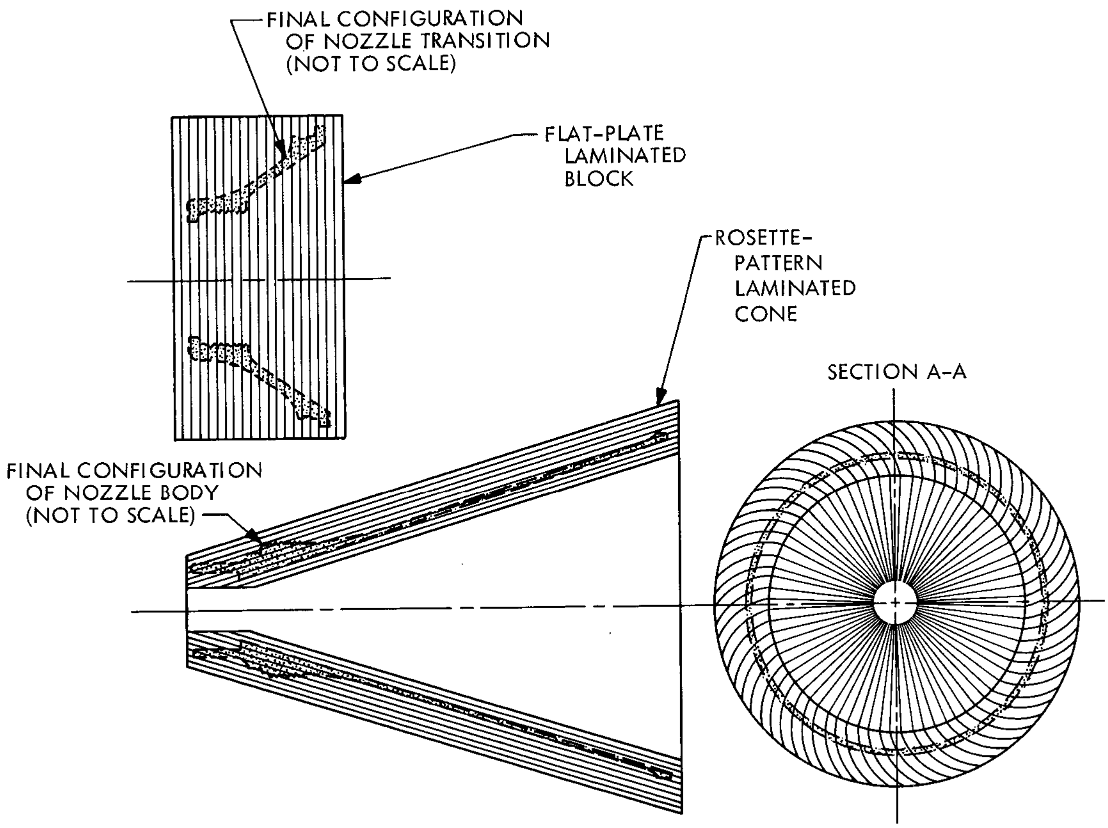


Fig. 2. Layup step in nozzle transition and body fabrication

