DAC-58065

COMPARATIVE STUDY OF THRUST-VECTOR-CONTROL SYSTEMS FOR LARGE, SOLID-FUELED LAUNCH VEHICLES

VOLUME I SUMMARY

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ABSTRACT

This contractual study is a comparative analysis of several advanced thrust vector control (TVC) system designs as applied to a large, solid-fueled launch vehicle consisting of a 260-inch diameter first stage and a 156-inch diameter second stage. The primary payload was a ballistic spacecraft, however the comparison also includes a winged spacecraft. The TVC systems evaluated were the Lockheed Lockseal omniaxial flexible nozzle, the Thiokol buried nozzle pintle modulated chamber gas secondary injection system, and the Vickers continuous flow auxiliary warm gas generator secondary injection system. A brief review was also made of Allegany Ballistics Laboratory chamber bleed in line pintle valve system in the cyclic on-off and fully modulating modes. A previously contracted Phase II Head-End Steering Study was used to provide design criteria such as the mission, launch vehicle, natural environment, vehicle geometry and aerodynamic uncertainness, maneuvering requirements, steering analysis, and provided some comparison with other TVC systems and the effects of fins. Included in the comparative analyses were the effects of control response, launch vehicle stability, interchangeables of TVC on the stages, ground operations, allowable flight path divergence, and reliability.

This document is the summary of the final report on NASA Contract No. NAS1-7109. It presents the summary of the work accomplished in Tasks I, II, and III. There are two companion documents; Volume II--Technical, and Volume III--Appendixes.

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Section 1
INTRODUCTION

The National Aeronautics and Space Administration (NASA) awarded the Douglas Aircraft Company a 6-month contract (NAS1-7109) to perform comparative analyses of 4 advanced thrust-vector-control (TVC) system designs as applied to a large, solid-fueld launch vehicle. The technical effort started 28 February 1967 and terminated 6 September 1967. The objective of this study was to summarize TVC design and performance data in a comparative format which will enable the NASA to judge the merits of each TVC concept for future application in research and development efforts.

The four TVC systems include as their principal components the Lockheed Lockseal, Thiokol hot gas pintle valve, Vickers warm gas valve, and Allegany Ballistics Laboratory (ABL) chamber bleed zero leak hot gas valve. Each of these systems deflect the thrust vector in a different manner, but only two basic principles are involved: nozzle gimballing and secondary gas injection into the nozzle. Two ABL secondary injection hot-gas valve designs were investigated during the first 9-week period for thrust vector control of large solid rocket motors. One injects hot gas in a pulsating or cyclic mode, full on or off; the other is fully modulated. The on-off concept was not studied in detail (see Appendix A. 5 for a discussion) because TVC requirements are met efficiently by a fully-modulating propellant gas valve which uses a balance plug to reduce actuation loads. The general valve design can be used either as a submerged valve, usually with a submerged nozzle, or an external valve with associated ducting. The submerged-valve design is best because of weight saving (see Appendix A. 5), and mounting the valves to provide accessibility, ease of maintenance, etc. makes this TVC concept generally identical to that of the Thiokol hot-gas TVC system. Detail design and materials used differ in the ABL and Thiokol hot-gas valves, but the primary interest of this study is to compare operation characteristics, requirements, and conditions rather than provide a detailed description of component parts. The Thiokol hot-gas TVC system was selected to represent this TVC technique, because performance predictions of this system are supported by large-scale valve (115 lb/sec flow rate) test data. Therefore, the general comparative data in this report pertaining to the Thiokol hot-gas valve applies to the ABL modulated valve design TVC concept.

The Lockheed Lockseal allows omniaxial nozzle deflection while providing an effective static seal of main-motor gases. Two gas injection systems are represented in the Thiokol and ABL hot-gas injection and the Vickers warm gas injection TVC methods. The Thiokol hot-gas valve and the ABL modulated valve uses the solid rocket motor (SRM) combustion chamber gas at 5,800°F. The pintle of these hot-gas valves can be extended or retracted to any required length to provide the flow of hot-gas necessary to meet thrust vector requirements. A gas generator, designed to operate with the Vickers warm gas valve, supplies injection gas at 2,000°F for this TVC technique. Each of these three TVC concepts were expanded into workable control systems for a two-stage SRM launch vehicle.

This task was initiated after Douglas personnel visited each of these companies and ABL. The cooperation and response to our request for information was excellent.

To obtain compatible comparison data, basic information was taken from previous study of vehicles using various control techniques--the Phase II Head-End Steering (HES) Study. Design criteria such as the mission (shown in Figure 1-1), Launch vehicle (shown in Figure 1-2), natural environment, vehicle geometric and aerodynamic uncertainties, maneuvering requirements, and steering analysis were obtained from this study, and data supplied by the TVC system manufacturers were used in this study's design and analytical tasks, resulting in consistent comparative data on TVC and vehicle systems as well as allowing general comparisons to be made with results of the Phase II HES Study. It should be noted that only general vehicle comparisons can be made between the two studies, because advances in solid rocket motor technology have been incorporated in this study resulting in changes in nozzle location and design. In addition, two of the three Phase II HES study launch vehicles have different first-and second-stage propellant

