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DYNAMIC PRESSURE STUDIES

Job Order 81-167

Prepared By

Lockheed Electronics Company, Inc.
Systems and Services Division
Houston, Texas

Contract NAS 9-15200

For

Mission Analysis and Planning Division

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

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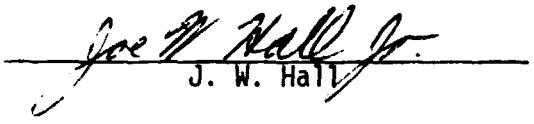

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13. ABSTRACT

This document summarizes investigations of the effects on dynamic pressure by errors in viscous interaction of air, navigation filter errors, and wind errors.

14. SUBJECT TERMS

DYNAMIC PRESSURE STUDIES

INTRODUCTION

This memorandum summarizes the results of investigations of the effects of various error sources on dynamic pressure. Investigated were: (1) errors in viscous interaction of air, (2) navigation filter errors, and (3) wind errors.

1. VISCOUS INTERACTION

For speeds above Mach 2, the dynamic pressure $\bar{Q}$ of the Shuttle is computed by the formula

$$\bar{Q} = \frac{|\hat{i}_V \cdot \Delta\hat{v}|}{\Delta t} \cdot \frac{M}{A \cdot C_D}$$

where

C_D = Drag coefficient

A = Frontal crossectional area

M = Mass

$\hat{v}$ = Velocity vector

$\hat{i}_V$ = Unit vector in direction of $\hat{v}$

$\Delta\hat{v}$ = Sensed change in velocity vector over a time period Δt

Δt = Time interval between accelerator samples

The drag coefficient is both downgraded and upgraded by an amount taken from Space Vehicle Dynamics Simulation profile. That is, $\bar{Q}$ bar is calculated for $C_D + \Delta C_D$ and $C_D - \Delta C_D$ and compared to the true or reference $\bar{Q} = \frac{1}{2}\rho v^2$. Table I gives a synopsis of the results.

TABLE I.– EFFECTS OF AIR VISCOSITY ON $\bar{Q}$

$$\begin{bmatrix} C_D + \Delta C_D \text{ used to calculate } \bar{Q}+ \\ C_D - \Delta C_D \text{ used to calculate } \bar{Q}- \end{bmatrix}$$

Altitude (ft)	$\bar{Q}$ (lb/sq ft)	C_D (%)	$\bar{Q}+$ (%)	$\bar{Q}-$ (%)
282,070	3.578	9.27	8.48	10.22
266,862	8.269	8.72	8.02	9.55
253,464	16.38	7.14	6.66	7.69
243,384	25.88	5.77	5.46	6.13
236,251	34.70	5.48	5.19	5.79
231,106	41.90	5.31	5.04	5.60
228,216	45.83	5.24	4.98	5.53
225,816	48.47	5.26	5.00	5.54
223,836	50.50	5.39	5.12	5.70
221,101	53.72	5.61	5.31	5.95
218,280	57.44	5.84	5.52	6.20
215,441	61.28	6.13	5.77	6.53
212,726	64.89	6.47	6.08	6.92
210,168	68.05	6.84	6.41	7.35
207,759	70.73	7.24	6.75	7.81
205,507	73.03	7.67	7.12	8.30
203,564	75.26	8.12	7.51	8.84
203,374	71.74	8.57	7.84	9.37
201,597	72.59	8.99	8.25	9.87
198,629	77.03	9.26	8.48	10.21
194,634	84.95	9.37	8.57	10.34
190,613	93.66	9.41	8.60	10.38
187,083	99.81	9.37	8.56	10.33
183,681	105.6	9.36	8.56	10.33
172,021	124.3	9.36	8.56	10.32
167,867	130.5	9.35	8.55	10.32

TABLE I.— Concluded.

Altitude (ft)	$\overline{Q}$ (lb/sq ft)	C_D (%)	$\overline{Q}+$ (%)	$\overline{Q}-$ (%)
158,007	131.9	9.33	8.53	10.29
151,381	130.9	9.29	8.50	10.24
147,313	116.2	9.87	8.98	10.95
141,527	129.0	11.09	9.99	12.48
135,113	146.1	12.59	11.18	14.40
128,963	163.4	14.29	12.50	16.67
123,110	180.1	16.16	13.91	19.27
117,573	191.8	18.10	15.32	22.10
112,005	209.2	19.96	16.64	24.94
107,429	212.3	21.66	17.80	27.64
101,983	219.1	22.90	18.63	29.70
95,902	221.8	23.6	19.09	30.89
89,194	228.5	23.07	18.74	29.99
82,690	212.5	14.12	12.38	16.45

2. NAVIGATION FILTER ERRORS

As with the viscous interaction study, eq. (1) is used in computing the dynamic pressure of the Shuttle for speeds greater than Mach 2. The dynamic pressure (table II, column 3) with the filter turned on is compared to the dynamic pressure with filter off and calculated by $\bar{Q} = \frac{1}{2} \rho v^2$ (table II, column 2).

