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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

# DESIGN NOTE NO. 1.4-7-49

# TAILCONE ON ORBITER ALTITUDE ATTAINABLE AT THE MAXIMUM ALT INTERFACE AIRSPEED

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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## GLOSSARY OF SYMBOLS

| | | |
|---|---|---|
| ALT | - | APPROACH AND LANDING TEST |
| CAS | - | CONTROL AUGMENTATION STEERING |
| cg | - | CENTER OF GRAVITY |
| JSC | - | JOHNSON SPACE CENTER |
| KCAS | - | KNOTS CALIBRATED AIRSPEED |
| KEAS | - | KNOTS EQUIVALENT AIRSPEED |
| MDTSCO | - | MCDONNELL DOUGLAS TECHNICAL SERVICES COMPANY |
| MSL | - | MEAN SEA LEVEL |
| RI | - | ROCKWELL INTERNATIONAL |
| SVDS | - | SPACE VEHICLE DYNAMICS SIMULATION |
| TBC | - | THE BOEING COMPANY |
| $V_{ALT}$ | - | ALT INTERFACE AIRSPEED |

## 1.0 SUMMARY

This report documents a preflight analysis for verification of the ALT mated vehicle incidence angle which maximizes the post separation altitude attainment by the orbiter at the maximum ALT interface airspeed (300 KEAS). In the analysis, altitude versus airspeed profiles are generated for each of the three incidence angles that include and bound the RI recommended incidence angle for both the forward and the aft cg tailcone on orbiter configurations. Results show that the RI recommended incidence angles maximize the orbiter post separation altitude attainable within an acceptable tradeoff between separation clearance capability and orbiter structural constraints. Within constraints, the incidence angle that maximizes the orbiter altitude at the maximum ALT interface airspeed for both the forward and aft cg orbiter tailcone on configurations is 6.0 deg.

The requirement for a parametric analysis of orbiter altitude attainable at the maximum ALT interface airspeed is stated in Section 2.0. The specifications, assumptions, and analytical approach used to determine orbiter altitude attainable at the maximum ALT interface airspeed are presented in Section 3.0. The results of the analysis are evaluated in Section 4.0. Conclusions and recommendations 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 maximum 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 both tailcone off and tailcone on, forward cg orbiter configurations (see Reference 2). The current analysis is concerned with the tailcone on orbiter for both the forward and aft cg configurations. The data base for the current analysis is also an update of that used in the referenced analysis. A similar analysis of the tailcone off orbiter configuration will be performed when additional data becomes available. Toward that end, this MDTSCO "Tailcone On Orbiter Altitude Attainable at the Maximum ALT Interface Airspeed" is performed for both the forward and aft orbiter cg locations.

## 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 verification of the orbiter altitude attainable at the maximum ALT interface airspeed (300 KEAS) and source data is referenced accordingly.

The ALT orbiter/carrier separation is simulated by the Space Vehicle Dynamics Simulation (SVDS) Program (see Reference 3) in two flight phases. The separation flight phase is initiated at the instant of the orbiter release and is defined to be 5 sec in duration. The post separation flight phase is terminated by the orbiter attainment of the maximum ALT interface airspeed.

### 3.1 Specifications

As stated in Reference 4, eight ALT free flights are currently planned. The first five flights are for a tailcone on orbiter configuration and the last three are for a tailcone off orbiter configuration. The maximum orbiter ALT interface airspeed included in flight test planning is 300 KEAS (see Reference 13). ALT Free Flights 1, 2, 4 & 5 correspond to a forward cg orbiter configuration and ALT Free Flight 3 corresponds to an aft cg orbiter configuration. During the post separation flight phase, the orbiter normal acceleration and local horizontal pitch attitude must be no less than 0.5 g's and -10 deg, respectively. (See Reference 13)

## 3.2 Assumptions

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

The data base assumptions are:

1) Orbiter configuration:
   a) 150K lb orbiter, forward and aft cg.
   b) Tailcone on.
   c) Body flap at -11.7 deg.
   d) Control system as defined in Reference 5.
2) Carrier configuration:
   a) Inflight spoilers deployed.
   b) Thrust at idle.
   c) Thrust magnitude as defined in Reference 6.
   d) Control system as defined in Reference 7.
3) Separation altitudes as defined in Reference 8.
4) Orbiter and carrier freestream and proximity aerodynamic data as defined in Reference 14.
5) Mass characteristics as defined in Reference 9.

