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SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

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ASSESSMENT OF RELATIVE VELOCITY AS INDEPENDENT VARIABLE FOR SPACE SHUTTLE FIRST STAGE GUIDANCE ATTITUDE COMMAND TABLES

MISSION PLANNING, MISSION ANALYSIS, AND SOFTWARE FORMULATION

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Prepared by: M. Kimbrough
M. Kimbrough
Dept. E904
Ext. 238

Prepared by: G. D. Zoerner
G. D. Zoerner
Ascent Guidance Task Manager
Dept. E914, Ext. 238

Approved by: T. H. Wenglinski
T. H. Wenglinski
Powered Flight, Separation, and
Consumables Technical Manager
Dept. E914, Ext. 228

Approved by:
W. E. Hayes
Project Manager
Mission Planning, Mission Analysis,
and Software Simulation
Dept. E914, Ext. 266

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1.0 SUMMARY

The selection of relative velocity as the independent variable for the space shuttle first stage guidance attitude command tables has been assessed to support the first stage guidance point design

The criteria for selecting the independent variable for first stage open loop guidance is to reduce or minimize performance dispersions, primarily those affecting structural loads. The products of angle-of-attack (α) and angle-of-sideslip (β) times dynamic pressure ($\bar{q}$) ($\bar{q}\alpha$ and $\bar{q}\beta$ respectively) are used as load indicators and minimizing their dispersions will indicate a minimum loads dispersion.

The results of this assessment confirm relative velocity as an acceptable steering independent variable.

2.0 INTRODUCTION

A previous study (Reference 1) showed that earth relative velocity (VE) is better than time. Altitude appeared to be the only formidable alternate to velocity because:

a. winds are primarily altitude dependent

b. winds are the largest dispersion source in terms of aero-loads performance

c. altitude is a measurable variable during ascent.

The reasons for performing this study are:

a. A performance analysis of the August Engineering Review Board Guidance Point Design showed larger than expected dispersions (see Reference 2).

b. The performance test plan for first stage guidance calls for justification of the choice of relative velocity as the independent variable (see Reference 3).

The reference mission for this study in the first orbital flight test (OFT-1), Reference 4. The groundrules and assumptions beyond Reference 4 are reviewed in section 2.1.

3.0 DISCUSSION

3.1 Groundrules and Assumptions

The groundrules describing the Reference 4 ascent trajectory are used for this analysis. In addition the following assumptions are made:

a. Assessment simulations are generated using the Space Vehicle Dynamics Simulation (SVDS) program operating in a three-degree-of-freedom, moment balance flight simulation mode without load relief. This assumes that 3D trends are similar to those of 6D. The lack of load relief should magnify the dispersions for more visible results.

b. This analysis terminates after first stage and the steering used throughout first stage is defined by the attitude angles being a function of either independent variable (relative velocity or altitude).

c. The reference flight profile has been reshaped to eliminate a discontinuity found in the angle-of-attack history.

d. Steering for either independent variable must fly the same nominal.

3.2 Results

3.2.1 Base Case and Steering Verification

This assessment study is based on the OFT-1 trajectory documented in Reference 4 and reshaped per groundrule C. The new profile is shown in Figure 1 in terms of $\bar{q}\alpha$. Both the altitude and velocity steering tables consist of the same 20 time slices from the base case, Table 1. Flying both sets of steering under nominal conditions (mean vector wind, standard system performances, no failures) resulted in trajectories closely matching the base case. Included in the dispersion results of the following section,data show little deviation between each nominal and that each closely follows the desired $\bar{q}\alpha$ profile as required in groundrule d.

3.2.2 Dispersion Data

The dispersion cases are composed of one-by-one simulations of the $\pm$ web action-time values (4.71%) of the Reference 5 flight performance reserve analysis and each of the four critical real winds from the Reference 6 OFT-1 real winds analysis for loads assessment. The web action results are compared in Table 2 for both the altitude and velocity dependent data. Generally, the $\bar{q}$ dispersions are higher for the velocity data and both the α and β dispersions are higher for the altitude data. The net load indicators, $\bar{q}\alpha$ and $\bar{q}\beta$ show no significant difference for either independent variable. The altitude data do however show a significant reduction in dispersions at solid rocket booster (SRB) staging for both altitude and velocity trajectory state variables.