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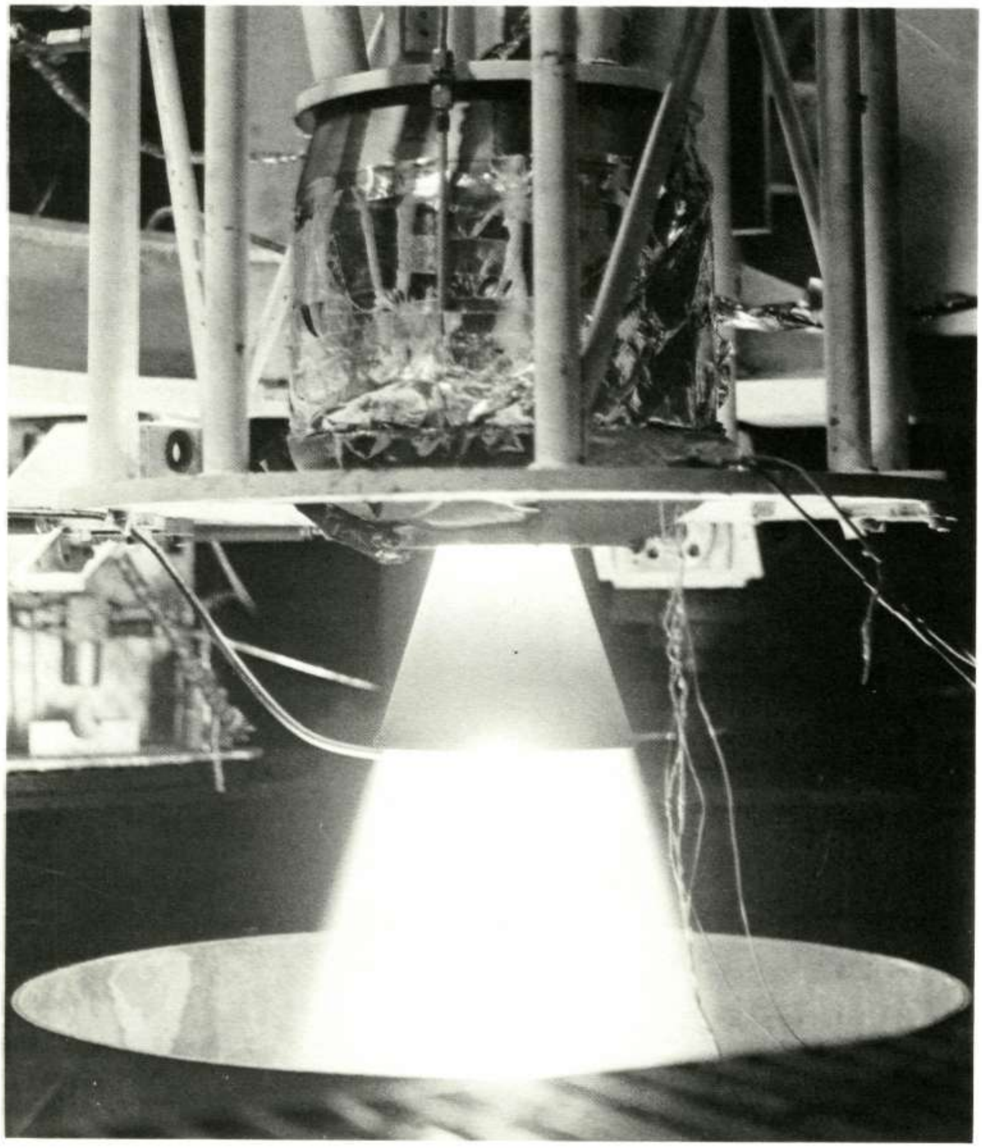