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 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.
3) The carrier maintains the mated vehicle equilibrium glide pitch attitude command for the duration of the separation flight phase.

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 maximum ALT interface airspeed.
2) The orbiter control system remains in the CAS mode, during which time the orbiter performs a commanded -1 deg/sec pitchover maneuver in order to attain the maximum ALT interface airspeed. (The orbiter pitch attitude is limited to -10 deg).
3) The carrier attitude command is pitched up an incremental 2 deg at a 2 deg/sec rate in order to moderate carrier post separation airspeed buildup.
4) The carrier is commanded to bank to the left at a rate of 10 deg/sec until a roll attitude of -30 deg is reached. The -30 deg roll attitude is held until a heading change of approximately -30 deg is made at which time the carrier is commanded to roll back to wings level.

Assumptions which simplify the analytical approach are:

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

2) Only orbiter tailcone on configurations (ALT Free Flights 1 thru 5) are analyzed. The analysis is performed for a light weight orbiter.

3) For each of the two orbiter cg (forward and aft) configurations, three incidence angles are analyzed, those being the R-I recommended incidence angle (Reference 10) and 0.5 deg on either side.

4) Only the second launch opportunity mass characteristics are analyzed. (These are the same mass characteristics to be used for a single launch opportunity mission).

### 3.3 Analytical Approach

The overall approach consists of parameterizing with respect to incidence angle the orbiter altitude-airspeed attainment for each orbiter configuration consistent with ALT Free Flights 1 through 5. For each configuration, the incidence angle which results in the highest orbiter altitude at the maximum ALT interface airspeed is then identified.

Toward that end, a two step analytical approach common to each incidence angle and orbiter cg configuration is used. The first step is to generate the separation initial conditions required to produce the RI recommended initial relative normal acceleration and orbiter pitch acceleration (0.753 g's and 2.38 deg/sec$^2$ for the forward orbiter cg configuration and 0.901 g's and 3.39 deg/sec$^2$ for the aft orbiter cg configuration, see Reference 10). The Mated Trim program is used for that purpose (see Reference 11).

The second step is to generate the altitude-airspeed profiles for each of the two orbiter cg configurations using the SVDS program. At the beginning of the post separation flight phase, the orbiter is immediately commanded to pitch over at a - 1 deg/sec rate to the -10 deg local horizontal pitch attitude specification. The -10 deg pitch attitude is held as the orbiter accelerates to the maximum ALT interface airspeed. Also during this time, the carrier aircraft executes a 30 deg left turn in order to evade the flight plane of the orbiter.

## 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 that yields the maximum orbiter altitude at the maximum ALT interface airspeed are discussed. Finally, the results which give rise to the conclusions and recommendations summarized in Section 5.0 are discussed.

The equilibrium glide separation initial conditions which satisfy the separation design requirements of 0.753 g's relative normal acceleration and 2.38 deg/sec$^2$ orbiter pitch acceleration for the forward orbiter cg configuration and 0.901 g's relative normal acceleration and 3.39 deg/sec$^2$ orbiter pitch acceleration for the aft orbiter cg configuration, are tabulated in Tables 1 and 2, respectively. Reference 10 states that the carrier overspeed constraint limits the maximum separation airspeed to a mach number of 0.675 or an airspeed of 292 KCAS. From the outlined procedure and the mated configuration V-N diagrams presented in References 10 and 12, respectively, the maximum separation airspeed is limited to 268 KEAS for the forward cg orbiter configuration and 266 KEAS for the aft orbiter cg configuration. The more constraining separation airspeed limit is that from the mated configuration V-N diagram and disqualifies incidence angles less than 6.0 deg.

The orbiter steering summary for the forward cg orbiter configuration is tabulated in Table 3. The range of separation airspeeds required to produce the 0.753 g's relative normal acceleration and 2.38 deg/sec$^2$ orbiter pitch acceleration target conditions (see Reference 10) is 253.9 KEAS to 282.7 KEAS. The orbiter airspeed attained when the Orbiter first begins to accelerate ranges from 237.8 KEAS to 267.5 KEAS. The pitch attitude and flight path angle at the maximum ALT interface airspeed are -10.0 deg and -14.2 deg, respectively. The minimum orbiter normal load factor during the orbiter pitch over maneuver satisfies the 0.5g design specification for all three incidence angles.