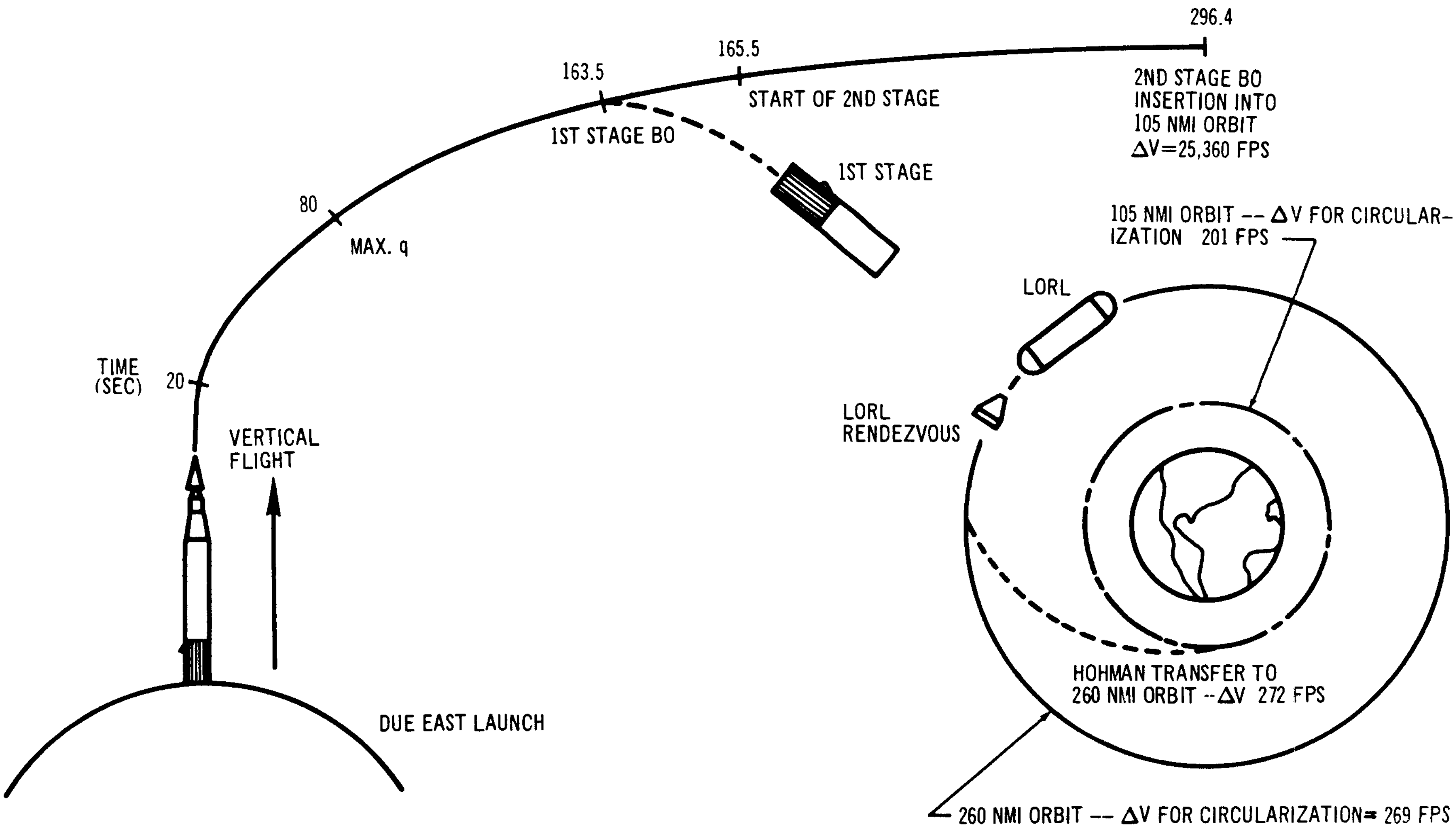


Figure 1-1. Mission Profile

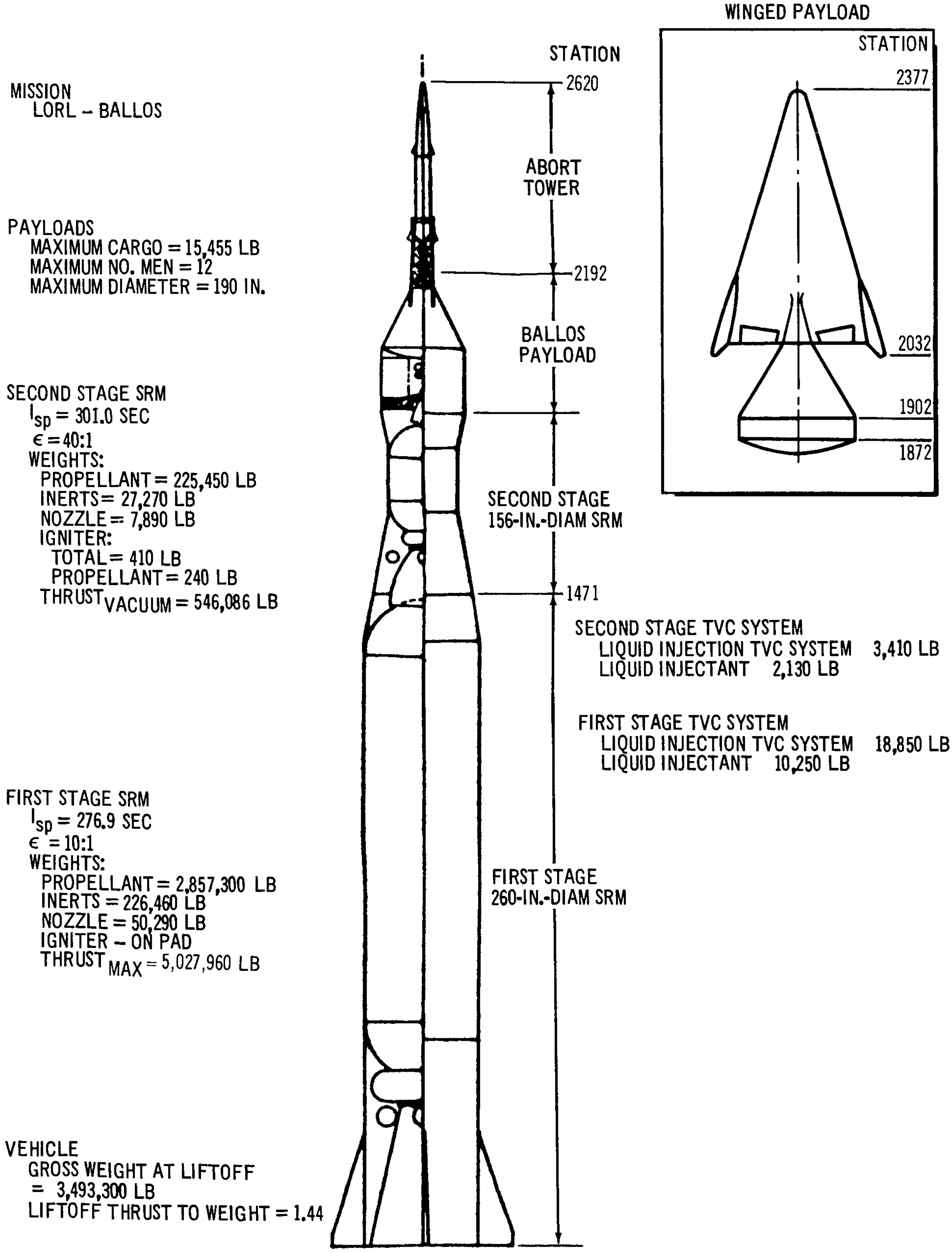


Figure 1-2. Basic Launch Vehicle and Payloads (Extracted from Phase II HES Study)

loadings as a result of normalizing launch vehicles to a specific payload in 260-nmi orbit. Fins for aerodynamic stabilization of the launch vehicles studied were not added (as applied in the Phase II HES effort) to allow a more direct comparison of the candidate TVC techniques.

