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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
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SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

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ORBITER ALTITUDE AT ALT INTERFACE BASED ON ALSES (APPROACH AND LANDING SHUTTLE ENGINEERING SIMULATION) ANALYSES

MISSION PLANNING, MISSION ANALYSIS
AND SOFTWARE FORMULATION

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GLOSSARY OF SYMBOLS

ALSES	Approach and Landing Shuttle Engineering Simulation
ALT	Approach and Landing Test
CAM	Carrier Aircraft Modification
FSSR	Functional Subsystem Software Requirements
JSC	Johnson Space Center
KEAS	Knots Equivalent Airspeed
MDTSCO	McDonnell Douglas Technical Services Company
RI	Rockwell International
SVDS	Space Vehicle Dynamics Simulation
TBC	The Boeing Company

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1.0 SUMMARY

A parametric analysis of orbiter altitude at ALT interface is required to support the ALT flight test planning which is based on operational requirements. This report documents the details of the orbiter altitude attainable at ALT interface determined by the Approach and Landing Shuttle Engineering Simulation (manned). The analysis culminated in the verification of the trends observed in the same analysis previously performed on the Space Vehicle Dynamics Simulation (unmanned). Altitude variations attributable to pilot steering variability ranged between 492 ft higher to 383 ft lower.

The requirement for this parametric analysis is elaborated upon in Section 2.0. The specifications, assumptions, and analytical approach used to determine the orbiter altitude at ALT interface are presented in Section 3.0. The results of the analytical approach are evaluated in Section 4.0. Conclusions and recommendations are summarized in Section 5.0. Supporting references are listed in Section 6.0.

2.0 INTRODUCTION

A parametric analysis of orbiter altitude at ALT interface is required to support the ALT flight test planning which is based on operational requirements. (See Reference 1.) The analysis is required to determine orbiter altitude attainment at ALT interface for each of two ALT interface requirements. The same analysis was conducted previously on the offline (unmanned) Space Vehicle Dynamics Simulation (see Reference 2). That analysis was compromised by restrictive steering limitations inherent in the simulation constraints (constant orbiter pitch rate commands). One of the conclusions of the previous analysis was that a variable pitch rate command capability (pilot input) could conceivably enhance the pullup capability (altitude attainment) of the orbiter. Toward that end this MDTSCO parametric analysis of orbiter altitude at ALT interface is conducted on the (manned) Approach and Landing Shuttle Engineering Simulation (ALSES).

3.0 DISCUSSION

This section summarizes the specifications, assumptions, and analytical approach used in this analysis. Maximum utilization of previous analyses is made in order to expedite the determination of the orbiter altitude attainable at ALT interface. Source data is referenced accordingly in the subsequent text.

In this analysis, the orbiter ALT interface attainment is simulated by the Approach and Landing Shuttle Engineering Simulation (ALSES) in one flight phase. The post separation flight phase is initialized at three seconds after physical separation of the orbiter from the carrier and terminated at orbiter attainment of the required ALT interface condition. During that time, the orbiter executes a pitch maneuver (pilot input) to attain one of two candidate ALT interface conditions.

3.1 Specifications

As stated in Reference 1, the orbiter altitude at ALT interface attainment is to be maximized for each of two post separation sequences. The first sequence consists of accelerating the orbiter to achieve an airspeed of 250 KEAS at the highest possible altitude (steady conditions at 250 KEAS are not required). During the period from orbiter separation until attainment of 250 KEAS, normal acceleration must be at least .5g's and pitch attitude must be no steeper than 30 degrees nose down from the local horizontal. The second sequence consists of decelerating the orbiter to achieve an airspeed of 200 KEAS at the highest possible altitude (steady state conditions at 200 KEAS are not required). During the deceleration, the angle of attack must be no higher than 10 deg and normal acceleration must be no higher than 1.5g's.

3.2 Assumptions

Three categories of assumptions are used in the analysis of orbiter altitude attainment at ALT interface. Category one entails the data base assumptions. Category two consists of the flight sequence assumptions. Category three contains all other assumptions which serve to simplify the analytical approach.

The data base assumptions are as follows:

1) Orbiter configuration:

   A) Tailcone off and tailcone on.

   B) Body flaps at 0 deg and -11.7 deg for the respective tailcone configurations.

   C) Control system as defined in Reference 3.

2) Orbiter free stream aerodynamics as defined in Reference 4.

3) Orbiter mass properties as defined in Reference 5.

The post separation flight phase sequence assumptions are as follows:

1) The post separation flight sequence is initialized at the termination of a 3 sec separation flight sequence during which time the orbiter is steered by a constant +2 deg/sec (nose-up) pitch rate command.