The results of critical real winds are included with web action dispersions in squatcheloid format at Mach 1.25 in Figures 2 and 3 for altitude and velocity data respectively. Again, no significant difference is seen between the altitude and velocity data in terms of the load indicators.

The wind and web action dispersions are shown over the entire Mach range in terms of $\bar{q}\alpha$ in Figures 4 and 5 for altitude and velocity, respectively. These data show that the previous results seen above at max $\bar{q}$ and Mach = 1.25 apply throughout first-stage.

4.0 CONCLUSIONS

The assumption has been made that time, earth relative velocity, and altitude are the best candidates for the independent variable of the guidance first-stage steering tables. Each of them have been shown to be able to fly the nominal trajectory equally well. Therefore, the selection criteria becomes dependent on dispersions, particularly those affecting ascent loads. A previous analysis (Reference 1) eliminated time in favor of velocity. The results presented here show no reason to change from velocity, especially if one considers the software impact. Additionally, the dispersion results seen here are considered acceptable for systems and performance margins.

In that no better variable than velocity is available and that the performance of the velocity based steering tables is acceptable, the verification of velocity as the independent variable is considered complete.

5.0 REFERENCES

1. MDTSCO TM No. 1.4-7-168, "Comparison of Relative Velocity Versus Time Referenced Steering Attitude Polynomials," dated 19 January 1976.
2. MDTSCO TM No. 1.4-7-341, "First Stage Performance Analysis," November 1976.
3. JSC Memorandum No. FM-44(76-157), "First Stage Guidance Performance Test Plan," dated 7 December 1976.
4. JSC Internal Note No. 77-FM-14, "Ascent Reference Flight Profile for OFT-1," dated 7 March 1977.
5. Presentation by J. Jones/RI, "Flight Performance Reserve," Ascent Performance Panel Meeting, 1 September 1976.
6. MDTSCO TM No. 1.4-7-402, "OFT-1 Winds Status," dated 22 March 1977.

TABLE 1. OPEN LOOP STEERING TABLE
LAUNCH PLUMBLINE SYSTEM
PITCH, YAW, ROLL SEQUENCE

T	V_E	HD	PITCH	YAW	ROLL
0.0	0.0	183.49	0.0	0.0	61.749
6.397	98.79	463.74	0.0	0.0	61.749
9.397	157.37	843.49	-2.59	0.0	82.49
12.397	220.53	1403.49	-5.41	0.0	120.00
18.397	360.90	3116.23	-10.68	0.0	175.00
20.397	412.09	3874.98	-11.96	0.0	180.00
23.397	489.47	5197.47	-13.34	-1.25	183.96
28.00	598.10	7622.21	-14.79	-4.31	196.61
34.30	734.55	11641.20	-16.48	-5.72	199.30
43.00	883.44	18207.17	-18.95	-7.76	202.12
55.00	1091.50	28816.6	-22.12	-10.91	205.61
61.00	1219.49	34819.11	-23.26	-12.33	207.07
69.00	1452.14	43802.82	-25.90	-14.53	207.97
77.00	1785.64	54434.38	-30.85	-15.40	204.58
85.00	2181.78	67036.23	-36.15	-15.66	200.85
91.00	2503.66	77789.19	-39.47	-16.79	199.88
95.00	2730.14	85561.91	-41.26	-17.44	199.15
106.00	3383.22	109302.06	-46.31	-19.41	198.17
112.00	3746.00	123593.26	-48.46	-20.15	197.54
122.68	4010.84	150166.70	-51.61	-20.94	196.37

TABLE II. COMPARISON OF RELATIVE VELOCITY REFERENCED VS. ALTITUDE REFERENCED STEERING ATTITUDE POLYNOMIALS
DISPERSION (Δ) AT SELECTED EVENTS
(Δ) = PERTURBED CASE - RESPECTIVE NOMINAL

