research report

DESIGN OF THE SANDIA HIGH-ALTITUDE SAMPLER ROCKET SYSTEM (HAS)

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ABSTRACT

This report presents the characteristics incorporated in the design of a ballistic rocket system that is capable of carrying recoverable payloads varying in weight from 75 to 200 pounds to altitudes of 600,000 to 1,000,000 feet (msl).
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<td>$C_{D_w}$</td>
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<td>$C_f$</td>
<td>Skin friction-drag coefficient</td>
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<td>$M$</td>
<td>Mach number, $\frac{V}{C}$</td>
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<td>$r$</td>
<td>Fin thickness ratio</td>
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<td>$L$</td>
<td>Body length or reference length, ft</td>
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<td>$K_s$</td>
<td>Equivalent sand-grain diameter</td>
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<td>$\kappa$</td>
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<td>$K_B$</td>
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<td>$K$</td>
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<td>$\delta$</td>
<td>Nose-section drag-brake angle, deg.</td>
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<td>C. P.</td>
<td>Center of pressure, in.</td>
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LIST OF SYMBOLS (cont)

\[
\begin{align*}
\alpha & \quad \text{Angle of attack, deg.} \\
\left( C_{M_{\alpha}} + C_{M_{\theta}} \right) & \quad \text{Pitch damping coefficient, } \frac{1}{\text{rad}} \\
S_t & \quad \text{Total fin area projected on the longitudinal plane for two fins, ft}^2 \\
S & \quad \text{Reference area (cross-sectional area } \pi d^2/4), \text{ ft}^2 \\
L_t & \quad \text{Distance from fin C. P. to rocket C. G., ft} \\
T_{1/2} & \quad \text{Time required for an oscillation to damp to half amplitude, sec} \\
I & \quad \text{Pitch moment of inertia, slug-ft}^2 \\
q & \quad \text{Dynamic pressure, lb/ft}^2 \\
V & \quad \text{Flight velocity, ft/sec} \\
a_E & \quad \text{Re-entry or entrance angle of attack, deg.} \\
k_2 & \quad \text{Static-stability parameter} \\
k_1 & \quad \text{Dynamic-stability parameter} \\
\beta & \quad \text{Altitude constant, } \frac{1}{22,000} \text{ ft}^{-1} \\
y & \quad \text{Altitude measured from sea level, ft} \\
P & \quad \text{Pressure at prescribed altitude} \\
P_o & \quad \text{Sea-level pressure, lb/ft}^2 \\
G & \quad \text{Shear modulus, lb/in.}^2 \\
T & \quad \text{Temperature, } ^\circ\text{F} \\
\lambda & \quad \text{Taper ratio} \\
X & \quad \text{A parameter which is a function of panel aspect ratio and thickness ratio (used in aeroelastic calculations) lbs/in.}^2
\end{align*}
\]
SUMMARY

This report summarizes the aerodynamic, mechanical, and electrical design characteristics that were employed in the development of the Sandia High-Altitude Sampler Rocket System (HAS). It presents wind-tunnel-test data and a detailed discussion of the estimation of aerodynamic parameters for the three stages of the HAS rocket system. It includes typical flight trajectories, animated trajectory and physical characteristics of the vehicle, and the method and design used for recovery of the nose section. Comparison of the estimated aerodynamic parameters with wind-tunnel-test data is made and in general shows good agreement. No attempt is made to present performance characteristics, since they are already documented in SCTM-401-60-(71).
CHAPTER I -- THE HAS ROCKET SYSTEM

Introduction

The HAS rocket system was developed as a high-altitude research rocket capable of carrying a recoverable payload, varying in weight from 200 to 75 pounds, to altitudes of 600,000 to 1,000,000 feet msl (see Frontispiece). The system consists of a solid-propellant, three-stage ballistic rocket. The first stage constitutes a Nike I M-5 booster; the second stage consists of six Viper I-B motors in an annular cluster; the third stage is a seventh Viper I-B that fits inside the cluster. The third-stage nose utilizes drag doors, a parachute, and a flotation system for nose (payload) recovery from water. The vehicle follows a ballistic trajectory from initial boost phase till nose separation, at which time (a few seconds after apogee) four nose drag doors are opened. The nose re-enters the atmosphere with the drag doors extended and slows down to approximately 540 feet per second at 30,000 feet msl, at which point the parachute is deployed and a flotation bag is inflated. In order to minimize dispersion, the third-stage fins are canted three-tenths of a degree, which imparts an average roll rate of 6 revolutions per second to the third stage.

Five development rounds have been fired to date, in which performance, stability, separation, vibration, and other aerodynamic data have been obtained. Analysis and discussion of the rounds and the data obtained from them are presented in a separate report and therefore are not included here. This report summarizes the aerodynamic, electrical, and mechanical characteristics of the HAS rocket-system configuration. Vehicle performance and dispersion characteristics are presented in Reference 23.

Vehicle Characteristics

The HAS rocket system, (Figure 1) is a three-stage pitch- and yaw-stabilized ballistic vehicle with no roll stabilization, powered by solid-propellant motors. The first stage burns until 3.3 seconds after lift-off. Separation between the first and second stages is accomplished at approximately 3.5 seconds by differential drag between the two units. The first set of three Viper I-B motors of the second stage fire at 6.5 seconds after launch; the second set of three Viper I-B's fire after burnout of the first set, which is 12.5 seconds, and the final set of Vipers burn out at 18.3 seconds. The second-stage cluster remains intact until 21.3 seconds, at which time three explosive bolts and three pistons separate the second-stage cluster from the third stage. The third stage coasts until 27.0 seconds, at which time it fires and burns until 32.6 seconds. Nose separation is initiated a few seconds after apogee (this time varies as a function of launch angle); at this time four explosive bolts and a piston separate the nose at Station 52.40 from the rest of the third stage; simultaneously, the four drag doors on the nose are opened. The nose follows a free-fall trajectory and re-enters the atmosphere, and through the action of the drag doors keeps slowing down until, at approximately 30,000 feet (msl), a spring-loaded, 8-foot-diameter solid parachute, made of alternate gores of
orange and silver metallized material, is deployed by the action of a pressure switch and an explosive wire cutter. Simultaneously, a 2-cubic-foot Mylar, tetrahedron-shaped flotation bag with nylon webbing is inflated through the use of carbon dioxide gas (Figure 9). Also, at this instant, radar chaff that has been packed with the parachute is released for radar tracking. As soon as the parachute section of the nose hits the water, a sea dye composed of a mixture of carbowax and fluorescent dye is released. This dye produces a greenish-yellow slick that lasts from 8 to 12 hours. These events are depicted in Figure 2.

A Nike I M-5 motor is used for the first stage, a cluster of six Viper I-B motors is used for the second stage, and a Viper I-B motor is used for the third stage. Power-plant characteristics are listed in Table I, and typical static-test thrust curves are presented in Figures 3 and 4 for the Viper I-B and the Nike M-5 motors, respectively. Typical variations of weight, center of gravity, and pitching moment of inertia, with flight time (for the individual stages) are shown in Figures 5, 6, and 7, respectively. The exact weight, center of gravity, and moment of inertia vary from rocket to rocket; however, these variations with time should be essentially as pictured.

All three stages are fin-stabilized. The first stage employs the three standard Nike I M-5 booster trapezoidal double-wedge fins. The second stage consists of three built-up fins with a sweepback of 45 degrees, and a modified double-wedge section. The fins were made large enough to provide the necessary damping and static stability to the second stage; also they were made structurally sound to avoid bending torsion-type flutter. Three slab, single-wedge-section fins are used to stabilize the third stage. The fins are canted one-third of a degree, in order to provide spin to the third stage, thus minimizing dispersion. Four conical drag doors on the nose section provide the necessary drag to slow down the nose after it re-enters the atmosphere to provide for parachute deployment. In the launch configuration, the fins of the Nike booster and the second stage are in line, and the fins of the third stage are interdigitated with the second stage and the Nike booster.

The nose section consists of a 3/4-power ogive nose cone (Figure 10) with a short cylindrical afterbody, followed by a conical boattail. The nose section houses the telemetry instrumentation, radar beacon, parachute, flotation bag, and recovery aids (Figure 8).

Typical Flight Trajectory

A summary is presented here of the general performance capabilities of the HAS vehicle.

The IBM 704 EDPM rocket-trajectory program was used in computing the vehicle trajectory. This program is designed to compute the trajectory for any number of stages of a rocket starting from any point in space with any initial velocity, provided the characteristics of the rocket (drag, thrust, etc.) are known. The trajectories are calculated in a two-dimensional plane, and Coriolis effect is neglected. The basic Newtonian equations of motion are used to determine the vehicle trajectories. These equations are:

\[
\frac{dV}{dt} = \frac{T}{M} \cos \alpha - \frac{C_D \rho S V^2}{2M} - g \sin \theta
\]
\[
\frac{d\theta}{dt} = - \frac{(T/M \sin a + g \cos \theta)}{V}
\]

\[
\frac{dh}{dt} = V \sin \theta
\]

\[
\frac{dR}{dt} = V \cos \theta.
\]  \hspace{1cm} (1)

with the initial conditions:

\[
h(t_0) = h_o
\]

\[
R(t_0) = R_o
\]

\[
V(t_0) = V_o
\]

\[
\theta(t_0) = \theta_o
\]

\[
t_0 = 0.
\]

The differential equations are solved numerically through the use of the Runge Kutta method. The calculated trajectory uses the 1959 ARDC atmosphere to obtain the local atmospheric properties such as temperature and pressure. Trajectories depicting the general performance capabilities of the HAS vehicle have been calculated for various launch angles (Figures 11 through 13). These trajectories were calculated for sea-level launchings.
Figure 1. Typical Configuration, Three-Stage HAS Vehicle
Figure 2. HAS Animated Trajectory

1st Stage Separation

2nd Stage Separation

3rd Stage Separation

Nose Separation

3rd Stage Motor

Nose Section

Parachute Deployment

NOTE: Trajectory Not to Scale
Figure 3. HAS Typical Viper I-B, Thrust-versus-Time Curve, 60°F
Figure 4. HAS Typical Nike I M-5 Booster, Thrust-versus-Time Curve
Figure 5. HAS Weight Variation During Burning versus Time
Figure 6. HAS Weight Variation versus Center of Gravity
Figure 7. HAS Pitching Moment of Inertia versus Time (sec)
Figure 8. HAS Nose Section
Figure 9. HAS Nose Section Recovery System
\[ r = K \left( x \right)^{3/4} \]

where: 

\[ K = \frac{4.5}{(27)^{3/4}} = 0.3812 \]