Two payload shapes were included to allow the effect of vehicle stability on control system response to be evaluated. The primary payload is the ballistic Ballos spacecraft with maneuvering engines and cargo module. The secondary payload, used only in stability and control analyses, is a modified HL-10.

The study was structured into three tasks: Task I, Initial Design and Analysis; Task II, System and Mission Requirements; and Task III, Comparative Analysis. Task I terminated with a review of the first 9 weeks of technical effort, presenting basic data relative to the candidate TVC and vehicle systems. During Task I design criteria was established, TVC system data were obtained from reports and consultation, data and analytical techniques were substantiated, initial concepts for TVC and launch vehicle system integration were made, and the approach to completing the remainder of the study and obtaining meaningful comparisons was developed. This approach, implemented in Task II, refined the vehicle structural and configuration design relative to the installation of each TVC concept. To obtain TVC requirements and design systems to meet them, vehicle geometry, stiffness, and weight data are calculated and input into the stability and control analyses. In addition to the resulting TVC requirements, this vehicle design effort provides comparative data relative to dimensions, stage weights, reliability, and payload weight. Task II includes the following vehicle-oriented studies:

1. Development of a family of launch vehicle configurations that show the effects of each of the three TVC systems.
2. Integration of the TVC and roll-control systems into the basic launch vehicle.
3. Preparation of weight statements for the vehicle, stages, TVC systems, and ancillary subsystems.
4. Development of vehicle-payload trade factors.
5. Determination of stability and control comparison data and requirements used to design TVC and roll-control systems.

TVC and roll-control system design integration, sizing, and performance data were developed by the following:

1. Investigation of the gas injection TVC systems to determine significant parameters in selecting injector location.
2. Placement of injector nozzle location and determining the number and size of valves.
3. Sizing the gas generator and ducting used in the warm gas TVC system.
4. Determination of roll control propellant requirements and system placement.
5. Design of actuators, power systems, and electronic subsystems required to operate the complete TVC system.
6. Determination of SRM I_{sp} losses resulting from TVC.

Reliability analyses were performed for all TVC and launch vehicle systems. Figures of merit were calculated for the TVC systems, roll-control systems, stages, and vehicles. A final matrix of all possible combinations of these is presented in this report.

During Task III, the technical data were put into comparative format.

Comparisons are shown for the following:

1. Vehicle size, stability, and payload capability.
2. TVC/vehicle system design integration.
3. TVC requirements and control system response as a function of payload shape, fins, and control system.
4. Actuator and electronic system designs.
5. Reliability and weights for stage, vehicle, TVC, and roll-control systems.
6. Launch operation consideration.

Section 2
VEHICLE COMPARISONS

Vehicle configurations which use each of the candidate TVC systems in both stages of the basic launch vehicle--Configuration V from the Phase II HES Study--are shown in Figure 2-1. Figure 2-2 shows Configurations IV, V, and VI developed in the Phase II HES Study. The approach used to develop the HES Study vehicles differs from that used to develop the launch vehicles in this study. Propellant loadings were sized for a specific payload weight in the HES Study, while the propellant loading in this study was held constant and payload penalties or gains were determined. The data shown reflect five steering techniques; warm gas injection, gimbal nozzle, hot gas injection, head-end steering, and liquid injection TVC; two payload shapes: a ballistic Ballos spacecraft and a lifting winged, modified HL-10 spacecraft; the effect of first stage fins on TVC requirements; and the effect of nozzle submergence on vehicle geometry. The data for Configurations I through IIIA were developed in this study, and the data for Configurations IV, V, and VI were extracted from the Phase II HES Study Report No. SM-51872.

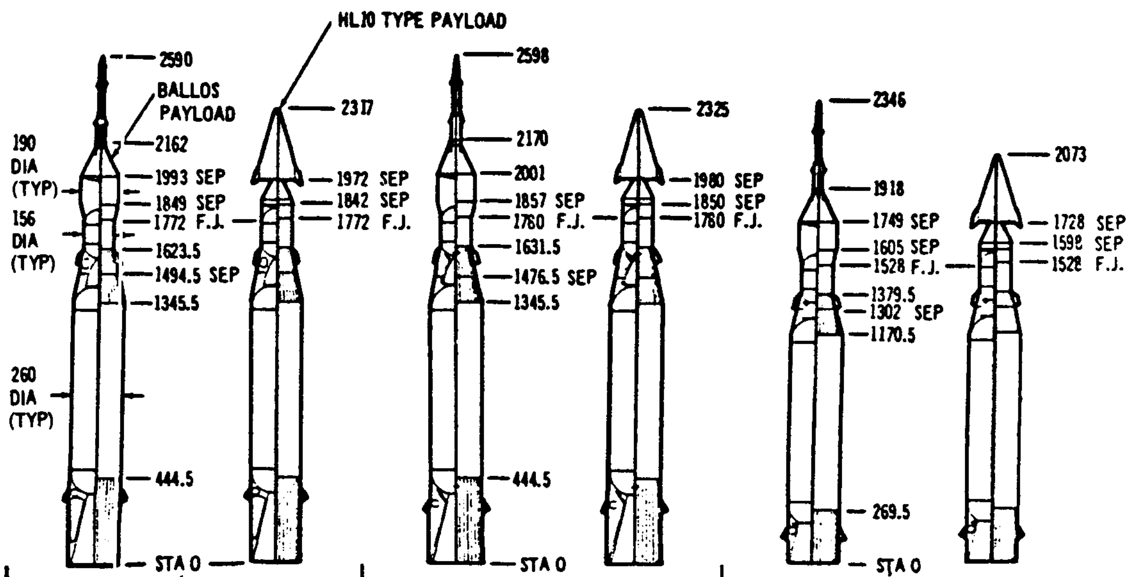
Reliability values are relative to Configuration VI, for this vehicle was used as a base for reliability comparison in the Phase II HES Study. Vehicles using the advanced TVC systems show higher reliability than those using head-end steering and liquid-injection thrust-vector control (LITVC). This can be explained in part by the differences in methodology used in the two studies; however, LITVC is a complex system with an inherently low reliability, and head-end steering must operate without failure for the full duration of the mission.