EVENTS	REF	SRB WEB ACTION	DYNAMIC PRESSURE (a) LB/FT²	DYN PRES X PITCH ANGLE OF ATTACK (qα) LB-DEG/FT²	DYN PRES X YAW ANGLE OF ATTACK (qβ) LB-DEG/FT²	PITCH ANGLE OF ATTACK (α)	YAW ANGLE OF ATTACK (β)	ALTITUDE FT	RELATIVE VELOCITY FT/SEC	RELATIVE FLIGHT DATA ANGLE DEG
MACH = 1.25 (INTERPOLATED)	HD	NOM	(548.33)	(-1580.24)	(74.64)	(-2.87)	(.135)	(36611.20)	(1260.06)	(58.55)
	HD	+	-38.51	- 313.91	+92.39	- .84	+.192	+1499.06	- 9.03	-1.40
	HD	-	+50.27	+ 393.86	-111.66	+ .892	-.196	-2024.51	+ 7.63	+1.63
	RVEL	NOM	+ .28*	- 42.41*	+ 6.72*	- .02*	+.013*	- 9.73*	+.2644*	+ .002*
	RVEL	+	-46.55	+ 4.08	+26.99	- .27	+.067	+1977.50	-16.32	- .25
	RVEL	-	+58.64	+ 153.68	-75.66	+ .54	-.078	-2301.87	+10.62	+ .508
MAX Q	HD	NOM	(549.2)	(-1104.30)	(76.51)	(-2.01)	(.139)	(46301.31)	(1528.58)	(56.01)
	HD	+	-23.46	- 236.28	+56.19	- .54	+.094	- 59.25	-33.71	- .52
	HD	-	+49.53	- 53.79	-42.65	+ .08	-.083	-8823.71	-193.08	+23.22
	RVEL	NOM	0*	+ 11.67*	-10.95*	+ .02*	-.20*	+ 1.25*	+ .05*	+ .05*
	RVEL	+	-33.64	- 53.52	-79.41	- .02	-.15	+ 161.25	-41.5	+ .45
	RVEL	-	+58.53	- 358.47	+36.53	- .39	+.049	-8990.21	-186.84	+ 2.04
SRB STAGE SEP	HD	NOM	(28.8)	(62.09)	(-.57)	(2.14)	(-.02)	(15036.90)	(4007.98)	(37.84)
	HD	+	-1.42	-21.94	+ .603	- .68	+.021	+717.75	-42.1	- .67
	HD	-	+1.54	+22.54	- .66	+ .64	-.02	-790.0	+36.54	+ .72
	RVEL	NOM	- .109*	- 5.33*	- .012*	- .20*	-.006*	+186.44*	+ .72*	- .07*
	RVEL	+	-2.86	-20.38	- .582	- .79	-.03	+1314.56	-61.83	+ .14
	RVEL	-	+3.34	+ 8.98	+ .349	+ .05	+.103	-2265.18	+54.17	- .06

NOTES: (1) ( ) ACTUAL VALUE; (2) * = $(\text{NOMINAL})_{\text{RVEL REF'D}} - (\text{NOMINAL})_{\text{HD REF'D}}$

TABLE II (CONTINUED)

EVENTS	REF	SRB WEB ACTION	PITCH ATTITUDE ACTUAL DEG	YAW ATTITUDE ACTUAL DEG.	MACH NO.							
MACH = 1.25 (INTERPOLATED)	HD	NOM	(-23.78)	(-12.77)	(1.25)							
	HD	+	- .462	- .37	0							
	HD	-	+ .529	+ .50	0							
	RVEL	NOM	+ .07*	+ .05*	0*							
	RVEL	+	+ .085	+ .08	0							
	RVEL	-	- .06	- .23	0							
MAX Q	HD	NOM	(-27.06)	(-14.73)	(1.58)							
	HD	+	+ .02	+ .01	- .03							
	HD	-	+ 3.02	+ 1.45	- .25							
	RVEL	NOM	+ .03*	+ .1*	0*							
	RVEL	+	+ .62	+ .10	+ .05							
	RVEL	-	+ 2.39	+ 1.24	- .24							
SRB STAGE SEP	HD	NOM	- 51.60	-20.93	3.70							
	HD	+	0	0	+ .05							
	HD	-	+ .09	+ .02	+ .04							
	RVEL	NOM	+ .19*	+ .3*	0*							
	RVEL	+	+ .68	+ .15	- .7							
	RVEL	-	- .19	- .03	+ .06							

