123/67
10 cep

HAS 113

MARTIN
MARIETTA

MARTIN COMPANY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

C-92A Systems for Nuclear
Auxiliary Power (SNAP)
-Isotopic SNAP Program
M-3679 (46th Ed.)

CONST. PLACES

Fig. 1300, MN. 65

DISTRIBUTION OF HEAT AND PRESSURE
ON THE SNAP 19 FUEL CAPSULE IN
HYPERSONIC FLOW

MND-3607-93 (Vae 1)

March 1967

Volume I
of
Two Volumes

LEGAL NOTICE

This report was prepared as an account of government sponsored work. Neither the United States nor the Commission nor any person acting on behalf of the Commission makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness or usefulness of the information contained in this report, or that the use of any information, apparatus, method or process disclosed in this report may not infringe upon privately owned rights or that the use of any information apparatus method or process disclosed in this report may not infringe upon the rights of any person acting on behalf of the Commission. Includes any employee or contractor of the Commission or employee of such contractor, to the extent that such employee or contractor of the Commission or employee of such contractor prepares, with the Commission or his employment with such contractor.

Prepared by: W. Lambert
and
T. Coughlin

Approved by:

H/S Nickel, Jr.
H/S Nickel, Jr.

John J. Jicha, Jr.
J. Jicha, Jr.

J. L. Powell, Jr.
J. L. Powell, Jr.

Martin Marietta Corporation
Baltimore, Maryland 21203

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

MARTIN MARIETTA CORPORATION

Baltimore,
Maryland
21203

June 19, 1967

Refer to: 3607-1053
ABB:845

U. S. Atomic Energy Commission
P. O. Box 5400
Albuquerque Operations Office
Albuquerque, New Mexico 87115

Attention: Mr. L. W. Otski
Area Manager

Subject: Contract AT(30-1)-3607, Submittal of Contractual
Data

Reference: (a) Martin Marietta Specification MN-10225
Contractor Delivery Requirements List

(b) Martin Marietta Letter 3607-999 dated
22 May 1967

Enclosure: (1) Revised pages 12 and 13 to MND 3607-93
Pressure and Heat Distribution Test Report (U)

Gentlemen:

1. Enclosure (1) is herewith submitted to the C-92a distribution requirements for insertion in MND 3607-93, which was submitted in accordance with reference (a), item 35, by reference (b). Enclosure (1) should be inserted in MND 3607-93 replacing the present like-numbered pages.

2. Should you have any questions concerning the contents of this letter or the enclosure, please contact Mr. J. Jicha at Phone No. 687-3800 (Area Code 301) Extension 9103.

Very truly yours,

MARTIN MARIETTA CORPORATION

A. B. Baikauskas
Contract Administrator
Nuclear Division

HMCK: t

Page 2

Refer to: 3607-1053

C-92a Distribution

cc: Mr. R. Luikens - Sandia - w/o encl.

can be seen, the greatest radial variation in pressure coefficient occurs in the range $25^\circ < \alpha < 70^\circ$, and is significantly higher over the leeward radius. Figure 17 of Reference 2 presents the capsule moment coefficient, both theoretical (incorporated with previous test data on a flat face cylinder) and present test data, as a function of attack angle. In the same range of angle of attack where the wide spread of data occurred in the pressure test, the force test data greatly exceeded theoretical expectations, again indicating that the contoured face effects on capsule aerodynamics increase markedly in this range of α . This same diametrical pressure distribution is presented in Figure 70 in such a manner that it can be compared to Figure 71 (extracted from Reference 3, which is a similar plot for the flat face of a cylinder at $M = 8$). There is no agreement between the two whatsoever, again indicating the significance of the recesses. In Appendix A a discussion of the flow across the recessed face of the fuel capsule and that across a flat face explains the differences between Figure 70 and Figure 71.

The results of the hypersonic heat distribution tests are presented in Figures 72 through 203. Data from thermocouple (T.C.) 41 was considered non-valid after comparisons with neighboring thermocouples, and noting its lack of response to various tunnel conditions. This thermocouple was later found to be inadequately attached. The data obtained at the higher angles of attack for T.C. 49 and T.C. 50 were also questionable due to the lack of trend consistency at the pressures tested. No explanation is available for this occurrence but it must be assumed that the thermocouple installations at these points were deficient.