Fig. 3. C/C nozzle during firing

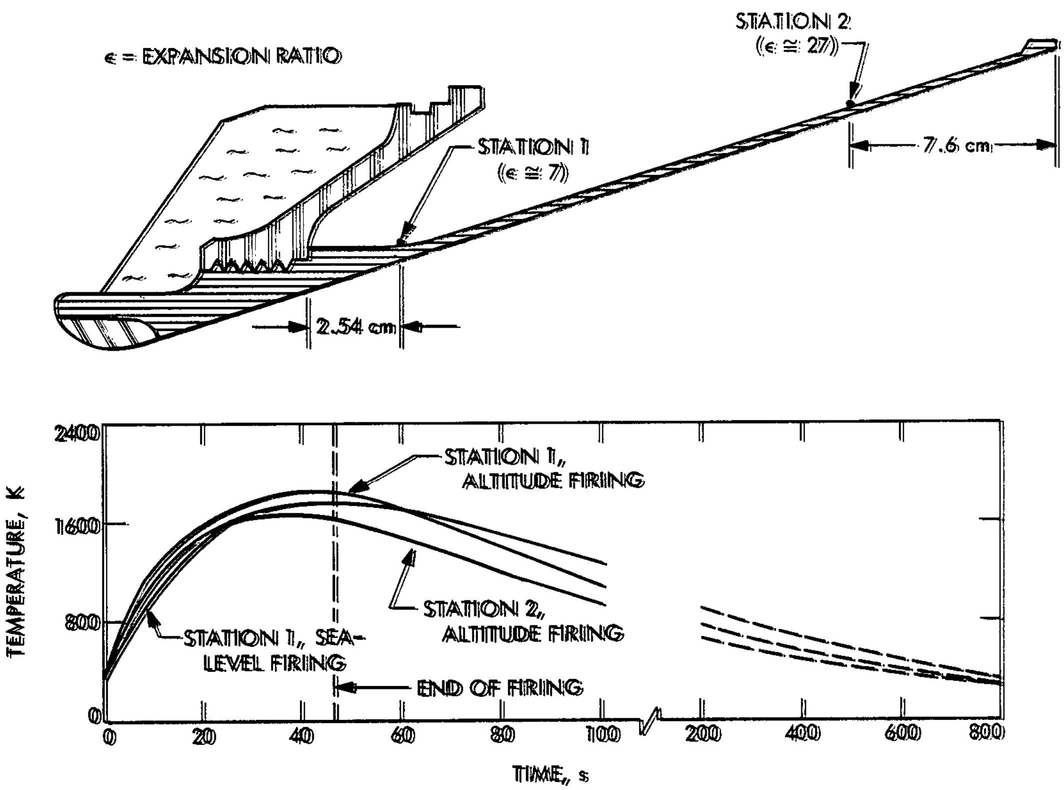


Fig. 4. Measured nozzle surface temperatures during and after static firing of flight-weight motor

