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C92-A Systems for Nuclear
Auxiliary Power (SNAP)
-Isotopic SNAP Program
M-3679 (46th Ed.)

SNAP 19 CAPSULE FORCE AND STABILITY
TEST CONDUCTED IN THE NASA LANGLEY
31-INCH CONTINUOUS FLOW HYPERSONIC
TUNNEL AT MACH 10

MND-3607-90
December 1966

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FOREWORD

This report was prepared under United States Atomic Energy Commission Contract AT(30-1)-3607 and covers Item 2(e) of the proposed experimental program for SNAP 19, dated January 1966.

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SUMMARY

A full-scale SNAP 19 capsule force and stability test was conducted in the NASA Langley Research Center 31-inch Continuous Flow-Hypersonic Tunnel. Data are presented for a Mach number equal to 10 and for Reynolds numbers, 0.758×10^6 , 0.490×10^6 and 0.348×10^6 , for model angles of attack from 0° to 90° . The objectives of the test were: (1) to obtain aerodynamic force and moment data in the continuum regime; and (2) to determine how the capsule pitching moment was affected by the notches in the face of the capsule. The effect of the notches in the face of the capsule was investigated from angles of attack from 35° to 90° . Shadowgraph pictures, taken at each angle of attack, were valuable in determining the effect of the notches.

The results showed that, in the range tested, Reynolds number effect was negligible. The normal and axial force variation with angle of attack was similar to that predicted by application of the Newtonian theories. The magnitude of the axial force coefficient was nearly that predicted by the modified Newtonian theory. The normal force coefficient was nearly equivalent to the Newtonian values up to approximately 65° angle of attack. From 65° to 90° angle of attack, the normal force coefficient followed the modified Newtonian results. The largest variation between the measured results and theory occurred where the notch effect was significant. Here, the Newtonian theory differed from the measured results by a maximum of 12% for the normal force coefficient and 50% for the axial force coefficient.

The pitching moment could not be predicted by theory. However, the variation of the pitching moment with angle of attack was similar to previous low Reynolds number results (MND-3607-89). Again, as in the low Reynolds number tests, the capsule had two stable trim points. In both tests, the more stable trim point was at 90° .

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SYMBOLS AND DEFINITIONS

α	Angle of attack	deg
A	Axial force	lb
β	Angle of sideslip	deg
C_A	Coefficient of axial force	$144 \times A/qS$
C_D	Coefficient of drag force	$144 \times D/qS$
C_L	Coefficient of lift force	$144 \times L/qS$
C_m	Coefficient of pitching moment	$m/qS\ell$
C_N	Coefficient of normal force	$144 \times N/qS$
cg	Reference center for moments centered at 50% of ℓ	
D	Drag force	lb
L	Lift force	lb
ℓ	Reference length (6.11 inches)	in.
m	Pitching moment	in. -lb
M_∞	Free stream Mach number	
N	Normal force	lb
μ	Coefficient of free stream viscosity	slugs/ft-sec
P_0	Stagnation pressure	psia
P_∞	Free stream static pressure	psia
P_{T_2}	Total pressure behind the shock	psia
q	Dynamic pressure	psf
R_N	Reynolds number per foot	$\rho V/\mu, 1/\text{ft}$

R_ℓ	Reynolds number based on model length	$\rho V \ell / 12 \mu$
ρ	Free stream density	slugs/ft ³
S	Reference area (6.98 in. ²)	
T_0	Stagnation temperature	°F
V	Free stream velocity	ft/sec

I. INTRODUCTION

The SNAP 19 radioisotopic-fueled thermoelectric generator has been designed for use on the Nimbus B satellite. Establishment and confirmation of the safety of the system throughout the regime from fueling to ultimate re-entry of the fuel capsule are required.

Calculations performed at Martin and Sandia indicated the potential existence of aerodynamic and aerothermodynamic conditions under which the fuel particulate would not maintain integrity, producing a shifting of the particle size distribution downward and leading to an unsatisfactory condition from the safety aspect. The potentiality of fuel size degeneration upon re-entry emphasized the need for an accurate description of the aerodynamic and aerothermodynamic properties of all systems and subsystems housing the fuel.

The aerodynamic and burnup analyses of the SNAP 19 RTG mounted in the Nimbus B satellite involve various configurations (the spacecraft, the generator and the fuel capsules) which are difficult to analyze insofar as the aerodynamic characteristics and the aeroheating distributions are concerned. The various theoretical methods available for use in analysis are generally applied to more conventional configurations, and extrapolation of these methods to other configurations could be misleading. Experimental data are required to support extrapolation of the theoretical methods to the geometric shapes used in the Nimbus B-SNAP 19 configuration.

The capsule was designed to withstand impact during booster abort, which does not subject the power supply to high rates of aerodynamic heating. During normal re-entry, however, the capsule is subjected to high heating rates. The heating of the fuel capsule upon re-entering the atmosphere will be a function of its motions and average attitude with respect to the velocity vector. These characteristics are determined by the aerodynamics and the flight path parameters.

The aerodynamic parameters during re-entry will vary as the capsule passes through the various flow regimes from transition to continuum flow. However, existing hypersonic test data needed to accurately predict these parameters are very limited. In order to substantiate the theoretical estimates on the aerodynamic force and moments used to describe the trajectory, a series of tests was planned at varying Reynolds numbers.

The nominal trajectory for the capsule, freed from the generator at an altitude of 280,000 feet, results in flight Reynolds numbers of 600 to 2.96×10^5 based on the capsule length of 6.11 inches. Force

tests were run in the Low Density Hypersonic Tunnel, AEDC, at a Mach number of 9.37 and Reynolds number of 1200 to obtain data in the lower Reynolds number range. These results are presented in Ref. 1. In addition, force tests were run at Mach 10 in the NASA-Langley 31-inch Continuous Flow Hypersonic Tunnel at Reynolds numbers ranging from approximately 0.8×10^6 to 0.2×10^6 . The force and moment data from this test will be used directly in determining the flight motions in the continuum regime via an analog computer program.