The non-dimensional heat transfer rate (the capsule heating characteristic presented in Figures 72 through 203) is the ratio of the local capsule heat transfer rate to the stagnation point heat transfer rate of a 1-foot-radius sphere at tunnel flow conditions and having a wall temperature of 540°R . The local heat transfer rates are calculated from the thermocouple data using the digital program described in Appendix C. Each local heating rate is presented in the program output also in Appendix C. The stagnation point heating rate of the sphere is obtained from the following equation, Reference 4:

$$(1) \quad \dot{q}_{o(\text{sphere})} = 0.94 (\rho\mu)_w^{0.1} (\rho'\mu')_o^{0.4} C (T_o - T_w) \cdot$$

$$\left[\frac{1}{r} \left\{ 2\bar{R}T_o' \left(\frac{1 - P_1'}{P_0'} \right) \right\}^{0.5} \right]^{0.5} g$$

Calculation of $\dot{q}_{o(\text{sphere})}$ for a specific condition (including data sources) is presented in Appendix C, and the results for the 31 run conditions are listed in Table IV. The condensed version of this equation presented in Reference 3

$$(2) \quad \dot{q}_{o(\text{sphere})} = \frac{17600}{\sqrt{r}} \left(\frac{\rho_{\infty}}{\rho_{S.L.}} \right)^{0.5} \left(\frac{V_{\infty}}{26,000} \right)^{3.15}$$

was originally intended for use in the sphere calculation but it did not produce results in agreement with those from Equation (1) and the measured test data, therefore it was not used. A possible reason for this disagreement is that Equation (2) is based on assumptions valid for atmospheric re-entry conditions which may not be valid for forced flow because of dissociation effects and others.

Figures 72 through 137 present the local non-dimensional heating rate versus angle of attack for each thermocouple. In the first 25 of these plots, which represent data from the thermocouples on the end cap of the capsule, the maximum heating rate is in the 40° to 50° angle of attack range. Here the closest theoretical approximation to determining heat transfer rates is for a flat disk. With appropriate shape factors and size relationships, the ratio for a theoretical disk should vary smoothly from 1.55 at $\alpha = 0^\circ$ to zero at $\alpha = 90^\circ$. For thermocouple 1, located in the center of the end cap (Figure 72), the test curve differs markedly from the flat face theoretical values. At $\alpha = 0^\circ$ the recessed surface is farther from the shock wave than a flat face would have been and the heat transfer rate is therefore reduced. At $\alpha = 40^\circ$ the heat transfer rate is drastically increased because the flow tends to enter the recess; a similar effect was previously observed in force model tests of the capsule. Finally, near $\alpha = 90^\circ$ the heat transfer rate approaches zero as expected.

Figures 97 through 137 are representative of the thermocouples on the sleeve of the capsule. Thermocouple 51, located at the midpoint of the capsule sleeve and at $\theta = 0^\circ$ (Figure 121), shows close correlation between theoretical and experimental results. At $\alpha = 0^\circ$ the heat transfer ratio is near zero and smoothly approaches the theoretical stagnation point ideal of 2.0 at $\alpha = 90^\circ$. The theoretical stagnation point ideal is again obtained by applying shape factors and size relationships.

As in the pressure tests the variances of the non-dimensional heating with total pressure was less on the sleeve than on the end cap.

All of the heating rate data is available from Figures 72 through 137 but, as in the pressure data presentation, Figures 138 through 168 present the data in a different manner. For a given $\bar{X}/L$ the non-dimensional heating rate is plotted versus meridian angle. Thermocouple 41 has been removed from this presentation as have T.C. 49 and T.C. 50, where applicable. These 31 plots, each representing a specific tunnel configuration, present the data for the sleeve of the capsule.

Figures 169 through 199 present the heat transfer data for a given meridian angle on the end cap of the capsule versus radial distance from the centerline. Each page represents a certain tunnel configuration with the six plots per page each depicting one of the six test meridians.