The orbiter steering summary for the aft cg orbiter configuration is tabulated in Table 4. The range of separation airspeeds required to produce the 0.901 g's relative normal acceleration and 3.39 deg/sec$^2$ orbiter pitch acceleration target conditions (see Reference 10) is 251.6 KEAS to 280.7 KEAS. The orbiter airspeed attained when the orbiter first begins to accelerate ranges from 233.5 KEAS to 264.2 KEAS. The pitch attitude and flight path angle at the maximum ALT interface airspeed are -10.0 deg and -13.8 deg, respectively. The minimum orbiter normal load factor during the orbiter pitch over maneuver satisfies the 0.5g design specification for all three incidence angles.

Illustrated in Figures 1 and 2 are the altitude-airspeed profiles for the forward and aft orbiter cg configurations, respectively. From Figures 1 and 2, it is shown that the lower incidence angle corresponds to the higher separation airspeed for separation clearance and to the higher orbiter altitude at the maximum ALT interface airspeed. However, due to the maximum separation airspeed constraint, the allowable incidence angle which maximizes orbiter altitude at the maximum ALT interface for both orbiter cg configurations is 6.0 deg.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions that are derived from Section 4.0 are:

1) The mated configuration V-N diagram is more constraining on the maximum separation airspeed than is the carrier overspeed.
2) The lower incidence angle corresponds to the higher separation airspeed and to the higher orbiter altitude at the maximum ALT interface airspeed.
3) The maximum separation airspeed constraint limits the allowable incidence angle to no less than 6.0 deg and therefore limits the orbiter altitude attainable at the maximum ALT interface airspeed.
4) Without violating any known constraints, an incidence angle of 6.0 deg maximizes orbiter altitude at the maximum ALT interface airspeed for both orbiter cg configurations.

It is recommended that an incidence angle of 6.0 deg be retained for the orbiter tailcone on, forward and aft cg configurations.

## 6.0 REFERENCES

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

2) MDTSCO Design Note No. 1.4-7-40, "Maximization of Orbiter Altitude at ALT Interface Airspeed," dated 31 May 1976.

3) JSC Internal Note No. 76-FM-26 (JSC-11157), "Space Vehicle Dynamics Simulation (SVDS) Program Description Revision 1, dated 30 November 1976.

4) JSC Memo No. CT-76-90 "ALT Mission Objectives Document, Sections I & IV Review," dated 14 June 1976.

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-0033C, Revision 1, "Orbiter/747 Carrier Separation Aerodynamic Data Book," dated November 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) TBC Doc. No. D180-18409-1 "747 CAM/Orbiter Launch Performance," Revision G.

9) TBC Doc. No. D180-18401-13, "747 Space Shuttle Orbiter Carrier Aircraft Modification (CAM) Mass Properties Status Report," dated November 1976.

10) RI IL No. IGNCV/76-1018, "ALT Launch Incidence Angle, Launch Velocity, and Orbiter Elevon Position Update," dated 21 December 1976.

11) MDTSCO Design Note No. 1.4-7-19, "ALT 747/Orbiter Mated Trim Computer Program," dated 17 November 1975.

12) RI IL No. IGNCV/76-991, "Comparison of Several Possible ALT Launch Conditions," dated 5 November 1976.

13) JSC Internal Note No. 76-FM-121 (JSC-11844) "Operational Flight Profiles for Approach and Landing Test (ALT) Orbiter With Tailcone (Free-Flight Missions 1 through 5), 20 January 1977.

14) MDTSCO TM No. 1.4-4-7-403, "Update of ALT Separation Aerodynamics Data Base," 31 March 1977.

## Table 1

## EQUILIBRIUM GLIDE SEPARATION INITIAL CONDITIONS
## FOR FORWARD CG ORBITER CONFIGURATION
## TAILCONE ON; 150000 LB ORBITER; CG @ 63.9% $L_B$

| | | | |
|---|---|---|---|
| RELATIVE NORMAL ACCELERATION (G's) | 0.753 | 0.753 | 0.753 |
| ORBITER PITCH ACCELERATION ($DEG/SEC^2$) | 2.38 | 2.38 | 2.38 |
| INCIDENCE ANGLE (DEG) | 5.5 | 6.0 | 6.5 |
| ORBITER ELEVON (DEG) | 0.373 | 0.045 | -0.208 |
| MSL ALTITUDE (FT) | 23900 | 24500 | 24900 |
| AIRSPEED (KEAS) | 282.7 | 267.7 | 253.9 |
| MACH NUMBER | 0.685 | 0.657 | 0.628 |
| FLIGHT PATH ANGLE (DEG) | -9.30 | -8.67 | -8.13 |
| CARRIER ANGLE OF ATTACK (DEG) | 2.21 | 2.67 | 3.18 |
| CARRIER PITCH ATTITUDE (DEG) | -7.09 | -6.00 | -4.95 |
| CARRIER STABILIZER POSITION (DEG) | 1.673 | 1.689 | 1.822 |
| CARRIER ELEVATOR POSITION (I/O; DEG) | 0.0/3.0 | 0.0/3.0 | 0.0/3.0 |