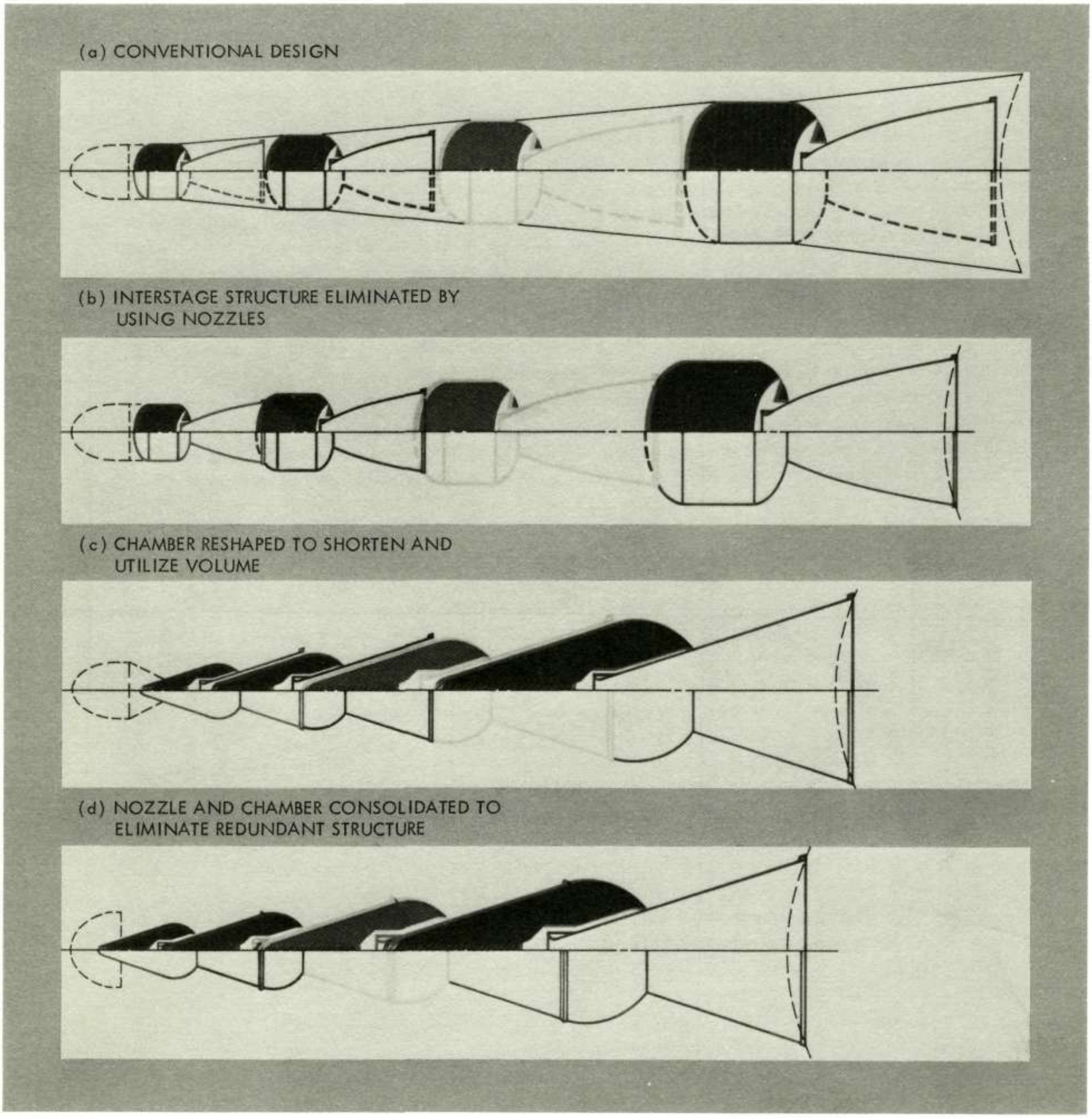


Fig. 5. Evolution of conesphere concept

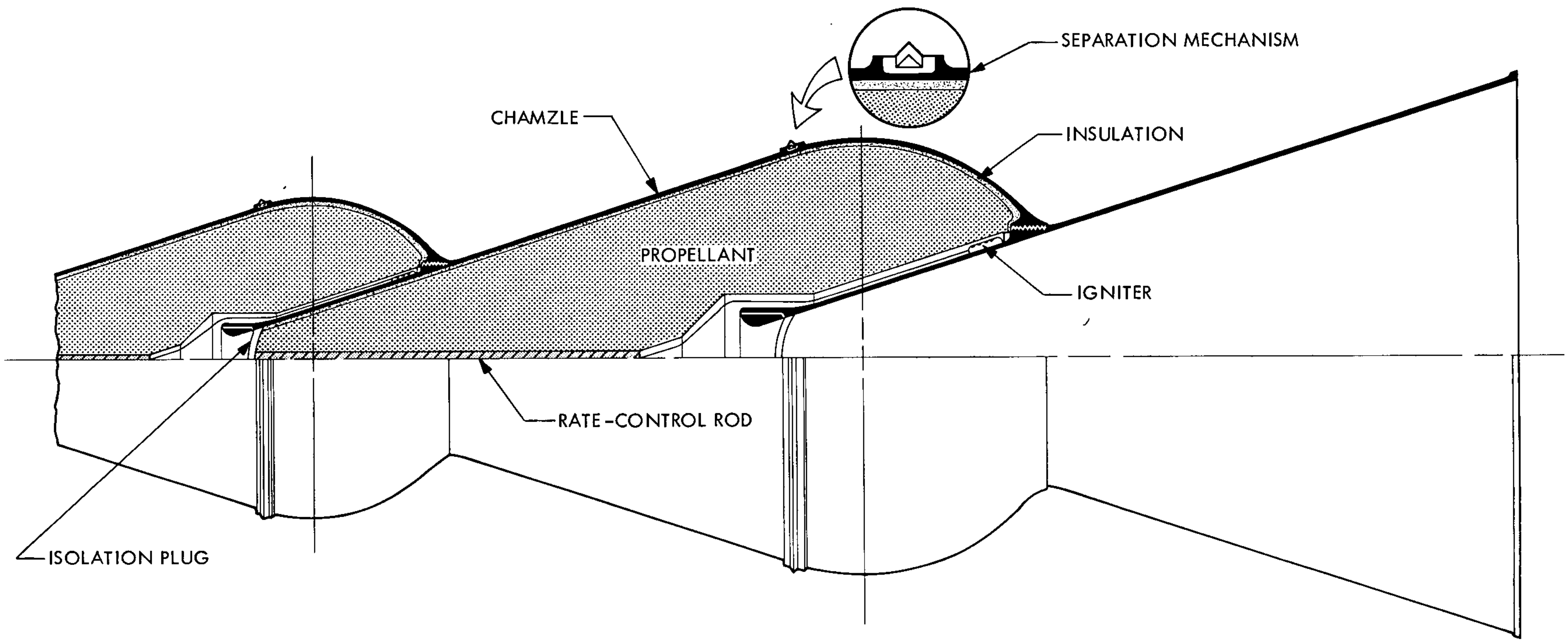


Fig. 6. Conesphere motor