FOREWORD

This report presents the results of the SNAP 19 fuel capsule hypersonic pressure and heat distribution testing at a Mach number of 10 in the Continuous Flow Hypersonic Tunnel at the Langley Research Center, Langley Field, Virginia. It was prepared under United States Atomic Energy Commission Contract AT(30-1)-3607 and covers Item 2(b) of the Proposed Experimental Program for SNAP 19 dated January 1966.

SUMMARY

Hypersonic pressure and heat transfer rate distribution tests on the SNAP 19 fuel capsule were conducted in the NASA Langley Research Center 31-inch Continuous Flow Hypersonic Tunnel. The dual objectives of the test program were to obtain experimental pressure data and to determine heat transfer rates to support theoretical methods of predicting the reentry behavior of the fuel capsule. Both objectives were achieved with data being ascertained for a nominal Mach number of 10, Reynolds number range of 0.5×10^6 to 1.7×10^6 per foot, and over an angle of attack of 0° to 90° .

Two full-scale fuel capsule models were utilized, one for obtaining pressure data, and the other for obtaining the temperature histories necessary in finding heat transfer rates. The pressure model was constructed of stainless steel, and was instrumented with forty-eight pressure sensors. The heat transfer model was thin shell Inconel construction, and was instrumented with sixty-seven thermocouples flush with the outside of the shell.

In the pressure tests significant effects of the recessed face on capsule aerodynamics were noted. Comparison of the test data to previous test data for a flat-faced cylinder, including theoretical corrections for the recessions, showed differences in the angle of attack range $25^\circ < \alpha < 70^\circ$. The present results correlate with the findings of force model tests (Ref. 2) which produced a capsule pitching moment above theoretical expectations for the range $25^\circ < \alpha < 70^\circ$. A correlation between the pressure on the face of the capsule and shadowgraphs taken during the force model testing explain this increase in pressure in terms of the flow characteristics. Outside of this α range the pressure coefficient at the center of the capsule face closely approached the modified Newtonian values ($1.84 \cos^2 \alpha$).

On the barrel of the capsule the windward-side pressure coefficient variation with angle of attack closely approached the modified Newtonian value of $1.84 \sin^2 \alpha$ throughout the 90° range of α . Along the barrel of the capsule, for a given meridian angle, the pressure coefficient was relatively flat, as expected, and increased as the angle of attack increased.

The effect of Reynolds number variations on pressure coefficient was seen to be negligible.

In the heat transfer tests there was generally good agreement between test data and the theory. Results were in good agreement with the basic Fay-Riddell equation for stagnation heating.

On the face of the capsule the experimental results differed from theoretical expectations. When comparing the test results with the theory associated with a flat disk, the $25^\circ < \alpha < 70^\circ$ range again was the region of most significant difference. The local non-dimensional heat transfer

ratio, which is the ratio of local heating rate to the stagnation heating rate of a 1-foot radius sphere, at the center of the recessed face had a lower than expected value at $\alpha = 0^\circ$, reached a maximum value at $\alpha = 40^\circ$, and approached zero at $\alpha = 90^\circ$. The theoretical curve for a flat face has a value of 1.55 for $\alpha = 0^\circ$ and decays smoothly to zero at $\alpha = 90^\circ$. A possible explanation for the lower initial value is the increased distance from the shock due to the recession, and the drastically increased heating rate over the mid-range of α is explained by the flow characteristics in the recession area.

At the midpoint of the capsule barrel, when it faced the flow, the non-dimensional heat transfer ratio closely approached the theoretical values of zero at $\alpha = 0^\circ$ and two at $\alpha = 90^\circ$, varying smoothly between these extremes.

As in the pressure tests the variation of Reynolds number had little effect on the non-dimensional heating rate.

The experimental non-dimensional pressure coefficient was determined with an accuracy of approximately 1% while the non-dimensional heat transfer rate is accurate to approximately 3%. Heat transfer data reproducibility was demonstrated in two test runs at nominally duplicate tunnel conditions; quantitative differences averaged less than 3%.