This report presents the results of the force test on the SNAP 19 capsule; the test was conducted in the 31-inch Continuous Flow Hypersonic Tunnel at NASA-Langley Research Center, Langley Field, Virginia, beginning June 27, 1966 and ending June 30, 1966.

II. FACILITY DESCRIPTION AND INSTRUMENTATION

The facility used for obtaining the aerodynamic force and moment data on the fuel capsule at Mach 10 is the NASA Continuous Flow Hypersonic Tunnel located at Langley Research Center, Virginia. The wind tunnel is of the closed circuit type, with a blowdown starting cycle. The test medium is air, which is heated by an electrical resistance heater.

A flow diagram of the system is shown in Fig. 1. After the heater is brought to operating temperature with subsonic flow through the tunnel, hypersonic flow is established on a blowdown cycle. Air is discharged from the air storage (bottle field) and flows through one of the two heaters shown (only one heater is used for $M = 10$). From the heater, the flow is expanded through the rectangular nozzle and passes through the 31-inch square test section, diffuser and cooler, and then into the vacuum sphere. The tunnel is then transferred to the compressors for continuous operating. The bottle field and vacuum sphere are cut off from the circuit, using shutoff valves. In Fig. 1, the starting circuit is shown by the thin arrows and the continuous flow circuit is shown in heavy arrows. The tunnel, heaters and aftercooler are shown across the middle of this figure; the blowdown circuit with 900 cubic feet of air at 2,500 psia and a 40-foot vacuum sphere are indicated at the top of the figure, and the continuous circuit across the lower half of the figure. For Mach 10, five compressors are used, developing an overall pressure ratio of 375:1; for higher Mach numbers, six compressors are used with an available pressure ratio of 700:1. The drive is rated at 25,000 hp.

The Mach 10 tunnel is capable of continuous operation from 250 psia to 2250 psia stagnation pressure and is operated at a maximum stagnation temperature of 1500° F. The tunnel has a 31- by 31-inch test section equipped with fused quartz windows for optical viewing. All hypersonic components are stainless-clad, water-cooled sections using a closed-circuit, distilled-water system operating at 150 psi. The contoured nozzle is constructed of beryllium copper and cooled by a separate distilled-water system operating at 1,500 psi.

Examples of normal operating conditions are:

Mach number	10
Stagnation pressure (atmospheres)	15 to 100
Stagnation temperature (°R)	1400 to 1900
Reynolds number per foot	0.5×10^6 to 1.7×10^6

Fig. 1. Schematic Diagram of the Langley Continuous-Flow Hypersonic Tunnel

Operating conditions are further illustrated in the tunnel calibration curves presented in Fig. 2. The facility is also capable of Mach 12 operation, but to date it has been run only as a blowdown tunnel at this Mach number.

The Langley water-cooled HCF-04 six-component balance was used for this test. The maximum loading for this balance is given as:

$$N = 35 \text{ lb}$$

$$A = 80 \text{ lb}$$

$$m = 35 \text{ in. -lb.}$$

A 30° bent sting was used for this test. With a straight sting, the sting angle range is -3° to 28.5° . By using a 30° bent sting, a total angle range of 1.5° to 58.5° is obtained (all angles can be considered positive because the capsule is axisymmetric). When the 30° bent sting is inverted, the angle range is from 1.5° to 33° ; and with an upright sting, the angle range is 27° to 58.5° .

The sting angle range with the 30° bent sting installed is shown in Fig. 3.

Fig. 2. Tunnel Operating Conditions

III. MODEL DESCRIPTION

Two full-scale SNAP 19 capsule models were used for this investigation. Dimensions of the capsule are shown in Fig. 4. One model, Model A, was mounted through the base, the other, Model B, was mounted through the cylinder wall. A photograph of the models is presented in Fig. 5(a). An exploded view of Model A is shown in Fig. 5(b). The cylinder (capsule) is constructed from 321 stainless steel, while the balance adapter is constructed from 17-4 stainless steel. The adapter is isolated from the capsule, using the insulating washers shown. A similar view of side-mounted Model B is shown in Fig. 5(c). Drawings of the models are shown in Fig. 6.

Using the 30° bent sting, the sting angle range, as noted in Fig. 3, would not allow testing at 0° or 90° without rotating the balance adapter. Therefore, the balance adapter for each model was rotated 5° from the axis, as shown in the drawings, Fig. 6. With the balance adapter rotated 5°, the angle-of-attack range for the models was:

Model A	Sting upright	$22^\circ \leq \alpha \leq 53.5^\circ$
	Sting inverted	$-3.5^\circ \leq \alpha \leq 28^\circ$
Model B	Sting upright	$36.5^\circ \leq \alpha \leq 68^\circ$
	Sting inverted	$62^\circ \leq \alpha \leq 93.5^\circ$

These angle ranges are illustrated in Figs. 7(a) and 7(b) for Models A and B, respectively. Photographs of the models mounted in the tunnel are shown in Fig. 8.

In order to evaluate the effects of the notched face of the capsule, an end plate, shown in Fig. 9, was constructed for mounting in the face of the capsule, providing a smooth-faced right circular cylinder. This end plate was tested on Model B only.