NOTES: (1) ( ) ACTUAL VALUE; (2) * $(\text{NOMINAL})_{\text{RVEL}} - (\text{NOMINAL})_{\text{HD REF'D}}$

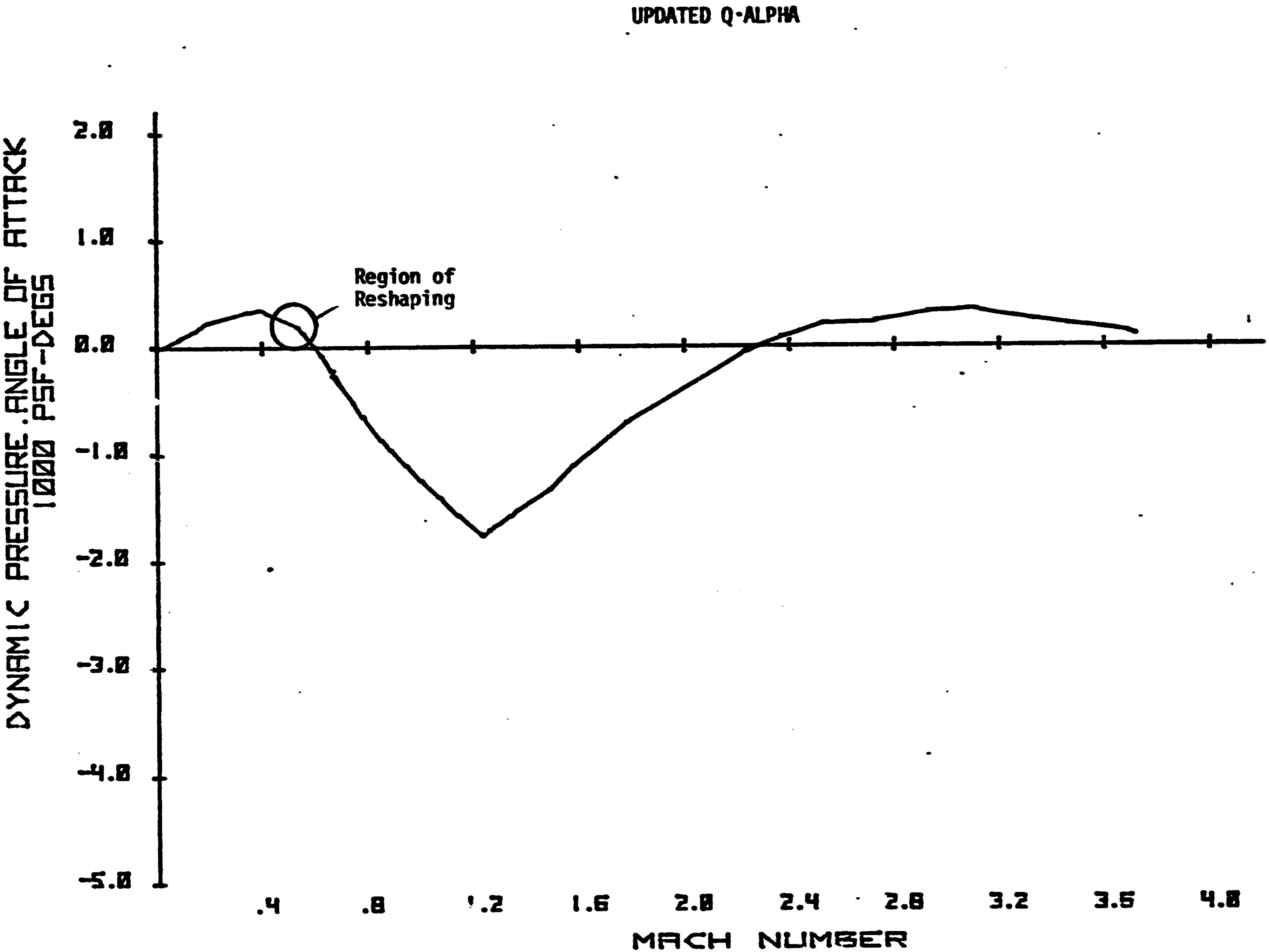
UPDATED Q-ALPHA
DYNAMIC PRESSURE.ANGLE OF ATTACK
1000 PSF-DEGS
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
Region of
Reshaping
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
MACH NUMBER