TABLE OF CONTENTS

	Page
LEGAL NOTICE	ii
FOREWORD	iii
SUMMARY	iv
TABLE OF CONTENTS	vi
LIST OF TABLES	vii
LIST OF FIGURES	viii
SYMBOLS AND DEFINITIONS	xxiii
I. INTRODUCTION	1
II. FACILITY DESCRIPTION	3
III. MODEL DESCRIPTION AND INSTRUMENTATION	5
IV. TEST PROCEDURE	7
V. ACCURACY OF DATA	10
VI. DATA PRESENTATION AND DISCUSSION	11
VII. CONCLUSIONS	15
VIII. REFERENCES	16
TABLES	17-21
FIGURES	22-224
APPENDIX A - CORRELATION OF PRESSURE TEST RESULTS WITH SHADOWGRAPHS FROM FORCE MODEL TESTS.	A-1
APPENDIX B - LANGLEY RESEARCH CENTER HYPERSONIC PRESSURES DIGITAL PROGRAM RESULTS.	B-1
APPENDIX C - LANGLEY RESEARCH CENTER HYPERSONIC HEATING RATE DIGITAL PROGRAM	C-1

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
I	Physical Properties of Models	18
II	SNAP 19 Fuel Capsule Hypersonic Pressures Run Schedule	19
III	SNAP 19 Fuel Capsule Hypersonic Heating Rates Run Schedule	20
IV	Stagnation Point Heating Rates of a 1-Foot-Radius Sphere for Tunnel Flow Conditions and a 540° R Wall Temperature	21

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Schematic Diagram of the Langley Continuous-Flow Hypersonic Tunnel	22
2	Tunnel Operating Conditions - M, To, Core.	23
3	Tunnel Operating Pressure Conditions	24
4	Tunnel Installation	25
5	Pressure Model Instrumentation.	26
6	Heat Rate Model Instrumentation	27
7	SNAP 19 Capsule Full Scale Pressure Model Drawing	28
8	SNAP 19 Full Scale Heat Distribution Model Drawing	29
9	Sting and Adapter Drawing	30
10	Model Installation at the Langley Facility.	31
11	Model Installation With the 30° Wedge Fairing in Place	32
12	Pressure Coefficient Along the Capsule Barrel, Run No: 19, $P_o = 1205$ psia, $\alpha = 0$ deg., $Re = 1.53 \times 10^6$ /ft.	33
13	Pressure Coefficient Along the Capsule Barrel, Run No: 20, $P_o = 1205$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 1.55 \times 10^6$ /ft.	34
14	Pressure Coefficient Along the Capsule Barrel, Run No: 22, $P_o = 1204$ psia, $\alpha = 15$ deg., $Re = 1.55 \times 10^6$ /ft.	35
15	Pressure Coefficient Along the Capsule Barrel, Run No: 23, $P_o = 1204$ psia, $\alpha = 25$ deg., $Re = 1.55 \times 10^6$ /ft.	36
16	Pressure Coefficient Along the Capsule Barrel, Run No: 24, $P_o = 1205$ psia, $\alpha = 40$ deg., $Re = 1.54 \times 10^6$ /ft.	37
17	Pressure Coefficient Along the Capsule Barrel, Run No. 38: $P_o = 1206$ psia, $\alpha = 50$ deg., $Re = 1.55 \times 10^6$ /ft.	38

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
18	Pressure Coefficient Along the Capsule Barrel, Run No: 39, $P_o = 1197$ psia, $\alpha = 65$ deg., $Re = 1.55 \times 10^6$ /ft.	39
19	Pressure Coefficient Along the Capsule Barrel, Run No: 40, $P_o = 1197$ psia, $\alpha = 80$ deg., $Re = 1.54 \times 10^6$ /ft.	40
20	Pressure Coefficient Along the Capsule Barrel, Run No: 41, $P_o = 1197$ psia, $\alpha = 90$ deg., $Re = 1.52 \times 10^6$ /ft.	41
21	Pressure Coefficient Along the Capsule Barrel, Run No: 25, $P_o = 753$ psia, $\alpha = 0$ deg., $Re = 1.03 \times 10^6$ /ft.	42
22	Pressure Coefficient Along the Capsule Barrel, Run No: 26, $P_o = 753$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 1.00 \times 10^6$ /ft.	43
23	Pressure Coefficient Along the Capsule Barrel, Run No: 29, $P_o = 756$ psia, $\alpha = 15$ deg., $Re = 0.94 \times 10^6$ /ft.	44
24	Pressure Coefficient Along the Capsule Barrel, Run No: 30, $P_o = 755$ psia, $\alpha = 25$ deg., $Re = 1.00 \times 10^6$ /ft.	45
25	Pressure Coefficient Along the Capsule Barrel, Run No: 28, $P_o = 753$ psia, $\alpha = 40$ deg., $Re = 0.96 \times 10^6$ /ft.	46
26	Pressure Coefficient Along the Capsule Barrel, Run No: 42, $P_o = 758$ psia, $\alpha = 50$ deg., $Re = 0.96 \times 10^6$ /ft.	47
27	Pressure Coefficient Along the Capsule Barrel, Run No: 43, $P_o = 760$ psia, $\alpha = 65$ deg., $Re = 1.00 \times 10^6$ /ft.	48
28	Pressure Coefficient Along the Capsule Barrel, Run No: 44, $P_o = 754$ psia, $\alpha = 80$ deg., $Re = 0.98 \times 10^6$ /ft.	49
29	Pressure Coefficient Along the Capsule Barrel, Run No: 45, $P_o = 754$ psia, $\alpha = 90$ deg., $Re = 0.99 \times 10^6$ /ft.	50

