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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

DESIGN NOTE NO. 1.4-7-40

MAXIMIZATION OF ORBITER ALTITUDE AT ALT INTERFACE AIRSPEED

MISSION PLANNING, MISSION ANALYSIS
AND SOFTWARE FORMULATION

31 May 1976

This Design Note is Submitted to NASA Under Task Order No. D0508, Task Assignment A, in Partial Fulfillment of Contract NAS 9-14960.

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(NASA-CR-147752) MAXIMIZATION OF ORBITER ALTITUDE AT AL INTERFACE AIRSPEED, MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE (MCDONNELL-DOUGLAS ASTRONAUTICS) 29 P HC $4.00 CSCL 22A G3/13

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GLOSSARY OF SYMBOLS

ALT	-	APPROACH AND LANDING TEST
CAS	-	CONTROL AUGMENTATION STEERING
c.g.	-	CENTER OF GRAVITY
JSC	-	JOHNSON SPACE CENTER
MDTSCO	-	MCDONNELL DOUGLAS TECHNICAL SERVICES COMPANY
MSL	-	MEAN SEA LEVEL
M_D	-	MAXIMUM DIVE MACH NUMBER
RI	-	ROCKWELL INTERNATIONAL
TBC	-	THE BOEING COMPANY
V_{ALT}	-	ALT INTERFACE AIRSPEED
V_D	-	MAXIMUM DIVE AIRSPEED

1.0 SUMMARY

This report documents the details of the determination of the separation initial conditions (i.e. incidence angle) that maximizes orbiter altitude at the ALT interface airspeed. In the analysis, optimum altitude-airspeed profiles are generated for each orbiter incidence angle and tailcone configuration. Results show that the highest separation altitude does not result in the highest altitude at ALT interface airspeed. The altitude attainable at ALT interface airspeed should therefore be considered in the selection of the initial conditions (i.e. incidence angle). Without violating any known constraints, the incidence angles that maximize orbiter altitude at the ALT interface airspeeds are 7.0 deg for ALT Free Flight 1 and 5.5 deg for ALT Free Flight 6.

The requirement for a parametric analysis of orbiter altitude attainable at ALT interface airspeed is stated in Section 2.0. The specifications, assumptions, and analytical approach used to determine orbiter altitude attainable at ALT interface airspeed are presented in Section 3.0. The results of the analysis are evaluated in Section 4.0. Conclusions are summarized in Section 5.0. Supporting reference sources are listed in Section 6.0.

2.0 INTRODUCTION

A parametric analysis of the orbiter altitude attainment at the ALT interface airspeed is required to satisfy the operational requirements for separation studies (see Reference 1) and to support the ALT flight test planning. A similar MDTSCO analysis was previously performed for two discrete candidate ALT interface airspeeds (see Reference 2). The current parametric analysis is an extension of the referenced analysis and parameterizes orbiter altitude attainment at ALT interface airspeed with respect to ALT interface airspeed. The data base of the current analysis is also an update of that used in the referenced analysis. Toward that end, this MDTSCO "Maximization of Orbiter Altitude at ALT Interface Airspeed" is performed for both the tailcone off and tailcone on orbiter configurations.

3.0 DISCUSSION

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

- The ALT orbiter/carrier separation is simulated by the Space Vehicle Dynamics Simulation Program in two flight phases. The separation flight phase is initiated at the instant of orbiter release and is defined to be 5 sec in duration. The post separation flight phase is terminated at the attainment of ALT interface airspeed.

3.1 Specifications

As stated in Reference 4, six free flights are currently scheduled. The first 5 flights are for a tailcone on orbiter configuration and the last, tailcone off. For ALT Free Flight 1, the orbiter will accelerate to 270 KEAS at an altitude above 20,000 ft MSL after separation. For ALT Free Flight 6, the orbiter will accelerate to 255 KEAS at an altitude above 16,500 ft MSL after separation. Reference 1 states that during the period from separation until the ALT interface airspeed is achieved, the orbiter normal acceleration and local horizontal pitch attitude must be at least 0.5 g's and greater than 30 deg nose down, respectively.

Alternative orbiter steering during the post separation flight phase is also analyzed in order to investigate the possibility of achieving higher altitude for slower potential ALT interface airspeeds (V_{ALT} < 239 KEAS).

3.2 Assumptions

Three catagories of assumptions are required to analyze orbiter altitude attainment at ALT interface airspeed. The first category contains the data base assumptions. The second category consists of the flight sequence assumptions. The third category is all of the other assumptions that simplify the analytical approach.

The data base assumptions are:

1) Orbiter configuration:

   a) Tailcone on and off.

   b) Body flap at -11.7 deg.

   c) Control system as defined in Reference 5.

2) Carrier configuration:

   a) Inflight spoilers deployed.

   b) Thrust at idle.

   c) Thrust as defined in Reference 6.

   d) Control system as defined in Reference 7.

3) Separation altitudes as defined in Reference 3.

4) Aerodynamic data as defined in Reference 6.

5) Mass characteristics as defined in Reference 8.

The flight phase sequence assumptions are divided into two subcategories, the separation flight phase sequence assumptions and the post separation flight phase sequence assumptions.

The separation flight phase sequence assumptions are:

1) The separation flight phase is defined to be 5 sec in duration.

2) The carrier maintains the mated vehicle equilibrium glide pitch attitude command until 4 sec after separation. The carrier then pitches up at 2 deg/sec to the carrier

equilibrium glide pitch attitude command required to maintain the separation airspeed.

