may be defined from the ratio of the measured increase in drag for a slotted flare to the calculated increase in drag for an unslotted non-separating flare ($\Delta C_{D_m}/\Delta C_{D_c}$).

Conclusions

Conical slotted or unslotted flares create drag without lift. Models with fixed spoilers show a strong coupling between lift and drag. Cylindrical bodies with spikes permit a wide variation of drag and independent variation or adjustment of lift forces if changes in spike length and spike deflection angles are considered.

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Astrobee D: An Advanced Technology Meteorological Rocket Vehicle

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SPACE General Company, a Division of Aerojet-General Corporation, conducted a study for NASA in 1968 to apply advanced propulsion techniques to small rocket vehicles for low-cost, high-reliability soundings in the near-Earth region 50 km–140 km (D region for physics and synoptic meterological applications). Existing propulsion units capable of operation in this region were deemed to be too large, too expensive or unreliable. Emphasis was placed on the investigation of new propulsion techniques, including self-pressurizing and monopropellant liquids, and long-burning solids.

Ground rules selected for this study on the basis of mission analysis were as follows: a) single stage, dual-thrust propulsion; b) complete vehicle weight, in meteorological configuration, not to exceed 200 lb; c) gross payload weight of 20 lb with a net useful 10 lb for the meteorological configuration; d) fineness ratio (length/diameter propulsion unit) on the order of 15–20; and e) acceleration level not over 25 g's.

In addition, optimization studies conducted at that time indicated performance, stability and dispersion requirements were optimized with a vehicle of approximately 1 sec boost at 4000 lb thrust followed by 20–30 sec of sustain thrust at a lower level.

The motor design parameters given in Table 1 were established after an extensive survey of using agencies. Although they did not meet every requirement of all agencies, they provided substantial improvements over existing systems.

Previous studies have indicated that to acheive a 140-km altitude would require either a boosted-Dart type of vehicle or a two-stage vehicle. Either staging concept reduces the inherent reliability of the system and potentially adds cost by the addition of a second stage, either inert or propulsive.

Table 1 Astrobee D design features

Boost/sustain thrust level ratio	~3:1
Maximum diam., in.	6
Max. length, in.	110
Motor wt, lb	181
Propellant wt, lb	133
Inert wt, lb	45
Duration, sec	15 minimum
Total impulse (vac 70°F) lb-sec	33,000 minimum
Temperature limits, °F	−40 to +135 −65 (goal)
Max. spin rate, rps	10
Lift-off accel. (motor +20 lb) g's	15 minimum
Max. acceleration (motor + 20 lb) g's	20 maximum
Minimum wall thickness	0.046
Performance with 10 lb of structure (include fins, ogive, shroud) ft	10 to 450,000 minimum

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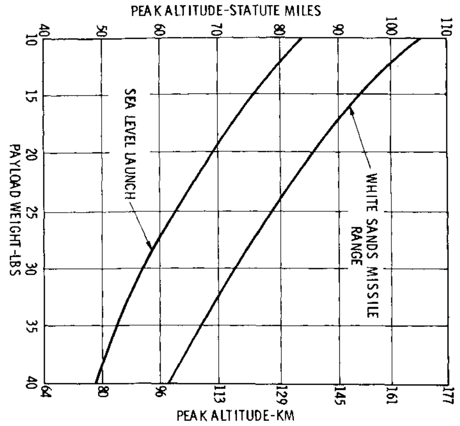

Fig. 1 Astrobee D peak altitude vs payload weight, $QE = 86°$.

The excellent mechanical properties, high impulse, and the burning rate control of the Aerojet-developed HTPB (hydroxyl terminated polybutadiene) propellant provided the basis for a propulsion system which could achieve both a high initial thrust for reduction of wind effects as well as an extended sustainer burning time approaching that achieved by end-burning rockets. Performance of the Astrobee D is shown in Fig. 1.