Figure 10. HAS High Supersonic 3/4-Power Ogive
Figure 11a. HAS Trajectory, Altitude versus Range
Figure 11b. First-Stage Booster Trajectory, HAS Rocket, Altitude versus Range
Figure 11c. Second-Stage Booster Trajectory, HAS Rocket, Altitude versus Range
Figure 12a. Nose and Third-Stage Impact Trajectories, $\Theta = 75$ degrees
Figure 12b. HAS Trajectory, Velocity versus Time
Figure 12c. First-Stage Booster Trajectory, HAS Rocket, Velocity versus Time
Figure 13a. Second-Stage Booster Trajectory, HAS Rocket, Velocity versus Time
Figure 13b. HAS Payload Weight versus Altitude
Figure 13c. HAS Nose (Drag Doors Extended), Altitude versus Velocity
### TABLE I

**ROCKET-MOTOR CHARACTERISTICS**

#### Nike I M-5 Booster Motor

**Performance (sea level)**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Average thrust (77°F)</td>
<td>43,000 lb</td>
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<tr>
<td>Action time of burning (77°F)</td>
<td>3.3 sec</td>
</tr>
<tr>
<td>Total impulse</td>
<td>141,900 lb-sec</td>
</tr>
<tr>
<td>Specific impulse (77°F)</td>
<td>197.9 sec</td>
</tr>
<tr>
<td>Total impulse initial weight</td>
<td>71.7 sec</td>
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**Weight (lb)**

<p>| | |</p>
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<tr>
<td>Propellant</td>
<td>738</td>
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<td>Case</td>
<td>257.3</td>
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<tr>
<td>Nozzle</td>
<td>96.0</td>
</tr>
<tr>
<td><strong>Total Weight</strong></td>
<td><strong>1,091.3</strong></td>
</tr>
</tbody>
</table>

#### Viper I-B Motor

**Performance (sea level)**

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Average thrust (60°F)</td>
<td>5,411 lb</td>
</tr>
<tr>
<td>Action time of burning (60°F)</td>
<td>5.6 sec</td>
</tr>
<tr>
<td>Total impulse (60°F)</td>
<td>30,302 lb-sec</td>
</tr>
<tr>
<td>Specific impulse (60°F)</td>
<td>211.5 sec</td>
</tr>
<tr>
<td>Total impulse initial weight</td>
<td>159.2 sec</td>
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**Weight (lb)**

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<td>Propellant</td>
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<td>Case</td>
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<tr>
<td>Nozzle</td>
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</tr>
<tr>
<td><strong>Total Weight</strong></td>
<td><strong>190.4</strong></td>
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CHAPTER II -- AERODYNAMIC DESIGN

Aerodynamic-Design Philosophy

The necessity of boosting or placing a specific payload at a prescribed altitude dictated the amount of impulse required to counter the nose weight and drag. Various motors and combinations could have provided the necessary impulse. However, another salient requirement was that the vehicle required to carry this payload must not only have the necessary impulse but must also be low in cost, and, if possible, use motors which are presently available. Therefore, a three-stage configuration (as described under Vehicle Characteristics) was chosen. The first and second stages were placed in tandem, and the third stage was enclosed in the second-stage cluster of Viper I motors. It was believed necessary to encircle the third stage with the second-stage cluster rather than to place it in tandem, in order to prevent any adverse aeroelastic bending effects that might result from employing too long a configuration.

The size of the payload established the minimum permissible diameter of the HAS rocket nose section. The nose fineness ratio was established by an optimization study which balanced weight against drag for various nose fineness ratios, and took into consideration the stability criteria. On this basis, the nose fineness ratio was selected on the low side of the optimum band. Having fixed the fineness ratio, the forebody shape for the nose was selected, through the use of data in Reference 5, to be a 3/4-power body. This body shape gave the minimum foredrag for a given fineness ratio. For example, it has 20 percent less foredrag than a cone of the same fineness ratio. The connection between the cylindrical portion of the nose and the third-stage motor is shaped like a conical boattail; it was designed to provide a minimum drag connection between the nose cylindrical body and the motor cylinder.

Optimization further dictated two salient design criteria, based on a weight-drag trade-off basis and on the stability criterion that the optimum three-fin-wing body combinations employed for the third and second stages should exploit low-aspect-ratio, swept-back fins with wedge-shaped airfoil sections, as established by wind-tunnel tests conducted on the HAS rocket, exploratory literature, and theoretical studies. Through these studies it was found that swept-back low-aspect-ratio surfaces have minimum center-of-pressure travel with varying Mach numbers. In addition, large increases in lift-curve slope at high supersonic Mach numbers can be obtained through the use of wedge-shaped airfoil sections. For example: 4.4 times the flat plate effectiveness (lift-curve slope) can be obtained with a surface using a wedge half-angle of 15 degrees at a Mach number of 7. Through the use of such sections, the area required to stabilize the second and third stages was greatly reduced. The Nike booster fins were fixed, as far as fin section was concerned, and no changes were made. It was found that the original second-stage fin design did not provide the required static stability, and also that the fins were susceptible to bending torsion-type flutter. Consequently, the second-stage fins were redesigned with optimization not only for stability and drag but also for the structural integrity necessary to prevent bending-torsion flutter.
The third- and second-stage fin surfaces were mounted in the extreme rear of the body, with the trailing edge in line with the base of the body. This tended to improve the fin-body interference characteristics, since the negative pressure region that is created when there is a boattail was effectively cut off, and the center of pressure of the fin-body combination was moved aft of that of the fins alone.

The second-stage fins were designed so that in the launch configuration they are in line with the fins of the Nike booster, whereas the third-stage fins are interdigitated with the second-stage and Nike fins. By placing the larger fin surfaces in line, the construction of the launcher was simplified. Also, there is little difference between the use of fins in line and interdigitated fins insofar as pitching moment and normal force coefficients are concerned. However, axial-force coefficients of in-line fin configurations are generally lower at low angles of attack than interdigitated fin configurations. This may result from the wake of the forward fins reducing the drag of the rear fins. It is believed that during the boost phase, the roll effectiveness of the forward fins (second- and third-stage fins) will be cancelled when the Nike-booster fins are in the rear. This ineffectiveness is caused by the downwash of the forward fins acting on the rear fins in a direction to counteract the rolling moment that might be produced by the forward fins. However, since the third-stage fins are canted and also interdigitated, there might be some small roll movement during boost.

The effect of high-angle-of-attack stability characteristics during the boost phase was considered for the HAS rocket. High angles of attack during the boost phase require consideration, since there is a remote possibility that these high angles may be caused by high winds, launcher tip-off, or from the necessity of operating at large angles of attack to produce sufficiently large restoring moments to counteract or overcome moments due to thrust misalignment. Also, when the succeeding stage or stages forward of the booster employ fins of low-aspect ratio, the problem of stabilizing at high angles of attack may be severely aggravated because of the large nonlinear normal force inherent with low-aspect-ratio surfaces. Limitations on the maximum allowable wind during lift-off were made in order to avoid any adverse wind effects. The launcher was designed to minimize the amount of tip-off angle that may be encountered at launch. The thrust misalignment was known to be small, and the booster aerodynamic moment was expected to be sufficient to counter the maximum misalignment.

The effect of the special stability problem that may exist because of the nonlinearity characteristics associated with the low-aspect-ratio fins of the succeeding stages (if it should become necessary to operate at high angles of attack during boost) was countered by judicious choice of booster-fin aspect ratio. Consideration of the problem of employing the proper aspect ratio on the booster fin when the succeeding stages employ low-aspect-ratio fins requires special attention. Since the stability of the combination in the launch condition originates from a rather small difference between the large stabilizing-moment contribution of the booster fins and the large destabilizing-moment contribution of the succeeding stages at high angles of attack, the increasing destabilizing normal force, coupled with the nonlinear normal force of the succeeding stages, would tend to overcome the linearly increasing, stabilizing normal force of the booster fins. The immediate solution to this problem might seem to be to increase the booster-fin aspect ratio. However, booster fins of higher aspect ratio than the succeeding stages are susceptible to earlier stall and, consequently, may promote instability of the combination at very high angles of attack, even though for the succeeding stages alone the moment contribution may be relatively linear. Therefore, the boosting of stages employing low-aspect ratio focuses attention upon the effects of booster-fin aspect ratio. Specifically, it implies the
The desirability of employing low-aspect-ratio booster fins in conjunction with low-aspect-ratio fins on succeeding stages, if it should be necessary to operate at high angles of attack. In light of the above discussion, the booster-fin aspect ratio used for the HAS rocket was properly chosen. It was found that standard Nike M-5 Jato booster fins were satisfactory; therefore, they were employed unchanged for the HAS booster.

The nose section is composed of a conical nose forebody, a short cylindrical section, and a recoverable boattail afterbody. A major aerodynamic parameter of concern was to provide the sufficient amount of drag necessary to slow the nose for parachute deployment. This was done by placing four drag doors as integral parts of the boattail. These doors not only provide the required drag but also help to stabilize the nose section, since the nose without the drag doors is statically unstable. (See Nose Characteristics, page 40, Chapter II.)

It is believed that the HAS rocket system employs an aerodynamic configuration which is approximately optimized within hardware and cost limitations. It is felt also that it has the inherent features which permit extensions of the system performance, since it can have provision for an added stage and should require little or no physical change for adequate aerodynamic characteristics at higher Mach numbers and altitudes.

Aerodynamic Characteristics

The aerodynamic characteristics of the HAS rocket configuration were determined by wind-tunnel tests in the JPL 20-inch supersonic tunnel, the Sandia Corporation tunnel, and the AEDC 12-inch tunnel, and through theoretical estimates. These tests and estimates were made for all three stages and the nose section (References 1, 2, and 21). The aerodynamic parameters obtained are discussed in the following paragraphs.

Drag

The zero-lift drag characteristics for the first, second, and third stages and for the nose section (Figures 14 through 27) were obtained from wind-tunnel data and theoretical estimates. The estimated drag characteristics are broken down into three components: wave drag, friction drag, and base drag. The drag created by each separate component of each stage is presented (Figures 15, 18 and 22), also, the effects of thrust on drag (Figures 14, 17, and 21). The first-stage booster drag after separation is shown in Figure 16.

The procedure used in estimating the wave, friction, and base drags was as follows:

Wave-drag estimates were made for the fins, flares, and nose. In the computation of fin wave drag, linear theory was used by the employment of the following equation (Reference 11):

\[ C_{Dw} = \frac{\kappa A^2}{\sqrt{M^2 - 1}}, \]  

(2)
where:

\[ C_{D_w} = \text{fin wave-drag coefficient} \]

\[ \lambda = \text{fin thickness ratio} \]

\[ M = \text{Mach number} \]

\[ \kappa = 4, \text{ for first stage (double-wedge section)} \]

\[ \kappa = 6, \text{ for second stage (modified double-wedge section)} \]

\[ \kappa = 1, \text{ for third stage (single-wedge section)} \]

The fin wave drag was corrected for the effect of sweepback. The second-stage fin wave drag was also corrected for the loss of pressure at tips. This was necessary, since the second-stage fin had to be redesigned in order to establish the necessary stability and structural rigidity required for the second stage, therefore requiring that the exact aerodynamic characteristics of the fin be known. The drag characteristics of the second stage through the use of the redesigned fin were greatly improved over the original slab fin design (Figure 19). At subsonic speeds, the fin wave drag for the first-stage booster was obtained from Reference 4. The fin wave drag for the second and third stages was assumed to be zero at subsonic Mach numbers. The estimated wave drag for the second- and third-stage fins is shown in Figures 20 and 23.

