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HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-7-50

SEPARATION OPERATIONAL LIMITS FOR ALT FREE FLIGHTS 1 THROUGH 5

MISSION PLANNING, MISSION ANALYSIS, AND SOFTWARE FORMULATION

31 MARCH 1977

This Design Note is submitted to NASA under Task Order No. D0608, Task Assignment A, Contract NAS 9-14960

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GLOSSARY OF SYMBOLS

ALT	Approach and Landing Test
h	Altitude (MSL)
KEAS	Knots Equivalent Airspeed
L_B	Reference Body Length
$N_{Z_{rel}}$	Relative Normal Acceleration
$N_{Z_{orb}}$	Orbiter Normal Load Factor
RI	Rockwell International
SCA	Shuttle Carrier Aircraft
V	Airspeed
α	Angle of Attack
$\ddot{\theta}_{orb}$	Orbiter Pitch Acceleration At Separation
$\Delta\theta$	Incidence Angle
δe_{orb}	Orbiter Elevon Setting

1.0 SUMMARY

This report documents the details of an analysis to determine the orbiter/SCA separation operational limits for the current target conditions of ALT free flights 1 through 5. The separation operational limits are used to verify that no separation design constraints are violated. The operational limits represent the acceptable dispersions in attainment of separation target conditions which assure safe separation. Safe separation is based on satisfying all specified separation design criteria except orbiter altitude at ALT interface airspeed. Separation operational limits are defined for each of the five orbiter tailcone on ALT free flight missions based upon preflight (wind tunnel) aerodynamics. The effect of carrier pilot steering compensation due to off-nominal flight conditions (as determined in the Boeing Launch Simulation No. 3) is determined to be within the separation operational limits. It is recommended that the current target conditions be retained for free flights 1 through 5 until ALT captive-inert postflight data is available for reverification.

2.0 INTRODUCTION

A design rationale which includes flight test verification of the target separation conditions that satisfy all ALT separation design requirements was proposed in Reference 1. That proposal was instrumental in the formalization of the ALT separation support requirements as specified in Reference 2. A pictorial representation of those support requirements is reproduced in Figure 1. This design note documents the results of a MDTSCO off line analysis which contributes to the development of the criteria for modifying ALT separation configuration/flight conditions as depicted at the bottom of Figure 1.

Reconfiguring the incidence angle between ALT flights requires demating and remating of the orbiter/SCA. Likewise, reconfiguring separation elevon position between captive inert flights requires demating and remating of the orbiter/SCA. It is therefore an overall objective of the design rationale to determine the incidence angle and separation elevon position which have a high probability of being retained for all of the orbiter tailcone on configuration ALT flights.

An additional objective entails selecting separation initial accelerations which accommodate the maximum launch airspeed compatible with vehicle constraints. Accordingly R I recommended in Reference 3 the incidence and target separation initial conditions for ALT free flights 1 through 5 (orbiter tailcone on configuration).

In order to verify that no separation design constraints are violated, separation operational limits are generated by MDTSCO for the R I prescribed separation target conditions.

3.0 DISCUSSION

Safe separation is based upon satisfying all known ALT separation design criteria except orbiter altitude at ALT interface airspeed. The operational limits represent the acceptable dispersions in attainment of separation target conditions which assure safe separation. Separation operational limits are expressed in terms of separation SCA angle of attack versus separation airspeed.

The dispersions in separation conditions that are expected to occur during the five second crew decision time have been determined to be approximately ± 0.7 degrees in SCA angle of attack and ± 5 KEAS in airspeed (see References 4 and 5). The objective of this analysis is to verify that this pilot steering capability is within the separation operational limits for the R I recommended target separation conditions.