Fig. 3. Diagram Showing Sting Angle Range, Using the 30° Bent Sting

Fig. 4. SNAP 19 Capsule Model

Fig. 5(a). Photographs of SNAP 19 Capsule Models

Fig. 5(b). Exploded View of Capsule Model A

Fig. 5(c). Exploded View of Capsule Model B

QUANTITY / DASH NO. ODD DASH NO. SHOWN	PART OR IDENTIFYING NO. EVEN DASH NO. OPP	ZONE	SH	SER SYM	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	ISSUE COND	MATERIAL SPECIFICATION	FINISH OR * MFR CODE	REV.
1	1	-21			CAP	1/125 DIA. x 1	17-4 PH CORR. BAR	ANN	AMS-5644	H.T. 190,000	
2	3	*10-32NF x .38 LG.			ALLEN CAP SCREW						
4	4	*8-36NF x 3/8 LG.			ALLEN CAP SCREW						
1		-29 ASSEMBLY			WELDMENT						
2	2	-17			PIN	M/F #10-32NF	ALLEN SET SCREW				A
8	6	-15			INSULATOR	.065 x 1 x 1	ASBESTOS PHENOLIC				A
1		-13			ADAPTOR BLOCK	.50 x 2 x 3	321 CORR. STEEL BAR		Q8-S-763 CONDA		
1		-11			ADAPTOR ~ BALANCE	2.75 DIA. x 4	17-4 PH CORR. BAR	ANN	AMS-5644	H.T. 190,000	A
1		-7			ADAPTOR ~ BALANCE	2.75 DIA. x 5	17-4 PH CORR. BAR	ANN	AMS-5644	H.T. 190,000	A
1		-5			END CAP	3.000 DIA. x 2	321 CORR. STEEL BAR			(CTRLESS GD.)	
1		-3			CYLINDER	3.000 DIA. x 7	321 CORR. STEEL BAR			(" ")	
1		-1			CYLINDER	3.000 DIA. x 7	321 CORR. STEEL BAR		Q8-S-763 CONDA	(CTRLESS GD.)	
29	19	9									
LIST OF MATERIAL											

Fig. 6(a). Model Drawings

Fig. 6(b). Model Drawings

Fig. 7(a). Angle of Attack Range for Model A

Fig. 7(b). Angle of Attack Range for Model B

Fig. 8(a). Photograph of SNAP 19 Capsule Model A Mounted in the NASA 31-Inch Continuous Flow Hypersonic Tunnel

Fig. 8(b). Photograph of SNAP 19 Capsule Model B Mounted in the NASA 31-Inch Continuous Flow Hypersonic Tunnel

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IV. TEST PROCEDURE

The capsule models were tested at angles of attack from 0° to 90° in approximately 5° increments. The 30° bent sting was rolled 180° , as shown in Figs. 7(a) and 7(b), to obtain the desired angle of attack range for each model. The sequence of events is shown below and in the Run Program, Table 1.

<u>Runs</u>	<u>Model</u>	<u>Sting Position</u>	<u>Model Angle-of-Attack Range (deg)</u>
1 to 4	A	Rolled 180°	0 to 30
5 to 8	A	Upright	20 to 55
9 to 12	B	Upright	35 to 65
13 to 16	B	Rolled 180°	65 to 90
17	C	Rolled 180°	65 to 90
18	C	Upright	35 to 65

Note that here and in Table 1 the angle-of-attack range shows the approximate angles tested and differs slightly from the limit ranges given in Fig. 7. Force data were recorded for four total pressures and, consequently, four Reynolds numbers. They were $P_0 = 1200$ psia ($R_\ell = 0.758 \times 10^6$), $P_0 = 750$ psia ($R_\ell = 0.490 \times 10^6$), $P_0 = 500$ psia ($R_\ell = 0.348 \times 10^6$) and $P_0 = 250$ psia ($R_\ell = 0.178 \times 10^6$). Runs 4, 8, 12 and 16 with $P_0 = 250$ psia were voided because of discrepancies with data reduction. These discrepancies were attributed to tunnel behavior.

After completing the desired runs, the capsule was modified by inserting an end plate in the face of the model, thereby making the capsule a smooth-faced, right circular cylinder. This modified model (C) was tested from 65° to 90° . Model C was tested to determine the effect of the notches in the face of the capsule on the normal and axial force and pitching moment.

The measured values (N , A and m) were reduced to coefficient form in the body axis system (C_N , C_A and C_m) and the stability axis system (C_L , C_D and C_m). Figure 10 presents the two axes systems.

TABLE 1
Run Program

<u>Run No.</u>	<u>Model</u>	<u>Mach No.</u>	<u>α Range (deg)</u>	<u>R_L $\times 10^{-6}$</u>	<u>q (psf)</u>	<u>T_0 (°F)</u>
1	A	10.460	0 to 30	0.758	228.74	1353
2	A	10.395	0 to 30	0.490	145.07	1323
3	A	10.330	0 to 30	0.348	99.74	1283
4	Void					
5	A	10.460	20 to 55	0.759	221.45	1346
6	A	10.395	20 to 55	0.492	145.52	1324
7	A	10.330	20 to 50	0.335	99.27	1313
8	Void					
9	B	10.460	35 to 65	0.754	227.46	1353
10	B	10.390	35 to 65	0.509	145.89	1294
11	B	10.330	35 to 65	0.332	98.38	1313
12	Void					
13	B	10.460	65 to 90	0.776	227.17	1324
14	B	10.395	65 to 90	0.512	145.95	1287
15	B	10.330	65 to 90	0.333	99.31	1318
16	Void					
17	C	10.460	65 to 90	0.754	226.63	1349
18	C	10.460	35 to 65	0.746	226.46	1359

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V. ACCURACY OF DATA

According to the facility, the angle of attack was set to within $\pm 1/20^\circ$ of the designated value and the Mach number was accurate to within ± 0.02 . The recording errors are considered to be negligible. The stagnation pressure accuracy was given as $\pm 1/10$ of 1%; therefore, the dynamic pressure, q , should be within $\pm 1\%$ of the recorded value.