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
30	Pressure Coefficient Along the Capsule Barrel, Run No: 31, $P_o = 499$ psia, $\alpha = 0$ deg., $Re = 0.67 \times 10^6$ /ft.	51
31	Pressure Coefficient Along the Capsule Barrel, Run No: 33, $P_o = 499$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 0.66 \times 10^6$ /ft.	52
32	Pressure Coefficient Along the Capsule Barrel, Run No: 34, $P_o = 499$ psia, $\alpha = 15$ deg., $Re = 0.66 \times 10^6$ /ft.	53
33	Pressure Coefficient Along the Capsule Barrel, Run No: 35, $P_o = 499$ psia, $\alpha = 25$ deg., $Re = 0.67 \times 10^6$ /ft.	54
34	Pressure Coefficient Along the Capsule Barrel, Run No: 36, $P_o = 498$ psia, $\alpha = 40$ deg., $Re = 0.67 \times 10^6$ /ft.	55
35	Pressure Coefficient Along the Capsule Barrel, Run No: 46, $P_o = 498$ psia, $\alpha = 50$ deg., $Re = 0.66 \times 10^6$ /ft.	56
36	Pressure Coefficient Along the Capsule Barrel, Run No: 47, $P_o = 499$ psia, $\alpha = 65$ deg., $Re = 0.66 \times 10^6$ /ft.	57
37	Pressure Coefficient Along the Capsule Barrel, Run No: 48, $P_o = 504$ psia, $\alpha = 80$ deg., $Re = 0.67 \times 10^6$ /ft.	58
38	Pressure Coefficient Along the Capsule Barrel, Run No: 49, $P_o = 504$ psia, $\alpha = 90$ deg., $Re = 0.67 \times 10^6$ /ft.	59
39	Pressure Coefficient On The Capsule Face, Run No: 19, $P_o = 1205$ psia, $\alpha = 0$ deg., $Re = 1.53 \times 10^6$ /ft.	60
40	Pressure Coefficient On the Capsule Face, Run No: 20, $P_o = 1205$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 1.55 \times 10^6$ /ft.	61
41	Pressure Coefficient On The Capsule Face, Run No: 22, $P_o = 1204$ psia, $\alpha = 15$ deg., $Re = 1.56 \times 10^6$ /ft.	62