3.1 Separation Design Criteria, Constraints, and Dispersions

The separation incidence angle, airspeed, and orbiter elevon setting were determined based upon retaining common incidence angles for flights 1 through 5, maximizing separation airspeed, maximizing ALT interface altitude, and achieving nominal initial separation accelerations of approximately 0.75 g relative normal acceleration and between 0 and 6 deg/sec^2 orbiter pitch acceleration. The upper limit on nominal target separation airspeed is defined by orbiter structural loads. This limit is 5 KEAS less than 1.1 g on the V-n diagram for the orbiter 75% limit load. Figure 2 presents a portion of the orbiter 75% structural limit load V-n diagram for the free flight 1 through 5 separation configurations (see Reference 6). For flights 1, 2, 4, and 5 (63.9% L_B orbiter cg

The data base assumptions are as follows:

1) Orbiter and carrier freestream and proximity aerodynamics are defined in Reference 7.
2) Carrier engine thrust is defined in Reference 8.
3) Orbiter control system is defined in Reference 9.
4) Carrier control system is defined in Reference 10.
5) Second launch attempt mass properties are defined in Reference 11.

3.2 Analytical Approach

The analytical approach used to generate the separation operational limits for each of the two target conditions is illustrated in the flow chart of Figure 3.

The first step is to select a candidate separation constraint. Each of the first five constraints listed above is analyzed independently in order to determine the one which constitutes the most restrictive separation operational limit. Worst case dispersions of constraint parameters are generated by the root sum square technique. The constraint dependent root sum square composite dispersions for aerodynamic coefficients and elevon setting are tabulated in Table 2. The first two columns are the composite dispersions which maximize the forward and aft strut forces. The attach point recontact constraint is represented by the negative of the same composite dispersions, which minimize the strut forces. The cone angle constraint is represented by the arctangent of the longitudinal relative acceleration divided by the normal relative acceleration.

The mated vehicle is then trimmed in pitch for a sequence of combinations of angle of attack, and airspeed near the target condition, and the constraint parameter is calculated. At each airspeed, the angle of attack limit is obtained by interpolating for the angle of attack for which the constraint is equaled.

The separation operational limits are defined by the constraints which result in the most restrictive angle of attack limit. The equilibrium glide angle of attack at the target separation airspeed is determined for one of the most restrictive constraint composite dispersions. The envelope of pilot steering capability to achieve the target separation airspeed and angle of attack in the presence of design winds under analogous dispersed conditions (see References 4 & 5) is then overlayed. The process is repeated for each of the most restrictive constraints. The composite envelope of pilot steering capability is then comprised of the superposition of each of the individual envelopes.

Acceptability of target separation conditions is verified by the non intersection of the composite envelope of pilot steering capability and the separation operational limits.

The operational limits are initially defined with the Mated Trim Program (Reference 11). They are then verified by simulation of post separation dynamic responses using the Space Vehicle Dynamic Simulation (Reference 12).

4.0 RESULTS

Figures 4 and 5 present the separation operational limits expressed in terms of carrier angle of attack and airspeed for ALT free flights no. 1, 2, 4, and 5 and flight no. 3 respectively. The ultimate limits represent the angle of attack/airspeed boundary with no dispersions. The operational limits are the angle of attack/airspeed boundary with the composite 1σ aerodynamic and elevon dispersions. These limits represent the amount of allowable pilot variation about the equilibrium glide target without violating a separation constraint. The upper limit on carrier angle of attack is defined by the orbiter load factor or the aft attach recontact constraints. The lower limit on carrier angle of attack is defined by the forward load cell vernier limit of 50000 lbs. For neither configuration do the constraints of orbiter angle of attack or separation cone angle define a more restrictive limit for the airspeed range investigated.

The pilot accuracy in achieving and maintaining equilibrium glide at the separation target condition is illustrated on each figure. The pilot variability is compatible with the operational limits and no separation constraints are violated.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions derived from this analyses are as follows:

1) The separation operational limits generated for the target conditions of ALT free flights 1 through 5 based on 1σ wind tunnel aerodynamic data dispersions verify that no separation constraints are violat

2) The most restrictive constraints which define the operational limits are the aft attach point recontact constraint and the 2g orbiter normal load factor constraint.

3) The pilot steering capability derived from ALT Separation Simulation No. 3 is within the separation operational limits.

It is therefore recommended that the separation target conditions tabulated in Table 1 be retained for free flights 1 through 5 until ALT captive inert postflight data is available for reverification.

6.0 REFERENCES

1. MDTSCO TM No. 1.4-7-272, "Flight Test Verification of ALT Separation Initial Conditions," 27 July 1976.

2. NASA Memorandum EX32/7609-180, "ALT Separation Support Requirements," 23 September 1976.

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

4. TBC D180-18407-5, "ALT Launch Simulation No. 3 and Captive Flight Test Simulation No. 1 - 30 Day Report," 24 November, 1976.