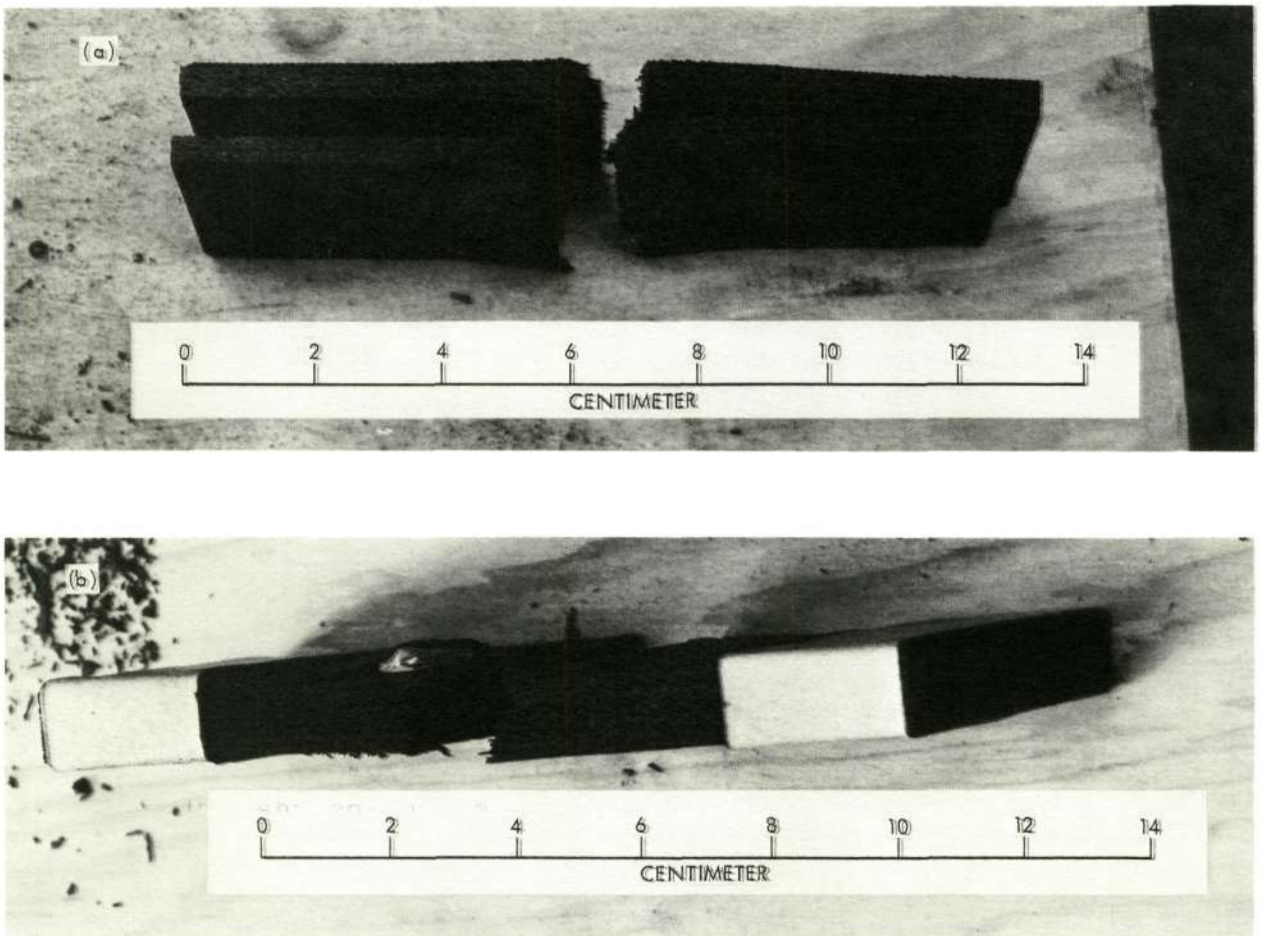


Fig. 7. C/C sample (5-gr silver 0.16-cm (1/16-in.) standoff, low-density) after shaped-charge cutting: (a) sample 1, (b) sample 2