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
42	Pressure Coefficient On The Capsule Face, Run No: 23, $P_o = 1204$ psia, $\alpha = 25$ deg., $Re = 1.55 \times 10^6$ /ft.	63
43	Pressure Coefficient On The Capsule Face, Run No: 24, $P_o = 1205$ psia, $\alpha = 40$ deg., $Re = 1.54 \times 10^6$ /ft.	64
44	Pressure Coefficient On The Capsule Face, Run No: 38, $P_o = 1206$ psia, $\alpha = 50$ deg., $Re = 1.55 \times 10^6$ /ft.	65
45	Pressure Coefficient On The Capsule Face, Run No: 39, $P_o = 1197$ psia, $\alpha = 65$ deg., $Re = 1.55 \times 10^6$ /ft.	66
46	Pressure Coefficient On The Capsule Face, Run No: 40, $P_o = 1197$ psia, $\alpha = 80$ deg., $Re = 1.54 \times 10^6$ /ft.	67
47	Pressure Coefficient On The Capsule Face, Run No: 41, $P_o = 1197$ psia, $\alpha = 90$ deg., $Re = 1.52 \times 10^6$ /ft.	68
48	Pressure Coefficient On The Capsule Face, Run No: 25, $P_o = 753$ psia, $\alpha = 0$ deg., $Re = 1.03 \times 10^6$ /ft.	69
49	Pressure Coefficient On The Capsule Face, Run No: 26, $P_o = 753$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 1.00 \times 10^6$ /ft.	70
50	Pressure Coefficient On The Capsule Face, Run No: 29, $P_o = 756$ psia, $\alpha = 15$ deg., $Re = 0.94 \times 10^6$ /ft.	71
51	Pressure Coefficient On The Capsule Face, Run No: 30, $P_o = 755$ psia, $\alpha = 25$ deg., $Re = 1.00 \times 10^6$ /ft.	72
52	Pressure Coefficient On the Capsule Face, Run No: 28, $P_o = 753$ psia, $\alpha = 40$ deg., $Re = 0.96 \times 10^6$ /ft.	73
53	Pressure Coefficient On The Capsule Face, Run No: 42, $P_o = 758$ psia, $\alpha = 50$ deg., $Re = 0.96 \times 10^6$ /ft.	74
54	Pressure Coefficient On The Capsule Face, Run No: 43, $P_o = 760$ psia, $\alpha = 65$ deg., $Re = 1.00 \times 10^6$ /ft.	75

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
55	Pressure Coefficient On The Capsule Face, Run No: 44, $P_o = 754$ psia, $\alpha = 80$ deg., $Re = 0.98 \times 10^6$ /ft.	76
56	Pressure Coefficient On The Capsule Face, Run No: 45, $P_o = 754$ psia, $\alpha = 90$ deg., $Re = 0.99 \times 10^6$ /ft.	77
57	Pressure Coefficient On The Capsule Face, Run No: 31, $P_o = 499$ psia, $\alpha = 0$ deg., $Re = 0.67 \times 10^6$ /ft.	78
58	Pressure Coefficient On The Capsule Face, Run No: 33, $P_o = 499$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 0.66 \times 10^6$ /ft.	79
59	Pressure Coefficient On The Capsule Face, Run No: 34, $P_o = 499$ psia, $\alpha = 15$ deg., $Re = 0.66 \times 10^6$ /ft.	80
60	Pressure Coefficient On The Capsule Face, Run No: 35, $P_o = 499$ psia, $\alpha = 25$ deg., $Re = 0.67 \times 10^6$ /ft.	81
61	Pressure Coefficient On The Capsule Face, Run No: 36, $P_o = 498$ psia, $\alpha = 40$ deg., $Re = 0.67 \times 10^6$ /ft.	82
62	Pressure Coefficient On The Capsule Face, Run No: 46, $P_o = 498$ psia, $\alpha = 50$ deg., $Re = 0.66 \times 10^6$ /ft.	83
63	Pressure Coefficient On The Capsule Face, Run No: 47, $P_o = 499$ psia, $\alpha = 65$ deg., $Re = 0.66 \times 10^6$ /ft.	84
64	Pressure Coefficient On The Capsule Face, Run No: 48, $P_o = 504$ psia, $\alpha = 80$ deg., $Re = 0.67 \times 10^6$ /ft.	85
65	Pressure Coefficient On The Capsule Face, Run No: 49, $P_o = 504$ psia, $\alpha = 90$ deg., $Re = 0.67 \times 10^6$ /ft.	86
66	Variation of Pressure Coefficient With Angle of Attack for Two Significant Orifices, Numbers 1 and 38.	87