5. MDTSCO DN No. 1.4-7-46, "Preliminary Analysis of the Boeing ALT Separation Simulation No. 3," 6 December 1976.

6. RI IL No. 1GNCV/76-991, "Comparison of Several Possible ALT Launch Conditions," 5 November 1976.

7. MDTSCO TM No. 1.4-7-403 , "Update of ALT Separation Aerodynamic Data Base," 31 March 1977.

8. RI Report No. SD75-SH-0033C-1, "Orbiter/747 Carrier Separation Aerodynamic Data Book," November 1976.

9. RI Report No. SD73-SH-0180G. "Space Shuttle Separation System Data Book," January 1977.

10. NASA Memo EJ3-74-171, "Definition of 747 FCS and Orbiter FCS for Carrier/Orbiter Simulation at NASA," September 1974.

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

12. MDTSCO DN No. 1.4-7-19, "ALT 747/Orbiter Mated Trim Computer Program," 17 November 1975.

13. JSC IN No. 76-FM-26, "Space Vehicle Dynamics Simulation (SVDS) Program Description," 6 May 1976.

TABLE 1

TARGET SEPARATION EQUILIBRIUM GLIDE CONDITIONS

FLIGHT NO.	1,2,4,5	3
ORBITER CG (% L_B)	63.9	65.9
W_{orb} (LBS)	150000	150000
$\Delta\theta$ (DEG)	6.0	6.0
δe_{orb} (DEG)	0.0	1.5
V(KEAS)	267	264
$N_{Z_{rel}}$ ([illegible])	.74	.88
$\ddot{\theta}_{orb}$ (DEG/SEC²)	2.50	3.58

TABLE 2

Root Sum Square Composite Dispersions

T/C ON; CG @ 63.9% L_B; W_{orb} = 150,000 Lbs; $\Delta\theta$=6 deg; δe_{orb}=0°; V_{sep} = 270 KEAS; $\eta_{Z_{rel}}$=.767g; θ_o=2.65 deg/sec²

PARAMETERS	DISPERSION 1σ VALUES	COMPOSITE DISPERSION VALUES*				
		MAX. FWD. STRUT LOAD (Δ_{RSS}=12692LB)	MAX. AFT STRUT LOAD (Δ_{RSS}=13866LB)	MAX. α_{orb} (Δ_{RSS}=.4178°)	MAX. $\eta_{Z_{orb}}$ (Δ_{RSS}=.2034g)	MAX. CONE ANGLE (Δ_{RSS}=6.75°)
$\Delta C_{L_{747}}$	±.0259	-.0031	-.0042	-.0183	-.0051	.0006
$\Delta C_{D_{747}}$	±.0051	-.0001	0	0	0	-.0011
$\Delta C_{M_{747}}$	±.0409	-.002	-.0025	-.0115	-.0032	-.0007
$\Delta C_{L_{orb}}$	±.0531	+.0247	.0460	-.0329	.0514	-.0224
$\Delta C_{D_{orb}}$	±.0181	+.0017	-.0006	-.0012	..0007	.0159
$\Delta C_{M_{orb}}$	±.0335	+.0292	-.0150	-.0055	-.0015	-.0004
$\Delta\delta e_{orb}$	±0.3°	-.006	+.04	-.194	.035	.005
CONSTRAINT NO.		1 & 2	1 & 2	3	4	5

* The composite dispersion values are used as sets of dispersions that produce the same magnitude change in a constraint parameter as would be obtained from executing the 1σ dispersions individually and computing the RSS effect on the same constraint parameter.