2) The time duration of the post separation flight phase is determined by the orbiter attainment of one of the two ALT interface specifications.

Assumptions which simplify the analytical approach are as follows:

1) Only nominal system and environmental conditions are assumed.

2) Only the light weight orbiter (150,000 lb, forward c.g.) is analyzed for both the tailcone off and tailcone on configurations.

3) The initial conditions used are consistent with six trial incidence angles for the tailcone off configuration and five trial incidence angles for the tailcone on configuration (see Reference 2).

3.3 Analytical Approach

The overall analytical approach consists of parameterizing with respect to incidence angle (separation airspeed) the orbiter altitude attainment at each of two ALT interface requirements for both orbiter tailcone configurations. The incidence angle (separation airspeed) which results in the highest orbiter altitude attainment for each of the two ALT interface requirements is then identified for each of the two orbiter tailcone configurations. Toward that end, a three step analytical approach common to each incidence angle (separation airspeed), each ALT interface requirement, and each orbiter tailcone configuration is used.

The first step is to initialize the ALSES at the initial conditions tabulated in the run matrix of Table 1. The second step is to pilot input the orbiter steering which best satisfies the specifications enumerated in Section 3.1. The third step is to evaluate the conditions which maximize orbiter altitude at ALT interface for each tailcone configuration at each ALT interface requirement.

4.0 RESULTS

This section contains the discussion of results which justify the conclusions and recommendations summarized in Section 5.0. The discussion pertains to the determination of the incidence angle (separation airspeed) which facilitates the highest orbiter altitude attainment at each of the two ALT interface requirements for each of the two tailcone configurations.

The results for the 200 KEAS ALT interface requirements are tabulated in Table 2. The maximum orbiter altitude at ALT interface is attainable for an incidence angle of 6.0 deg for both tailcone configurations. The identical result was obtained from the previous analysis performed on the offline simulation for the tailcone off configuration (see Reference 2). The offline simulation results indicated that a 6.5 deg incidence angle is slightly better for the tailcone on configuration. The difference in results is attributable to the slightly higher maximum normal load factor (1.7g's) incurred in the ALSES results (pilot input).

The results for the 250 KEAS ALT interface requirements are tabulated in Table 3. The maximum orbiter altitude at ALT interface is attainable for an incidence angle of 6.5 deg and 5.5 deg for the tailcone on and tailcone off configurations, respectively. The identical results were obtained from the previous analysis performed on the offline simulation for both tailcone configurations (see Reference 2).

The difference in orbiter altitude attainable at ALT interface between the ALSES and SVDS simulations (see Figure 1) ranges between 492 ft higher and 383 ft lower (ALSES result minus SVDS result). The differences are attributable to flight parameter variations introduced by pilot steering.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the conclusions and recommendations derivable from the results presented in Section 4.0.

The conclusions derived in Section 4.0 are as follows:

1) The highest orbiter altitude at the 250 KEAS ALT interface condition is attainable for a 5.5 deg and 6.5 deg incidence angle for the tailcone off and tailcone on configurations, respectively. The corresponding separation airspeeds are 269 KEAS and 258 KEAS, respectively.

2) The highest orbiter altitude at the 200 KEAS ALT interface condition is attainable for a 6.0 deg incidence angle for both tailcone configurations. The corresponding separation airspeeds are 257 KEAS and 269 KEAS for the tailcone off and tailcone on configurations, respectively.

The recommendations derived from Section 4.0 are as follows:

1) Use offline (SVDS) simulations for ALT separation parametric analyses. The simulation results are sufficiently accurate to establish tradeoffs and trends.

2) Use manned (ALSES) simulations for evaluating ALT separation parameters which are sensitive to the variability of pilot input.

6.0 REFERENCES

1) JSC Memo No. CT-75-111, "Operational Requirements for Separation Studies", 21 October 1975.

2) MDTSCO Design Note No. 1.4-7-26, "Parametric Analysis of Orbiter Altitude at ALT Interface", 30 January 1976.

3) RI Document No. SD74-SH-0271A, "Level C Funct.nal Subsystem Software Requirements Document", November 1974.

4) RI Document No. SD75-SH-0033-A, "Orbiter/747 Carrier Separation Aerodynamic Data Book", August 1975.

5) TBC Document No D180-18401-6, "Boeing 747 Space Shuttle Orbiter/Carr Aircraft Modification (CAM) Mass Properties Status Report", September 1975.