The nose ogive wave drag, which was optimized for the least drag at high supersonic speeds, was computed through the use of modified Newtonian theory (Reference 5) and is shown in Figure 27. The total nose drag and the component drag from subsonic to supersonic speeds for the nose section alone were obtained from Reference 4, and are shown in Figure 26. Also shown in this figure are the experimental drag data as obtained from the SCARF III Wind Tunnel (Reference 21). The nose-section drag was corrected for the added wave drag and decrease in base drag due to the boattail section. The nose-section drag with the drag doors extended (\( \delta = 30 \) degrees), as obtained from SCARF III data, is shown in Figure 25, along with the estimated values. The nose-section drag-coefficient variation with drag-door angle is shown in Figure 24. The data indicate the expected trend, with the lower brake angle (increase toward perpendicularity of the drag door to the airstream) giving the higher drag. These data show dips in some of the curves at subsonic speeds. The dips apparently indicate the area in which the flow separates and blankets the body cylinder and then reattaches at some speed as the result of the formation of local shocks.

In the computation of wave drag for the second-stage cone flare, the flare pressure coefficients were assumed to be equal to those on a cone with the semi-vertex angle equal to the flare angle (Figure 28). The second-stage-flare pressure coefficient was not reduced to allow for reduced dynamic pressure close to the body, caused by the strong bow shock. An estimate showed this effect to be fairly small at Mach numbers < 5 (approximately 98 percent of the cone theory). Also, the effects of boundary-layer separation ahead of the flare were ignored; this would also tend to reduce the effective angle, thus decreasing the drag. Therefore, the over-all wave-drag estimate for the cone flare was conservative.
In the estimation of skin-friction drag, the method of Reference 6 was used to calculate the skin friction for a flat plate from the imcompressible-flow theory for \( M = 0 \), and is expressed by

\[
C_f \left. \right|_{M = 0, \text{ flat plate}} = \left[ 1.89 + 1.62 \log_{10} \frac{L}{K_s} \right]^{-2.5},
\]

where

\( C_f = \) skin-friction coefficient based on wetted area

\( L = \) body length

\( K_s = \) equivalent sand-grain diameter (0.0016 was used for computation).

It was necessary to correct the expression so that it is applicable to a cylindrical body. Therefore, the following empirical relation obtained from Reference 7 was used.

\[
C_f \left. \right|_{M = 0, \text{ flat plate}} = C_f \left. \right|_{M = 0, \text{ flat plate}} \left[ 1 + \frac{60}{3FR} + 0.0025 \overline{FR} \right],
\]

where

\( \overline{FR} = \) body fineness ratio.

Through the use of the above expression, the skin-friction drag for the incompressible-flow theory (\( M = 0 \)) was calculated. However, the skin friction must be corrected because the Mach number is not zero, but the friction drag would be lower because of the effect of aerodynamic heating. Therefore, the effect of Mach number was taken into account and was estimated from the data of Reference 8. The appropriate values for the ratio of temperature at the skin to free-stream temperatures were obtained from the aerodynamic heating calculations discussed under Aerodynamic-Heating Analysis and thus used in the calculation of the skin-friction drag for the first, second, and third stages.

The base-drag estimates for burning and non-burning were based on the data of References 4 and 9.

The estimated drag data compare favorably with the wind-tunnel-test data. Most of the differences can probably be attributed to the difference between Reynolds numbers, and to boundary-layer separation at the second-stage flare which occurs predominately at \( M > 3.0 \). Both the wind-tunnel-test data and the estimated data exhibit strong variations with Mach numbers, decreasing rapidly with increasing Mach number.

**Static-Stability Characteristics at Zero Angle of Attack (Normal-Force-Coefficient Slope, Pitching-Moment-Coefficient Slope and Center of Pressure)**

The static-stability characteristics (normal-force-coefficient slope, pitching-moment-coefficient slope, and center of pressure at zero angle of attack) have been obtained for each stage and for the nose section from wind-tunnel tests and from theoretical estimates. These data are presented both comparatively and

*All pitching-moment coefficients are based about the nose (Station 0).
individually in Figures 29 through 56. The theoretical estimates were obtained by estimating the characteristics of the individual components (fins, flares, body, etc.) and then combining the results. The stability characteristics of the various components can be seen in Figures 32 through 35, 38 through 43, and 48 through 53. The wind-tunnel data were obtained from tests conducted on the various stages and on the nose section at the Sandia Corporation wind tunnel, the AEDC 12-inch tunnel, and the JPL 20-inch supersonic tunnel. The following methods were used in making the theoretical estimates.

**Fin Characteristics** -- The fin normal-force slopes at supersonic speeds were obtained for all three stages through the use of linear theory* and from References 4, 10, and 11. At subsonic speeds the normal-force-curve slopes were obtained from Reference 10. The second-stage normal-force coefficient was corrected for aspect ratio (pressure loss at fin tips) by the use of linear theory, Reference 11 (Figures 41 and 42). The fin-body interference effects at supersonic speeds were obtained from Reference 12. This same reference was used to calculate fin-body interference effects at subsonic speeds, since the slender-body-theory parameters on which this calculation is based are not dependent upon Mach number and the effect of Mach number enters only through $C_{Na}$. In calculating the fin-body interference effects, both the effect of the body on fin normal force and the effect of fin on body lift were taken into account. The latter effect was corrected for no afterbody effects, by multiplying the fin-interference lift factor by the ratio of the planar body area affected by the fin to that which would have been affected had there been an afterbody. The boundary lines for the areas had been determined by the corresponding Mach lines. See figure below.

\[
\frac{K'_B}{A'} = \frac{K_B}{A} \tag{5}
\]

\[
K'_B = K_B \frac{A'}{A}.
\]

*This solution does not take into account presence and growth of the boundary layer; however, for the high Reynolds numbers and low angles of attack encountered here, this theory should give satisfactory results."
where

\[ K'_B \text{ and } K_B \] are interference lift factors,

\[ A' \text{ and } A \] are planar body areas affected by the fin.

At subsonic speeds the afterbody effects were neglected, since there is a lesser tendency of normal force to be carried downstream at these speeds. Therefore, through the use of these interference factors the combined fin and body normal forces were obtained.

The fin pitching-moment-coefficient slopes were determined by assuming the fin normal-force center of pressure to be at 25 percent mac (mean aerodynamic chord) at subsonic speeds and 50 percent mac at supersonic speeds. The pitching-moment coefficients were based around the nose (Station 0).

**Nose Characteristics** -- The nose ogive pressure coefficient as a function surface slope was computed from Newtonian theory by the use of the following equation:

\[
C_p = 2 \sin^2 \delta,
\]

which was obtained from Reference 13 (Figure 52). The above equation is good for Mach numbers equal to or greater than 3, for the particular hypersonic similarity parameter (K) in question. Reference 13 indicates that the above equation for \( K < 1 \) gives poor results. Therefore, for supersonic Mach numbers less than 3, the Newtonian theory was modified by computing the stagnation pressure coefficient from compressible-flow theory as that behind a normal shock. The nose ogive normal-force-curve slope as a function of Mach number can then be obtained by integration of the pressure coefficient. The normal-force-coefficient slopes as a function of Mach number on the entire nose section (Figure 51) were obtained from References 14 and 15, with correction made for boattail effects. The nose normal-force data were extrapolated for Mach numbers greater than 5.

The carryover normal force on the cylindrical section aft of the nose ogive was derived from data obtained from References 14 and 15. The nose-section center of pressure without the boattail was estimated from Reference 15 (Figure 53); it indicates movement aft of the center of pressure with increase in Mach number until a maximum constant value is reached. The normal-force-slope curve (Figure 51) exhibits a dip in the transonic region; this is a typical characteristic for cylindrical bodies with roughly conical noses. This phenomenon involves the establishment of alternating positive and negative pressure areas on the cylinder when the shock pattern on the body is formed at sonic speeds. This same characteristic is evident in the center-of-pressure curve (Figure 53) where this phenomenon causes the center of pressure to suddenly move forward as sonic speed is reached, and thereafter move rapidly aft with increasing Mach number.

The aerodynamic characteristics of the nose section with the drag doors extended and closed were determined by wind-tunnel tests conducted in the Sandia SCARF III Wind Tunnel (Reference 21 and Figures 53 through 56). It can be seen from Figure 53 that the nose section is statically unstable with the drag doors closed. This is generally typical for cone cylinders, especially for this nose section, since the cylindrical portion is quite short in comparison with the conical forebody. Therefore, it can be expected that the forebody (nose ogive) contributes the major part of the total normal force, thus placing the center of pressure at
or forward of the nose-cylinder junction. This center-of-pressure forward movement in the HAS nose section is further increased by the destabilizing effect of the boattail (due to negative pressure created by the boattail). With the drag doors extended, this destabilizing effect is lessened and in some cases the nose section is statically stable (Figure 54). This is due to the stabilizing force created by the drag doors (positive-pressure region). From Figure 54 it can also be seen that the stabilizing effect improves with the decrease of δ (that is, with increase towards perpendicularity of the drag doors to the airstream) at supersonic speeds. This is understandable, since, as δ is decreased, the drag increases, and consequently, the stability effect is increased (the stability effect being dependent on the total force created by the drag doors). It is suspected from the data shown in Figure 53, where the center of pressure obtained from the wind-tunnel test corresponds at Mach numbers greater than 1.9 to the estimated center of pressure for a constant-slope cylinder (no boattail), that the flow is separating and does not follow the boattail, but instead acts like the flow on a cylinder. If this separation occurs, the destabilizing effect of the boattail decreases and the total nose-section drag increases.

As shown in Figure 54, at supersonic speeds (Mach numbers greater than 2.0) the nose section is stable only in the region corresponding to the proper δ (generally around 0 degrees). For δ's greater than 60 degrees, the nose section is unstable for all Mach numbers. It is planned to vary the drag-brake angle (δ) in flight development rounds in order to confirm the wind-test data and to define the region where the drag-stability trade-off is optimum. When the parachute is deployed during flight, the nose should be unstable; during reentry, the nose should be statically stable (provided that the proper δ is chosen).

**Body Characteristics** -- The normal-force-coefficient slope for the Nike booster body was estimated from Reference 15, using the data for the lift on a circular cylinder with a 10-degree semi-vertex-angle conical nose. The body normal-force-coefficient slopes and center of pressure of the second and third stages were obtained from the data in Reference 16 (Figures 38 and 50). In the above estimates, the body lift was assumed to be a function of only free-stream Mach number and fineness ratio. The center of pressure on the Nike booster body was assumed to be one diameter aft of the cone shoulder, although the data in Reference 15 show some tendency of the center of pressure to shift aft with Mach number; however, this variation is not well defined. Using the data of Figures 38 and 50 and the Nike booster (C_{N_a} and C. P.), the pitching-moment-coefficient slopes were calculated for the various bodies (Figure 39).