3) The carrier roll attitude command is initiated 2 sec after separation.

   a) The carrier roll attitude command is rate limited to -10 deg/sec.

   b) The carrier roll attitude command is limited to -30 deg.

4) The orbiter control system is in the CAS (rate command) mode during which time the orbiter pitch rate command is a constant 2 deg/sec for the first 3 sec and 0 deg/sec for the remaining 2 sec.

The post separation flight phase sequence assumptions are:

1) The time duration of the post separation flight phase is determined by the orbiter attainment of the ALT interface airspeed requirements.

2) The carrier pitch and roll maneuvers are a continuation of those initiated in the separation flight phase.

3) The orbiter control system remains in the CAS mode, during which time the orbiter performs a 0.5g pitchover maneuver in order to attain the ALT interface airspeed requirement. (Pitch attitude comman' limited to -30 deg).

Assumptions which simplify the analytical approach are:

1) Only nominal conditions are assumed. No system nor environmental tolerances are analyzed.

2) Only ALT Free Flights 1 and 6 are analyzed. These flights are for a light weight, forward c.g. orbiter.

3) All 7 incidence angles are analyzed for each of the 2 flights.

3.3 Analytical Approach

The overall analytical approach consists of parameterizing with respect to incidence angle (separation initial conditions) the orbiter altitude-airspeed attainment for two orbiter post separation steering sequences for each of two orbiter configurations consistent with ALT Free Flight Nos. 1 and 6. For each free flight, the incidence angle which results in the highest orbiter altitude at the required ALT interface airspeed is then identified.

Toward that end, a three step analytical approach common to each incidence angle and orbiter configuration is used (i.e. 7 incidence angles and 2 orbiter configurations). The first step is to generate the separation initial conditions required to produce the 0.75 g's relative normal load factor and the 4 deg/sec^2 orbiter pitch acceleration at the instant of separation. The mated trim program is used for this purpose (see Reference 9).

The second step is to generate the altitude-airspeed profiles for the nominal orbiter post separation steering. At the beginning of the post separation flight phase, the orbiter is immediately pitched over at a rate consistent with maintaining the normal load factor at the 0.5 g specification. The 0.5 g's is maintained until the local horizontal pitch attitude reaches the -30 deg specification. At that time, a 0 deg/sec rate is commanded in order to maintain the pitch attitude no steeper than -30 deg.

The third step is to generate the altitude-airspeed profiles for the alternate orbiter post separation steering. The alternate orbiter post separation steering is the same as the nominal steering with one exception. The 0 deg/sec pitch rate command of the separation flight phase is maintained for a period of time before initiation of the 0.5g pitch over. The period of time is parametrically determined such that the airspeed attained when the orbiter first begins to accelerate in an alternate steering case is equal to that in a nominal steering case with a 0.5 deg higher incidence angle.

4.0 RESULTS

This section first discusses the results of the analytical approach outlined in Section 3.0. Then the results which determine the incidence angle (separation initial conditions) that yields the maximum orbiter altitude at ALT interface airspeed are discussed. Finally, the results which give rise to the conclusions and recommendations summarized in Section 5.0 are discussed.

The separation equilibrium glide airspeed requirements are illustrated in Figure 1. The separation airspeeds from Figure 1, which satisfy the separation design requirements of 0.75 g's relative normal acceleration and 4 deg/sec^2 orbiter pitch acceleration, are tabulated for each incidence angle in Tables 1 and 2 for the tailcone on and off configurations, respectively. The airspeed required to satisfy the design requirements exceeds the carrier maximum recommended separation airspeed (V_D or M_D minus a 25 KCAS pad) for incidence angles less than 7.0 deg for the tailcone on configuration and 5.0 deg for the tailcone off configuration. Reference 10 states that the pilot accuracy in obtaining the separation airspeed is within -1 KEAS to +3 KEAS. To insure that the carrier airspeed constraint is not exceeded, the 5.0 deg incidence angle for the tailcone off configuration should also be disqualified.

The tailcone on configuration steering summary is tabulated in Table 1 for the nominal orbiter post separation steering and in Table 3 for the alternate steering. The carrier airspeed constraint limits the acceptable incidence angles to 7.5 deg and 7.0 deg. The range of separation airspeed required to produce the 0.75g relative normal load factor and 4 deg/sec^2 orbiter pitch acceleration design requirements is 241.9 KEAS to 252.5 KEAS. The orbiter airspeed attained when the orbiter first begins to accelerate ranges from 227.2 KEAS to 239.0 KEAS. The terminal pitch attitude and flight path angle range from -29.0 deg to -27.2 deg and from -31.6 deg to -29.8 deg respectively. The minimum orbiter normal load factor during the orbiter pitch over maneuver is 0.46g for the range of acceptable incidence angles.

The tailcone off configuration steering summary is tabulated in Table 2 for the nominal orbiter post separation steering and Table 4 for the alternate steering. The carrier airspeed constraint limits the acceptable range of incidence angles from 7.5 deg to 5.5 deg. The range of separation airspeeds required to produce the 0.75g relative normal load factor and 4 deg/sec^2 orbiter pitch acceleration design requirements is 219.8 KEAS to 264.8 KEAS. The orbiter airspeed attained when the orbiter first begins to accelerate ranges from 192.1 KEAS to 238.2 KEAS. The terminal pitch attitude and flight path angle range from -30.0 deg to -27.0 deg and from -34.0 deg to -29.1 deg respectively. The minimum orbiter normal load factor during the orbiter pitch over maneuver ranges from 0.45 g to 0.46 g.