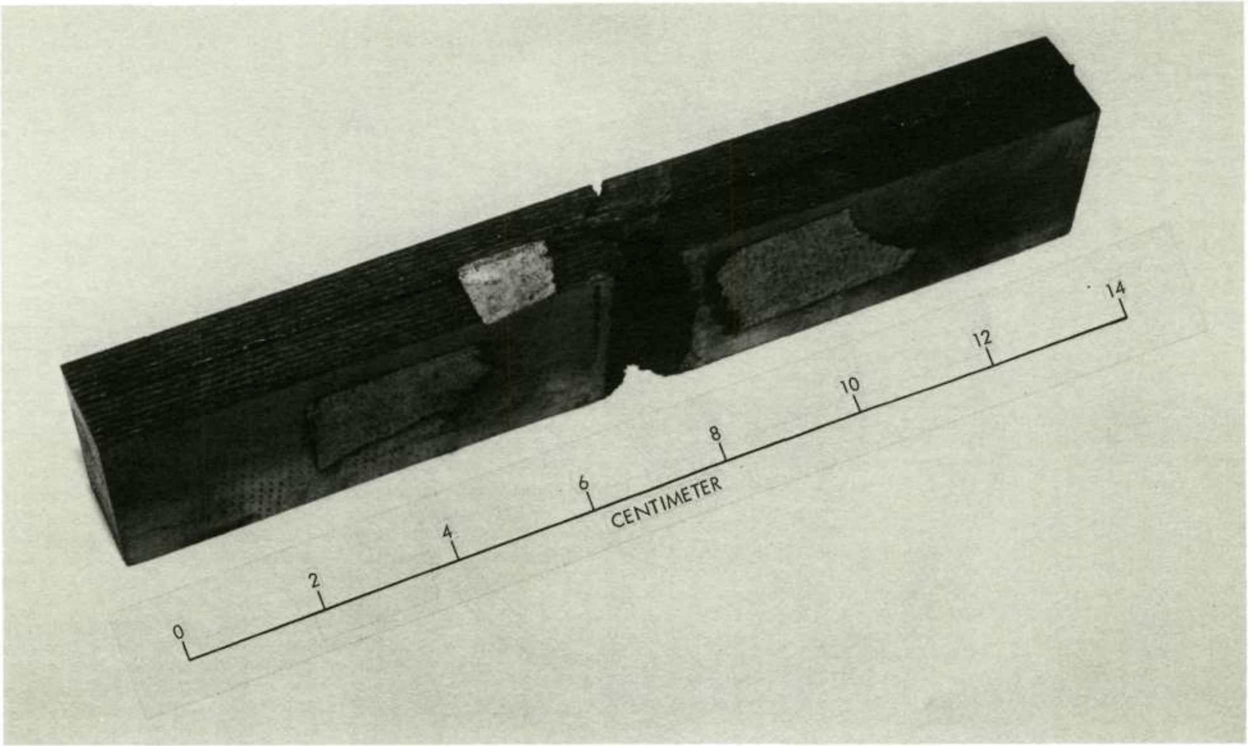


Fig. 8. C/C sample (15-gr lead sheath 0.32-cm (1/8 in.) standoff high-density) after shaped-charge cutting