FIGURE 1

MPAD SUPPORT REQUIREMENTS FOR ORBITER/SCA SEPARATION

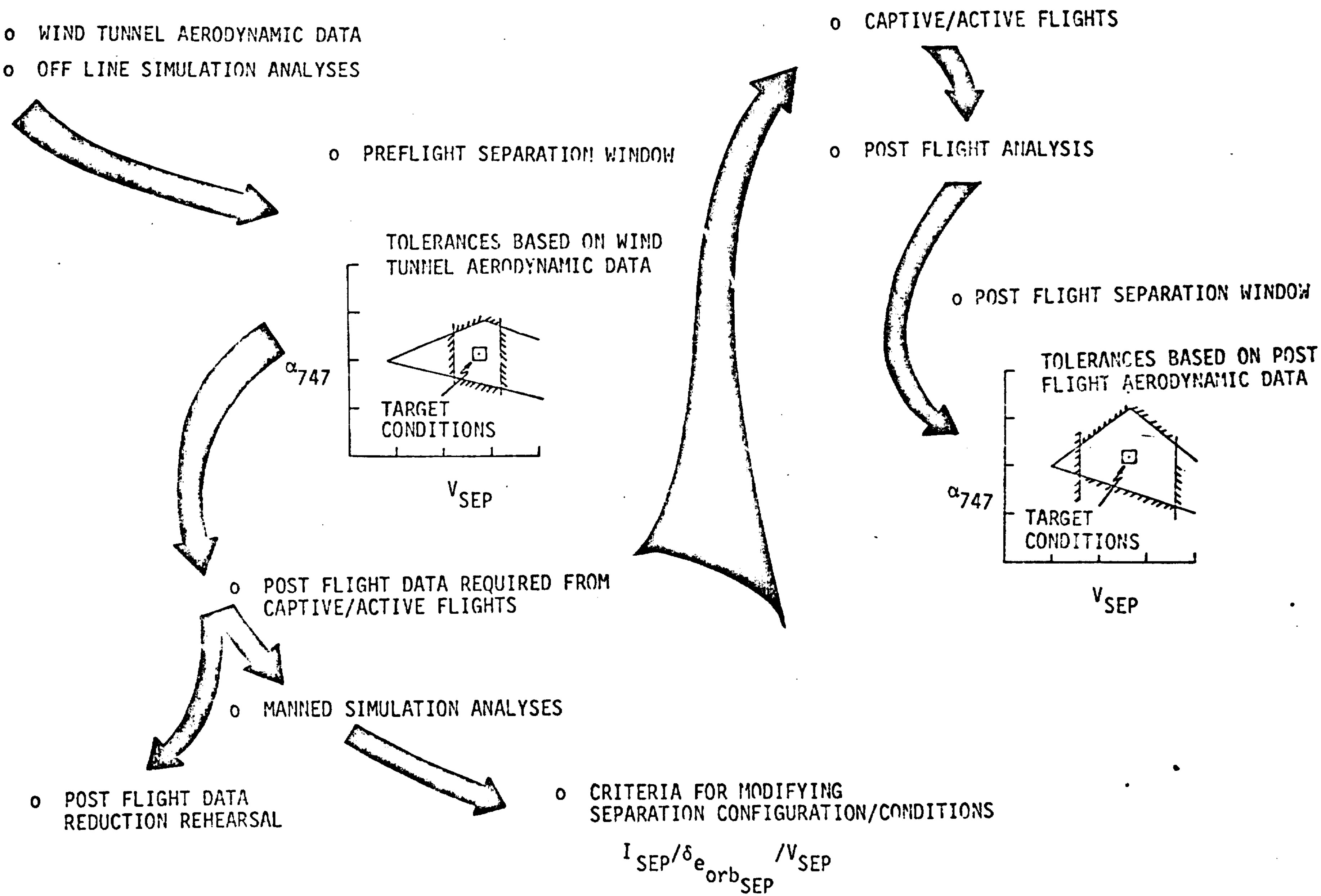
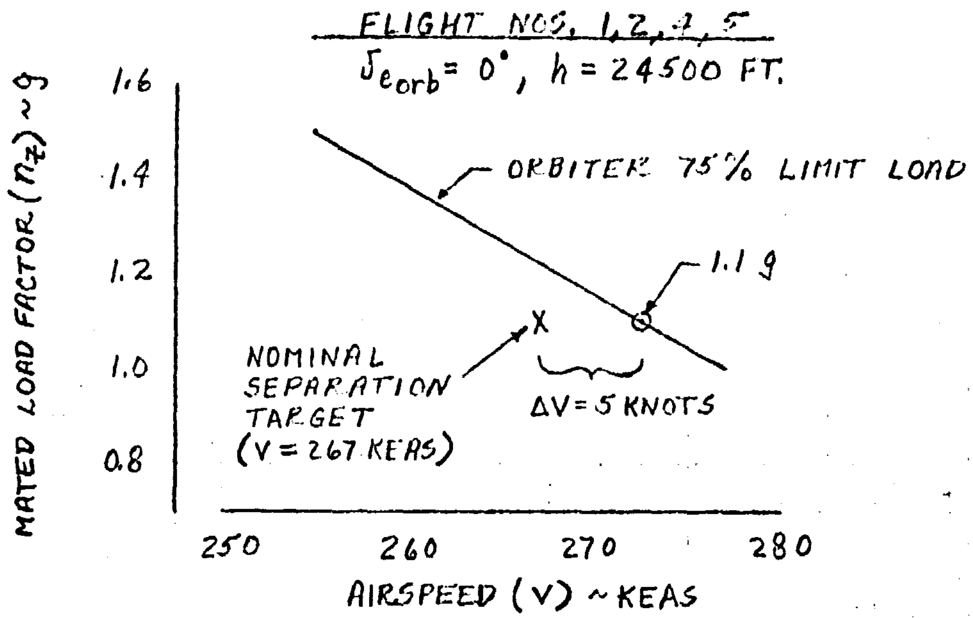