## Table 2

EQUILIBRIUM GLIDE SEPARATION INITIAL CONDITIONS FOR

AFT CG ORBITER CONFIGURATION

TAILCONE ON; 15000 LB ORBITER; CG @ 65.9% $L_B$

| | | | |
|---|---|---|---|
| RELATIVE NORMAL ACCELERATION (G's) | 0.901 | 0.901 | 0.901 |
| ORBITER PITCH ACCELERATION (DEG/SEC$^2$) | 3.39 | 3.39 | 3.39 |
| INCIDENCE ANGLE (DEG) | 5.5 | 6.0 | 6.5 |
| ORBITER ELEVON (DEG) | 1.748 | 1.578 | 1.503 |
| MSL ALTITUDE (FT) | 24000 | 24600 | 25100 |
| AIRSPEED (KEAS) | 280.7 | 265.6 | 251.6 |
| MACH NUMBER | 0.681 | 0.653 | 0.625 |
| FLIGHT PATH ANGLE (DEG) | -9.18 | -8.58 | -8.08 |
| CARRIER ANGLE OF ATTACK (DEG) | 2.20 | 2.66 | 3.17 |
| CARRIER PITCH ATTITUDE (DEG) | -6.98 | -5.92 | -4.91 |
| CARRIER STABILIZER POSITION (DEG) | 1.865 | 1.900 | 2.050 |
| CARRIER ELEVATOR POSITION (I/O; DEG) | 0.0/3.0 | 0.0/3.0 | 0.0/3.0 |

**Table 3**

ORBITER STEERING SUMMARY FOR

FORWARD CG ORBITER CONFIGURATION

TAILCONE ON; 150000 LB ORBITER; CG @ 63.9% $L_B$

| | | | |
|---|---|---|---|
| INCIDENCE ANGLE (DEG) | 5.5 | 6.0 | 6.5 |
| AIRSPEED AT SEPARATION (KEAS) | 282.7 | 267.7 | 253.9 |
| TIME DURATION $\dot{\theta}_c$ = 2 DEG/SEC (SEC) | 3.0 | 3.0 | 3.0 |
| TIME DURATION $\dot{\theta}_c$ = 0 DEG/SEC (SEC) | 2.0 | 2.0 | 2.0 |
| TIME DURATION $\dot{\theta}_c$ = -1 DEG/SEC (SEC) | 12.5 | 14.3 | 15.8 |
| TIME DURATION $\theta_c$ = -10 DEG (SEC) | 18.0 | 26.8 | 28.4 |
| AIRSPEED WHEN $\dot{V}$ = 0 (KEAS) | 267.5 | 252.1 | 237.8 |
| ALT INTERFACE PITCH ATTITUDE (DEG) | -10.0 | -10.0 | -10.0 |
| ALT INTERFACE FLIGHT PATH ANGLE (DEG) | -14.2 | -14.2 | -14.2 |
| MINIMUM NORMAL LOAD FACTOR (G's) | 0.625 | 0.64 | 0.655 |

## Table 4

ORBITER STEERING SUMMARY FOR

AFT CG ORBITER CONFIGURATION

TAILCONE ON; 150000 LB ORBITER; CG @ 65.9% $L_B$

| | | | |
|---|---|---|---|
| INCIDENCE ANGLE (DEG) | 5.5 | 6.0 | 6.5 |
| AIRSPEED AT SEPARATION (KEAS) | 280.7 | 265.6 | 251.6 |
| TIME DURATION $\dot{\theta}_c$ = 2 DEG/SEC (SEC) | 3.0 | 3.0 | 3.0 |
| TIME DURATION $\dot{\theta}_c$ = 0 DEG/SEC (SEC) | 2.0 | 2.0 | 2.0 |
| TIME DURATION $\dot{\theta}_c$ = -1 DEG/SEC (SEC) | 12.0 | 14.0 | 15.5 |
| TIME DURATION $\theta_c$ = -10 DEG (SEC) | 22.0 | 28.0 | 33.0 |
| AIRSPEED WHEN $\dot{V}$ = 0 (KEAS) | 264.2 | 248.5 | 233.5 |
| ALT INTERFACE PITCH ATTITUDE (DEG) | -10.0 | -10.0 | -10.0 |
| ALT INTERFACE FLIGHT PATH ANGLE (DEG) | -13.8 | -13.8 | -13.8 |
| MINIMUM NORMAL LOAD FACTOR (G's) | 0.62 | 0.64 | 0.66 |