**Second-Stage-Flare Characteristics** -- The normal-force-coefficient slope (Figure 43) and the center of pressure were estimated for the second-stage-cone flare by using compressible-flow theory for a cone of the same semi-vertex angle and frontal area. The flare normal force was not corrected for reduction in flare effectiveness because of the loss of dynamic pressure close to the body, which, in turn, is caused by the strong bow shock. As mentioned previously under Drag, this effect was fairly small at Mach numbers less than 5 and was ignored. The flare center of pressure was assumed to be at one-third of the flare length ahead of the base.

**Total Characteristics** -- After the stability characteristics of the individual components of all three stages had been estimated, the pitching-moment and normal-force slopes of the various components were combined to obtain the total C_{M_a}'s and C_{N_a}'s for the three stages (Figures 29, 30, 34, 35, 44, and 45). The centers of pressure for the various stages were obtained by dividing the total C_{M_a} by the total C_{N_a} for each stage (Figures 31, 36, and 46).
The agreement between estimated stability characteristics and wind-tunnel tests for all three stages is fairly good (Figures 29 through 31, 34 through 36, 44 and 45). Over-all, the variation between estimated values and wind-tunnel values ranges from 3 percent to 15 percent, the best agreement being obtained at low supersonic Mach numbers and the worst at high supersonic Mach numbers. In general, the over-all agreement seems good. The poor agreement at high Mach numbers, in the first- and second-stage data, could be attributable to the boundary separation on the second-stage-cone flare. From schlieren photos taken in the wind-tunnel test (Reference 1), this is known to occur. This would tend to decrease the over-all flare effectiveness and thus lower the $C_{N\alpha}$ values; however, no estimate of this effect was made. Another area of possible error could be the effects of interference between the third-stage fins and the second-stage fins; this would thus cause the loss of some of the over-all effectiveness of the fins. No estimate of this effect was made. The estimated center-of-pressure values show the best agreement with the wind-tunnel values. This may be somewhat fortuitous in consideration of the previously discussed normal-force and pitching-moment slope comparison.

The static stability of the second stage is marginal at Mach numbers greater than 4 (Figure 37), where the static margin is plotted as a function of Mach number. Figure 34 shows that the second-stage body normal-force slope is greater than the fin normal force for Mach numbers greater than 2.7, and contributes approximately 60 percent of the total normal force at Mach numbers greater than 4.0. This large contribution, coupled with the forward center of pressure of the body, is a distinct disadvantage in fin-stabilizing the second stage through a large Mach-number range, even though the body center of pressure moves rearward as the normal force increases with Mach. The net effect would be to move the second-stage-configuration center of pressure forward, since the tail-fin normal-force slope remains essentially constant. This static stability at high Mach numbers should be adequate, since additional static margin could be attained, if necessary, by proper ballasting of the second stage. Also, the second stage should not exceed angles of attack $+3^\circ$ degrees. However, this problem could be further complicated, if for some cause the second stage achieves angles of attack of 10 degrees or greater, since the body normal force increases as a nonlinear function of angle at high $\alpha$'s. The static stability for the first and third stages is more than adequate (Figures 37 and 47).

Dynamic-Stability Characteristics

The dynamic-stability characteristics of the HAS rocket (Figures 57 through 62) that are considered in this analysis are the pitch damping coefficient, the pitch natural frequency, and the time required for an initial oscillation to damp to half amplitude.

The pitch damping coefficient, which is generally expressed as consisting of two terms ($C_{M\phi} + C_{M\alpha}$), was calculated by assuming that the contribution of the tail to damping in pitch overrides that of the body, and by neglecting the damping term $C_{M\alpha}$. The assumption for ignoring the damping created by the body can be justified, since the combined centers of gravity and moments are much closer to the body center of pressure than to the tail or fin center of pressure; therefore, the tail damping far outweighs the body damping.
The second assumption is justified by the fact that the HAS rocket is designed to fly as a ballistic rocket aligned in the flight direction in such a way that the angles of attack will be very small, essentially zero \((\dot{\alpha} = 0)\), so that the only motion left will be the sinusoidal motion of \(\dot{\theta}\). Therefore, through the use of these assumptions, the pitch damping coefficient was calculated from the following equation (Reference 22).

\[
C_{M_{\theta}} = 2(57.3) C_N a_t \frac{S_t}{S} \left( \frac{l_t}{l} \right)^2,
\]

where

- \(S_t\) = total fin area projected on the longitudinal plane for two fins
- \(S\) = reference area
- \(l_t\) = distance from fin C. P. to rocket C. G.
- \(l\) = reference length.

The pitch damping coefficient as a function of Mach number is shown for each stage, in Figure 57.

Since the damping force cannot produce a motion but only affect the rate at which motion takes place, a convenient way to get a significant insight into the damping force is to calculate the time required for an oscillation to damp to half amplitude. This was done for each stage by the use of the following equation obtained from Reference 22,

\[
T_{1/2} = \frac{1.386 I (2V)}{C_{M_{\theta}} q S l^2},
\]

where

- \(S\) = reference area
- \(I\) = pitch moment of inertia
- \(l\) = reference length
- \(q\) = dynamic pressure
- \(V\) = flight velocity.

The time required for each stage to damp to half amplitude for an initial oscillation is shown in Figures 58, 59, and 60 as a function of Mach number for a typical trajectory.

The damping characteristics for the first and second stages are very good. The damping for the third stage is not as pronounced as for the first and second stages; however, this is understandable, since the third stage is flying at high altitudes and high Mach numbers, thus leading to low damping forces.
The pitch natural frequency for the HAS rocket during a typical trajectory (Figure 61) was calculated. Since the pitch frequency was low, it was felt necessary to calculate the roll rate for the second and third stages. A roll-rate bandwidth was calculated for the second stage (Figure 61), based on the lower and upper limits for roll rate that would be encountered during a typical trajectory. These limits were based on maximum and minimum misalignment of the second-stage fin and on the built-in fin incidence angle on the third stage. As can be seen, it is quite possible for the second stage to experience some roll-rate pitch coupling at Mach numbers between 1.65 and 2.45 during the ascending portion of the trajectory; however, the period in which the rocket is in the bandwidth is at most 3 seconds, and it is felt that this time is not long enough to cause any adverse effects. The third roll rate was calculated also (Figure 62). This rate was based on a fin incidence angle of 0.3 degree (built-in cant for third-stage roll rate). This rate is too high to get into the adverse condition of pitch roll coupling.

No calculations for damping in roll were made. Since the vehicle is not roll-stabilized, there should be continual roll about the longitudinal axis, not only of the third stage, but also of the second stage and possibly of the first stage, due to the asymmetric loading on the fins. Also, since the vehicle has a finite moment of inertia about its longitudinal axis, the rolling motion will cause the axis of the body, when disturbed, to oscillate in pitch and yaw. In the lower atmosphere where damping forces are present, the oscillation will be at a minimum, since the vehicle is stable in pitch and yaw. In the upper atmosphere where the damping forces are very small, the vehicle will gyrate at a constant amplitude. The magnitude of this constant-amplitude oscillation is a prime function of roll rate and moment of inertia. The gyration of the vehicle may affect to a larger degree, both in amplitude and frequency, the subsequent oscillations before and after nose separation.

Stability Analysis of the Re-Entry Problem of the Nose Section

Since the HAS nose section has to re-enter the atmosphere, it is necessary to know some of its re-entry characteristics. Friedrich and Dore (Reference 17) found that when a rocket enters the atmosphere at high supersonic speeds, it is possible for the angular oscillations to become divergent. This is possible if the descent drag is of such magnitude that the decelerations are very large. There is a possibility that serious divergence of the amplitude of angular oscillation may occur. The analysis made here, to determine some stability characteristics of the re-entry nose section, is a rough estimate only, and is not intended to be exact or complete.

Through the use of the following equation obtained from Reference 18,

$$\frac{a}{a_e} = \frac{1}{\sqrt{\pi}} \frac{1}{k_2^{1/4}} e^{\beta y} \left( k_1 e^{-\beta y} + \frac{\beta y}{4} \right)$$

(9)
where

\[ a = \text{angle of attack} \]
\[ a_E = \text{entrance angle of attack} \]
\[ k_2 = \text{static-stability parameter} \]
\[ k_1 = \text{dynamic-stability parameter} \]
\[ \beta = \text{altitude constant} = \frac{1}{22,000} \text{ ft}^{-1} \]
\[ y = \text{altitude measured from sea level (ft)}. \]

The envelope curve for angular-oscillation-amplitude ratio of the nose as a function of altitude was calculated (Figure 63). As indicated by this figure and by the dynamic-stability parameter of \( k_1 = -7.0 \), the nose should be dynamically stable when it enters the atmosphere. Figure 64 depicts a rough estimate of the altitude variation of oscillations for the nose. It is seen from this curve that the nose angular oscillations should be damped fairly well at an altitude of 100,000 feet, thus indicating both static and dynamic stability of the nose.

Aeroelastic Effects

An aeroelastic analysis which includes a flutter analysis and a partial analysis of the aeroelastic effects on static stability was made on the HAS rocket. The flutter analysis was based on the method presented in Reference 19, in which a composite chart is presented (based on test data) for prediction into the bending-torsion-type flutter. This chart is based on a shape-altitude parameter and the material shear modulus. This shape parameter takes into account the fin-aspect ratio, thickness ratio, taper ratio, and altitude pressure. Through the use of this chart, in which a definite boundary divides a no-flutter region from a flutter region, the flutter boundaries for each of the stages were calculated (Figure 65). As previously mentioned under Aerodynamic-Design Philosophy, the second stage's originally designed fins were in the bending-torsion flutter region (Figure 65). The fins were redesigned into a more rigid built-up fin to give a greater shear modulus and fin geometry consistent with a lower-shape parameter. With the present fin, the second-stage boundary* is within the safe region although very close to the flutter region (Figure 65). In the redesign of the second-stage fin, the fin could have been designed so that it would have been well within the safe region; however, since the second stage was statically unstable, the redesign of the fins had to be a compromise, not only from a flutter standpoint, but also from a stability and weight standpoint. The flutter boundaries for the rest of the stages are well within the no-flutter region, and it is felt that they should be safe.

*Boundaries shown in Figure 65 show the limits that each stage would experience during a typical trajectory, and do not depict a flutter failure boundary.
The effects of body bending on the aerodynamic-stability parameters were determined by using a con-
servative estimate in calculating the bending or deflection of a uniform beam, with the maximum aerodynamic
load concentrated at the ends of the stage in question. This was done for the second and third stages and
showed that the effect of body bending on each of these stages was so small that the effect on the movement
of the center of pressure was less than 0.1 inch for the second stage and less than one inch for the third
stage. Since the effect on the normal-force slope was negligible, it was felt that any further aeroelastic-effects analysis was unwarranted.