FIGURE 2
ALT NOMINAL SEPARATION AIRSPEED LIMITS FOR FREE FLIGHTS 1-5



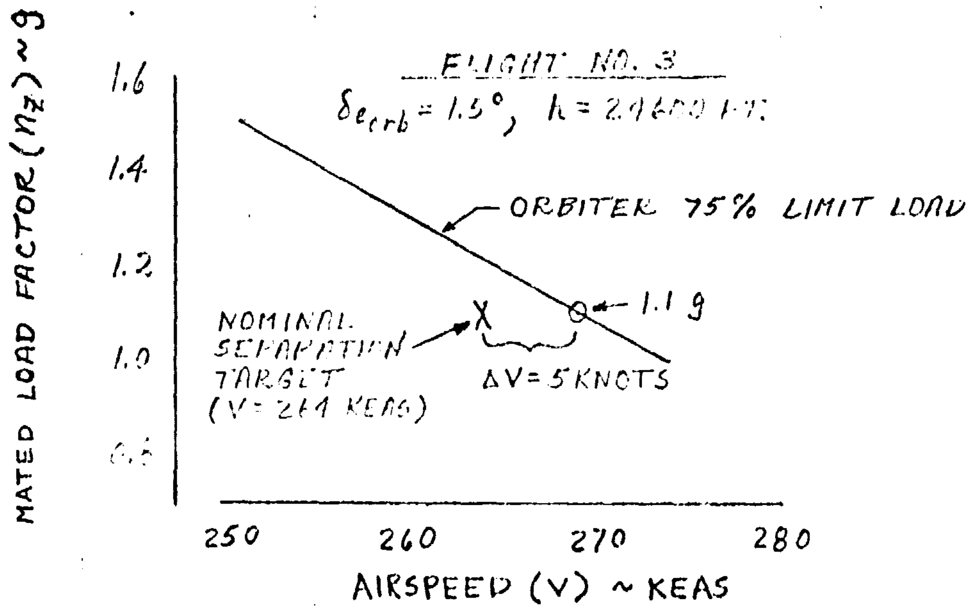


FIGURE 3

METHOD OF DETERMINATION OF SEPARATION OPERATIONAL LIMITS

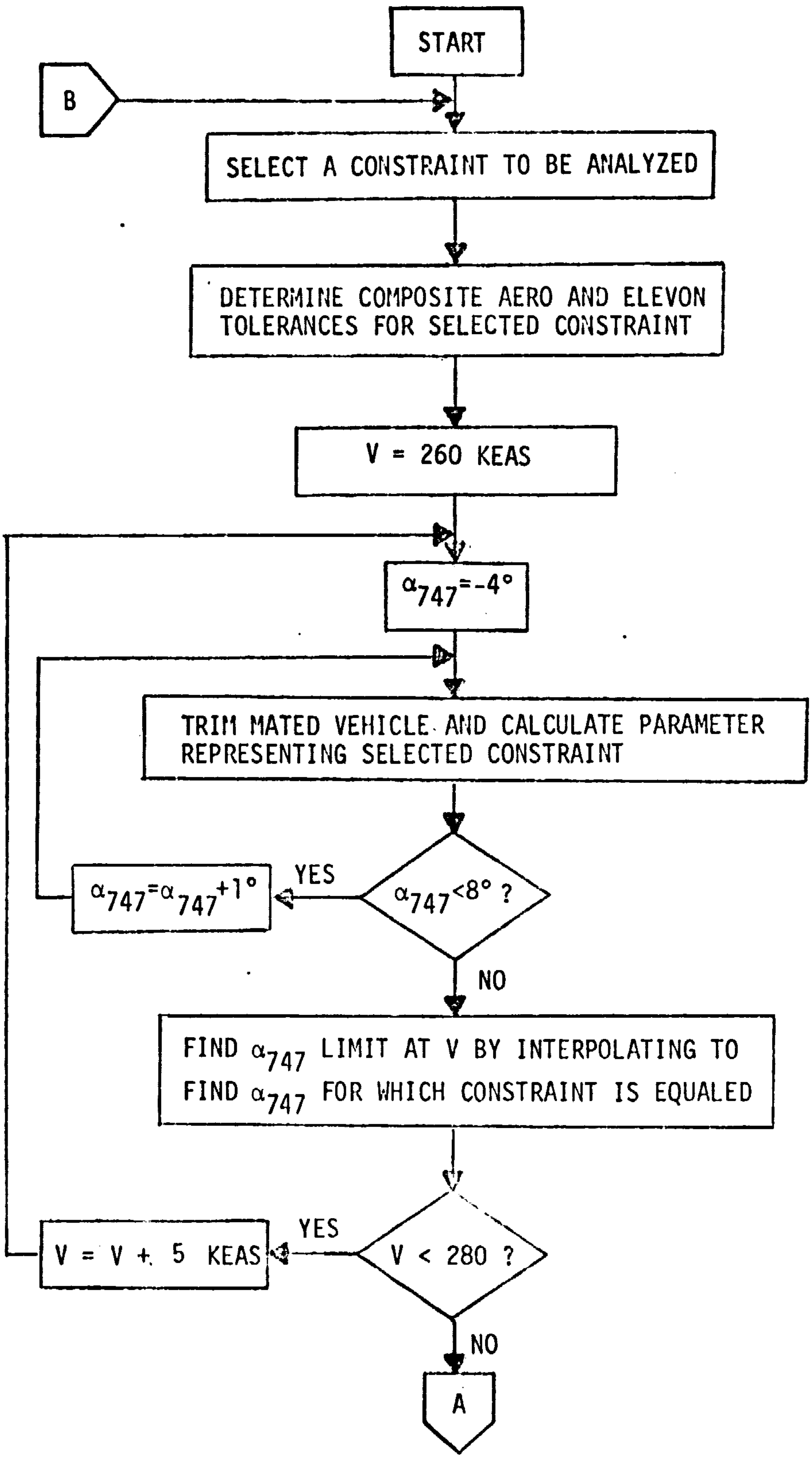