FIGURE 1

ALTITUDE DEPENDENT SQUATCHELOID PIERCE POINTS

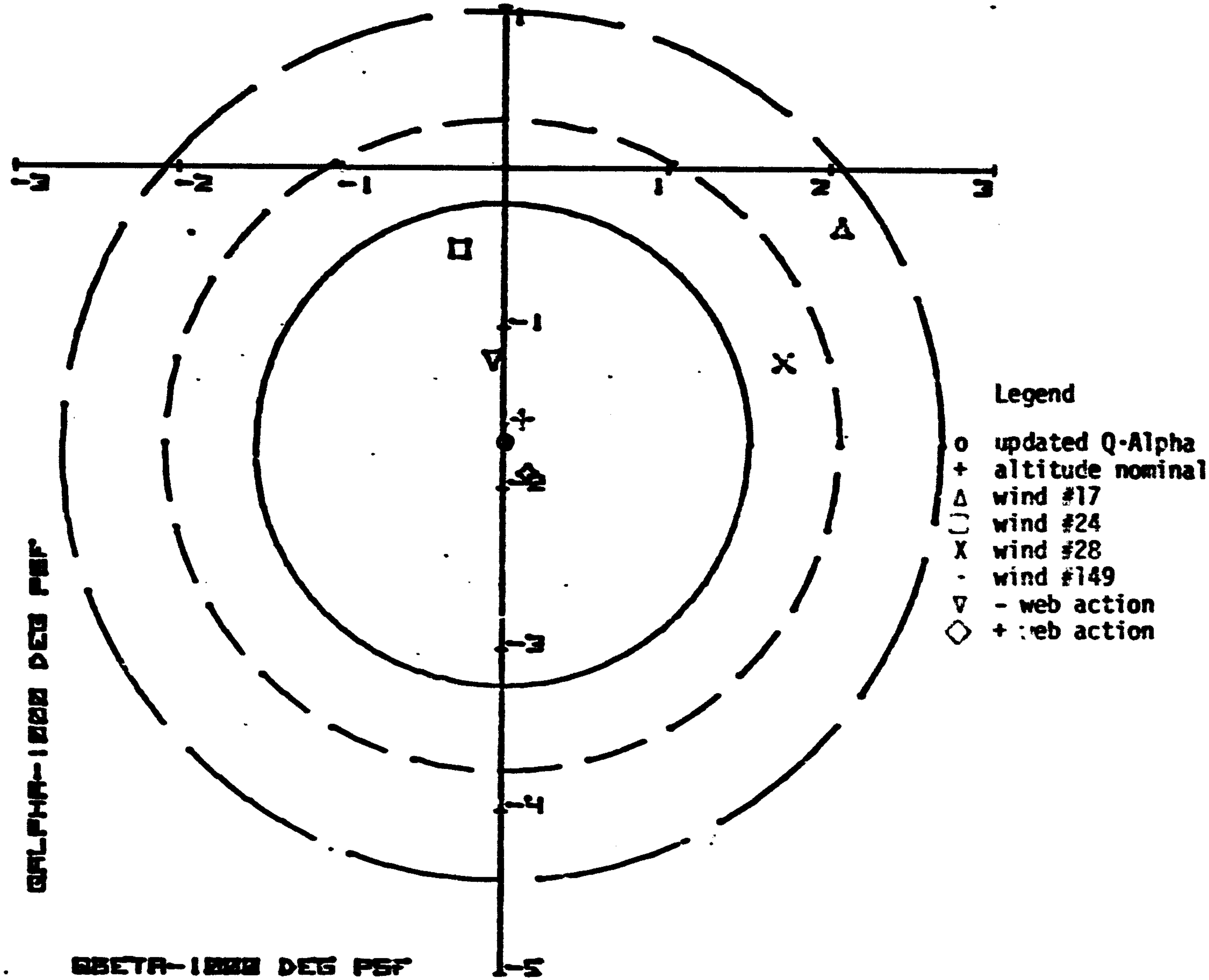