The accuracy of the balance was given as $\pm 1/2\%$ of the maximum loads. The maximum loads that can be measured with the Langley HCF-04 water-cooled balance and the corresponding accuracies for the coefficients are presented below.

<u>Component</u>	<u>Maximum Load</u>	<u>lb or in. -lb</u>	<u>Accuracy</u>		
			$C_{( )_{P_0}} =$ <u>1200 psia</u>	$C_{( )_{P_0}} =$ <u>750 psia</u>	$C_{( )_{P_0}} =$ <u>500 psia</u>
N	35 lb	± 0.175	± 0.0158	± 0.0249	± 0.0362
A	80 lb	± 0.400	± 0.0361	± 0.0568	± 0.0827
m	35 in. -lb	± 0.175 in. -lb	± 0.00258	± 0.00408	± 0.00593

A few repeat points were obtained during the test. Of these, all were within 1% of the maximum measured values for each coefficient, and well within the $1/2\%$ of the maximum balance loads.

The test data are shown in Table 2.

TABLE 2

Tabulated Data--Test 17, 31-Inch Continuous Flow Hypersonic Tunnel

Run 1 (Model A)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
3	-0.04	0.96	0.0074	1.7836	-0.0003	-0.0225	1.7835	-0.013	0.762	10.460	228.90	-0.042	1349.
4	-0.04	5.96	0.0777	1.7847	0.0055	-0.1081	1.7832	-0.061	0.753	10.460	228.71	0.070	1359.
5	-0.09	10.97	0.1570	1.7838	0.0091	-0.1851	1.7811	-0.104	0.750	10.460	228.64	0.058	1363.
6	-0.15	15.96	0.2503	1.7705	0.0100	-0.2463	1.7711	-0.139	0.747	10.460	228.57	0.040	1367.
7	-0.15	20.96	0.4005	1.7607	0.0045	-0.2558	1.7874	-0.143	0.745	10.460	228.52	0.011	1369.
8	-0.10	25.95	0.6605	1.7400	-0.0067	-0.1675	1.8536	-0.090	0.760	10.460	228.66	-0.010	1350.
9	-0.10	28.80	0.8455	1.7281	-0.0057	-0.0916	1.9217	-0.048	0.771	10.460	228.90	-0.007	1337.
10	0.00	0.96	0.0065	1.7943	-0.0003	-0.0236	1.7941	-0.013	0.777	10.460	229.01	-0.047	1331.

Run 2 (Model A)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
21	0.00	0.96	0.0196	1.7629	0.0042	-0.0100	1.7629	-0.006	0.492	10.395	145.07	0.215	1320.
22	0.00	5.96	0.0789	1.7763	0.0085	-0.1060	1.7749	-0.060	0.492	10.395	145.06	0.108	1321.
23	0.00	10.96	0.1538	1.7697	0.0103	-0.1855	1.7666	-0.105	0.491	10.395	145.05	0.067	1322.
24	-0.05	15.96	0.2436	1.7518	0.0087	-0.2474	1.7513	-0.141	0.491	10.395	145.09	0.036	1322.
25	-0.05	20.95	0.3916	1.7373	0.0023	-0.2555	1.7625	-0.145	0.490	10.395	145.07	0.006	1324.
26	-0.05	25.94	0.6623	1.7129	-0.0084	-0.1538	1.8300	-0.084	0.490	10.395	145.06	-0.013	1325.
27	-0.05	28.74	0.8419	1.6965	-0.0066	-0.0776	1.8923	-0.041	0.490	10.395	145.06	-0.008	1325.
28	0.00	0.96	0.0124	1.7716	0.0043	-0.0173	1.7715	-0.010	0.488	10.395	145.07	0.346	1328.

Run 3 (Model A)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
39	0.00	0.96	0.0158	1.7437	0.0018	-0.0134	1.7437	-0.008	0.354	10.330	99.79	0.114	1267.
40	0.00	5.96	0.0758	1.7466	0.0063	-0.1059	1.7451	-0.061	0.356	10.330	99.84	0.084	1261.
41	0.00	10.96	0.1481	1.7337	0.0084	-0.1841	1.7302	-0.106	0.352	10.330	99.84	0.056	1273.
42	-0.05	15.95	0.2410	1.7192	0.0078	-0.2408	1.7193	-0.140	0.347	10.330	99.79	0.032	1284.
43	-0.05	20.95	0.3834	1.6930	0.0031	-0.2472	1.7182	-0.144	0.345	10.330	99.70	0.008	1290.
44	-0.05	25.94	0.6483	1.6596	-0.0059	-0.1430	1.7760	-0.081	0.343	10.330	99.67	-0.009	1294.
45	-0.05	28.69	0.8359	1.6435	-0.0055	-0.0557	1.8431	-0.030	0.343	10.330	99.66	-0.007	1295.
46	0.00	0.96	0.0180	1.7197	0.0018	-0.0107	1.7198	-0.006	0.342	10.330	99.64	0.101	1298.

TABLE 2 (continued)

Run 5 (Model A)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
3	-0.00	21.36	0.4547	1.6733	-0.0720	-0.1934	1.7432	-0.111	0.767	10.460	227.60	-0.004	1344.
4	-0.00	25.01	0.6589	1.6755	-0.0097	-0.1111	1.7960	-0.062	0.761	10.460	227.49	-0.015	1344.
5	-0.01	30.02	0.9738	1.6357	0.0009	0.0247	1.9035	0.013	0.759	10.460	227.46	0.001	1346.
6	-0.06	35.06	1.3094	1.6024	0.0338	0.1514	2.0638	0.073	0.757	10.460	227.41	0.026	1349.
7	-0.05	40.11	1.6562	1.5311	0.0911	0.2557	2.2327	0.112	0.756	10.460	227.38	0.055	1350.
8	-0.05	45.14	1.9996	1.4264	0.1268	0.3992	2.4235	0.165	0.755	10.460	227.37	0.063	1351.
9	-0.05	50.16	2.2942	1.1702	0.1335	0.5560	2.5240	0.220	0.757	10.460	227.39	0.058	1349.
10	-0.05	53.15	2.4492	1.0290	0.1242	0.6452	2.5770	0.250	0.767	10.460	227.52	0.051	1337.