Aerodynamic-Heating Analysis

The skin-temperature variation with flight time for various locations on the nose section and on the
second-stage fin was analytically calculated (Figures 63 and 64). The aerodynamic-heating calculations
were made through the use of the author's aerodynamic-heating-analysis program (Reference 20), which is
presently being coded into the IBM 704 computer. The thin-skin solution was used in calculating skin temper-
atures, and the following assumptions were employed. The thermal conductivity is assumed to be infinite
so that there is no temperature gradient within the skin, and heat transfer was considered to be one-
dimensional so that there is no heat conduction along the skin. Re-radiation of heat transfer from the skin
to the air was taken into account throughout the calculations, with an emissivity of 0.7 assumed for the skin.
For design purposes and in order to obtain a more conservative estimate of skin temperatures, a turbulent
boundary layer was used.

The nose stagnation point (Station 0) (Figure 66) reaches a maximum temperature of \(1760^\circ\text{F}\) during
the exit portion of the trajectory and a maximum temperature of \(1580^\circ\text{F}\) during the re-entry phase. The
maximum temperatures of the nose at other stations are much lower than the stagnation temperature. Since
the nose is made of mild steel, it is felt that these maximum temperatures should have no adverse effect on
the nose section.

The skin-temperature variation on the second-stage fin is shown in Figure 67. The leading-edge tem-
peratures are between \(1300^\circ\text{F}\) and \(1400^\circ\text{F}\). Since the fin is constructed of an aluminum magnesium alloy, it
was necessary to place a stainless steel cap along the leading edge of the second-stage fin. By the use of
this cap, any adverse temperature effects should be lessened. The fin temperatures behind the leading edge
are about \(600^\circ\text{F}\) (Figure 67), and it is believed that the fin would have satisfactory structural properties at
these temperatures.
Figure 14. HAS First-Stage Drag Coefficient versus Mach Number
Figure 15. HAS First-Stage Drag Components
Figure 16. HAS Nike Booster Drag Coefficient After Separation versus Mach Number
Reference Area -- 2.405 ft$^2$

Figure 17. HAS Second-Stage Drag versus Mach Number
Figure 18. HAS Second-Stage Drag Components
Estimated 30° Swept-Back Fin

Single Wedge (slab) 30° Swept-Back Fin - Wind Tunnel

Modified Double Wedge (Built-up) 45° Swept-Back Fin - Wind Tunnel

Figure 19. HAS Second-Stage Drag Characteristics
Figure 20. HAS Wave Drag versus Mach Number, Second-Stage Fin
Figure 21. HAS Third-Stage Drag Coefficient versus Mach Number
Figure 22. HAS Third-Stage Drag Components
Figure 23. HAS Third-Stage Fin Drag Coefficient versus Mach Number

Estimated

Wave Drag Coefficient ($C_D$)

- No Sweepback
- 30° Sweepback

Mach Number

2 3 4 5 6 7 8 9 10
Figure 24. HAS Nose Section Drag Coefficient Variation With Drag-Door Angle ($\delta$) versus Mach Number
Figure 25. HAS Nose Drag With Drag Doors Extended versus Mach Numbers
Figure 26. HAS Nose Drag Characteristics
Figure 27. HAS Nose Ogive Wave Drag versus Mach Number

Nose Pressure Drag Coefficient ($C_D$)

Mach Number

Estimated Extrapolated
Figure 28. HAS Second-Stage Cone Flare Pressure Coefficient versus Mach Number
Figure 29. HAS First-Stage Normal Force Coefficient Slope versus Mach Number
Figure 30. HAS First-Stage Pitching Moment Coefficient Slope versus Mach Number
Figure 31. HAS First-Stage Center of Pressure versus Mach Number
Figure 32. HAS First-Stage Booster Fin Normal Force Coefficient Slope versus Mach Number
Figure 33. HAS First-Stage Booster Fin Pitching Coefficient Slope versus Mach Number
Figure 34. HAS Second-Stage Normal Force Coefficient Slope versus Mach Number
Figure 35. HAS Second-Stage Moment Coefficient Slope versus Mach Number
Figure 36. HAS Second-Stage Center of Pressure versus Mach Number
Figure 37. HAS First- and Second-Stage Center of Pressure and Center of Gravity versus Mach Number
Figure 38. HAS Second-Stage Nose Body Normal Force Coefficient Slope and Center of Pressure versus Mach Number
Figure 39. HAS Second- and Third-Stage Nose Body Moment Coefficient Slope versus Mach Number
Estimated

\( \frac{dC_N}{d\alpha} \psi = \frac{4 \cos \psi}{\sqrt{M^2 \cos^2 \psi - 1}} \quad \psi = 45^\circ \)

NOTE: Not Correct for Tip Effects

Figure 40. HAS Second-Stage Fin Normal Force Coefficient Slope versus Mach Number
Figure 41. HAS Second-Stage Fin Moment Coefficient versus Mach Number

Note: Moment Coefficient about Nose. No Correction for Swept-Back Tip Effects.
Figure 42. HAS Second-Stage Fin Normal Force Coefficient Correction For Aspect Ratio (Tip Effects)

\[ R \geq \sqrt{M^2 - 1} \]
Figure 43. HAS Normal Force Coefficient Slope versus Mach Number, Second-Stage Cone Flare
Figure 44. HAS Third-Stage Normal Force Coefficient Slope versus Mach Number
Figure 45. HAS Third-Stage Pitching Moment Coefficient Slope versus Mach Number
Figure 46. HAS Third-Stage Center of Pressure versus Mach Number
Figure 47. HAS Third-Stage Static Margin versus Mach Number
Figure 48. HAS Third-Stage Fin Normal Force Coefficient Slope versus Mach Number
Figure 49. HAS Third-Stage Fin Pitching Moment Coefficient Slope versus Mach Number
Figure 50. HAS Third-Stage Nose Body Normal Force Coefficient Slope and Center of Pressure versus Mach Number
Figure 51. HAS Normal Force Coefficient Slope on Nose Section versus Mach Number
Figure 52. HAS Nose Ogive Pressure Coefficient
Figure 53. HAS Nose Section Center of Pressure versus Mach Number
Figure 54. HAS Nose Center of Pressure With Drag Doors Extended versus Mach Number
Figure 55. HAS Nose Section Normal Force Coefficient Slope Variation With Drag Door Angle (θ) versus Mach Number
Figure 56. HAS Nose Section Pitching Moment Coefficient Slope Variation With Drag Door Angle versus Mach Number
Figure 57. HAS Pitch Damping Coefficient versus Mach Number
Figure 58. HAS First Stage, Time to Damp to Half Amplitude versus Mach Number
Figure 59. HAS Second Stage, Time to Damp to Half Amplitude versus Mach Number
Figure 60. HAS Third Stage, Time to Damp to Half Amplitude versus Mach Number
Figure 61. HAS Pitch Frequency and Second-Stage Roll Rate versus Mach Number (During Typical Trajectory)
Figure 62. HAS Third-Stage Roll Rate versus Mach Number (During Typical Trajectory)
Dynamically Stable

\[ K_1 = -7.0 \]

Dynamically Unstable

\[ K_1 = 0 \]

\[ \left( \frac{\alpha}{\alpha_E} \right) = \frac{1}{\sqrt{\pi} K_2^{1/4}} e^{\left[ K_1 e^{-\beta y} + \beta y \right]} \]

Figure 63. HAS Nose Re-Entry Oscillation Amplitude Ratio
Figure 64. HAS Nose Section Re-Entry
Oscillation Amplitude Ratio versus Altitude
Estimated

2nd Stage
(Original Fins)

FLUTTER REGION

2nd-Stage (Present Boundary Fins)

3rd-Stage Boundary

1st Stage
(Sea level)

NOTE: Boundaries for each stage do not depict the flutter failure limits, but the limits that each stage will reach during a typical trajectory.

Figure 65. HAS Flutter Boundaries for First, Second, and Third Stages
Figure 66. HAS Skin Temperature Variation With Flight Time for Various Locations on the Nose Section
Figure 67. HAS Second-Stage Skin Temperature Variation With Flight Time for Various Locations on The Fin
CHAPTER III -- MECHANICAL DESIGN

Nose Assembly

The nose assembly (Figure 68) is designed to carry an instrument payload of approximately 65 pounds, plus a recovery package consisting of an 8-foot-diameter parachute, a 2-cubic-foot flotation bag with inflation gear, and sea-water dye-marker capsules. The completed nose assembly weighs approximately 100 pounds. The maximum diameter of the nose is 9 inches, and the over-all length is 52.4 inches. The nose cone is a low-drag, 3/4-power ogive shape with a base diameter of 9 inches and a length of 27 inches. It is fabricated from 0.060-inch-thick deep-drawing-quality mild steel, rolled, welded, and spun to final shape. Machined mild-steel rings are welded to the front and rear of the spun member. A machined mild-steel nose cap is screwed to the forward ring, and the rear ring is drilled and countersunk for attachment of the cone to the cylindrical nose section by means of twelve No. 6 flathead high-strength screws.

The cylindrical portion, or telemetering section, of the nose, is a 9-inch-diameter cylinder, 15 inches long. There are on this section two diametrically opposite flats, or wells, one inch deep and 12 inches long. These wells accommodate flush-mounted antennas which are protected by molded Fiberglas covers (Figure 68). This section of the nose is made of low-carbon-steel seamless tubing machined to a wall thickness of 0.090 inch. A bulkhead of 0.090-inch-thick mild-steel sheet is welded in the aft end of this cylinder, and the same material is welded to form the bottom and ends of the antenna wells. The forward end of the cylinder is left thick enough to accommodate an O-ring groove and blind tapped holes for making a pressure-tight seal with the nose cone. All connectors and other attachments to this section were also sealed. This compartment is sealed primarily to prevent arcing of electronic components at high altitude and salt-water damage to components, since the flotation bag is large enough to float the nose assembly without reliance on the buoyancy of the package itself. In the aft end of this section of the nose are four lugs to which are connected the recovery parachute risers. To the aft side, or outside, of the bulkhead are attached mounting blocks for a pressure-actuated switch and three carbon dioxide gas bottles. The switch senses outside ambient pressure and is used to initiate parachute deployment. The gas bottles are used for inflation of the flotation bag and are actuated upon deployment of the parachute by lanyards attached to the parachute risers.