FIGURE 2

VELOCITY DEPENDENT SQUATCHELOID PIERCE POINTS

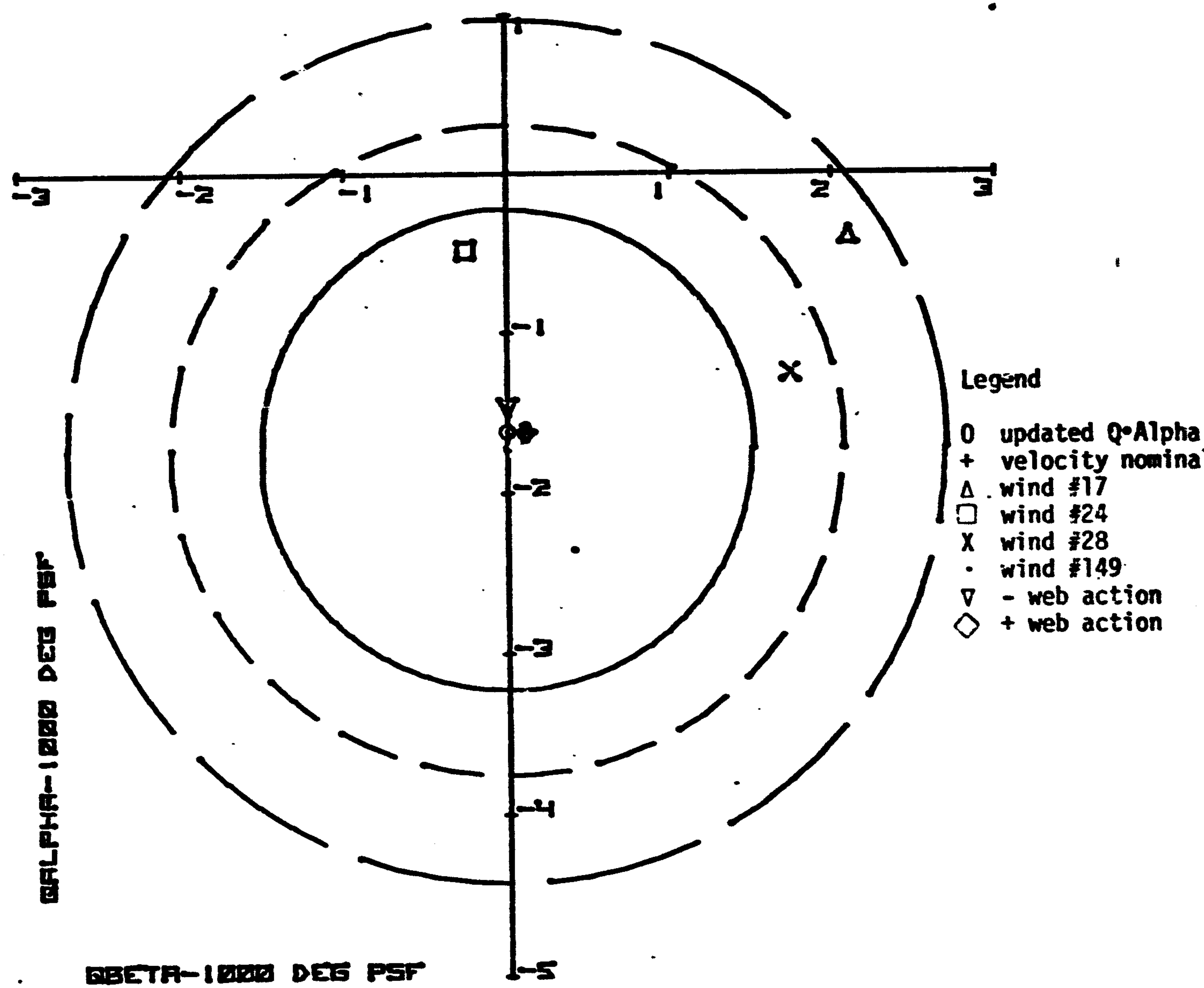