The effect on the control system of a winged payload is also shown in this figure. During first-stage flight the thrust-vector deflection angles are higher than those for a similar vehicle with a ballistic payload shape, but still well within the capabilities of all TVC systems. However, for second-stage flight, control requirements are established by stage separation transients. The second-stage vehicle diverges during the coast period after

NOTES:

1. TVC SYSTEM NOT DESIGNED FOR WINGED PAYLOAD CONFIGURATIONS IA AND IIIA.

2. COMPARATIVE DATA FOR CONFIGURATION IIA & IIAF, WHICH INCLUDES FINS, ARE SHOWN ON TABLE 3-7

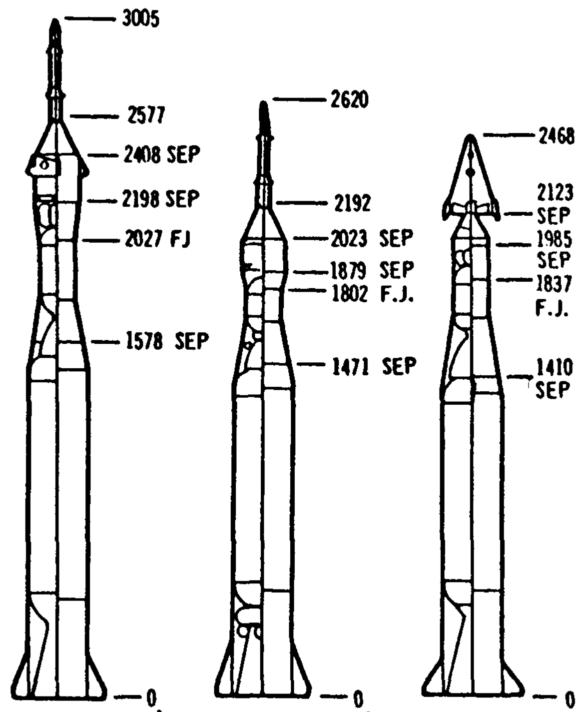


CONFIGURATION		I	IA	II	IIA	III	IIIA
VEHICLE DATA							
GROSS WEIGHT AT LIFTOFF	(LB)	3,634,608	3,619,753	3,470,997	3,456,142	3,472,352	3,457,495
RELIABILITY RELATIVE TO CONFIGURATION VI (HES)		1.015	1.015	1.029	1.029	1.017	1.017
ΔPAYLOAD RELATIVE TO CONFIGURATION V (HES)	(LB)	-9,840	(1)	1,460	1,460	100	(1)
FIRST STAGE DATA							
WEIGHT	(LB)	3,299,986	3,299,986	3,149,348	3,149,348	3,150,959	3,150,959
MAXIMUM THRUST	(LB)	5,028,000	5,028,000	5,028,000	5,028,000	5,028,000	5,028,000
I_{SP}	(SEC)	276.9	276.9	276.9	276.9	276.9	276.9
TVC SYSTEM		WARM GAS	WARM GAS	LOCKSEAL	LOCKSEAL	HOT GAS	HOT GAS
MAXIMUM THRUST-VECTOR DEFLECTION ANGLE	(DEG)	2.32	2.46	2.47	2.80	2.09	2.54
MAXIMUM CONTROL THRUST	(LB)	177,488	216,300	217,000	246,000	183,200	222,500
WEIGHT OF PROPELLANT USED FOR TVC	(LB)	102,152	(1)	0	0	25,200	(1)
ΔI_{SP} DUE TO TVC		-1.45	(1)	0	0	-0.59	(1)
SECOND STAGE DATA							
WEIGHT	(LB)	280,507	280,407	267,534	267,434	267,278	267,178
MAXIMUM THRUST	(LB)	546,000	546,000	546,000	546,000	546,000	546,000
I_{SP}	(SEC)	301.0	301.0	301.0	301.0	301.0	301.0
TVC SYSTEM		WARM GAS	WARM GAS	LOCKSEAL	LOCKSEAL	HOT GAS	HOT GAS
MAXIMUM THRUST-VECTOR DEFLECTION ANGLE	(DEG)	6	6	6	6	6	6
MAXIMUM CONTROL THRUST	(LB)	6,038	6,098	12,880	12,880	7,850	7,850
WEIGHT OF PROPELLANT USED FOR TVC	(LB)	8,738	(1)	0	0	3,135	(1)
ΔI_{SP}		-1.39	(1)	0	0	-0.23	(1)

Figure 2-1. Study Launch Vehicle Comparisons

NOTES:

1. DIFFERENCES BETWEEN PHASE II HES STUDY VEHICLE CONFIGURATIONS IV, V, & VI AND THE VEHICLES DEVELOPED FOR THE TVC SYSTEM STUDY ARE
   - CONFIGURATIONS IV, V, & VI HAVE FIRST STAGE FINS DESIGNED TO PRODUCE MINIMUM CONTROL MOMENT
   - FIRST AND SECOND STAGE NOZZLES ARE NOT SUBMERGED.
   - FIRST AND SECOND STAGE PROPELLANT LOADING FOR CONFIGURATION IV AND VI DIFFER FROM THE BASIC LAUNCH VEHICLE - CONFIGURATION V.
2. DATA PERTAINING TO CONFIGURATIONS IV (HES), V (HES), & VI (HES) ARE OBTAINED FROM DOUGLAS REPORT NO. SM-51872, PHASE II STUDY OF HEAD-END STEERING FOR A SIMPLIFIED MANNED SPACE VEHICLE, MARCH 1966.
3. N/A - NOT APPLICABLE.