FIGURE 1

ORBITER ALTITUDE-AIRSPEED PROFILES FOR
FORWARD CG ORBITER CONFIGURATION
TAILCONE ON; 150000 LB ORBITER; CG @ 63.9% $L_B$

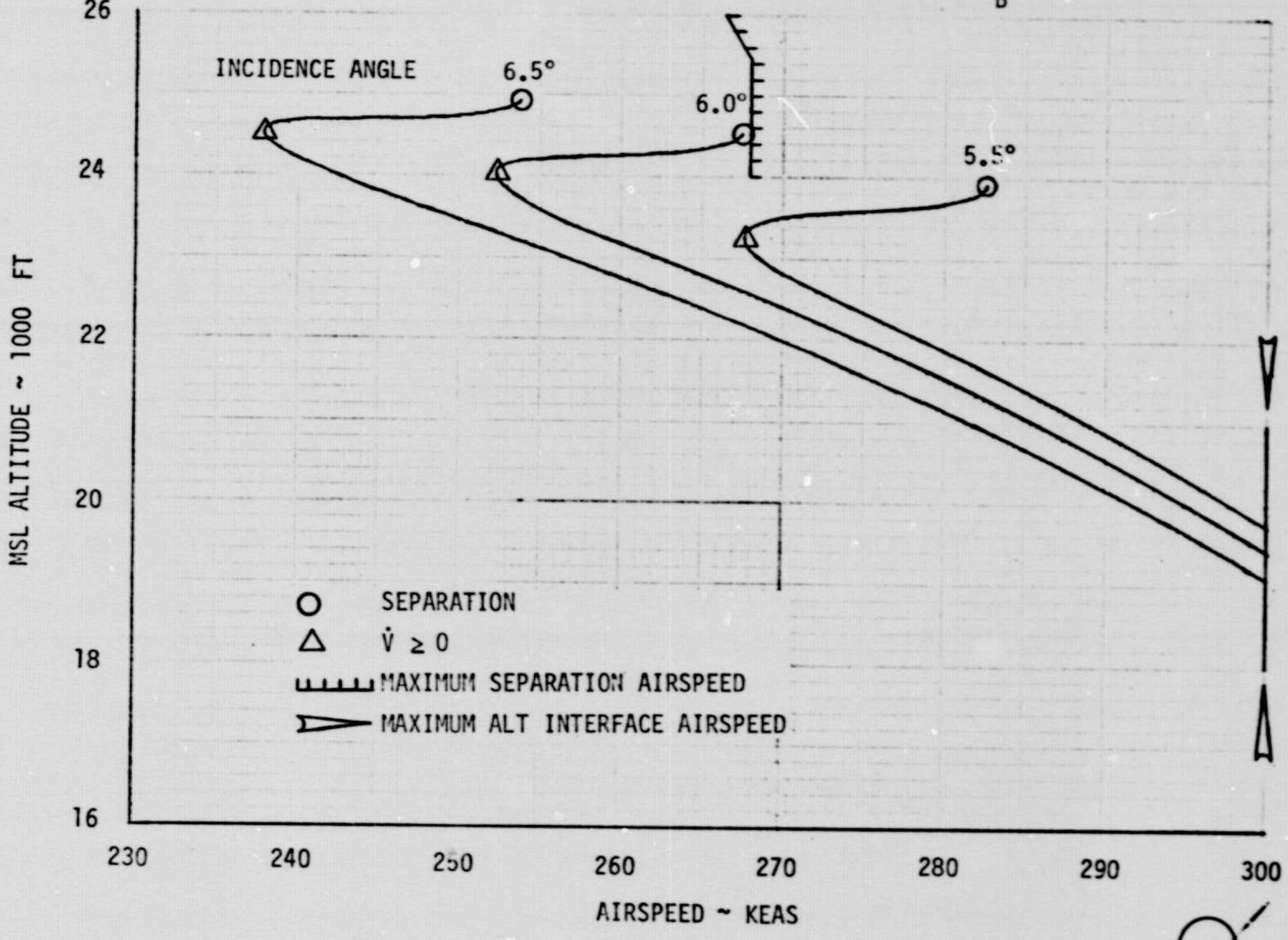


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