Illustrated in Figures 2 and 3 are the altitude-airspeed profiles for the nominal orbiter post separation steering cases for the tailcone on and off configurations respectively. Figures 4 and 5 illustrate the altitude-airspeed profiles for the alternate steering. By comparing the nominal steering with the alternate steering for both tailcone configurations, it is evident that the nominal steering attains the higher altitude for a given airspeed and incidence angle. However, at the airspeed where the orbiter first begins to accelerate, a 7.0 deg incidence angle using the alternate steering attains a higher altitude than a 7.5 deg incidence angle using the nominal steering. This analysis has shown that in general there is a range of airspeeds for any two adjacent incidence angles where the alternate post separation steering for the lesser of the two incidence angles can attain a higher altitude at a given airspeed in that range than the nominal steering.

Aside from the carrier airspeed constraint, Figures 2 and 3 show that an incidence angle of 6.0 deg attains the highest altitude at the 270 KEAS ALT interface airspeed requirement for the ALT Free Flight 1 and that an incidence angle of 5.0 deg attains the highest altitude at the 255 KEAS ALT interface airspeed requirement for the ALT Free Flight 6. If the ALT interface airspeeds are reduced from 270 KEAS to 255 KEAS for the tailcone on configuration and from 255 KEAS to 240 KEAS for the tailcone off configuration, the incidence angle that maximizes altitude at the ALT interface airspeed increases to 6.5 deg and to 5.5 deg for the tailcone on and tailcone off configurations respectively.

The assumption that the incidence angle that maximizes the separation altitude also maximizes orbiter altitude at the ALT interface airspeed is disproved as shown in Figures 2 and 3. Incidence angles of 6.5 deg and 6.0 deg maximize the separation altitude for the tailcone on and tailcone off configurations respectively. As stated above, incidence angles of 6.0 deg and 5.0 deg maximize orbiter altitude at the ALT interface airspeed for the tailcone on and tailcone off configurations respectively. The orbiter altitude attainable at the ALT interface airspeed should therefore be considered in selecting the optimum incidence angle instead of the separation altitude.

When the carrier airspeed constraint is taken into account, the allowable incidence angles which maximize orbiter altitude for ALT Free Flights 1 and 6 are 7.0 deg and 5.5 deg respectively. This results in a reduction of the orbiter altitude attainable at the ALT interface airspeed of 1300 ft for ALT Free Flight 1 and 450 ft for ALT Free Flight 6.

5.0 CONCLUSIONS

This section summarizes the conclusions.

The conclusions that are derived from Section 4.0 are:

1) The altitude attainable at the ALT interface airspeed should be considered in selecting the optimum incidence angle.
2) The incidence angle that attains the highest altitude at the ALT interface airspeed is a function of the ALT interface airspeed.
3) The incidence angle that maximizes the separation altitude does not correspond to the incidence angle that maximizes orbiter altitude at the ALT interface airspeed.
4) The orbiter alternate post separation steering can attain higher altitudes for ALT interface airspeeds less than 239 KEAS.
5) Without violating any known constraints, the incidence angles that maximize orbiter altitude at the ALT interface airspeed are 7.0 deg for ALT Free Flight 1 and 5.5 deg for ALT Free Flight 6.

6.0 REFERENCES

1) JSC MEMO NO. CT-75-111, "OPERATIONAL REQUIREMENTS FOR SEPARATION STUDIES," DATED 21 OCTOBER 1975.

2) MDTSCO DN NO. 1.4-7-26, "PARAMETRIC ANALYSIS OF ORBITER ALTITUDE AT ALT INTERFACE," DATED 30 JANUARY 1976.

3) RI IL NO. SAS/AERO/75-658, "UPDATE OF ALT LAUNCH ALTITUDE," DATED 13 NOVEMBER 1975.

4) JSC 09918, "MISSION OBJECTIVES DOCUMENT SHUTTLE APPROACH AND LANDING TESTS," ALT CDR 4.2.2.

5) RI DOC. NO. SD 74-SH-0271A, "LEVEL C FUNCTIONAL SUBSYSTEM SOFTWARE REQUIREMENTS DOCUMENT," DATED 13 AUGUST 1975.

6) RI DOC. NO. SD-75-SH-0033B, "ORBITER/747 CARRIER SEPARATION AERODYNAMIC DATA BOOK," DATED MARCH 1976.

7) JSC MEMO NO. EJ3-74-171, "DEFINITION OF 747 FCS AND ORBITER FCS FOR CARRIER/ORBITER SIMULATIONS AT NASA," DATED SEPTEMBER 1974.

8) RI IL NO. WTS/397-404/76-165, "ORBITER/747 MATED CONFIGURATION MASS PROPERTIES," DATED 3 MARCH 1976.

9) MDTSCO DN NO. 1.4-7-19, "ALT 747/ORBITER MATED TRIM COMPUTER PROGRAM," DATED 17 NOVEMBER 1975.

10) TBC DOC. NO. D180-18407-3, "ALT LAUNCH SIMULATION 2-30 DAY REPORT," DATED 3 FEBRUARY 1976.

Table 1

STEERING SUMMARY

ALT FREE FLIGHT NO. 1 (TAILCONE ON)

150,000 LB ORBITER CG @ 63.5% L_B .