Careful design of the forward attachments and the nozzle area has resulted in a clean aerodynamic design with a minimum of weight required for attachments of the payload and ogive and the stabilizing fins (see Fig. 2). The fin attachments are integral with the nozzle and yet provide for convenient adjustment of the fin assembly for selection of roll rate. The Astrobee D is designed to fly at either a 1 cps or a 10+ cps roll rate, depending upon payload weight and mission requirements.

After tests to determine the characteristics of various plastics and metallic materials, magnesium was selected as the fin material for the initial flight tests. The fin shape was a compromise between the requirements for low drag and good aeroelastic behavior. To minimize the thermal effects on the magnesium, a small stainless-steel cuff was attached to the leading edge. The fin panels were sprayed with a 0.010-in. coating of an ablation material.

To minimize weight and drag, the forward launch lug was designed to separate from the rocket subsequent to its release from the launcher. The aft lug remains affixed to the aerodynamic fairing in the nozzle area.

Solid Rocket Motor Design

Aerojet Solid Propulsion Company (ASPC) participated in the second phase of the previously cited program and provided a preliminary motor design based on existing propellant formulations that would meet the propulsion system criteria. This motor design required multiple cartridge-loaded grains because of propellant mechanical-properties constraints. Subsequent evaluation of this concept indicated it was not as cost-effective, nor did it have the inherent reliability desired. Therefore, a design study was conducted. The key criteria which evolved from the low-cost, high-reliability philosophy were: 1) keep the number of component parts to an absolute minimum, 2) use the lowest cost raw materials wherever possible, 3) minimize the processing and handling steps required in manufacturing, and 4) design so that a) manufacturing variables would not cause the motor to exceed performance criteria limitations, and b) a minimum amount of quality control would be required.

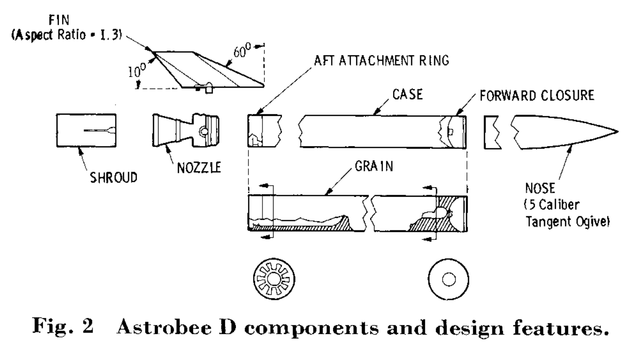

Fig. 2 Astrobee D components and design features.

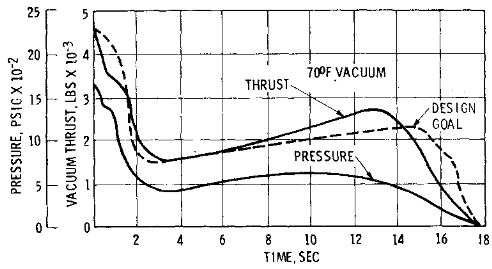

Fig. 3 Astrobee D vacuum thrust vs time goals.

A cylindrical-port grain configuration with radial fins in the aft end was selected for low cost, ease of processing and high volumetric loading. This grain design provides the dual thrust capability to meet a 17-g minimum lift-off thrust, and the lower sustain thrust and extended burning time required to reduce drag losses and minimize heating problems.

The motor case is made from 4130 alloy steel with a minimum ultimate tensile strength of 180,000 psi. The forward head assembly, the cylindrical portion and the aft closure are welded together after each part has been individually heat treated to eliminate heat-treat distortion.