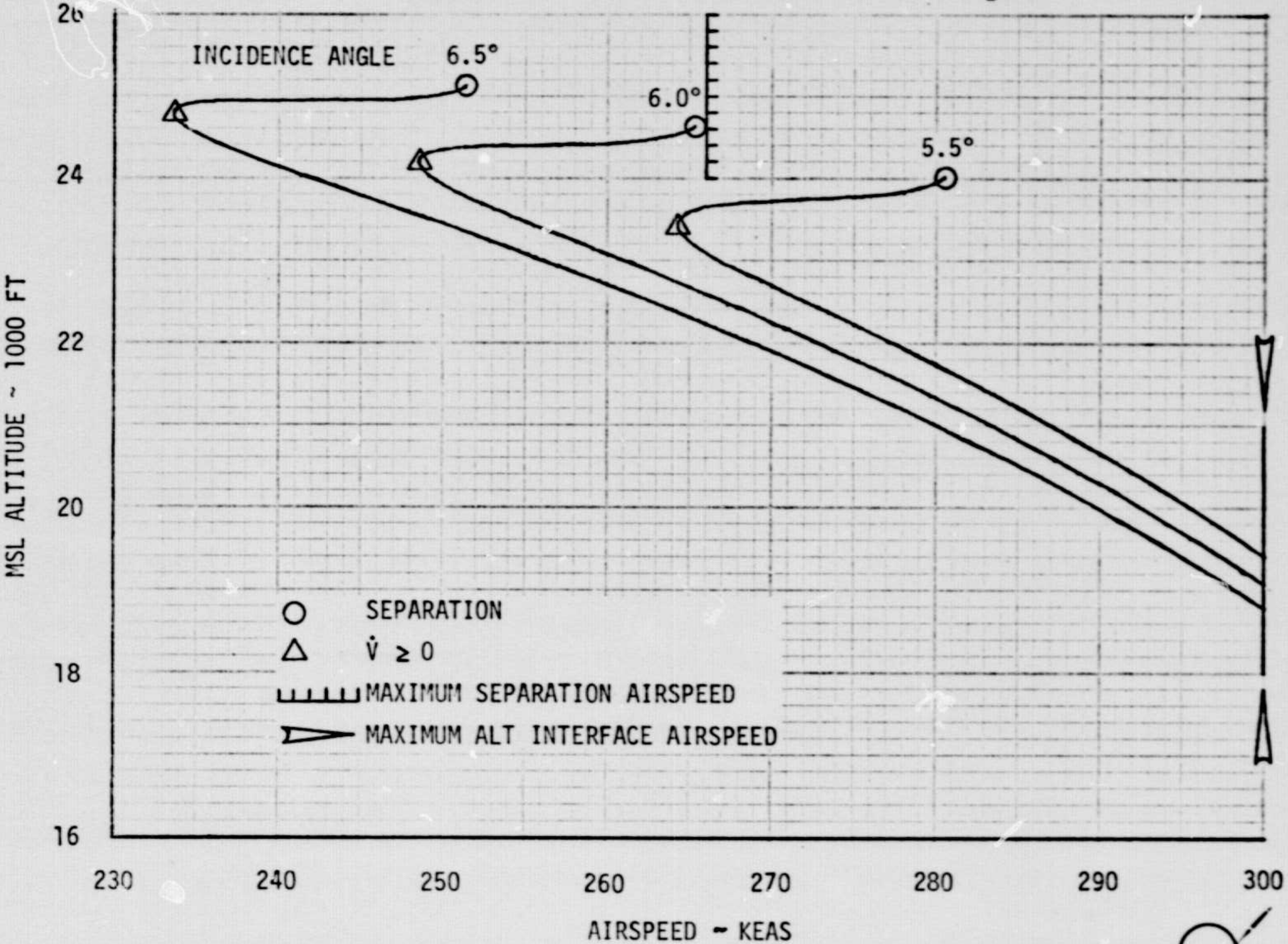
FIGURE 2

ORBITER ALTITUDE-AIRSPEED PROFILES FOR
AFT CG ORBITER CONFIGURATION
TAILCONE ON; 150000 LB ORBITER; CG @ 65.9% $L_B$

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