FIGURE 1 ORBITER ALTITUDE AT ALT INTERFACE

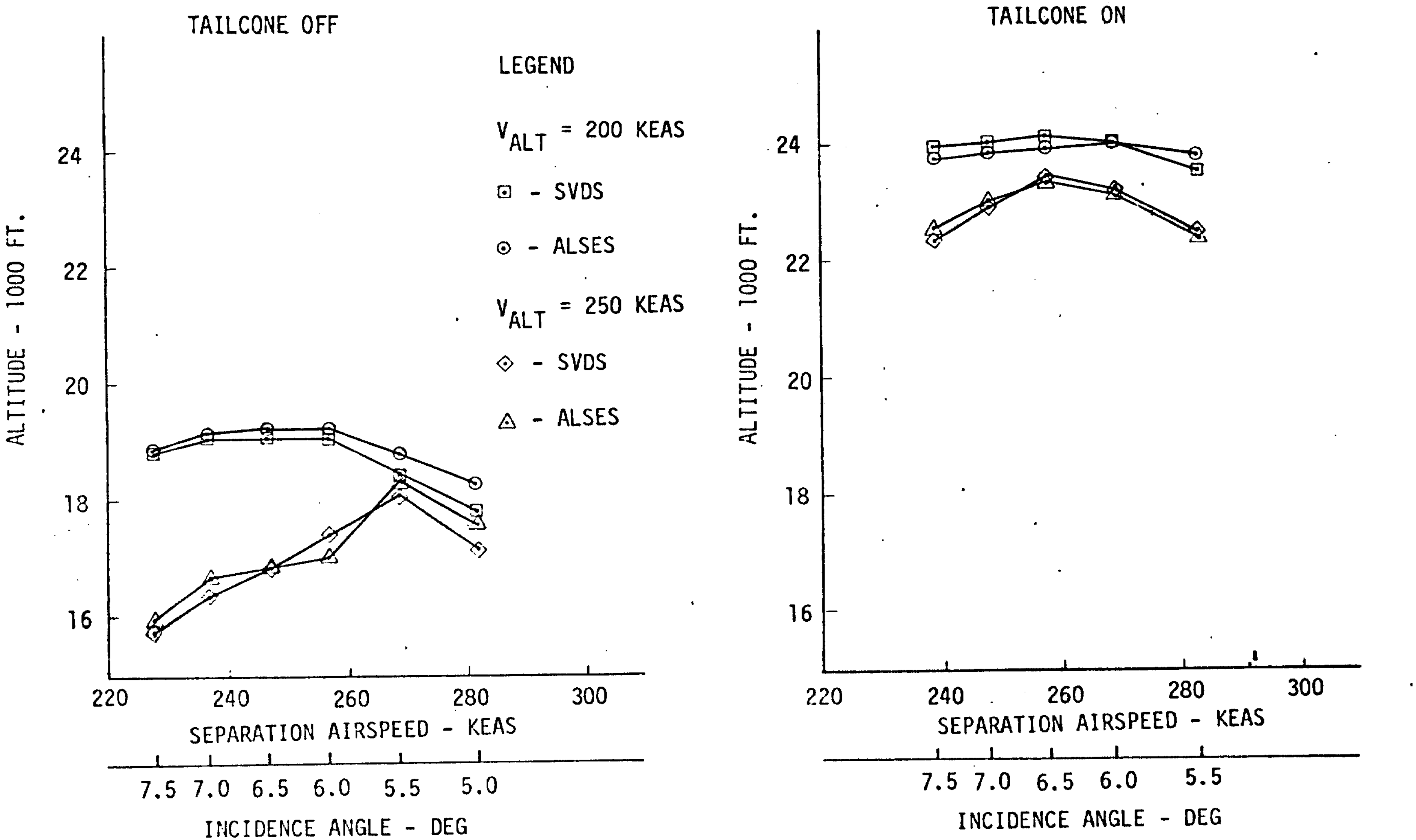

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TABLE 1

RUN MATRIX INITIAL CONDITIONS

RUN NO	TAIL CONE	RUN TERMINATION AT V (KEAS) & $\dot{V}$ (KEAS/S)		Q_o (DEG/S)	Q_{c_o} (DEG/S)	Z_{io} (FT)
1	ON	200	< 0	1.76	2.0	22704
2				1.79		23590
3				1.84		23816
4				1.88		23893
5				1.90		23851
6		250	> 0	1.76		22704
7				1.79		23590
8				1.84		23816
9				1.88		23893
10				1.90		23851
11	OFF	200	< 0	1.63		18095
12				1.68		18715
13				1.73		19238
14				1.76		19225
15				1.79		19202
16				1.80		18967
17		250	> 0	1.63		18095
18				1.68		18715
19				1.73		19238
20				1.76		19225
21				1.79		19202
22				1.80		18967