The nose section just aft of the telemetering section is called the parachute section. It is a frustum of a cone whose major diameter is 9 inches, and it tapers to a diameter of 7.1 inches at the aft end, with an over-all length of 9.4 inches. The section is fabricated of rolled and welded mild-steel sheet, 0.090 inch thick. Reinforcing rings are welded forward and aft. The forward ring is drilled and tapped for twenty-four No. 6-32 screws by which this section is attached to the telemetering section. The aft ring is drilled and countersunk for twelve No. 10-32 screws which attach the section to the nose separation ring. In the parachute-section surface there are four symmetrically placed cutouts for drag doors. Between each two of these cutouts is a pair of 1/2-inch-diameter steel tubes placed side by side against the inner surface of the section. Each pair of tubes is welded together and to the forward and aft reinforcing rings. These tubes
are necessary for structural strength and rigidity because of the relatively large drag-door cutouts. The four drag doors are rolled to fit flush with the conical surface of the section. They are hinged at their aft end and are attached at the forward end by a linkage which, when extended, allows the doors to sweep back at a predetermined angle (Figure 68). The linkage locks in the swept-back position. The doors are spring-loaded open but are held closed by spring-loaded latch rods which automatically release the doors upon separation of the nose from the third-stage motor. During preliminary handling of the nose assembly, the rods are held in the latched position by pullout pins which are removed when the nose is assembled to the third-stage motor. The purpose of the drag doors is to retard the nose on re-entry and to orient the unit in a nose-down attitude to facilitate parachute deployment. The parachute section is fitted with a liner, or parachute can, which is also frusto-conical in shape and is sized to leave a space of about one inch between its outer surface and the inner surface of the drag doors (Figure 69). The can is about 7.1 inches long, and is fabricated of 0.030-inch-thick aluminum sheet, rolled and riveted. It is attached to the forward reinforcing ring by four tabs and screws. The purpose of this can is to present a smooth surface to the parachute pack and thus prevent possible puncture or tearing of the pack by the springs and linkages of the drag doors. The space between the can and the drag doors is occupied by the drag-door linkage and release rods, four sea-dye-marker tubes, and electrical cables which must pass through this section. The four dye-marker tubes are attached by screws to the outside of the parachute can (Figure 69). The tubes are 0.75-inch-diameter copper tubing flattened to roughly elliptical shape, about 1/2-inch thick. Both ends are flattened completely and sealed by soldering. A 1/2-inch-diameter hole is drilled in the outside wall of each tube at its longitudinal center. The tubes are filled through this hole, and the dye is released through it by the action of the sea water. The quantity of dye is sufficient to last from 12 to 18 hours in the water. The dye produces a bright, yellowish-green slick in fresh or salt water.

The parachute section is attached at its aft end to the separation ring, which is an annular ring of L-shaped cross section, 6.7 inches outside diameter and 5.2 inches inside diameter (Figure 70). On the ring there are five bosses for explosive bolts and a separation piston. The explosive bolts are spaced symmetrically on the ring and are size 3/8-24. The separation piston is about 1-1/2 inches long and is actuated by a pyrotechnic-pressure cartridge which is fired simultaneously with the explosive bolts. The piston acts through a hole in the separation ring, against the third-stage nose adapter. Because of its off-center location, the piston imparts an angle of attack to the nose and thus insures rapid separation.

The separation ring is attached by the four explosive bolts to the third-stage nose adapter. The adapter is an annular ring about 3 inches long, whose outer surface continues along the taper of the parachute section to the diameter of the third-stage rocket motor, which is 6-1/2 inches (Figure 71). The adapter is screwed onto the motor by a 5-inch acme thread and is held against unscrewing by a setscrew. The forward surface of the adapter, in addition to being tapped for the explosive bolts, has a shoulder which fits snugly within the inside diameter of the separation ring. This arrangement removes shear loads from the explosive bolts. The outer surface of the nose adapter has three equally spaced bosses, or raised flats, to which the forward brackets of the second-stage rocket cluster are attached by means of three 9/16-18 explosive bolts threaded into the adapter.
Third-Stage Fin Assembly

The third-stage fin shroud is a cylinder 7.5 inches in diameter and 18.3 inches long, machined in two halves. It is made of 2024 T4 aluminum. It is split longitudinally to allow assembly to the third-stage motor without removal of the nozzle. The halves are held together by six 1/4-20 bolts. The inside surface of the shroud is machined to fit the nozzle-mounting flange of the motor, and to clear the expansion cone of the nozzle. There are in the outer shroud surface four equally spaced grooves into which a tang of each fin is fitted. The fin tangs are then held by eight 5/16 bolts in each fin, running radially through the shroud and tapped into the bottom of each fin tang. The grooves in the shroud are machined to give a right-hand incidence angle of 0°18' to each fin. The fin assembly is held against rotation relative to the motor by eight 3/8-16 setscrews. The forward end of the fin shroud is machined to a thickness of about 1/8 inch for an axial distance of one inch. This thin section is slotted at frequent regular intervals. Over the thin, slotted section fits a screw-tightened split ring which pulls the "fingers" down to the rocket-motor case and thus centers the forward end of the fin shroud. The fins are of clipped delta planform, with a root chord of 18 inches, a tip chord of 5 inches, and a height above the shroud surface of 20.1 inches. The fin is of constant-thickness slab construction, and is made of 7075 T6 aluminum plate, 0.50 inch thick. The leading edge of each fin has an 8.2-degree included-angle taper and a 0.010-inch-radius leading edge.

Second-Stage Cluster

The second-stage cluster consists of six Viper I rocket motors mounted in pairs. The two motors of a pair are rigidly connected to each other, side by side. Each pair is hinged at the aft end to a nucleus, or cluster adapter (Figure 72), and is attached at the forward end to the nose adapter of the third-stage motors by one 9/16-18 explosive bolt (Figure 71). The forward end of each pair is fitted with a sheet-metal fairing which slopes from just aft of the telemetering section of the nose back to the outside contour of the forward end of each motor of the second-stage pair (Figure 73). The three sections of the fairing overlap at the edges to present a continuous, smooth surface to the air flow (Figure 74). Each segment of the fairing is attached by a single 1/4-20 bolt to a fairing ejection piston mounted on the forward bracket of each pair. The fairing is supported at the forward end against the third-stage nose and at the aft end against the second-stage motors. When pulled down by the single mounting bolt, the fairing is rigidly mounted. Each fairing ejection piston, to which a fairing segment is attached, is held in its cylinder by a No. 6-32 high-strength screw. Each cylinder is fitted with a pyrotechnic-pressure cartridge which is fired simultaneously with the 9/16-18 explosive bolts which allow the cluster to separate. When the fairing ejection cartridge is fired, sufficient pressure is produced behind the ejection piston to break the No. 6-32 screw. The ejection piston and the fairing segment attached to it are then ejected clear of the unit. Each pair of motors of the second stage is held together at its forward end by a forward bracket assembly. The forward bracket assembly is a T-shaped section. The aft end, or cross, of the T, consists of two rings which fit over the forward end of each motor and accurately maintain the proper center distance between the two motors. The bracket is held in place by two lock rings which are threaded onto the 5-inch external acme thread provided on the front of each motor. The forward member, or leg of the T, is a channel-shaped
section which is welded to the cross member and tapers forward. At the forward end of this leg is an elongated hole through which the 9/16-18 explosive bolt is inserted to assemble the pair of motors to the cluster. Also on this leg of the bracket is welded the fairing ejection cylinder, which houses the ejection piston and the pyrotechnic-pressure cartridge.

The aft end of each pair of motors is held together, with the proper center distance between motors, by a welded assembly called the second-stage-fin adapter. It serves to hold the motors of a pair together, to hold the pair to the cluster adapter, and also as a mounting platform for the second-stage fin. The fin adapter is a mild-steel weldment in the form of a double, split, clamp ring, with a hollow triangular cross-section member cantilevered forward from the clamp ring. On the underside of the assembly (opposite the cantilevered-fin platform) is an arm with a hinge cut to fit the contour of the cluster adapter. The split clamp ring is machined to fit over the nozzle-mounting flanges of the motors, and each ring is held together by sixteen 1/4-20 bolts. In addition to the clamping action of the rings, six 1/2-inch setscrews in the rings and bearing on the motors are used to insure that the thrust developed by the motors is received by this assembly, rather than by the forward brackets, which are not designed for such a load. The second-stage fins, of which there are three, are fabricated of 0.090-inch-thick 7075 T6 sheet aluminum, riveted to cast aluminum alloy frames. The leading edge of each fin is fitted with a cap of stainless-steel sheet riveted in place. The root-chord length is 26 inches; the tip-chord length is 12 inches; and the leading edge is swept back 45 degrees. The maximum thickness at the fin root is 2-1/2 inches, and the tip thickness is just over one inch. The forward and aft thirds of the fin taper to a leading- and trailing-edge radius of about 1/8 inch. A fin mounting plate of 3/4-inch aluminum plate is bolted to the underside of the fin frame by eight 1/2-inch heat-treated bolts. The mounting plate is then attached to the fin mounting platform of the fin adapter by means of sixteen 5/16-inch heat-treated bolts, with two 1/2-inch dowel pins to maintain fin alignment with zero fin-incidence angle.

The three pairs of motors which make up the second-stage cluster are attached at their aft ends, by means of the hinges on the second-stage-fin adapters, to a piece called the aft-cluster adapter (Figure 72). This piece is a mild-steel tube, 8 inches in outside diameter, 10 inches long, with a 1/4-inch wall thickness. There is a bulkhead welded into this tube about 2 inches from its forward end, on which the third-stage motor rests at assembly. The tube forward of this bulkhead contains three slots to accommodate the three third-stage fins. The inside diameter of the aft end of this cluster adapter is machined to fit over the tube of the interstage adapter which is attached to the booster.

Second and Third Stages

The seven Viper motors of the second and third stages are all fired by electrical leads through the flight cap on the front end of the motors. This is not the normal method of firing a Viper motor, since the igniter is inserted through the nozzle and no provision is made for bringing electrical leads through the head end. However, it was deemed desirable in this application not to run conduit along the full outside length of the motors and thus have cables exposed to air loads at the aft end of the cluster. Therefore, each motor-head end cap is drilled and tapped in the field before assembly, to receive a high-pressure,
high-temperature, glass-to-metal seal connector. The firing signal is transmitted to the igniter through this connector and wires running through the center perforation of the propellant grain to the igniter at the aft end of each motor.

Since the Viper igniters used were not specifically designed for high-altitude use, there was some possibility that the igniters might disintegrate before firing, because of decompression at altitude. For this reason, a seal was devised to maintain launch-level atmospheric pressure in the chamber until the motors were fired. This seal consists of an aluminum plate, 1/4-inch thick, whose outer edge is beveled to fit the inside contour of the nozzle expansion cone. The outer edge of the seal plate, or nozzle closure, has a rim large enough to include an O-ring and four 1/4-inch setscrews, both designed to seat against the inside of the nozzle expansion cone. In use, the closure is forced into the nozzle, thus compressing the O-ring, and is held in place by a special fixture. After the four setscrews are tightened, the fixture is removed. It was determined by hydrostatic tests with a test nozzle that the seal will break loose at a chamber pressure of about 50 pounds per square inch. This pressure is low enough to eliminate the possibility of causing damage to the chamber upon firing. However, it is high enough to afford a factor of safety of three over the expected prefiring pressure differential of one atmosphere across the seal. The igniters are inserted in the normal manner before the nozzle closures are installed. The normal igniter support is strong enough to hold the igniter against the acceleration loads to which it is subjected before it is fired.