AIRSPEED WHEN $\dot{V}$=0 (KEAS)	227.2	239.0	252.1	266.6	283.9	
INCIDENCE ANGLE (DEG)	7.5	7.0	6.5	6.0	5.5	
AIRSPEED AT SEPARATION (KEAS)	241.9	252.5	264.0	276.9	292.7	
TIME DURATION $\dot{\Theta}c$=2 DEG/SEC (SEC)	3.0	3.0	3.0	3.0	3.0	
TIME DURATION $\dot{\Theta}c$=0 DEG/SEC (SEC)	2.0	2.0	2.0	2.0	2.0	
TIME DURATION $\dot{\Theta}c$ FOR 0.5g DIVE (SEC)	23.8	22.4	20.4	17.6	13.1	
TIME DURATION Θ=-30 DEG (SEC)	0.0	0.0	0.0	0.0	0.0	
TERMINAL PITCH ATTITUDE (DEG)	-29.0	-27.2	-24.5	-20.9	-15.3	
TERMINAL FLIGHT PATH ANGLE (DEG)	-31.6	-29.8	-27.1	-23.5	-18.0	
MINIMUM NORMAL LOAD FACTOR (G'S)	0.46	0.46	0.47	0.47	0.49	

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Table 2

STEERING SUMMARY

ALT FREE FLIGHT NO. 6 (TAILCONE OFF)

150,000 LB ORBITER CG @ 65% L_B

AIRSPEED WHEN $\dot{V}$=0 (KEAS)	192.1	201.6	212.6	224.4	238.2	252.8	
INCIDENCE ANGLE (DEG)	7.5	7.0	6.5	6.0	5.5	5.0	
AIRSPEED AT SEPARATION (KEAS)	219.8	228.6	238.9	250.7	264.8	279.8	
TIME DURATION $\dot{\Theta}c$=2 DEG/SEC (SEC)	3.0	3.0	3.0	3.0	3.0	3.0	
TIME DURATION $\dot{\Theta}c$=0 DEG/SEC (SEC)	2.0	2.0	2.0	2.0	2.0	2.0	
TIME DURATION $\dot{\Theta}c$ FOR 0.5g DIVE (SEC)	18.6	18.8	19.0	18.8	17.0	14.0	
TIME DURATION Θ=-30 DEG (SEC)	0.6	0.4	0.0	0.0	0.0	0.0	
TERMINAL PITCH ATTITUDE (DEG)	-30.0	-30.0	-30.0	-29.4	-27.0	-23.1	
TERMINAL FLIGHT PATH ANGLE (DEG)	-33.8	-33.3	-32.3	-31.5	-29.1	-25.2	
MINIMUM NORMAL LOAD FACTOR (G'S)	0.45	0.45	0.45	0.45	0.46	0.47	

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Table 3

STEERING SUMMARY

ALT FREE FLIGHT NO. 1 (TAILCONE ON)

150,000 LB ORBITER CG @ 63.5% L_B

ALTERNATE ORBITER STEERING

AIRSPEED WHEN $\dot{V}$=0 (KEAS)	227.3	239.1	252.1	266.6	
INCIDENCE ANGLE (DEG)	7.0	6.5	6.0	5.5	
AIRSPEED AT SEPARATION (KEAS)	252.5	264.0	276.9	292.7	
TIME DURATION $\dot{\Theta}c$=2 DEG/SEC (SEC)	3.0	3.0	3.0	3.0	
TIME DURATION $\dot{\Theta}c$=0 DEG/SEC (SEC)	9.0	10.6	13.0	17.0	
TIME DURATION $\dot{\Theta}c$ FOR 0.5g DIVE (SEC)	23.3	21.6	19.3	16.1	
TIME DURATION Θ=-30 DEG (SEC)	0.0	0.0	0.0	0.0	
TERMINAL PITCH ATTITUDE (DEG)	-28.7	-26.5	-23.8	-20.5	
TERMINAL FLIGHT PATH ANGLE (DEG)	-31.3	-29.1	-26.4	-23.1	
MINIMUM NORMAL LOAD FACTOR (G'S)	0.46	0.46	0.47	0.48	

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Table 4

STEERING SUMMARY

ALT FREE FLIGHT NO. 6 (TAILCONE OFF)

150,000 LB ORBITER CG @ 65% L_B

ALTERNATE ORBITER STEERING

AIRSPEED WHEN $\dot{V}$ = 0 (KEAS)	192.3	201.6	212.6	224.2	238.2	
INCIDENCE ANGLE (DEG)	7.0	6.5	6.0	5.5	5.0	
AIRSPEED AT SEPARATION (KEAS)	228.6	238.9	250.7	264.8	279.8	
TIME DURATION $\dot{\Theta}c$=2 DEG/SEC (SEC)	3.0	3.0	3.0	3.0	3.0	
TIME DURATION $\dot{\Theta}c$=0 DEG/SEC (SEC)	5.8	6.8	7.2	8.4	8.8	
TIME DURATION $\dot{\Theta}c$ FOR 0.5g DIVE (SEC)	18.0	18.0	28.2	16.0	12.0	
TIME DURATION Θ=-30 DEG (SEC)	1.0	1.0	0.0	0.0	0.0	
TERMINAL PITCH ATTITUDE (DEG)	-30.0	-30.0	-30.0	-27.3	-21.8	
TERMINAL FLIGHT PATH ANGLE (DEG)	-34.0	-33.8	-32.2	-29.6	-24.1	
MINIMUM NORMAL LOAD FACTOR (G'S)	0.45	0.45	0.45	0.46	0.47	