FIGURE 3

ALTITUDE DEPENDENT Q·ALPHA DISPERSIONS

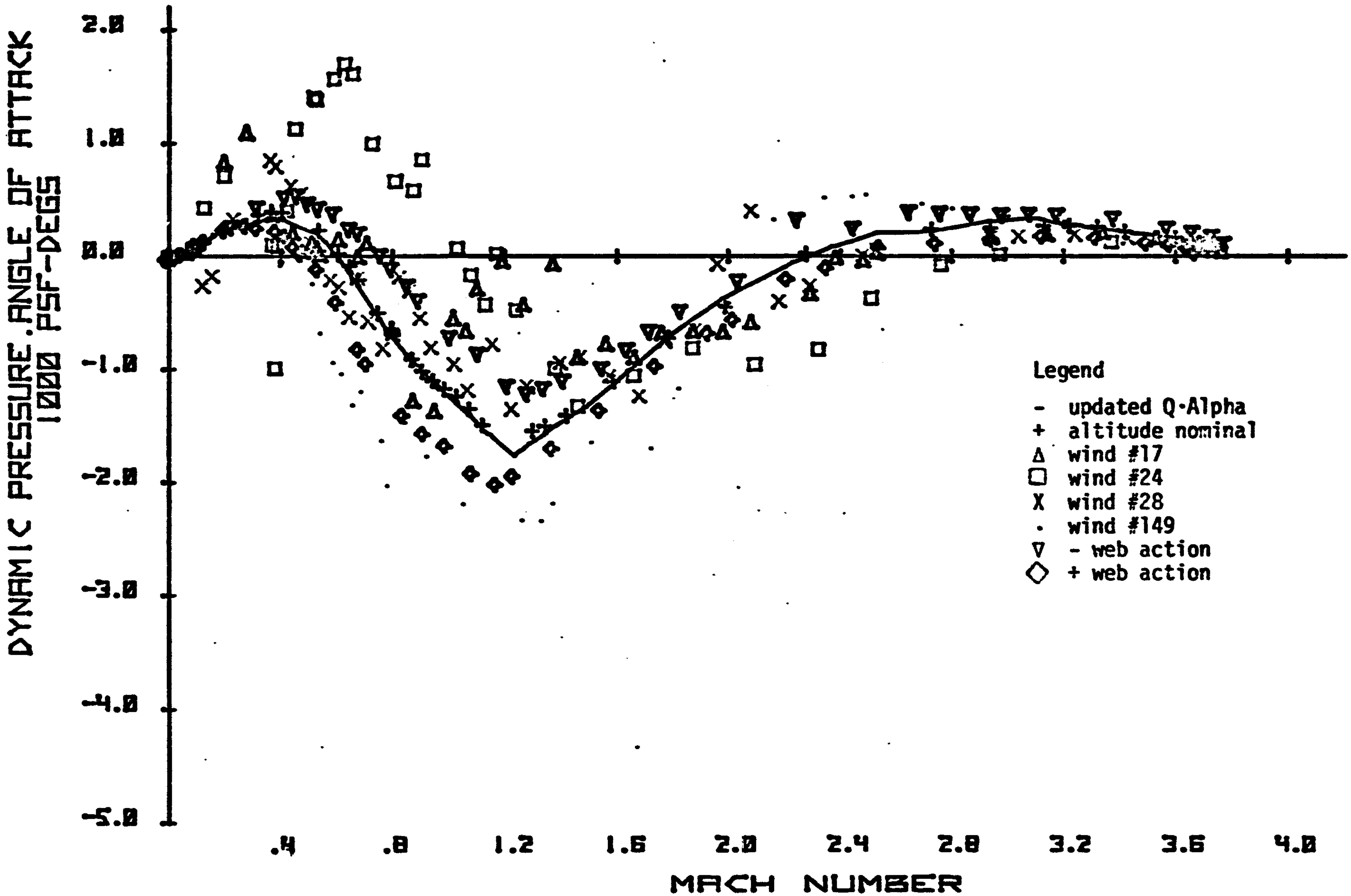