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
67	Pressure Coefficient Along the Barrel at $\theta = 0^\circ$ and $P_0 = 1200$ psia	88
68	Pressure Coefficient On the Face at $\theta = -5^\circ$, and $P_0 = 1200$ psia vs Angle of Attack	89
69	Pressure Coefficient On the Face at $\theta = 175^\circ$, and $P_0 = 1200$ psia vs Angle of Attack	90
70	Pressure Coefficient On the Face Along the Diameter $\theta = -5^\circ$ and 175° for All Angles of Attack, $P_0 = 1200$ psia	91
71	Flat Face Pressure Distribution Along the 0° , 180° Meridians (Reference 3).	92
72	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 1	93
73	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 2	94
74	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 3	95
75	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 4	96
76	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 5	97
77	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 6	98
78	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 7	99
79	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 8	100
80	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 9	101
81	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 10	102
82	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 11	103

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
83	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 12	104
84	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 13	105
85	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 14	106
86	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 15	107
87	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 16	108
88	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 17	109
89	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 18	110
90	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 19	111
91	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 20	112
92	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 21	113
93	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 22	114
94	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 23	115
95	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 24	116
96	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 25	117
97	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 26	118
98	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 27	119
99	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 28	120

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
100	Non Dimensional Rate vs Angle of Attack for Thermocouple 29	121
101	Non Dimensional Rate vs Angle of Attack for Thermocouple 30	122
102	Non Dimensional Rate vs Angle of Attack for Thermocouple 31	123
103	Non Dimensional Rate vs Angle of Attack for Thermocouple 32	124
104	Non Dimensional Rate vs Angle of Attack for Thermocouple 33	125
105	Non Dimensional Rate vs Angle of Attack for Thermocouple 34	126
106	Non Dimensional Rate vs Angle of Attack for Thermocouple 35	127
107	Non Dimensional Rate vs Angle of Attack for Thermocouple 36	128
108	Non Dimensional Rate vs Angle of Attack for Thermocouple 37	129
109	Non Dimensional Rate vs Angle of Attack for Thermocouple 38	130
110	Non Dimensional Rate vs Angle of Attack for Thermocouple 39	131
111	Non Dimensional Rate vs Angle of Attack for Thermocouple 40	132
112	Non Dimensional Rate vs Angle of Attack for Thermocouple 42	133
113	Non Dimensional Rate vs Angle of Attack for Thermocouple 43	134
114	Non Dimensional Rate vs Angle of Attack for Thermocouple 44	135
115	Non Dimensional Rate vs Angle of Attack for Thermocouple 45	136
116	Non Dimensional Rate vs Angle of Attack for Thermocouple 46	137

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
117	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 47	138
118	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 48	139
119	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 49	140
120	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 50	141
121	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 51	142
122	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 52	143
123	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 53	144
124	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 54	145
125	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 55	146
126	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 56	147
127	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 57	148
128	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 58	149
129	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 59	150
130	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 60	151
131	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 61	152
132	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 62	153

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
133	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 63	154
134	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 64	155
135	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 65	156
136	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 66	157
137	Non Dimensional Heating Rate vs Angle of Attack for Thermocouple 67	158
138	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 50, $P_o = 1205$ psia, $\alpha = 0$ deg., $Re = 1.58 \times 10^6$ /ft.	159
139	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 51, $P_o = 1207$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 1.63 \times 10^6$ /ft.	160
140	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 52, $P_o = 1207$ psia, $\alpha = 15$ deg., $Re = 1.63 \times 10^6$ /ft.	161
141	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 53, $P_o = 1206$ psia, $\alpha = 25$ deg., $Re = 1.62 \times 10^6$ /ft.	162
142	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 55, $P_o = 1203$ psia, $\alpha = 32 \frac{1}{2}$ deg., $Re = 1.61 \times 10^6$ /ft.	163
143	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 54, $P_o = 1207$ psia, $\alpha = 40$ deg., $Re = 1.62 \times 10^6$ /ft.	164
144	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 69, $P_o = 1204$ psia, $\alpha = 50$ deg., $Re = 1.55 \times 10^6$ /ft.	165
145	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 70, $P_o = 1200$ psia, $\alpha = 65$ deg., $Re = 1.57 \times 10^6$ /ft.	166