The firing of the second-stage motors and the separation of the cluster are controlled by timers, relays, and batteries mounted in boxes attached to the forward cluster bracket (Figures 70 and 75). The timer and relay boxes are sealed, and the entire package is covered by the nose fairings. Two mechanical timers in parallel are used to increase reliability. This entire package was originally located inside the aft cluster adapter, but it was moved to the forward location to facilitate accessibility for checkout and maintenance in the event of long delays between assembly and firing of the unit.

The third-stage firing and payload separation are controlled by two parallel mechanical timers and batteries mounted in the nose cone.

Booster

The booster motor is an M5 Jato rocket with the standard Nike Ajax booster three-fin configuration. The Nike Ajax thrust structure on the forward end of the motor is not used, however. In its place is an interstage adapter designed to fit inside the cylinder of the aft cluster adapter of the second stage. The interstage adapter consists of two rings machined from aluminum plate and a tube machined from seamless mild-steel tubing. The assembly is held together by bolts and is bolted to the booster motor, using the same threaded holes that are used for the Nike Ajax thrust unit. The tubular section is machined to a slip fit inside the second-stage cluster adapter, with a taper on the forward end to facilitate assembly of the cluster to the booster.

The standard Nike shoes are replaced by a one-piece forward shoe and a one-piece aft shoe which are designed to allow simultaneous disengagement of forward and aft shoes from the launcher rail. There are no shoes on the cluster assembly; it is supported only by the interstage adapter through the cluster
There is no connection between the booster and second stage other than the slip fit on the inter-stage adapter. Separation of booster and second stage is accomplished by the differential drag on the two units at booster burnout.
Figure 68. Nose Assembly With Drag Doors Open
Figure 69. View of Parachute Section Through Open Drag Door
Figure 70. Forward End of Cluster With Payload and Nose Fairing Removed
Figure 71. Forward End of Cluster
Figure 72. Rear View of Cluster
Figure 73. Second-Stage Cluster Nose Fairings
Figure 74. Second- and Third-Stage Cluster Ready for Hoisting to Launcher
Figure 75. Second-Stage Firing and Cluster Separation Control Package
Figure 76. Block Diagram, HAS Wiring
CHAPTER IV -- ELECTRICAL SYSTEM

Telemetry, Electrical System, and Instrumentation

The telemetry system (airborne) used in the HAS rocket consists of a Sandia Corporation FM-FM telemeter in a pressurized, hermetically sealed package, complete with power supply and instrumentation; it is contained in the nose section forward of nose Station 43. A block diagram of the telemetry system and the electrical systems of the second and third stages is shown in Figure 76. The general characteristics of the telemetry system are shown in Table II.

The telemetry transmitter which provides the necessary RF output is a Bendix TXV-13 type. This transmitter is frequency-modulated by a series of 12 Sandia-type subcarrier oscillators which, in turn, are frequency-modulated by the output of the sensing devices. The 12-channel oscillator mount is shown in Figure 77, and the oscillator wiring schematic in Figure 78.

The subcarrier oscillators used on the HAS vary, depending on the instruments. The subcarrier channels used are operated on the standard FM-FM subcarrier frequencies. In general, eight to ten channels are used for continuous data transmission, while the remaining channels are used for tell-tale events, in which four to eight inflight sequence events are monitored in two continuous subcarrier channels. A typical telemetering and instrumentation channel assignment is shown in Table III.

The nose-section electrical wiring used is shown in Figure 79. Although the instrumentation varies from rocket to rocket, a typical instrumented package is shown in Figures 80, 81, and 82. As shown, the component instruments are mounted on a specially designed telemetry plate. The two telemeter antennas used are the flush-mounted slot type and are installed on the periphery of the cylindrical portion of the nose section.

The cluster arming and firing circuitry used on the second stage is shown in Figure 83.

Radar Beacon

An uncoded radar beacon is used in the HAS rocket for tracking purposes. Two flush-mounted antennas are used in conjunction with the beacon and are installed in the periphery of the cylindrical portion of the nose section. The following are the general characteristics of the radar beacon:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beacon transmitter frequency</td>
<td>5735 megacycles</td>
</tr>
<tr>
<td>Beacon receiver frequency</td>
<td>5600 megacycles</td>
</tr>
<tr>
<td>Peak power</td>
<td>2 watts to each antenna</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>64 decibels</td>
</tr>
<tr>
<td>Pulse width</td>
<td>0.7 microsecond</td>
</tr>
<tr>
<td>Pulse delay</td>
<td>3.4 to 3.6 microseconds</td>
</tr>
</tbody>
</table>
### TABLE II
General Characteristics of the Telemetry System

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF power output</td>
<td>2.2 watts</td>
</tr>
<tr>
<td>Frequency range</td>
<td>223.5 megacycles</td>
</tr>
<tr>
<td>Potential information channels</td>
<td>12</td>
</tr>
<tr>
<td>Range (altitude)</td>
<td>1,000,000 feet</td>
</tr>
<tr>
<td>Range (azimuth)</td>
<td>1,000,000 feet</td>
</tr>
<tr>
<td>Operating life</td>
<td>25 minutes</td>
</tr>
</tbody>
</table>

### TABLE III
Telemetering and Instrumentation

<table>
<thead>
<tr>
<th>Information</th>
<th>Range</th>
<th>Frequency Response (cps)</th>
<th>Accuracy (%)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll-rate gyro</td>
<td>+3600°/sec</td>
<td>100</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Pitch-rate gyro</td>
<td>+100°/sec</td>
<td>40</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Pitch-rate gyro</td>
<td>+400°/sec</td>
<td>40</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Yaw-rate gyro</td>
<td>+100°/sec</td>
<td>40</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Yaw-rate gyro</td>
<td>+400°/sec</td>
<td>40</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Longitudinal acceleration</td>
<td>-15 to +35g</td>
<td>15</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Internal pressure</td>
<td>0-15 psi</td>
<td>10</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Internal temperature</td>
<td>0-200°F</td>
<td>10</td>
<td>5</td>
<td>Nose</td>
</tr>
<tr>
<td>Surface temperature 1</td>
<td>0-1200°F</td>
<td>10</td>
<td>5</td>
<td>Station 8</td>
</tr>
<tr>
<td>Surface temperature 2</td>
<td>0-800°F</td>
<td>10</td>
<td>5</td>
<td>Station 35</td>
</tr>
</tbody>
</table>

Sequence
- Firing of second three Vipers
- Cluster separation
- Nose separation (pressure-switch arm)
- Pressure-switch actuation

Sequence
- Third-stage fire
- Reefing-line cutter monitor
- Actuation of flotation equipment and its inflation
Figure 77. The 12-Channel Oscillator Mount
Figure 78. Schematic, 12-Channel OM 12-T, TS-61 Mount
Figure 79. Nose-Section Wiring
Figure 80. Instrumented Nose Package (side view)
Figure 81. Instrumented Nose Package (front view)
Figure 82. Instrumented Nose Package (side view)
Figure 83. Cluster Arming and Firing Circuitry

NOTES

1. RELAYS SHOWN IN SAFE POSITION
2. VIPERS 1, 3, 6 ARE 1st 3 VIPERS TO FIRE
   VIPERS 2, 4, 5 ARE 2nd 3 VIPERS TO FIRE
3. BATTERY 1 FIRES PRESSURE SQUIBS
   BATTERY 2 FIRES EXPLOSIVE BOLTS
   BATTERY 3 FIRES 1st 3 VIPERS
   BATTERY 4 FIRES 2nd 3 VIPERS
4. ALL BATTERIES ARE GROUND 24V0500
5. TIMER SWITCHES ARE SHOWN IN SAFE OR OPEN POSITION, EXCEPT TIMER ZERO WHICH IS SHOWN IN CLOSED POSITION
6. R-1, K-2, R-3 ARE 100WATT RESISTORS
CHAPTER V -- ASSEMBLY PROCEDURE

This section is provided primarily to give the sequence of assembly operations. More detailed descriptions of components and how they are joined are discussed under Mechanical Design.

Booster

The M5 Jato motor is removed from its shipping crate by means of fabric lifting straps and a crane, and is placed on the universal rocket-handling dolly (Figure 84). The Nike Ajax thrust structure and launching shoes are removed from the unit. The special one-piece forward and aft launching shoes are installed on the unit, and the three Nike fins are installed. The interstage adapter is installed. (It must be removed later for igniter installation.) The weight is measured by a scale suspended from the crane hook. The center of gravity is measured by moving the lifting straps until the unit hangs horizontally. This data is then recorded. A lifting fixture, consisting of two side rails and two steel bands around the motor, is installed, centered about the center of gravity of the unit. The dolly is then rolled to a position directly beneath the launcher rail, which is in a horizontal position (Figure 84). Two trolleys, with chain hoists attached, are installed on the trolley rails which run along either side of the launch rail. The trolleys are moved into position directly above the Nike motor lifting fixture. The chain hoists are attached to the lifting fixture, and the unit is manually lifted into position just beneath the rail. The motor, suspended from the trolleys, is then manually pulled back to the aft end of the launch rail. As the motor is lifted further by the chain hoists, the forward and aft shoes are guided onto the rail, and the unit is moved forward enough to allow installation of the motor support block, which is slipped onto the rail and locked in place by two locking pins. The chain hoists are released and the lifting fixture is removed from the booster motor.

Second- and Third-Stage Clusters

The Viper motors are removed from their shipping crates as needed, and the propellant grain is visually inspected for cracks or irregularities. The weight and the center of gravity of each motor are measured and recorded.

The third-stage Viper motor is lifted by hand into position on the universal motor-handling dolly. The third-stage nose adapter is screwed onto the forward end of the motor, and the third-stage fin assembly is attached to the aft end of the motor. The orientation of the fins with respect to the nose adapter is determined by means of a level placed on one of the flat bosses on the adapter, and a clinometer placed on each of two fins in turn. When properly oriented, the fin assembly is locked in position by the setscrews in the fin shroud. The third-stage igniter, after a visual inspection and a check of bridge-wire resistance, is installed in the motor. The nozzle closure is then installed, and the igniter lead wires are pulled out through
the front end of the motor. (The motors are shipped and handled, insofar as possible, without the head-end cap in place.) The dolly is then moved into position adjacent to the upright cluster-assembly stand, and a special lifting eye is attached to the nose adapter. The aft cluster adapter is placed in the upright cluster-assembly stand. The work platform is removed from the stand, and the third-stage motor is lifted by a mobile crane or hoist truck into position in the stand, with the motor resting in the forward end of the cluster adapter and held vertical by the adjustable support arms of the stand. A special gage-rod assembly is then used to accurately gage the distance between the hinge mounting holes on the cluster adapter and the 9/16-18 tapped holes in the third-stage nose adapter. This measurement is set and locked on the gage, as it must be used in assembling the pairs of motors for the second-stage cluster.