FIGURE 3 CONTINUED

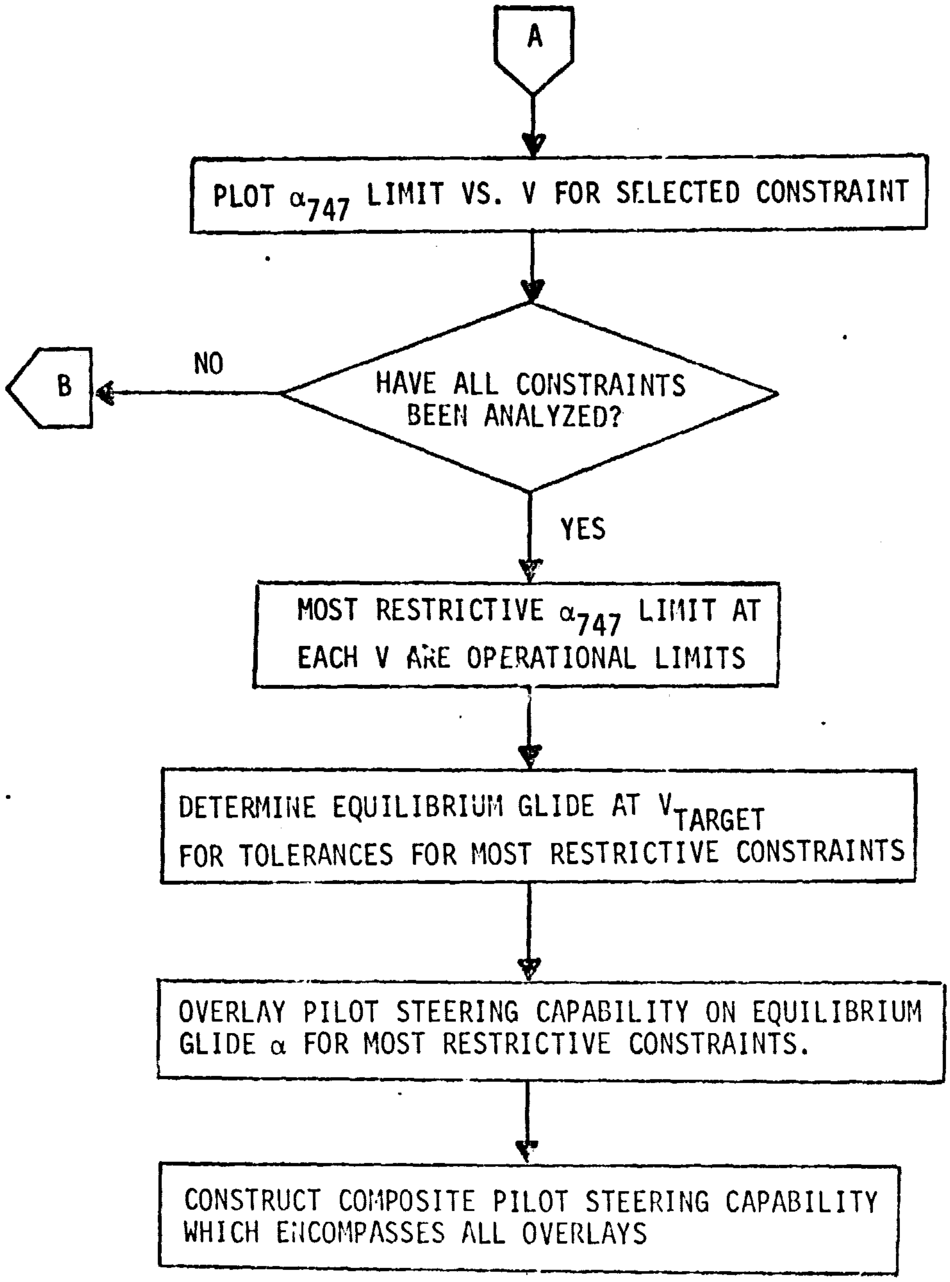


FIGURE 4

ALT FREE FLIGHT NOS. 1, 2, 4, 5 SEPARATION OPERATIONAL LIMITS

$\Delta\theta = 6°$, $\delta_{e_{orb}} = 0°$, $h = 24500$ FT.

LEGEND:

- ——— ULTIMATE LIMIT W/O DISPERSION
- \ \ \ \ OPERATIONAL LIMIT W/ DISPERSION
- X EQUILIBRIUM GLIDE W/O DISPERSION
- O EQUILIBRIUM GLIDE W/ $n_{z_{orb}}$ DISPERSION
- □ EQUILIBRIUM GLIDE W/ FWD. LOAD CELL DISPERSION
- ▽ EQUILIBRIUM GLIDE W/ AFT RECONTACT DISPERSION