1346

Run 6 (Model A)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
21	-0.00	21.40	0.4549	1.6859	0.0010	-0.1917	1.7356	-0.110	0.511	10.395	145.84	0.002	1290.
22	-0.00	25.00	0.6542	1.6552	-0.0068	-0.1066	1.7766	-0.060	0.497	10.395	145.74	-0.010	1315.
23	-0.00	30.01	0.9691	1.6253	0.0017	0.0260	1.8925	0.014	0.490	10.395	145.48	0.002	1326.
24	-0.05	35.03	1.2906	1.6017	0.0336	0.1373	2.0523	0.067	0.489	10.395	145.45	0.026	1329.
25	-0.05	40.06	1.6460	1.5689	0.0870	0.2499	2.2602	0.111	0.488	10.395	145.43	0.053	1331.
27	-0.05	45.09	1.9715	1.4113	0.1206	0.3925	2.3926	0.164	0.487	10.395	145.42	0.061	1331.
28	-0.05	50.09	2.2589	1.1561	0.1230	0.5624	2.4744	0.227	0.487	10.395	145.41	0.054	1333.
29	-0.05	53.09	2.4148	0.9799	0.1114	0.6668	2.5193	0.265	0.486	10.395	145.40	0.046	1334.

1324

Run 7 (Model A)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
40	-0.00	21.40	0.4443	1.6619	0.0041	-0.1927	1.7094	-0.113	0.336	10.330	99.27	0.009	1310.
41	-0.00	25.00	0.6413	1.6470	-0.0047	-0.1149	1.7637	-0.065	0.336	10.330	99.28	-0.007	1310.
42	-0.00	30.01	0.9526	1.6139	0.0032	0.0173	1.8740	0.010	0.334	10.330	99.24	0.003	1314.
43	-0.05	35.02	1.2343	1.5923	0.0339	0.1378	2.0415	0.067	0.334	10.330	99.23	0.026	1315.
44	-0.05	40.04	1.6296	1.5561	0.0860	0.2465	2.2397	0.110	0.334	10.330	99.23	0.053	1315.
45	-0.05	45.05	1.9433	1.3310	0.1135	0.3884	2.3581	0.165	0.335	10.330	99.29	0.058	1313.
46	-0.05	50.06	2.2242	1.1258	0.1143	0.5649	2.4280	0.233	0.335	10.330	99.33	0.051	1314.
47	-0.05	53.05	2.3629	0.9409	0.0964	0.6684	2.4540	0.272	0.334	10.330	99.32	0.041	1316.

1313

TABLE 2 (continued)

Run 9 (Model B)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
3	-0.04	36.97	1.3134	1.6397	0.0308	0.0631	2.0999	0.030	0.763	10.460	227.74	0.023	1342.
4	-0.04	39.96	1.5264	1.6450	0.0672	0.1136	2.2412	0.051	0.758	10.460	227.63	0.044	1348.
5	-0.04	45.01	1.8620	1.5288	0.1123	0.2353	2.3977	0.098	0.754	10.460	227.54	0.060	1353.
6	-0.04	50.05	2.1845	1.3152	0.1353	0.3944	2.5191	0.157	0.750	10.460	227.35	0.062	1357.
7	0.01	55.07	2.4478	1.0344	0.1256	0.5534	2.5991	0.213	0.750	10.460	227.35	0.051	1358.
8	0.01	60.07	2.6528	0.7445	0.0915	0.6782	2.6705	0.254	0.749	10.460	227.32	0.035	1359.
9	0.01	65.08	2.8508	0.5029	0.0726	0.7450	2.7973	0.266	0.752	10.460	227.29	0.025	1355.

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Run 10 (Model B)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
20	-0.04	37.00	1.3208	1.6477	0.0302	0.0632	2.1108	0.030	0.500	10.395	145.67	0.023	1310.
21	-0.04	39.97	1.5315	1.6504	0.0648	0.1135	2.2486	0.050	0.506	10.395	145.83	0.042	1299.
22	-0.04	45.00	1.8674	1.5337	0.1082	0.2359	2.4049	0.098	0.508	10.395	145.86	0.058	1296.
23	-0.04	50.03	2.1764	1.3152	0.1275	0.3902	2.5128	0.155	0.510	10.395	145.91	0.059	1292.
24	-0.09	55.04	2.4345	1.0345	0.1110	0.5473	2.5880	0.211	0.513	10.395	145.97	0.046	1286.
25	0.01	60.04	2.6374	0.7249	0.0746	0.6891	2.6470	0.260	0.514	10.395	145.98	0.028	1285.
26	0.01	65.05	2.8372	0.4838	0.0617	0.7583	2.7765	0.273	0.513	10.395	146.00	0.022	1287.

Run 11 (Model B)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
37	0.05	37.02	1.3115	1.6356	0.0289	0.0625	2.0955	0.030	0.338	10.330	98.57	0.022	1298.
38	0.05	39.98	1.5202	1.6537	0.0646	0.1024	2.2439	0.046	0.335	10.330	98.42	0.043	1306.
39	0.05	45.00	1.8457	1.5147	0.1024	0.2341	2.3761	0.099	0.333	10.330	98.39	0.055	1310.
40	0.05	50.01	2.1369	1.2803	0.1149	0.3922	2.4600	0.159	0.332	10.330	98.36	0.054	1314.
41	0.01	55.02	2.3830	0.9792	0.0873	0.5639	2.5138	0.224	0.330	10.330	98.33	0.037	1318.
42	0.01	60.02	2.5920	0.7060	0.0604	0.6836	2.5980	0.263	0.329	10.330	98.30	0.023	1321.
43	0.01	65.03	2.7906	0.4597	0.0552	0.7613	2.7238	0.280	0.328	10.330	98.29	0.020	1322.