CONFIGURATION		IV	V	VI
VEHICLE DATA				
GROSS WEIGHT AT LIFTOFF	(LB)	4,111,750	3,493,300	3,423,050
RELIABILITY RELATIVE TO CONFIGURATION VI (HES)		0.979	0.984	1.000
ΔPAYLOAD RELATIVE TO CONFIGURATION V (HES)	(LB)	(2)	(2)	(2)
FIRST STAGE DATA				
WEIGHT	(LB)	3,643,120	3,178,300	3,051,950
MAXIMUM THRUST	(LB)	5,729,055	5,028,000	4,902,153
I_{SP}	(SEC)	276.9	276.9	277.5
TVC SYSTEM		HES	LITVC	HES
MAXIMUM THRUST-VECTOR DEFLECTION ANGLE	(DEG)	± 30.0	0.27	± 30.0
MAXIMUM CONTROL THRUST	(LB)	18,100	23,500	21,500
WEIGHT OF PROPELLANT USED FOR TVC	(LB)	43,900	10,250	20,800
ΔI_{SP} DUE TO TVC		0	N/A	0
SECOND STAGE DATA				
WEIGHT	(LB)	353,430	267,610	299,560
MAXIMUM THRUST	(LB)	688,610	546,000	932,171
I_{SP}	(SEC)	302.6	301.0	302.6
TVC SYSTEM		HES	LITVC	HES
MAXIMUM THRUST-VECTOR DEFLECTION ANGLE	(DEG)	+ 30	3.5	± 30
MAXIMUM CONTROL THRUST	(LB)	4,000	33,400	6,000
WEIGHT OF PROPELLANT USED FOR TVC	(LB)	8,400	2,130	4,600
ΔI_{SP}		0	N/A	0

Figure 2-2. Phase II HES Study Launch Vehicle Data

separation, and the control system is sized to meet this condition. It was found that payload shape had little influence on second-stage control, for at separation inflight aerodynamic forces are low, while vehicle thrust mis-alignment and essentricity, which are insensitive to payload shape, are the dominant factors. The effect of first-stage fins can be seen when comparing Configuration V with any of the vehicles developed from it. Configuration V has optimum fins to minimize the control moment and shows a maximum thrust-vector deflection requirement of 0.27°. Nominal values may be below the sensitivity threshold limit of the most sophisticated control system. Vehicles without fins require deflection an order of magnitude greater and in the range of current launch vehicle requirements. It is for this reason that fins were not used in Configurations I through IIIA.

The results of the control-system sensitivity analysis have shown that the gas injection TVC systems offer no advantage over the gimballed nozzle TVC system, and vice versa, from a control-system dynamic response standpoint. This conclusion holds as well for a LITVC system and for the head-end steering system considered in the Phase II HES Study.

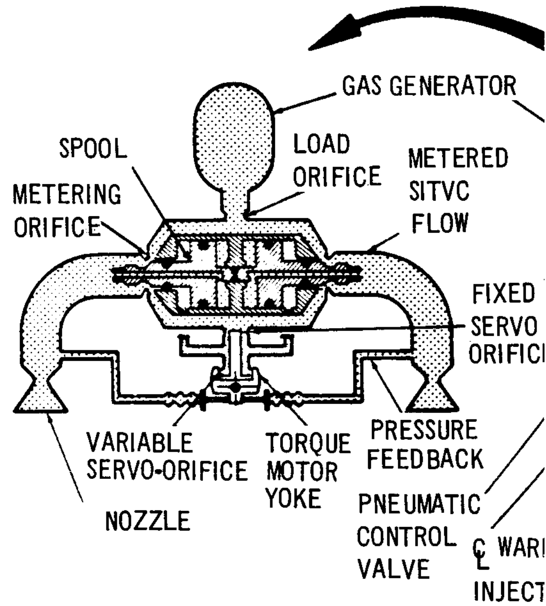
The primary advantage of a gas or liquid-injection TVC system is the fast response characteristic relative to the response characteristics of a gimballed nozzle TVC system. To take advantage of their fast response, the booster control-system response time must be increased beyond that presently used for large booster control systems. Even decreasing control-system response time did not significantly improve the overall control system performance; therefore, a fast TVC system response time beyond that available from a gimballed nozzle TVC system is not required.

The thrust-vector deflection angle requirement is directly proportional to the control moment needed to overcome the aerodynamic moment. Since the control moment is a function of both the thrust-vector deflection angle and the location of the side force with respect to the CG, the TVC system located the maximum distance from the vehicle CG will give the minimum thrust-vector deflection angle requirement. Further studies are required to determine if structural load relief and improvements in cost effectiveness are possible through head-end control.

Section 3
TVC COMPARISONS

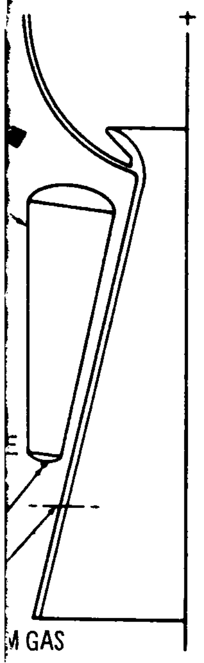
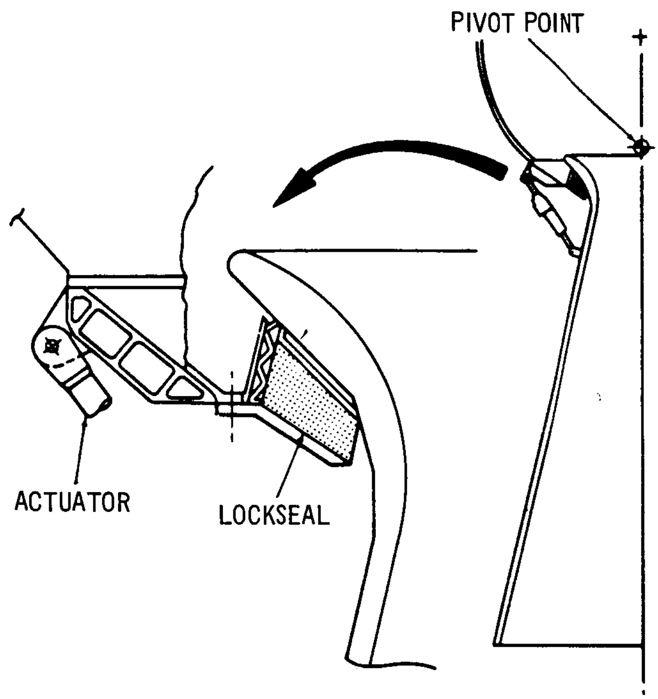
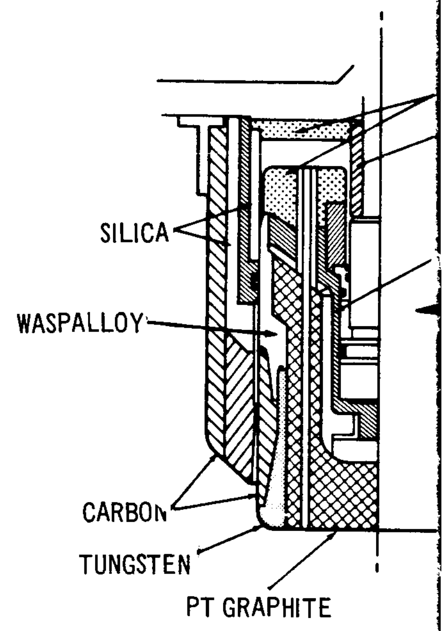
Figure 3-1 shows the TVC concepts evaluated in this study and salient parameters associated with each. Since the ABL on-off concept was not continued in the design effort, data pertaining to it are incomplete, but the data shown for the Thiokol modulated hot-gas valve are applicable to the ABL modulated valve concept. Similarly, the data shown for the Lockheed Lockseal TVC technique generally applies to the Thiokol flexible nozzle TVC method not shown in this report.