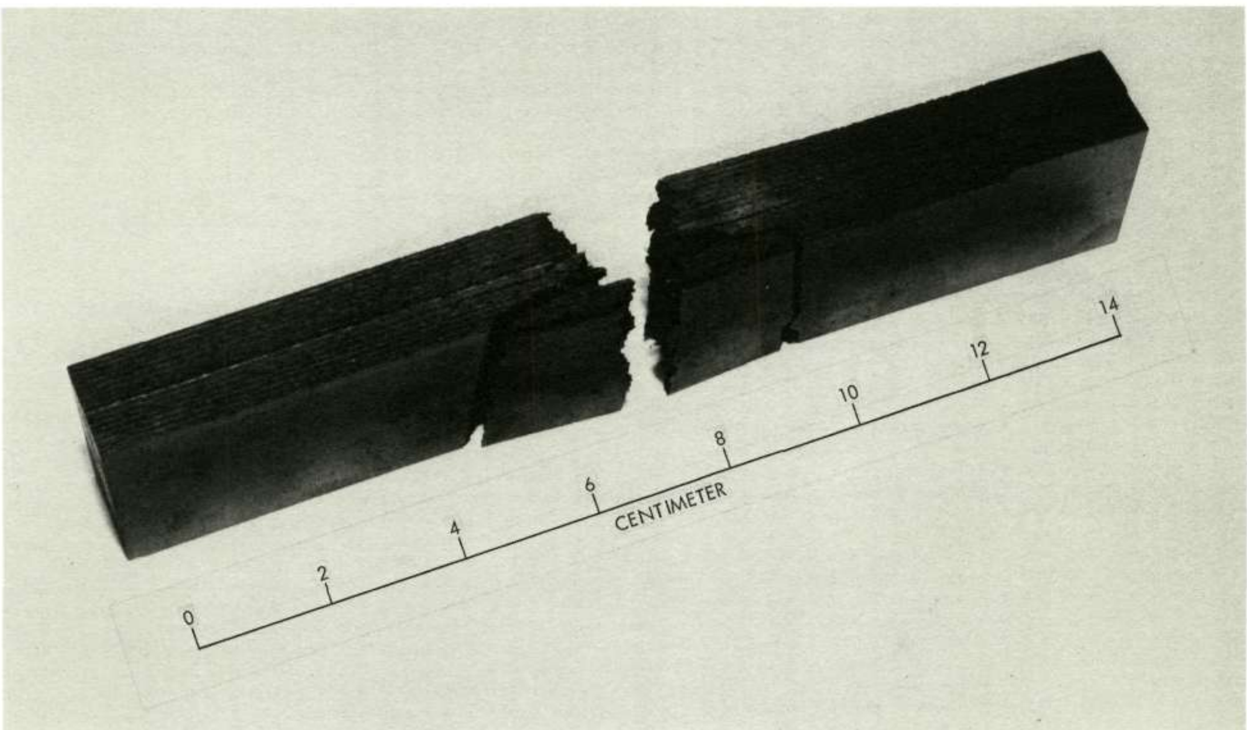


Fig. 9. C/C sample (15-gr lead sheath, 0 standoff high-density) after shaped-charge cutting