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TABLE 2 (continued)

Run 13 (Model B)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
3	0.01	65.93	2.7721	0.4388	0.0680	0.7298	2.7100	0.269	0.772	10.460	227.12	0.025	1328.
4	0.01	70.86	2.9264	0.2610	0.0636	0.7129	2.8502	0.250	0.776	10.460	227.20	0.022	1324.
5	-0.04	75.77	3.0489	0.1534	0.0606	0.6007	2.9930	0.201	0.776	10.460	227.20	0.020	1324.
6	-0.03	80.66	3.1305	0.0883	0.0543	0.4208	3.1034	0.136	0.777	10.460	227.21	0.017	1323.
7	-0.03	85.54	3.1797	0.0202	0.0407	0.2272	3.1716	0.072	0.776	10.460	227.20	0.013	1324.
8	-0.03	90.41	3.1957	-0.0465	0.0272	0.0239	3.1959	0.007	0.777	10.460	227.11	0.009	1323.
													1324

Run 14 (Model B)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
16	0.01	65.90	2.7544	0.4241	0.0572	0.7377	2.6875	0.274	0.512	10.395	145.94	0.021	1289.
17	0.01	70.82	2.9058	0.2450	0.0551	0.7232	2.8250	0.256	0.512	10.395	145.95	0.019	1288.
18	-0.04	75.73	3.0206	0.1485	0.0572	0.6006	2.9640	0.203	0.513	10.395	145.96	0.019	1287.
19	-0.03	80.62	3.1149	0.0820	0.0522	0.4266	3.0866	0.138	0.512	10.395	145.95	0.017	1288.
20	-0.03	85.50	3.1569	0.0175	0.0403	0.2302	3.1486	0.073	0.513	10.395	145.96	0.013	1287.
21	-0.03	90.37	3.1726	-0.0479	0.0275	0.0275	3.1729	0.009	0.513	10.395	145.97	0.009	1286.
													1287.5

Run 15 (Model B)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REY 10 ⁶	MACH	Q	CM/CN	TO F ⁰
29	0.01	65.88	2.7831	0.4112	0.0512	0.7620	2.7081	0.281	0.336	10.330	99.41	0.018	1310.
30	0.01	70.80	2.9499	0.2377	0.0518	0.7456	2.8640	0.260	0.335	10.330	99.33	0.018	1315.
31	-0.04	75.71	3.0722	0.1471	0.0550	0.6158	3.0134	0.204	0.333	10.330	99.30	0.018	1319.
32	-0.03	80.60	3.1463	0.0748	0.0507	0.4401	3.1163	0.141	0.333	10.330	99.28	0.016	1320.
33	-0.03	85.48	3.1837	0.0102	0.0400	0.2407	3.1746	0.076	0.332	10.330	99.28	0.013	1321.
34	-0.03	90.35	3.2093	-0.0582	0.0258	0.0387	3.2096	0.012	0.332	10.330	99.26	0.008	1323.
													1318

TABLE 2 (continued)

Run 17 (Model C)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REFY 10 ⁶	MACH	Q	CM/CN	TO F
3	0.05	64.22	2.7958	0.4432	0.0461	0.8170	2.7102	0.301	0.759	10.460	226.65	0.017	1343.
4	-0.05	74.24	3.0944	0.1953	0.0446	0.6524	3.0311	0.215	0.755	10.460	226.66	0.014	1348.
5	-0.05	79.25	3.1800	0.1266	0.0411	0.4689	3.1478	0.149	0.753	10.460	226.62	0.013	1351.
6	-0.05	84.25	3.2366	0.0623	0.0326	0.2624	3.2266	0.081	0.753	10.460	226.62	0.010	1351.
7	-0.05	89.24	3.2590	-0.0010	0.0219	0.0440	3.2588	0.013	0.751	10.460	226.58	0.007	1353.
													1349

Run 18 (Model C)

POINT	BETA	ALPHA	CN	CA	CM	CL	CD	L/D	REFY 10 ⁶	MACH	Q	CM/CN	TO F
3	0.05	36.92	1.2773	1.4861	0.0048	0.1286	1.9553	0.066	0.747	10.460	226.49	0.004	1358.
4	0.05	39.93	1.4616	1.4315	0.0154	0.2019	2.0359	0.099	0.746	10.460	226.46	0.011	1359.
5	0.06	44.96	1.7719	1.2906	0.0304	0.3418	2.1653	0.158	0.746	10.460	226.46	0.017	1359.
6	0.06	49.99	2.0783	1.0994	0.0436	0.4940	2.2987	0.215	0.745	10.460	226.43	0.021	1361.
7	0.01	55.02	2.3650	0.8872	0.0517	0.6287	2.4465	0.257	0.746	10.460	226.45	0.022	1360.
8	0.01	60.05	2.6167	0.6719	0.0515	0.7243	2.6027	0.278	0.746	10.460	226.46	0.020	1359.
9	0.01	65.07	2.8284	0.4586	0.0497	0.7764	2.7581	0.281	0.745	10.460	226.44	0.018	1360.
													1359

VI. PRESENTATION OF DATA AND DISCUSSION OF RESULTS

The primary objective of this test was to obtain aerodynamic force and moment data for the continuum regime. A secondary objective was to determine the effect of the notches on the face of the capsule on the pitching moment coefficient.