WARM GAS TVC (VICKERS)



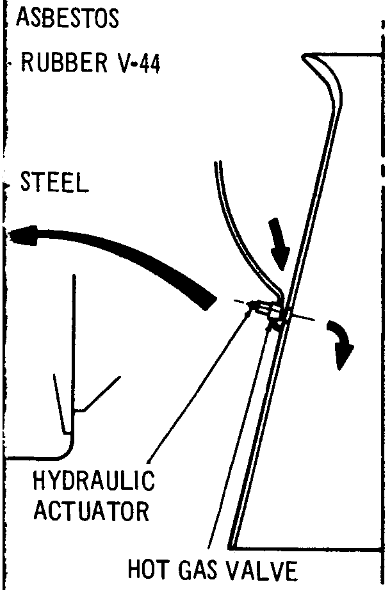
TWO-STAGE PNEUMATIC SERVO-VALVE SCHEMAT

STAGE	FIRST	SE
MAXIMUM THRUST VECTOR DEFLECTION (DEG)	2.02	
MAXIMUM THRST VECTOR DEFLECTION RATE (DEG/SEC)	7.5	1
MAXIMUM THRUST VECTOR DEFLECTION ACCELERATION (DEG/SEC^2)	30	20
FLOW RATE PER QUADRANT (LB/SEC)	560	18
NUMBER OF VALVES	8	
THRUST VECTOR CONTROL METHOD	GAS GENERATORS, T=2000° F	
TOTAL WEIGHT, TVC SYSTEM (LB)	156,631	14,28
RELIABILITY (PROBABILITY OF SUCCESS)	0.988937	

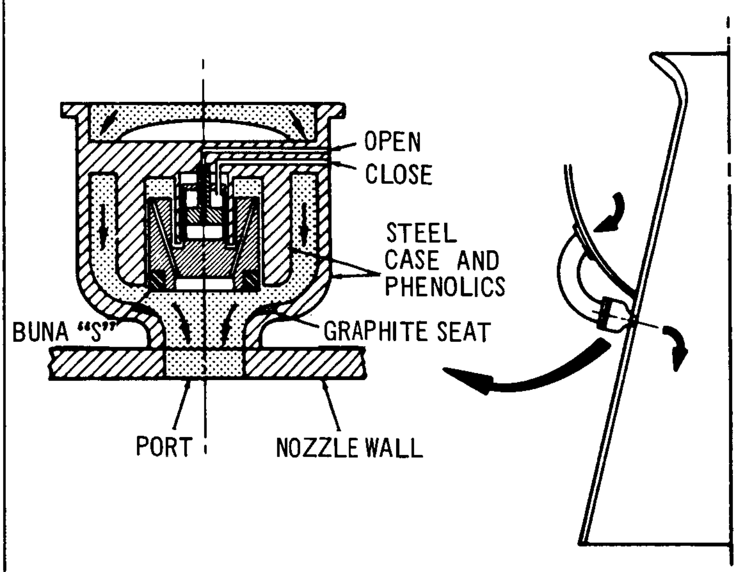
	GIMBAL NOZZLE TVC (LOCKHEED)		HOT GAS TVC (MODULA
 C	 		

COND	FIRST	SECOND	FIRST
6.00	2.47	6.00	2.09
5.0	7.5	15.0	7.5
)	30	200	30
)			445
4			16
	HYDRAULIC ACTUATORS		←
8	7,500	1,273	31,028
0.993959	0.998792	0.998840	0.991409

(THIOKOL)
TED)



HOT GAS (ABL)
(BASIC ON-OFF DESIGN)



SECOND	FIRST	SECOND
6.00	2.09	6.00
15.0	7.5	15.0
200	30	200
147	445	147
8	16	8
MAIN-MOTOR HOT GAS, T = 5,800°F		
4,890	NA	NA
0.995044	NA	NA

Figure 3-1. TVC Systems Comparisons

Section 4
PAYLOAD CAPABILITY

One measure of vehicle performance is the amount of cargo the vehicle can carry into the 260-nmi LORL orbit. Table 4-1 shows the change in weight that occurs for launch vehicles using each of the candidate TVC systems. Configurations I, II, and III use common TVC systems for both stages, but the parameters that cause the change apply mainly to the stage. Therefore, the cargo variation resulting from any interchange of stages to form a launch vehicle could be obtained. There will be a slight error introduced because of differing vehicle geometry and resulting control requirements which affect the parameters, but this should be small making a comparison of this type valid.

The payload of configuration V of the Phase II HES Study is used as the baseline for this evaluation. It has the capability of placing 15,455 lb of cargo and containers into the LORL orbit. The delta payload or cargo weights shown are obtained from a performance analysis and from the vehicle and TVC system design tasks that generated weight and ΔI_{sp}. The performance analysis considered payload as weight in a circular 260-nmi orbit. Since the Ballos spacecraft and its maneuvering propellants are not changed in this study, the change in weight can only occur in cargo capacity.