TABLE 1 (Continued)

RUN MATRIX INITIAL CONDITIONS

RUN NO	θ_o (DEG)	δ_e (DEG)	δ_{SB} (DEG)	δ_{BF} (DEG)	V_o (KEAS)	V_{TRUE} (KTS)	(FPS)	M -	α (DEG)
1	-0.39	-0.08	0	-11.7	283	406	686	0.67	7.73
2	1.37	-0.33			268	390	659	0.64	8.55
3	2.79	-0.57			256	374	632	0.62	9.28
4	4.01	-0.80			246	360	607	0.59	10.00
5	5.21	-1.07			236	345	583	0.57	10.78
6	-0.39	-0.08			283	406	686	0.67	7.73
7	1.37	-0.33			268	390	659	0.64	8.55
8	2.79	-0.57			256	374	632	0.62	9.28
9	4.01	-0.80			246	360	607	0.59	10.00
10	5.21	-1.07			236	345	583	0.57	10.78
11	-2.50	2.87			276	366	617	0.59	7.17
12	-0.85	2.70			263	352	594	0.57	7.91
13	1.06	2.53			250	338	571	0.55	8.74
14	2.64	2.43			240	324	547	0.53	9.47
15	4.17	2.34			229	310	523	0.50	10.30
16	5.57	2.24			220	296	499	0.48	11.09
17	-2.50	2.87			276	366	617	0.59	7.17
18	-0.85	2.70			263	352	594	0.57	7.91
19	1.06	2.53			250	338	571	0.55	8.74
20	2.64	2.43			240	324	547	0.53	9.47
21	4.17	2.34			229	310	523	0.50	10.30
22	5.57	2.24			220	296	499	0.48	11.09

TABLE I (Continued)

RUN MATRIX INITIAL CONDITIONS

RUN NO	m (SLUGS)	W (LBS)	X_{CG} (INCHES)	Y_{CG} (INCHES)	Z_{CG} (INCHES)	I_{XX} (SLUG - FT^2)	I_{YY} (SLUG - FT^2)	I_{ZZ} (SLUG - FT^2)	I_{XZ} (SLUG - FT^2)
1	4662	150000	1057.3	0.4	374.3	0.772×10^6	5.037×10^6	5.303×10^6	0.142×10^6
2									
3									
4									
5									
6									
7									
8									
9									
10									
11			1076.5	0.4	371.4	0.771×10^6	5.398×10^6	5.663×10^6	0.135×10^6
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									

TABLE 2

RESULTS FOR 200 KEAS ALT INTERFACE REQUIREMENT

RUN NO.	TAIL CONE	INCIDENCE ANGLE (DEG)	SEPARATION AIRSPEED (KEAS)	α_{MAX} (DEG)	n_{MAX} (G'S)	ALSES h_{MAX} (FT)	SVDS* h_{MAX} (FT)
1	ON	5.5	283	10.0	1.9	23807	23508
2	↓	6.0	269	10.3	1.7	24044	24077
3	↓	6.5	258	10.5	1.6	23950	24127
4	↓	7.0	248	10.2	1.6	23885	24048
5	↓	7.5	239	10.7	1.6	23741	23975
11	OFF	5.0	282	10.3	1.5	18265	17816
12	↓	5.5	269	10.2	1.5	18823	18450
13	↓	6.0	257	10.2	1.5	19246	19056
14	↓	6.5	247	10.5	1.5	19220	19088
15	↓	7.0	237	10.3	1.5	19150	19091
16	↓	7.5	228	11.0	1.5	18896	18873

*Results from Reference 2

TABLE 3

RESULTS FOR 250 KEAS ALT INTERFACE REQUIREMENT

RUN NO.	TAIL CONE	INCIDENCE ANGLE (DEG)	SEPARATION AIRSPEED (KEAS)	θ_{MIN} (DEG)	n_{MIN} (G'S)	ALSES h_{MAX} (FT)	SVDS* h_{MAX} (FT)
6	ON	5.5	283	-7	.2	22405	22485
7		6.0	269	-4	.3	23199	23212
8		6.5	258	-6	.3	23402	23479
9		7.0	248	-15	.2	23010	22948
10		7.5	239	-19	.3	22530	22372
17	OFF	5.0	282	-4	.6	17590	17098
18		5.5	269	-7	.3	18342	18061
19		6.0	257	-29	.2	17030	17413
20		6.5	247	-32	.2	16845	16817
21		7.0	237	-33	.2	16657	16328
22		7.5	228	-32	.2	15962	15752

*Results from Reference 2