Force and moment data were obtained for four Reynolds numbers. The lower Reynolds number results were discarded because of differences in the reduced data, which were attributed to tunnel flow characteristics. The variation of normal and axial force coefficient, with angle of attack for $R_\rho = 0.758 \times 10^6$, 0.490×10^6 and 0.348×10^6 , are shown in Figs. 11 and 12. The curves indicate that, in this range, Reynolds number had no effect on the aerodynamic coefficients. The measured normal and axial force coefficients are compared with those calculated using the Newtonian theory in Figs. 13 and 14, respectively. Normally, Newtonian theory is modified to give better agreement with test data. For example, on a flat plate, the Newtonian normal force coefficient is defined as:

$$C_N = 2 \sin^2 \alpha$$

For better agreement with test results, this is usually modified to be:

$$C_N = 1.84 \sin^2 \alpha$$

For comparison here, both the Newtonian and modified Newtonian values are presented.

The measured value of C_N at $\alpha = 90^\circ$ (Fig. 13) and the measured value of C_A at $\alpha = 0^\circ$ (Fig. 14) closely match the modified Newtonian curve, whereas the measured values of C_N and C_A are in better agreement with the Newtonian between $\alpha = 25^\circ$ and 65° . Both Newtonian curves could be considered acceptable for rough estimates. However, the differences between the measured and calculated results for $\alpha = 25^\circ$ to 65° show that forces not accounted for in the Newtonian theory are affecting the results. This difference is more evident for C_A (Fig. 14) than C_N (Fig. 13). In this range, the maximum deviation between the Newtonian theory and test results is approximately 12% for C_N and approximately 50% for C_A . For more refined values of the aerodynamic coefficients, experimental results must be used.

Fig. 11. Variation of Normal Force Coefficient with Angle of Attack
Showing Effect of Reynolds Number

Fig. 12. Variation of Axial Force Coefficient with Angle of Attack
Showing Effect of Reynolds Number

Fig. 13. Comparison of the Measured Normal Force Coefficients with Those Calculated Using Newtonian Theory

Fig. 14. Comparison of the Measured Axial Force Coefficients with Those Calculated Using Newtonian Theory

The variation of C_L and C_D with angle of attack is shown in Figs. 15 and 16. Figure 15 shows a discrepancy in matching the test results for Models A and B. The difference appears to be similar to an alpha shift. The apparent shift is not noticeable in the C_N and C_A curves.

In studying the test results, there is no justification to support an alpha shift, and the only conclusion that can be drawn is that the shift is possibly due to sting interference on one of the models. This effect cannot be determined.

The variation of the pitching moment with angle of attack is presented in Fig. 17. For the three Reynolds numbers tested, the pitching moment shows a pattern in the variation between $\alpha = 40^\circ$ and $\alpha = 70^\circ$. However, the differences shown are attributed to data scatter rather than Reynolds number effect.

The pitching moment about the capsule cg was estimated by using a combination of pressure results on a right circular cylinder (Ref. 2) and Newtonian theory (to account for the notches in the face of the capsule). As shown in Fig. 17, the pitching moment does not compare well with the measured results at high angles of attack. At low angles of attack, the effect of the notches in the capsule face is small. Consequently, for an angle-of-attack range ($0^\circ \leq \alpha \leq 30^\circ$), the estimated coefficients, using previous test results, compare favorably with the measured values. It is shown here and in Ref. 1 that the theory is not sufficient to estimate the pitching moment about the cg. Scarcity of previous test data, especially at the higher angles of attack, makes proper estimations of the pitching moment difficult. Hence, the test results in Fig. 17 must be assumed to provide the most accurate results.

Figure 18 presents a comparison between the measured moments and the moments obtained in the SNAP 19 capsule low Reynolds number force test (Ref. 1).

The conclusion that can be drawn from this comparison is that the pitching moment ($C_{m_{cg}}$) is nearly constant with Reynolds number.

In an effort to evaluate the effect of the notches in the face of the capsule, Model B was modified by inserting an end plate in the face of the model. This modified model was designated Model C. Comparisons of C_N and C_A for Models B and C are presented in Figs. 19 and 20. Here, the differences in both C_N and C_A are small. The trends show that C_N for the smooth face (Model C) is slightly lower than C_N for the notched face (Model B) from $35^\circ \leq \alpha \leq 60^\circ$ and

Fig. 15. Comparison of Measured Lift Coefficient Variation with Angle of Attack with that Calculated Using Newtonian Theory

Fig. 16. Comparison of Measured Drag Coefficient with Angle of Attack with Those Calculated Using Newtonian Theory

Fig. 17. Variation of Pitching Moment Coefficient with Angle of Attack Showing Effect of Reynolds Number

Fig. 18. Comparison of Pitching Moment Variation with Angle of Attack with that Measured at Very Low Reynolds Number and with Those Measured on Model C

Fig. 19. Variation of Normal Force Coefficient with Angle of Attack Showing Effect of Notches in Face of Capsule

Fig. 20. Variation of Axial Force Coefficient with Angle of Attack Showing Effect of Notches in Face of Capsule

slightly higher from $60^\circ \leq \alpha \leq 90^\circ$. The magnitude of C_A also appears to be lower for the smooth face model.

The major difference between the smooth and notched face capsules is shown in the pitching moment (Fig. 18). Between $35^\circ \leq \alpha \leq 65^\circ$, the notches in the face of the capsule produce a significant change in the pitching moment. The source of this difference can be seen in the flow characteristics.

To provide a better understanding of the flow characteristics over the capsule, shadowgraphs were taken at each angle of attack tested. Selected samples of these shadowgraph pictures are presented in Figs. 21 and 22 for the notched (Model B) and smooth faced capsules (Model C), respectively. Sketches of the overlaid shock patterns are shown in Fig. 23. The increased shock standoff distance for the notched face capsule at angles of attack from 35° to 65° (Figs. 21 and 23) indicates a large pressure rise on the upper portion of the face.