Table 4-1

VARIATION IN CARGO WEIGHT - 260-NMI ORBIT
COMPARED TO CONFIGURATION V (LITVC)

Items	Configuration (lb) I	II	III
Baseline First-Stage Dry Weight	310, 750	310, 750	310, 750
New First-Stage Dry Weight plus Retrorockets	337, 725	289, 439	291, 050
ΔWeight	26, 975	-21, 311	-19, 700
ΔCargo Weight	-3, 730	+2, 560	2, 360
First-Stage ΔI_{sp}	-1.45	---	-0.59
ΔCargo Weight	-730	---	-300
Baseline First-Stage Propellant Weight	2, 857, 300	2, 857, 300	2, 857, 300
New First-Stage Propellant Weight	2, 857, 300	2, 857, 300	2, 832, 080
ΔWeight	---	---	-25, 220
ΔCargo Weight	---	---	-460
Baseline Second-Stage Dry Weight	40, 030	40, 030	40, 030
New Second-Stage Dry Weight	45, 393	41, 208	40, 952
ΔWeight	5, 363	+1, 178	+922
ΔCargo Weight	-4, 950	-1, 100	-900
Second-Stage ΔI_{sp}	-1.09	---	-0.23
ΔCargo Weight	-430	---	-100
Baseline Second-Stage Propellant Weight	225, 450	225, 450	225, 450
New Second-Stage Propellant Weight	225, 450	225, 450	222, 315
ΔWeight	---	---	-3, 135
ΔCargo Weight	---	---	-500
Total Change in Cargo Weight	-9, 840	+1, 460	+100

Section 5
LAUNCH VEHICLE WEIGHT MATRIX

The first and second stages developed in this study can, with the proper arrangement of each stage represent nine launch vehicles which can accommodate the two payload shapes (Ballos and HL-10 type). A weight matrix has been developed for launch vehicles, exclusive of payload weight (defined here as weight above the second stage). These weights are shown in Tables 5-1, 5-2, and 5-3. Weight above the second stage is shown in Table 5-4.

Table 5-1

LAUNCH VEHICLE WEIGHT MATRIX--
HOT GAS FIRST STAGE (LB)

Items	Hot Gas	Warm Gas	Gimbal
Second Stage			
Aft Skirt	803	1,318	1,532
Nozzle	5,488	4,988	4,988
Motorcase	26,756	27,270	27,270
TVC System	1,755	5,500	1,273
TVC Control/System	100	100	100
Equipment and Instrumentation	4,558	4,552	4,558
Tunnels	47	47	47
Contingencies	1,445	1,612	1,440
Stage at Second-Stage Burnout	40,952	45,393	41,208
Igniter Propellant	240	240	240
Main Propellant	222,315	225,450	225,450
TVC Propellant	3,135	8,788	---
Roll Control Propellant	131	131	131
Stage at Second-Stage Ignition	266,773	280,002	267,029
First Stage	Hot Gas		
Aft Skirt	5,541	5,541	5,541
Nozzle	40,188	40,188	40,188
Motorcase	222,512	222,512	222,512
TVC System	5,208	5,808	5,808
TVC Control System	100	100	100
Forward Skirt	1,932	2,075	1,944
Equipment and Instrumentation	6,271	6,271	6,271
Tunnels	248	248	248
Contingencies	6,300	6,300	6,300
Stage at First-Stage Burnout	555,673	569,045	555,941
Main Propellant	2,832,080	2,832,080	2,832,080
TVC Propellant	25,220	25,220	25,220
Roll Control Propellant	2,609	2,609	2,609
Retrorocket Propellant	2,150	2,150	2,150
Stage at First-Stage Ignition	3,417,732	3,431,104	3,418,000

Table 5-2

LAUNCH VEHICLE WEIGHT MATRIX--
WARM GAS FIRST STAGE (LB)

Items	Hot Gas	Warm Gas	Gimbal
Second Stage			
Aft Skirt	803	1,318	1,532
Nozzle	5,488	4,988	4,988
Motorcase	26,756	27,270	27,270
TVC System	1,755	5,500	1,273
TVC Control System	100	100	100
Equipment and Instrumentation	4,558	4,558	4,558
Tunnels	47	47	47
Contingencies	1,445	1,612	1,440
Stage at Second-Stage Burnout	40,952	45,393	41,208
Main Propellant	222,315	225,450	225,450
TVC Propellant	3,135	8,788	---
Roll Control Propellant	131	131	131
Igniter Propellant	240	240	240
Stage at Second-Stage Ignition	266,773	280,002	267,029
	Warm Gas		
First Stage			
Aft Skirt	7,959	7,959	7,959
Nozzle	30,188	30,188	30,188
Motorcase	226,460	226,460	226,460
TVC System	54,279	54,279	54,279
TVC Control System	100	100	100
Forward Skirt	1,932	2,075	1,944
Equipment and Instrumentation	6,271	6,271	6,271
Tunnels	248	248	248
Contingencies	7,995	7,995	7,995
Stage at First-Stage Burnout	602,205	615,577	602,473
Main Propellant	2,857,300	2,857,300	2,857,300
TVC Propellant	102,352	102,352	102,352
Retrorocket Propellant	2,150	2,150	2,150
Roll Control Propellant	2,609	2,609	2,609
Stage at First-Stage Igntion	3,566,616	3,579,988	3,566,884

Table 5-3

LAUNCH VEHICLE WEIGHT MATRIX--
GIMBAL NOZZLE FIRST STAGE (LB)

Items	Hot Gas	Warm Gas	Gimbal
Second Stage			
Aft Skirt	803	1,318	1,532
Nozzle	5,488	4,988	4,988
Motorcase	26,756	27,270	27,270
TVC System	1,755	5,500	1,273
TVC Control System	100	100	100
Equipment and Instrumentation	4,558	4,558	4,558
Tunnels	47	47	47
Contingencies	1,445	1,612	1,440
Stage at Second-Stage Burnout	40,952	45,393	41,208
Igniter Propellant	240	240	240
Main Propellant	222,315	222,450	225,450
TVC Propellant	3,135	8,788	---
Roll Control Propellant	131	131	131
Stage at Second-Stage Ignition	266,773	280,002	267,029
	Gimbal Nozzle		
First Stage			
Aft Skirt	8,353	8,353	8,353
Nozzle	30,188	30,188	30,188
Motorcase	226,460	226,460	226,460
TVC System	7,500	7,500	7,500
TVC Control System	100	100	100
Forward Skirt	1,932	2,075	1,944
Equipment and Instrumentation	6,271	6,271	6,271
Tunnels	248	248	248
Contingencies	6,225	6,225	6,225
Stage at First-Stage Burnout	554,050	567,422	554,318
Main Propellant	2,857,300	2,857,300	2,857,300
Roll Control Propellant	2,609	2,609	2,609
Retrorocket Propellant	2,150	2,150	2,150
Stage at First-Stage Ignition	3,416,109	3,429,481	3,416,377

Table 5-4

WEIGHT ABOVE THE SECOND STAGE (LB)

	HL-10	Ballos
Spacecraft	15, 470	21, 895
Cargo and Adapter	23, 890	23, 470
Adapter Skirt	405	505
Total Weight	39, 765	45, 870
Launch Escape System	---	8, 750

Section 6
VEHICLE RELIABILITY VERSUS CONFIGURATION

Table 6-1 presents a reliability comparison of all potential vehicle configurations. This matrix is the results of considering all applicable combinations of TVC and roll-control systems with the launch vehicle. Roll-control systems designated APS are the baseline systems; hot gas refers to the dependent system using main-motor gas; and warm gas uses gases from the warm gas generators for roll-control.