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Figure 1

ALT ORBITER/CARRIER SEPARATION EQUILIBRIUM GLIDE AIRSPEED REQUIREMENTS

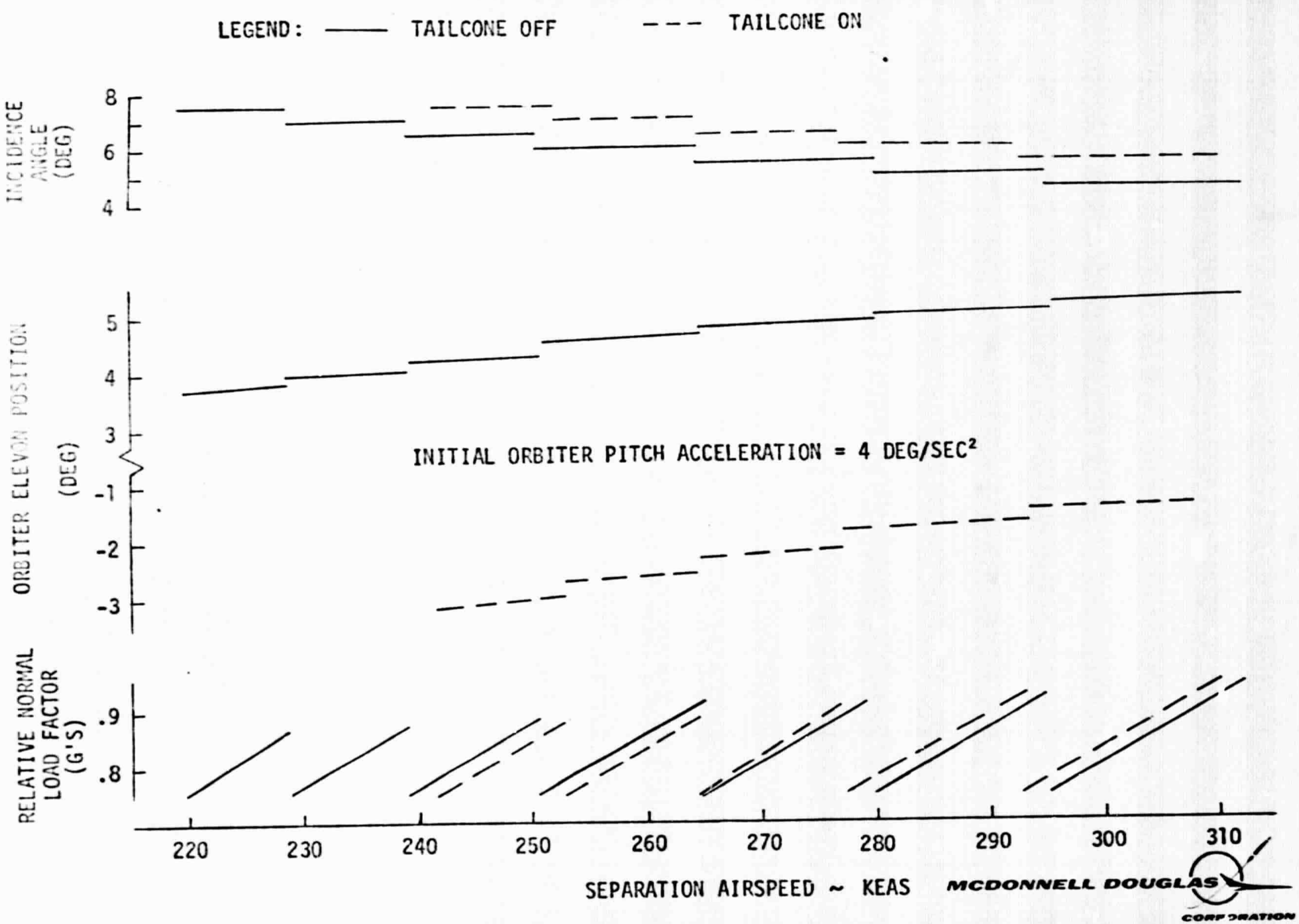

Figure 2

ORBITER ALT INTERFACE AIRSPEED ATTAINMENT
ALT FREE FLIGHT NO. 1 (TAILCONE ON)
150,000 LB ORBITER CG @ 63.5% L_B

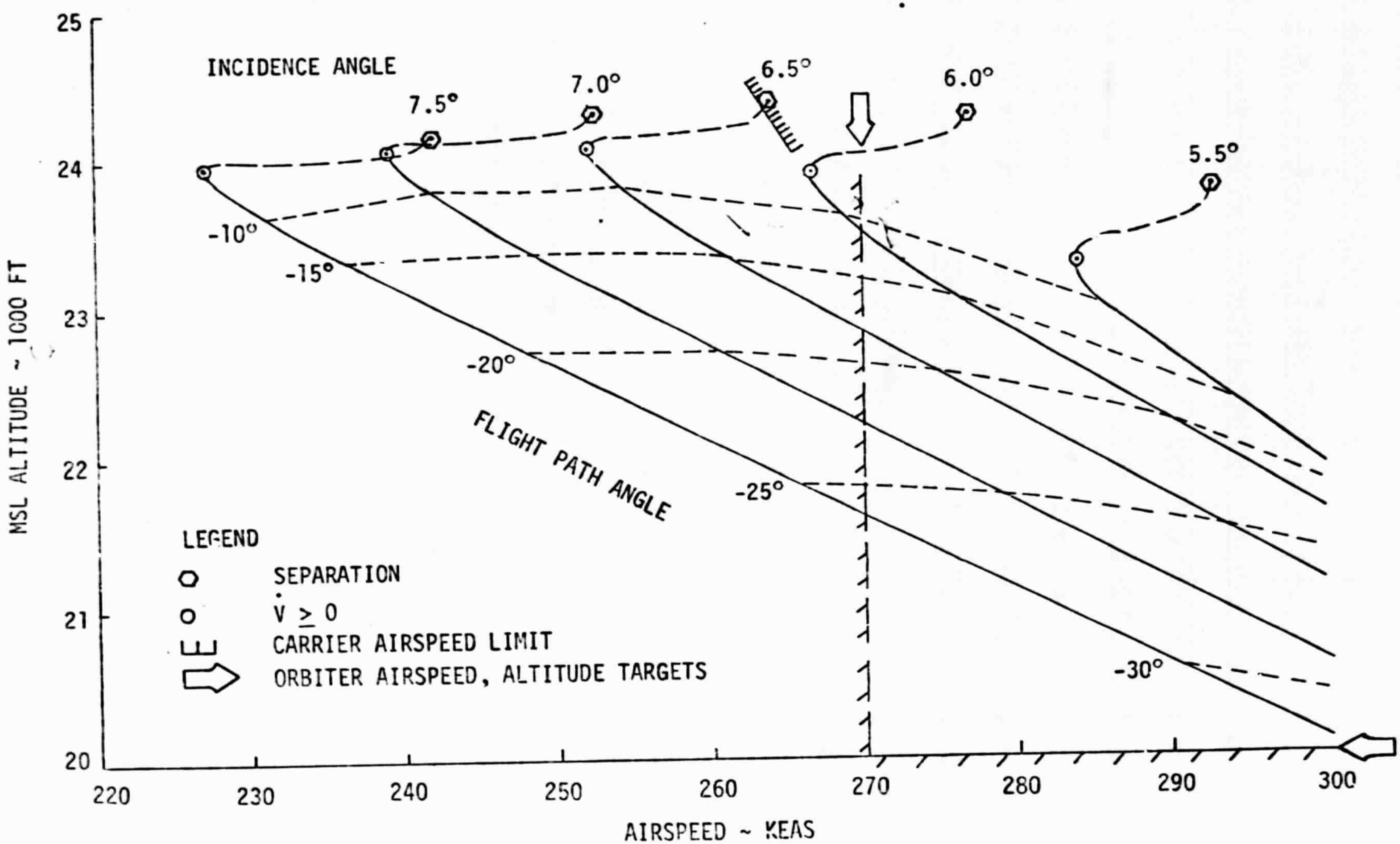

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Figure 3

ORBITER ALT INTERFACE AIRSPEED ATTAINMENT
ALT FREE FLIGHT NO. 6 (TAILCONE OFF)
150,000 LB ORBITER CG @ 65% L_B

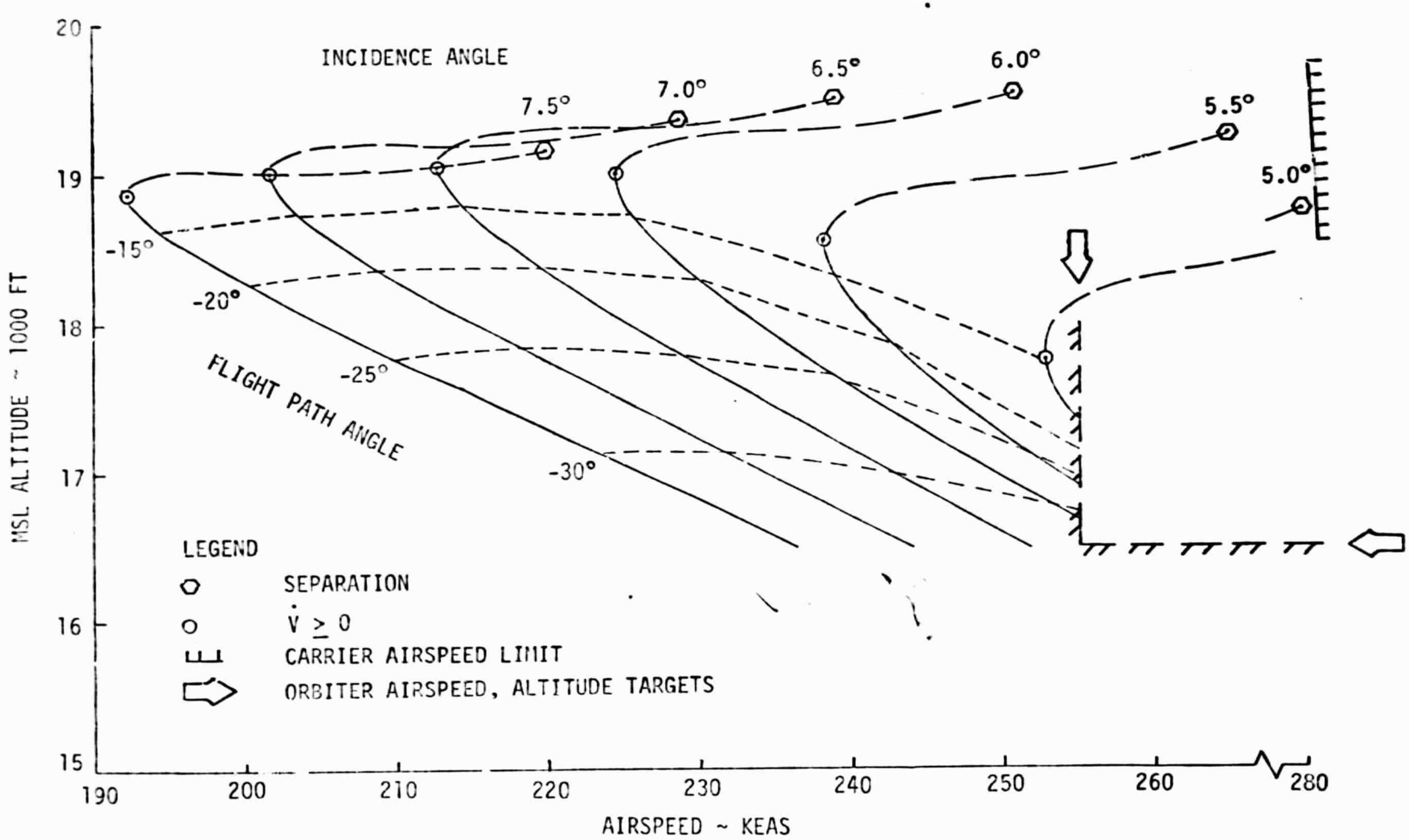

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Figure 4