FIGURE 4

VELOCITY DEPENDENT Q-ALPHA DISPERSIONS

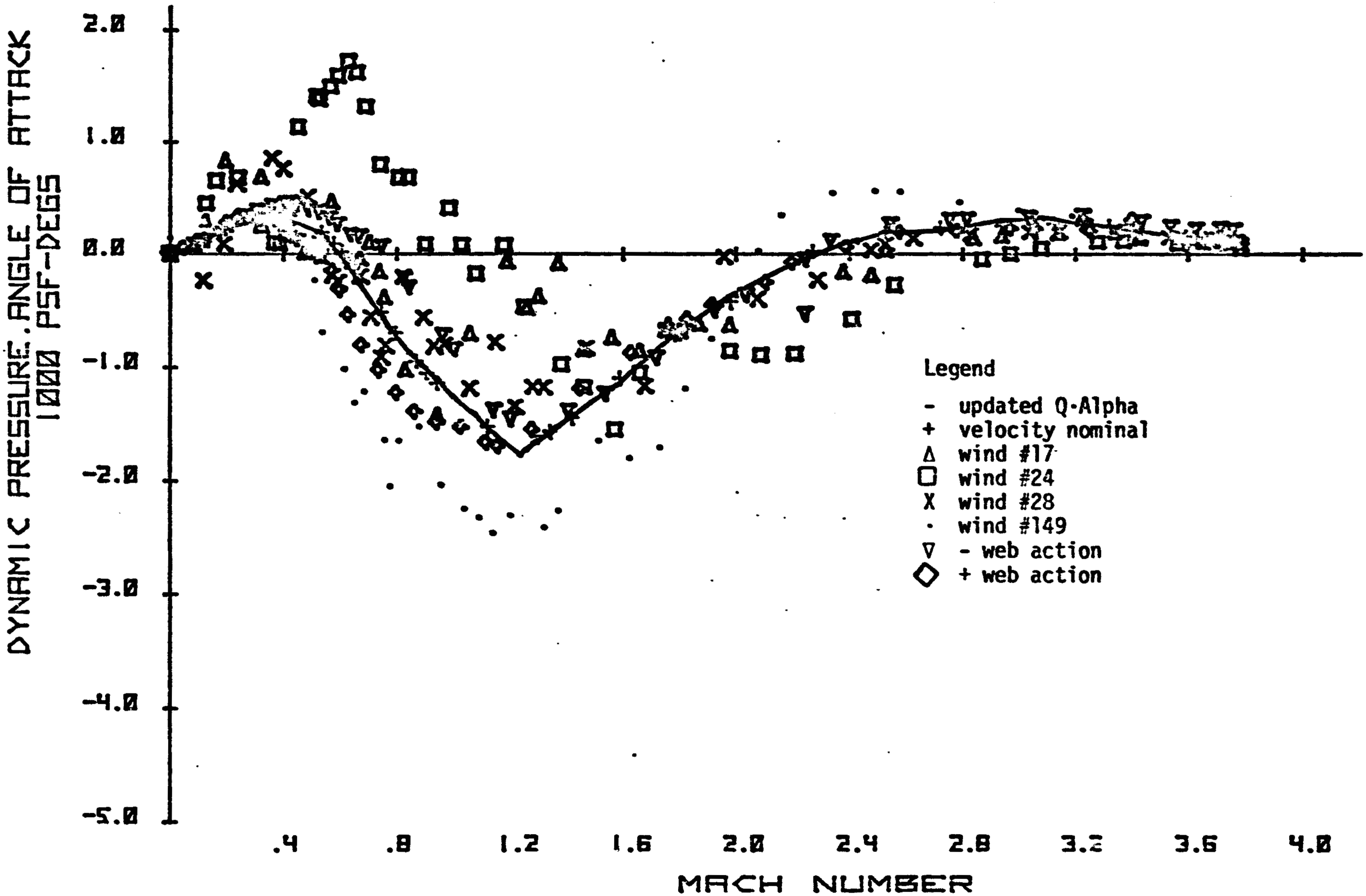

FIGURE 5