The launch vehicle consists of the 260-in. -diam SRM first stage and 156-in. -diam SRM second stage as defined in the Phase II HES Study (Douglas Report No. SM-51872). On the basis of results of that study, the first- and second-stage SRM reliabilities were determined to be 0.971 and 0.978, respectively. With the use of these SRM reliabilities in conjunction with the various combinations of TVC and roll-control systems reliabilities determined in this study, the reliabilities of the vehicle configurations were computed. These results allow the vehicle reliability parameter to be easily and quickly extracted for use, in conjunction with other performance data, in conducting a comparative analysis of any selected configuration.

Table 6-1 (Page 1 of 2)

RELIABILITY COMPARISON OF POTENTIAL LAUNCH VEHICLE CONFIGURATIONS

Motor		TVC System		Roll Control			
260-in. - diam	156-in. - diam	First Stage	Second Stage	First Stage	Second Stage	Vehicle	Ranking
0.971	0.978	Lockseal 0.998792	Lockseal 0.998840	APS 0.997	APS 0.999	0.944	1
0.971	0.978	Lockseal 0.998792	Hot Gas 0.995044	APS 0.997	APS 0.999	0.940	2
0.971	0.978	Lockseal 0.998792	Hot Gas 0.995044	APS 0.997	Hot Gas 0.993	0.934	5
0.971	0.978	Lockseal 0.998792	Warm Gas 0.993959	APS 0.997	APS 0.999	0.939	3
0.971	0.978	Lockseal 0.998792	Warm Gas 0.993959	APS 0.997	Warm Gas 0.992	0.932	7
0.971	0.978	Hot Gas 0.991409	Hot Gas 0.995044	APS 0.997	APS 0.999	0.933	6
0.971	0.978	Hot Gas 0.991409	Hot Gas 0.995044	APS 0.997	Hot Gas 0.993	0.927	11
0.971	0.978	Hot Gas 0.991409	Hot Gas 0.995044	Hot Gas 0.992	APS 0.999	0.928	10
0.971	0.978	Hot Gas 0.991409	Hot Gas 0.995044	Hot Gas 0.992	Hot Gas 0.993	0.923	15
0.971	0.978	Hot Gas 0.991409	Lockseal 0.998840	APS 0.997	APS 0.999	0.938	4
0.971	0.978	Hot Gas 0.991409	Lockseal 0.998840	Hot Gas 0.992	APS 0.999	0.933	6
0.971	0.978	Hot Gas 0.991409	Warm Gas 0.993959	APS 0.997	APS 0.999	0.933	6

Table 6-1 (Page 2 of 2)

Motor		TVC System		Roll Control			
260-in. - diam	156-in. - diam	First Stage	Second Stage	First Stage	Second Stage	Vehicle	Ranking
0.971	0.978	Hot Gas 0.991409	Warm Gas 0.993959	APS 0.997	Warm Gas 0.992	9.926	12
0.971	0.978	Hot Gas 0.991409	Warm Gas 0.993959	Hot Gas 0.992	APS 0.999	0.927	11
0.971	0.978	Hot Gas 0.991409	Warm Gas 0.993959	Hot Gas 0.992	Warm Gas 0.992	0.921	16
0.971	0.978	Warm Gas 0.988937	Warm Gas 0.993959	APS 0.997	APS 0.999	0.931	8
0.971	0.978	Warm Gas 0.988937	Warm Gas 0.993959	APS 0.997	Warm Gas 0.992	0.924	14
0.971	0.978	Warm Gas 0.988937	Warm Gas 0.993959	Warm Gas 0.991	APS 0.999	0.924	14
0.971	0.978	Warm Gas 0.988937	Warm Gas 0.993959	Warm Gas 0.991	Warm Gas 0.992	0.918	18
0.971	0.978	Warm Gas 0.988937	Lockseal 0.998840	APS 0.997	APS 0.999	0.934	5
0.971	0.978	Warm Gas 0.988937	Lockseal 0.998840	Warm Gas 0.991	APS 0.999	0.929	9
0.971	0.978	Warm Gas 0.988937	Hot Gas 0.995044	APS 0.997	APS 0.999	0.931	8
0.971	0.978	Warm Gas 0.988937	Hot Gas 0.995044	APS 0.997	Hot Gas 0.993	0.925	13
0.971	0.978	Warm Gas 0.988937	Hot Gas 0.995044	Warm Gas 0.991	APS 0.999	0.925	13
0.971	0.978	Warm Gas 0.988937	Hot Gas 0.995044	Warm Gas 0.991	Hot Gas 0.993	0.920	17

Section 7
LAUNCH OPERATIONS - TOTAL VEHICLE SYSTEM

In the consideration of the operational aspects for the total launch vehicle (first and second stage), it is readily observed that the gimbal nozzle system on both stages represents the most conventional approach. The fewer number of system components, the similarity of checkout--potentially utilizing common equipment with conventional procedures--and the relative ease of repair and replacement of critical components make such a flight-control-system network attractive. There would appear to be no need to perform a simultaneous ground checkout of both stages since flight performance of the stages is sequential and since sequential checkout would also have to be performed. Relatively simple-sequenced switching techniques can be applied, using the same control and instrumentation loop.

Either the warm gas or hot gas system could be applied to either stage, but each system has its operational drawbacks. To marry two stages having these systems only complicates and magnifies the scope of the problem. Further, to intermix the types of systems provides no distinct off-setting advantages and could further complicate the system since two types of operation procedures and possibly personnel would be required, as well as two sets of GSE. If a technical advantage in vehicle performance dictated two different stage systems, however, one of the hot gas systems (preferably second stage with only eight valves required) could be coupled with a movable nozzle system. Application of the warm gas system would still be less desirable since the handling and access problems associated with the gas generators are not condusive to simple on-pad operating procedures and reasonable checkout time with assurance of flight readiness.