ORBITER ALT INTERFACE AIRSPEED AT.AINMENT
ALT FREE FLIGHT NO. 1 (TAILCONE ON)
150000 LB ORBITER CG @ 63.5% L_B

ALTERNATE ORBITER STEERING

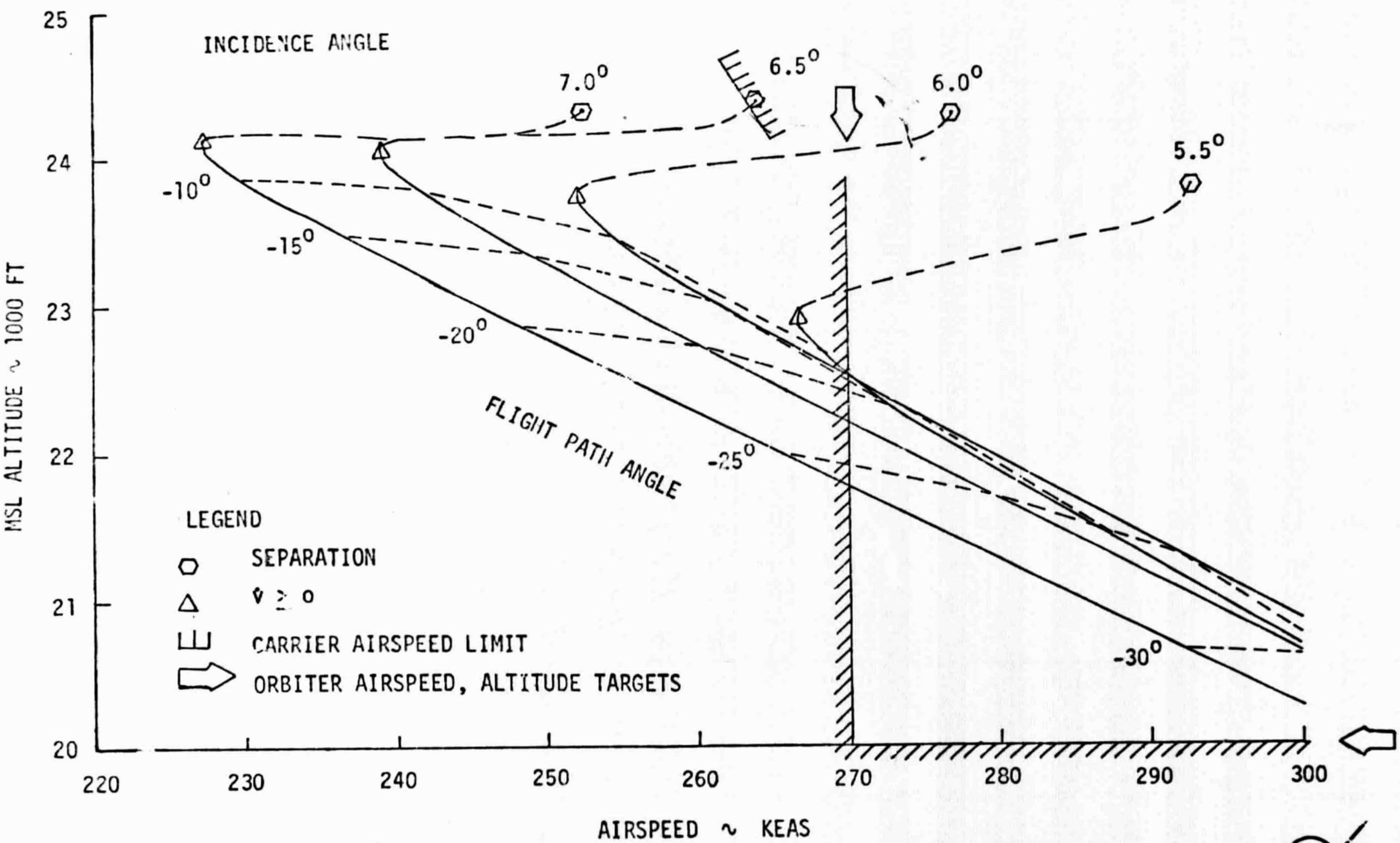

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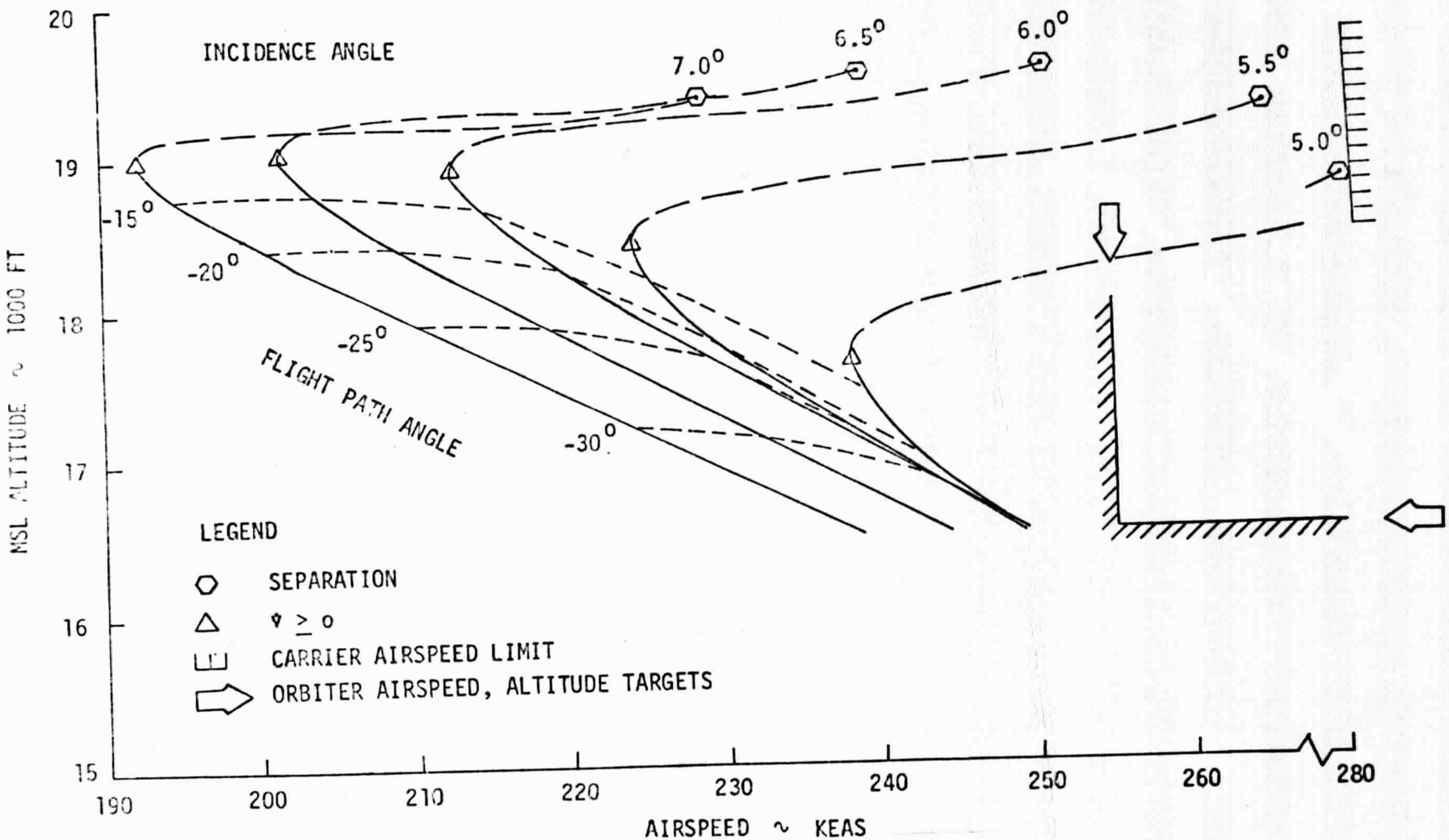
Figure 5

ORBIT.. ALT INTERFACE AIRSPEED ATTAINMENT
ALT FREE FLIGHT NO. 6 (TAILCONE OFF)
150000 LB ORBITER CG @ 65% L_B

ALTERNATE ORBITER STEERING



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LYNDON B. JOHNSON SPACE CENTER MEMORANDUM

REFER TO: LC-5-363

INITIATOR: LC/RBMerrifield:rl:5-19-76:2091

DATE: MAY 20 1976

TO: JM6/E. Robinson

CC:

ENCL:

FROM: LA3/Manager for Management Integration

SIGNATURE: R M Machell
Reginald M. Machell

SUBJ: Document Release Authorization

On September 23, 1975, by memorandum LC-5-260 from this office, you were requested to process document release authorizations for documents generated by the Space Shuttle Engineering and Operations Support Contract NAS 9-13970 according to the following criteria:

a. "May be announced in STAR (or CSTAR if classified)."

b. "May be made publicly available, except (1) classified material which should be released to security qualified requestors only, and (2) documents which may be released overseas that come under the jurisdiction of the Federal Early Domestic Dissemination Program."

The above referenced contract has been superseded by NAS 9-14960, but the processing of document release authorizations should continue to be guided by the same criteria. If any additional clarification of this criteria is needed, such requests should be addressed to LC/R. B. Merrifield, extension 2091.

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LYNDON B. JOHNSON SPACE CENTER MEMORANDUM

REFER TO	INITIATOR:	DATE
LC-5-363	LC/RBMerrifield:rl:5-19-76:2091	MAY 20 1976

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