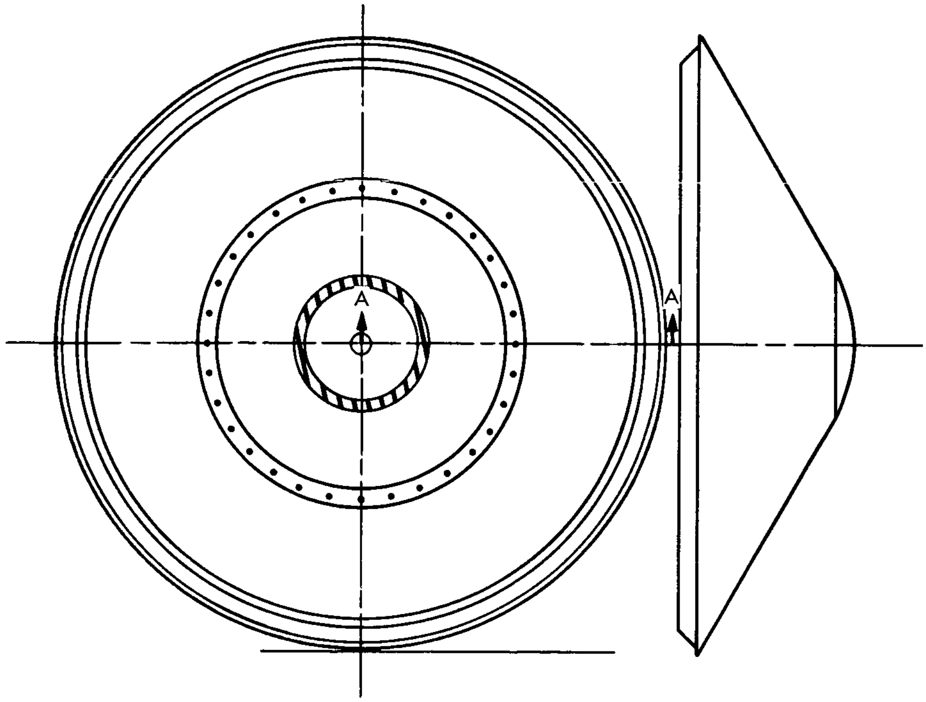


Fig. 10. Typical entry shell configuration

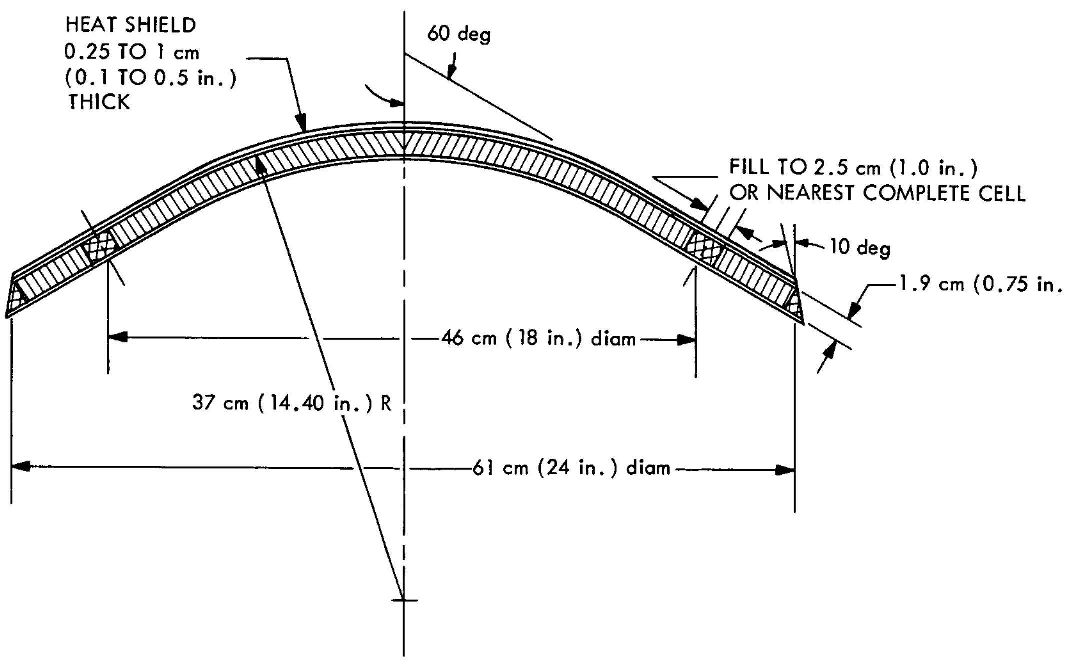


Fig. 11. Schematic of small doubly curved developmental aeroshells


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