The internal insulation system consists of a CTPB (carboxyl terminated polybutadiene) polymer which acts as a combination liner and insulation. Insulation thickness varies along the length of the chamber sidewall for varying

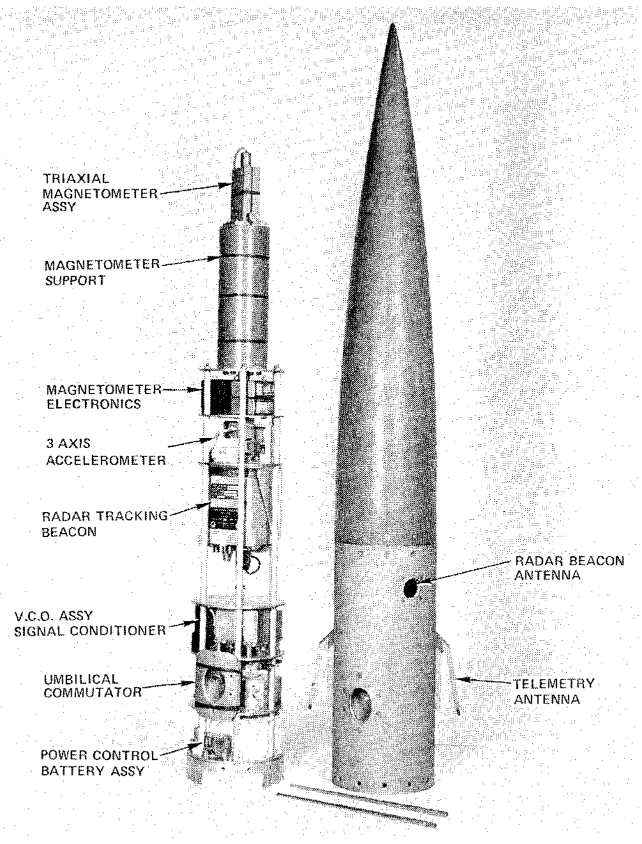

Fig. 4 Astrobee D diagnostic payload and nose cone.

Table 2 Flight test results

Parameter	Astrobee D No. 1 Predicted[a]	Astrobee D No. 1 Actual	Astrobee D No. 2 Predicted[a]	Astrobee D No. 2 Actual
Weight, lift-off, lb	226.1	227.0	226.1	227.5
Motor weight, lb	181.0	181.2	181.0	181.0
Payload weight, lb	32.5	33.2	32.5	33.2
Length, in.	154.0	154.0	154.0	154.0
Burnout velocity, fps	5,070	4,910	5,070	5,050
Burnout altitude, ft	39,250	44,500	39,250	43,500
Apogee altitude, kft	320.0	320.5	320.0	320.0
Apogee time, sec	146.4	147.3	146.4	147.1
Impact range, kft	205.0	179.5	205.0	224.0
Impact time, sec	296.5	298.0	296.5	297.0
Effective *QE*, deg	82.4	83.3	82.4	81.6
Maximum roll rate, cps	10.6	11.9	10.6	12.2
Maximum acceleration, boost, *g*'s	19.5	24.3	19.5	21.8
Maximum acceleration, sustain, *g*'s	19.0	No data	19.0	19.0
Impact miss distance, statute miles	...	2.3	...	2.3
Maximum inside wall temperature (tip)	...	392°F	...	370°F
Nose cone Sta. 18.5 with coating	...	311°F	...	332°F
Nose cone Sta. 18.5 without coating	...	351°F	...	No data

[a] Predicted data do not reflect corrections for launch site wind conditions and thus dispersion may not be inferred from this table.

degrees of protection, depending on the exposure time to hot exhaust gases. This material is also used to insulate the forward dome by potting the liquid material in place along with a thin sheet of vulcanized rubber which has a release agent on one side to act as a stress relief boot.

Motor ignition is accomplished by a simple, inexpensive, pellet-type igniter that is installed from the aft end of the motor and pushed to the forward end of the motor, where it is held in place by an open cell foam washer. Full motor thrust is achieved in 0.08 sec. Figure 3 shows that the average boost thrust is 3916 lb for 1.6 sec and sustain thrust is 1710 lb for 16 sec. Total vacuum impulse is 34,800 sec.

The dual-thrust nature of the motor resulted in a large plenum area at the aft end of the motor which would be subject to high heat transfer during the duration of the sustain portion. For the initial firings this area was insulated with molded rubber. Lower-than-expected erosion of insulation permitted substitution of linear for the rubber insulation on subsequent rounds.