For both models, the stagnation point appears to be on the cylinder surface in this angle-of-attack range and the sonic point occurs on the lower edge of the face. For the smooth face, the flow expands rather uniformly over the face. For the notched face capsule, the flow expands to a lower pressure because of the cavity formed by the notches. This is evident by the reduced shock standoff distance shown in the shadowgraphs. However, in trying to negotiate the upper portion of the notch (see Fig. 24), the flow separates and reattaches before expanding over the top edge of the disk. The compression waves produced by the pressure buildup in the separated region forced the shock standoff distance to increase as shown in the shock patterns in Figs. 21 and 23. The corresponding pressure variation along the centerline of the face is shown in Fig. 25 for $\alpha = 50^\circ$. These pressures are from preliminary test data to be reported in Ref. 3. Using these preliminary test results, the incremental pitching moment due to the pressure variation over the face was roughly calculated. This increment, when added to the pitching moment for smooth face Model C, produces a curve of the general shape measured on the capsule (Model B).

For angles of attack below 35° , the stagnation point would move up on the capsule face and the effect of the notches would be negligible. Also, above $\alpha \approx 70^\circ$, the flow would tend to separate in the cavity area, thus reducing the effect of the notches. On this basis, it was concluded that the peak in pitching moment from $35^\circ < \alpha < 65^\circ$ results from the notched face of the capsule.

$\alpha = 1^\circ$
Run No. 1
Model A
Reynolds No. 0.762×10^6

$\alpha = 6^\circ$
Run No. 1
Model A
Reynolds No. 0.753×10^6

$\alpha = 11^\circ$
Run No. 1
Model A
Reynolds No. 0.750×10^6

$\alpha = 16^\circ$
Run No. 1
Model A
Reynolds No. 0.747×10^6

$\alpha = 21^\circ$
Run No. 1
Model A
Reynolds No. 0.745×10^6

$\alpha = 25^\circ$
Run No. 5
Model A
Reynolds No. 0.761×10^6

Fig. 21. Shadowgraphs of the SNAP 19 Capsule at Mach 10

$\alpha = 30^\circ$
 Run No. 5
 Model A
 Reynolds No. 0.759×10^6

$\alpha = 35^\circ$
 Run No. 5
 Model A
 Reynolds No. 0.757×10^6

$\alpha = 40^\circ$
 Run No. 5
 Model A
 Reynolds No. 0.756×10^6

$\alpha = 45^\circ$
 Run No. 5
 Model A
 Reynolds No. 0.755×10^6

$\alpha = 50^\circ$
 Run No. 5
 Model A
 Reynolds No. 0.757×10^6

$\alpha = 53^\circ$
 Run No. 5
 Model A
 Reynolds No. 0.767×10^6

Fig. 21. (continued)

$\alpha = 66^\circ$
 Run No. 13
 Model B
 Reynolds No. 0.772×10^6

$\alpha = 71^\circ$
 Run No. 5
 Model B
 Reynolds No. 0.776×10^6

$\alpha = 76^\circ$
 Run No. 13
 Model B
 Reynolds No. 0.776×10^6

$\alpha = 81^\circ$
 Run No. 13
 Model B
 Reynolds No. 0.777×10^6

$\alpha = 86^\circ$
 Run No. 13
 Model B
 Reynolds No. 0.776×10^6

$\alpha = 90^\circ$
 Run No. 13
 Model B
 Reynolds No. 0.776×10^6

Fig. 21. (continued)

$\alpha = 37^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.747×10^6

$\alpha = 40^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.746×10^6

$\alpha = 45^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.746×10^6

$\alpha = 50^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.745×10^6

$\alpha = 55^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.746×10^6

$\alpha = 60^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.746×10^6

Fig. 22. Shadowgraphs of the Modified Capsule at Mach 10

$\alpha = 65^\circ$
 Run No. 18
 Model C
 Reynolds No. 0.745×10^6

$\alpha = 74^\circ$
 Run No. 17
 Model C
 Reynolds No. 0.755×10^6

$\alpha = 79^\circ$
 Run No. 17
 Model C
 Reynolds No. 0.753×10^6

$\alpha = 84^\circ$
 Run No. 17
 Model C
 Reynolds No. 0.753×10^6

$\alpha = 89^\circ$
 Run No. 17
 Model C
 Reynolds No. 0.751×10^6

Fig. 22. (continued)

Fig. 23. Comparison of Shock Patterns for Notch and Smooth Faced Capsules

Fig. 23. (continued)

Fig. 23. (continued)

Fig. 24. Sketch of Probable Flow Patterns for Notch and Smooth Faced Capsules

Fig. 25. Pressure Variation Along Vertical Centerline of Capsule Face for Angle of Attack of 50°

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VII. CONCLUSIONS

On the basis of the test results presented in this report, the following conclusions are made:

- (1) The test objectives originally set forth were fulfilled in that forces and moments were measured in the continuum flow regime, and the effects of the notches in the capsule face were determined.
- (2) In the range tested, Reynolds number effects were negligible.
- (3) Although the Newtonian theory could be used for estimating the forces on the capsule, it was concluded that experimental results should be used for more refined values.
- (4) The pitching moment about the capsule center could not be determined theoretically, and therefore must be determined experimentally.
- (5) Comparison of test data on a scaled SNAP 19 capsule test at very low Reynolds number with these test results indicated that variation of the pitching moment about the capsule center with Reynolds number is negligible.
- (6) In both the low Reynolds number test and this test, representing the transition and continuum regimes, respectively, the results indicated two stable trim points. The more stable trim point was at 90° , indicating that, with respect to static stability, the capsule should seek the 90° trim.

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VIII. REFERENCES

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