TABLE II.— NAVIGATION FILTER ERRORS

Time (sec)	$\bar{Q}$ w/o NAV (lb/sq ft)	$\bar{Q}$ w NAV (lb/sq ft)	$\Delta\bar{Q}$ (lb/sq ft)	$\Delta\bar{Q}$ (%)
1373.27	3.56	3.21	0.352	9.87
1398.23	8.38	7.37	1.015	12.11
1423.19	16.78	14.76	2.015	12.01
1448.15	26.50	23.63	2.873	10.84
1473.11	35.56	31.99	3.572	10.04
1498.07	42.50	38.54	3.967	9.33
1523.03	46.87	42.66	4.209	8.98
1549.91	49.49	45.31	4.181	8.45
1574.87	51.65	47.54	4.108	7.95
1599.83	54.60	50.45	4.154	7.61
1624.79	58.20	54.04	4.162	7.15
1649.75	61.92	57.79	4.125	6.66
1674.71	65.37	61.28	4.093	6.26
1699.67	68.45	64.35	4.099	5.99
1724.63	71.16	66.95	4.210	5.92
1749.59	73.47	69.14	4.331	5.89
1774.55	75.12	71.36	3.761	5.01
1799.51	72.02	68.10	3.915	5.44
1824.47	73.04	68.56	4.475	6.13
1849.43	77.68	72.35	5.332	6.86
1876.31	86.33	80.26	6.071	7.03
1901.27	94.64	88.5	6.139	6.49
1926.23	101.05	94.35	6.696	6.63

TABLE II.— Concluded.

Time (sec)	$\overline{Q}$ w/o NAV (lb/sq ft)	$\overline{Q}$ w NAV (lb/sq ft)	$\Delta\overline{Q}$ (lb/sq ft)	$\Delta\overline{Q}$ (%)
1951.19	106.57	99.82	6.742	6.33
1976.15	112.44	105.36	7.082	6.30
2001.11	118.78	111.23	7.550	6.36
2026.07	125.28	117.27	8.008	6.39
2051.03	131.90	123.66	8.238	6.25
2075.99	133.88	125.96	7.925	5.92
2100.95	133.20	125.38	7.819	5.87
2125.91	132.40	125.36	7.035	5.31
2152.79	131.45	125.38	6.074	4.62
2179.67	127.89	123.94	3.951	3.09
2200.79	114.83	112.80	2.034	1.77
2225.75	112.62	111.51	1.113	0.99
2250.71	123.81	120.30	3.502	2.83
2275.67	139.10	133.39	5.702	4.10
2300.63	153.62	147.74	5.881	3.83
2325.59	166.25	160.47	5.776	3.47
2350.55	176.64	168.01	8.628	4.88
2375.51	186.88	180.92	5.957	3.19
2400.47	186.48	183.50	2.985	1.60
2425.43	191.88	187.44	4.438	2.31
2450.39	199.45	191.05	8.4	4.21
2475.35	209.21	201.33	7.879	3.77
2500.31	207.88	190.63	17.254	8.30
2525.71	193.90	154.16	39.737	20.49
2550.73	204.92	216.59	11.672	5.70
2600.15	195.89	208.08	12.186	6.22
2650.07	202.34	215.06	12.726	6.29
2700.47	249.74	263.40	13.657	5.47
2750.07	302.70	302.47	0.228	0.08
2800.15	246.51	246.77	0.255	0.1

3. WIND ERRORS

The SSWIND model from the Space Shuttle Functional Simulator provides the wind profile used for this study. The wind direction is 135°, approximately a headwind, for the bulk of the trajectory. As before, eq. (1) is used in computing $\overline{Q}$ for speeds above Mach 2 and compared to $\overline{Q}$ calculated by $\frac{1}{2}\rho v^2$ (table III, column 2). The speed of the Shuttle becomes less than Mach 2 at approximately 76,000 ft altitude, which accounts for the sharp dip shown in column 3.

TABLE III.– WIND ERRORS

Altitude (ft)	$\overline{Q}$ (lb/sq ft)	$\Delta\overline{Q}$ (%)
266,862	8.269	19.83
253,464	16.38	14.49
243,384	25.88	9.03
236,251	34.70	17.16
231,106	41.90	20.08
225,816	48.47	20.70
221,101	53.72	14.59
218,280	57.44	10.43
215,441	61.28	6.94
212,726	64.89	3.99
210,168	68.05	1.09
207,759	70.73	1.86
205,507	73.03	4.83
203,564	75.26	32.91
203,374	71.74	22.70
201,597	72.59	27.28
194,634	84.59	28.30
187,083	99.81	25.85
180,058	111.4	24.01
172,021	123.8	23.38

TABLE III.– Concluded.

Altitude (ft)	$\bar{Q}$ (lb/sq ft)	$\Delta\bar{Q}$ (%)
167,867	130.5	24.13
161,305	132.1	24.11
154,566	131.7	23.53
150,850	125.9	16.49
150,488	126.3	0.06
150,411	118.1	8.62
147,313	116.2	8.31
141,032	130.3	8.29
128,963	163.4	9.97
123,110	180.1	10.26
117,573	191.8	11.00
112,005	209.2	6.34
107,429	212.3	1.11
101,983	219.1	6.37
89,194	228.5	17.31
82,007	209.4	25.21
76,867	179.6	25.66
76,630	200.4	7.19
70,040	212.1	5.22
61,286	219.3	4.14
48,610	191.8	9.44
38,639	211.1	15.99
36,024	224.8	17.58
28,791	248.4	15.43
22,915	265.5	21.96