Ten motors were built. Five were static fired on a spinning test facility; three were static fired nonspinning; and two were delivered for flight. Two of the eight static test rounds were anomalous in behavior. Round 2 had the igniter placed in the aft chamber area. On ignition, the igniter in the main ignition charge was expelled through the nozzle. This resulted in a hang-fire. Motor 7 was rejected after manufacture because of insufficient liner thickness. This motor was static-fired in nonspinning condition to determine the useful life of the subthickness liner. The remaining six static motors performed within specification.

Motor 6 was subjected to two full cycles from −40°F to +135°F and subsequently fired at ambient conditions. No separations or grain structural failures were observed, nor did the ballistics differ from the other motors in the same batch. Additional work, including low and high temperature firings, will be required to establish the operational temperature limits.

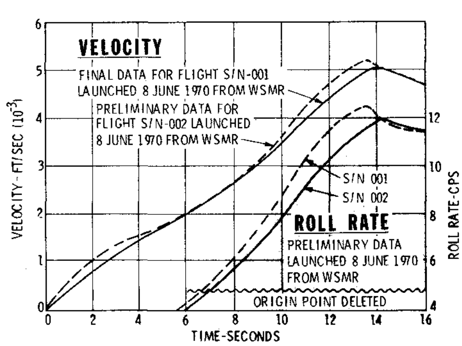

Fig. 5 Astrobee D velocimeter and roll rate vs time history data.

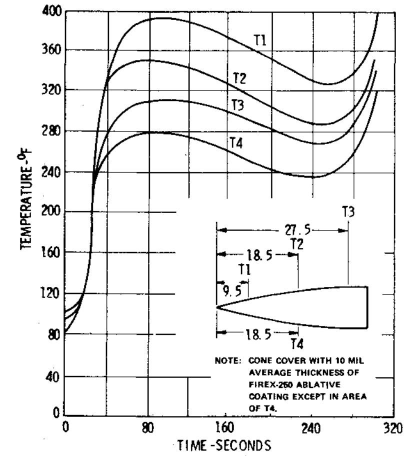

Fig. 6 Astrobee D temperature transducer locations in nose cone and flight S/N-001 data.

Flight Test Results

The two demonstration flight tests were conducted at the White Sands Missile Range on June 8, 1970. Range services were provided by the U.S. Army, White Sands Missile Range. Modification of the launcher, field services, and assembly support were provided by the U.S. Navy Missile Ordnance Test Facility. Materials and fabrication of the diagnostic payload were jointly supported by the Air Force Cambridge Research Laboratories and the NASA Goddard Space Flight Center. Table 2 shows a comparison of predicted and actual conditions for the two flight tests.

Figures 4–6 show various parameters measured during the flight tests. The instrumented payloads performed well with the exception of a VCO failure on the axial acceleration channel of Flight No. 1, one temperature gage which was damaged on installation, and an inoperative magnetometer for which no replacement was available. Flight-test results may be summarized as follows: 1) all test objectives were achieved; 2) vehicle performance was as predicted; 3) vehicle dynamic and aerodynamic stability was excellent; 4) there was no measurable coning in space; 5) impact dispersion was very low; 6) the nose and fin thermal coatings performed well; 7) vehicle roll rates were slightly higher than predicted but were consistent with each other; 8) no aerothermal-structural problems were observed; 9) diagnostic payloads returned excellent data on both rounds.

A second series of flight tests was conducted with meteorological payloads from NASA Wallops Island, Va., in January 1971. Six rounds were fired with 100% vehicle success. Five rounds fired at *QE*'s of 75 ± 1° achieved apogee altitudes of 425,000 ft ± 10,000 ft. One round fired at 80° *QE* achieved a 480,000-ft apogee. The payloads, which carried no telemetry, ejected 1-m Robin balloons at apogee. These payloads weighed 9.1 lb.

Operation of the Astrobee D at sea level with light payloads and in high winds (40 fps ballistic wind) was confirmed. No data other than radar performance were obtained on these rounds.