The next step is the assembly of the three pairs of motors that make up the second-stage cluster. Two Viper motors, after visual inspection of the grains and cases, are placed on the pair-assembly dolly. The motors rest on felt-lined wooden blocks which position them side by side at approximately the correct center distance. A forward bracket assembly is placed in position over the front end of the motors, and the lock rings which hold it in place are installed and locked. The second-stage fin adapter is now mounted loosely on the aft end of the pair. The gage mentioned above is now used to position the fin-adapter assembly in the correct axial position. The fin adapter is tightened and locked in position. The dolly is now moved into position adjacent to the upright cluster-assembly stand. A lifting eye is attached to the forward bracket, and the pair of motors is lifted by a crane into the stand adjacent to the third-stage motor. The hinge on the second-stage fin adapter is attached to the aft cluster adapter, and the forward bracket is attached to the third-stage nose adapter by a standard AN 9/16-18 bolt (which will be replaced by an explosive bolt later in the assembly procedure). The crane hook and lifting eye are now removed and the assembled pair is supported by the third-stage motor and by the adjustable support arms of the stand. The above procedure is repeated until all three pairs are assembled in the cluster-assembly stand.

The head-end cap, or flight cap, is installed in the third-stage motor, with the igniter leads attached to the connector in the cap, and a shorting plug installed on the outside of the connector. The flight caps are then installed in the six second-stage motors, with two wires attached to the connectors, strung down through the motors, and extending out the nozzles. Four pyrotechnic-pressure cartridges, three 9/16-18 explosive bolts, and four 3/8-24 explosive bolts are now checked for bridge-wire resistance and prepared for installation. The bridge-wire leads of all explosive devices are kept shorted together until final connection to their respective firing circuits. The three 9/16-18 standard AN bolts are replaced, one at a time, by the 9/16-18 explosive bolts. Pressure cartridges are installed in each of the three fairing ejection cylinders on the forward brackets. The nose separation ring is now attached to the third-stage nose adapter by the four 3/8-24 explosive bolts. A pressure cartridge is installed in the nose separation cylinder.

One of the second-stage fins is attached to a fin adapter. A special lifting ring is attached to the forward end of the cluster, and the bed of the cluster-handling dolly is attached to the side of the cluster just above the fin which has been attached. A three-legged sling is attached to the cluster lifting ring, and the cluster is lifted out of the assembly stand by a mobile crane (Figure 85). The cluster is moved into position adjacent to a cluster-handling dolly. By means of straps around the lower end of the cluster and attached to a hoist truck, the cluster is maneuvered into an attitude about 30 degrees from the vertical, with the attached bed on the underside. The cluster is lowered until a cross member on the bed, near the aft end,
engages a trunnion groove on the dolly and is locked in position (Figure 86). The straps are removed from the aft end of the cluster, and the unit is lowered into a horizontal position, with the bed resting on the dolly. All slings and lifting fixtures are then removed from the cluster.

The second-stage firing and separation control packages, contained in six metal boxes, are attached, one to either side of the three forward bracket assemblies. These packages contain a primary and a backup mechanical timer, relays, and batteries for sequence firing of the second-stage motors, and the explosive bolts, and pressure cartridges which initiate separation of the cluster. The boxes are contoured to fit beneath the sheet-metal fairings. The cables between these boxes are positioned with sufficient slack to allow free movement of the three pairs of motors relative to each other at separation.

The nose assembly is now moved into position just forward of the nose separation ring on the third-stage motor. A no-voltage check is made on the leads which fire the nose separation bolts and pressure cartridge, and these connections are made. The third-stage firing leads are fed out through an access hole in the nose adapter, and the third-stage igniter leads are fed out through the same hole. The nose is now assembled to the separation ring (Figure 87). The pullout pins through the drag-door release rods are removed at this time. A no-voltage check is made on the firing leads for the cluster separation devices (explosive bolts and pressure cartridges) and these connections are made. Final arming, or connection of firing leads to igniter leads, of the second-stage and third-stage motors, is deferred until the unit is on the launcher and the countdown is well advanced. The sheet-metal nose fairings are now attached to the unit, but must later be removed to accomplish final arming of these stages.

The M5 Jato igniter is checked for proper bridge-wire resistance and is installed in the M5 Jato motor. The interstage adapter must be removed for this operation and then re-installed.

The six Viper I igniters for the second-stage motors are visually inspected and checked for proper bridge-wire resistance. The igniters are then installed in the six second-stage motors, with their leads attached to the firing leads that were earlier strung through the motors from the flight-cap connector. The nozzle seals are installed in the six second-stage motors.

**Marriage of Booster and Cluster**

The cluster dolly is now moved into position under the horizontal launcher rail. The trolleys and chain hoists are moved into position above the center of gravity of the cluster, and twin strongbacks are attached to the cluster dolly bed at the center of gravity of the unit. The chain hoists are attached to the strongbacks, and the cluster, with bed attached, is lifted up near the rail (Figure 88). The unit, thus suspended from the trolleys, is moved back and fitted onto the interstage adapter of the booster (Figure 89). This operation is facilitated by manipulation of the chain hoists. Care must be taken to have the third-stage fin, which protrudes through the cluster, centered in its clearance slot in the launcher rail and boom. A nylon safety strap, which helps support the cluster when it is in a horizontal position on the launcher, is attached to the launcher boom. The dolly bed is now removed from the unit and lowered down to the dolly by the chain hoists (Figure 90). The chain hoists and trolleys are now removed from the launcher trolley rails.
The umbilical plug is attached to the nose for battery charging and telemetering checks prior to launch. A battery-charging lead is plugged into a receptacle provided for that purpose in the second-stage control package, through an access hole in one of the fairings. The unit remains in this condition until just prior to launch.

Final Arming

Final arming of the second- and third-stage motors is performed just prior to elevation of the launch rail to firing position. The umbilical plug to the nose, the battery-charging cable to the second-stage package, and the sheet-metal fairings are removed. The third-stage firing leads, protruding from the access hole in the nose adapter, are given a no-voltage check, and if satisfactory, are connected to the third-stage igniter leads. The connection is insulated, the leads are inserted into the nose adapter, and a cover plate is fastened over the access hole.

A no-voltage check is performed on the second-stage firing leads, and they are then connected to the six second-stage motors. Since these motors are not all fired simultaneously, care must be taken to match the proper firing leads and motors. The sheet-metal fairings are then replaced, and the umbilical plug is replaced on the nose.

The launcher is elevated to firing position, and the cable to the umbilical plug is attached to the launcher structure in such a way that when it falls clear of the nose, it will not foul the unit at launch. The nylon safety strap is now removed from the forward end of the cluster.

After final launch-elevation and azimuth adjustments have been made, and just prior to the final countdown, the booster igniter leads, protruding from the booster nozzle, are connected to the firing circuit after the proper safety checks have been made.
Figure 84. Booster Ready for Lifting to Launcher Rail
Figure 85. Cluster Being Lifted From Assembly Stand
Figure 86. Cluster Being Placed on Handling Dolly
Figure 87. Payload Being Installed on Cluster
Figure 88. Hoisting Cluster Into Position for Mating With Booster
Figure 89. Fitting Cluster on Interstage Adapter
Figure 90. Lowering Lifting Fixture From Assembled Cluster
CHAPTER VI -- LAUNCHING AND GROUND-SUPPORT EQUIPMENT

Launcher

The launcher used in this program (Figures 91 and 92) was designed at Sandia Corporation and contains some novel features (Reference 24). It is capable of azimuth adjustments through a range of 360 degrees, manually performed by one man. The launch elevation angle is adjustable through a range of 90 degrees, horizontal to vertical. This adjustment is made rapidly and smoothly by an electrically driven cable winch. The launcher boom and support structure are extremely rigid, which characteristic promotes accuracy, or trajectory repeatability.

Universal Rocket-Handling Dolly

This dolly (Figure 93) was designed to support and transport single, cylindrical rocket motors from 6 to 18 inches in diameter and approximately 4 to 12 feet in length. The rocket is supported on four rubber rollers so that it may be rotated easily. The rollers may be locked so that friction prevents rotation. The center distance of the rollers is varied to accommodate varying rocket diameters, and the axial location of one pair of rollers may be varied to accommodate varying lengths of rockets. The dolly is mounted on casters with semi-pneumatic rubber tires and is equipped with a towing tongue which may be attached on either the longitudinal or the transverse axis of the dolly.

Pair-Assembly Dolly

The pair-assembly dolly (Figure 94) was designed to facilitate assembling the three pairs of Viper I motors which make up the second-stage cluster. The dolly bed consists essentially of a pair of wooden, felt-lined chocks, one at either end, which hold the motors at approximately the correct center distance. This greatly facilitates installation of the hardware that holds the pair together. The dolly is equipped with casters so that the assembled pair may be moved easily to the cluster-assembly stand.

Cluster-Assembly Stand

The cluster-assembly stand (Figure 95) was designed to facilitate assembly of the seven Viper I motors which make up the second and third stages. The cluster is supported on a central pedestal about 30 inches above the ground, to allow easy access to the aft end of the cluster. The cluster is further supported by four adjustable arms that are moved in radially from the assembly-stand main supports and bear against the sides of the motors. These arms are adjustable in length so that they will bear against the completed cluster.
or any stage of the cluster buildup. Atop the assembly stand is a circular work platform built in four removable sections. The sections of platform are removed, as required, to install pairs of motors on the cluster and to remove the assembled cluster from the stand. The height of this work platform is such that the forward end of the cluster is at a convenient working level for a man standing on the platform.

Cluster-Handling Dolly

The cluster-handling dolly (Figure 96) was designed to transport the second- and third-stage clusters, in a horizontal attitude, from the cluster-assembly stand to the launcher, and to facilitate loading the cluster onto the launcher. The bed of the dolly consists of a steel frame with felt-lined wooden chocks and pads that bear against two motors of the cluster. The bed is removed from the dolly and attached to the upright cluster in the stand by means of a bolt at the forward end, two fabric straps, and two steel turnbuckles at the aft end. The procedure for lifting the cluster from the assembly stand to the dolly is described under Assembly Procedure. When the cluster is ready for lifting to the launch rail, two strongbacks are attached to the dolly bed, and the bed is released from the dolly. The cluster and the bed are then lifted to the launch position by the chain hoists on the launcher. When the cluster is fitted to the booster, and the nylon safety strap is in place beneath the cluster, the bed is detached from the cluster and lowered to the dolly.
Figure 91. HAS Launcher in Launch Position
Figure 92. HAS Launcher in Loading Position
Figure 93. Universal Rocket Handling Dolly
Figure 94. Pair Assembly Dolly and Cluster Assembly Gage
Figure 95. Cluster Assembly Stand
Figure 96. Cluster Handling Dolly
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