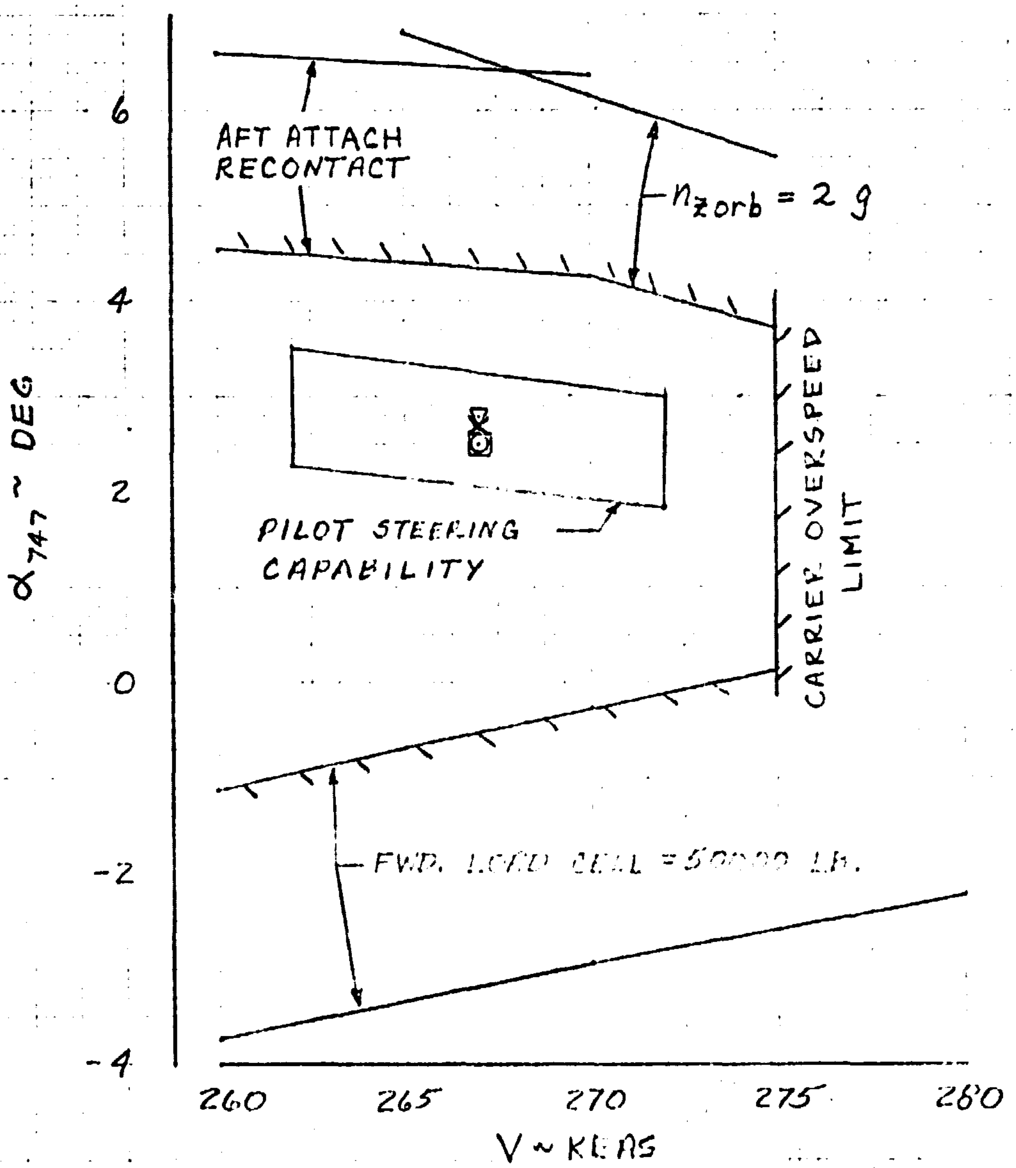


FIGURE 5

ALT FREE FLIGHT NO. 3 SEPARATION

OPERATIONAL LIMITS

$\Delta\theta = 6°$, $\delta_{e_{orb}} = 1.5°$, $h = 24600$ FT.

LEGEND:

——— ULTIMATE LIMIT W/O DISPERSION

\ \ \ \ \ OPERATIONAL LIMIT W/ DISPERSION

X EQUILIBRIUM GLIDE W/O DISPERSION

O EQUILIBRIUM GLIDE W/ $n_{z_{orb}}$ DISPERSION

□ EQUILIBRIUM GLIDE W/ FWD. LOAD CELL DISPERSION.