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
146	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 81, $P_O = 1004$ psia, $\alpha = 80$ deg., $Re = 1.42 \times 10^6$ /ft.	167
147	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 80, $P_O = 1006$ psia, $\alpha = 90$ deg., $Re = 1.38 \times 10^6$ /ft.	168
148	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 56, $P_O = 755$ psia, $\alpha = 0$ deg., $Re = 0.99 \times 10^6$ /ft.	169
149	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 57, $P_O = 756$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 1.03 \times 10^6$ /ft.	170
150	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 58, $P_O = 756$ psia, $\alpha = 15$ deg., $Re = 1.03 \times 10^6$ /ft.	171
151	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 59, $P_O = 756$ psia, $\alpha = 25$ deg., $Re = 1.04 \times 10^6$ /ft.	172
152	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 60, $P_O = 755$ psia, $\alpha = 32 \frac{1}{2}$ deg., $Re = 1.00 \times 10^6$ /ft.	173
153	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 61, $P_O = 756$ psia, $\alpha = 40$ deg., $Re = 1.00 \times 10^6$ /ft.	174
154	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 72, $P_O = 754$ psia, $\alpha = 50$ deg., $Re = 1.02 \times 10^6$ /ft.	175
155	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 73, $P_O = 754$ psia, $\alpha = 65$ deg., $Re = 1.02 \times 10^6$ /ft.	176
156	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 82, $P_O = 794$ psia, $\alpha = 80$ deg., $Re = 1.24 \times 10^6$ /ft.	177
157	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 79, $P_O = 767$ psia, $\alpha = 90$ deg., $Re = 0.97 \times 10^6$ /ft.	178

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
158	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 62, $P_O = 501$ psia, $\alpha = 0$ deg., $Re = 0.68 \times 10^6$ /ft.	179
159	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 63, $P_O = 501$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 0.68 \times 10^6$ /ft.	180
160	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 64, $P_O = 501$ psia, $\alpha = 15$ deg., $Re = 0.68 \times 10^6$ /ft.	181
161	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 65, $P_O = 500$ psia, $\alpha = 25$ deg., $Re = 0.68 \times 10^6$ /ft.	182
162	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 66, $P_O = 501$ psia, $\alpha = 32 \frac{1}{2}$ deg., $Re = 0.67 \times 10^6$ /ft.	183
163	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 86, $P_O = 497$ psia, $\alpha = 40$ deg., $Re = 0.72 \times 10^6$ /ft.	184
164	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 87, $P_O = 515$ psia, $\alpha = 40$ deg., $Re = 0.69 \times 10^6$ /ft.	185
165	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 74, $P_O = 503$ psia, $\alpha = 50$ deg., $Re = 0.65 \times 10^6$ /ft.	186
166	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 85, $P_O = 493$ psia, $\alpha = 65$ deg., $Re = 0.67 \times 10^6$ /ft.	187
167	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 83, $P_O = 520$ psia, $\alpha = 80$ deg., $Re = 0.68 \times 10^6$ /ft.	188
168	Non Dimensional Heating Rate Along the Barrel of the Capsule, Run No: 84, $P_O = 532$ psia, $\alpha = 90$ deg., $Re = 0.73 \times 10^6$ /ft.	189
169	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 50, $P_O = 1205$ psia, $\alpha = 0$ deg., $Re = 1.58 \times 10^6$ /ft.	190

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
170	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 51, $P_o = 1207$ psia, $\alpha = 7\ 1/2$ deg., $Re = 1.63 \times 10^6$ /ft.	191
171	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 52, $P_o = 1207$ psia, $\alpha = 15$ deg., $Re = 1.63 \times 10^6$ /ft.	192
172	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 53, $P_o = 1206$ psia, $\alpha = 25$ deg., $Re = 1.62 \times 10^6$ /ft.	193
173	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 55, $P_o = 1203$ psia, $\alpha = 32\ 1/2$ deg., $Re = 1.61 \times 10^6$ /ft.	194
174	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 54, $P_o = 1207$ psia, $\alpha = 40$ deg., $Re = 1.62 \times 10^6$ /ft.	195
175	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 69, $P_o = 1204$ psia, $\alpha = 50$ deg., $Re = 1.55 \times 10^6$ /ft.	196
176	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 70, $P_o = 1200$ psia, $\alpha = 65$ deg., $Re = 1.57 \times 10^6$ /ft.	197
177	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 81, $P_o = 1004$ psia, $\alpha = 80$ deg., $Re = 1.42 \times 10^6$ /ft.	198
178	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 80, $P_o = 1006$ psia, $\alpha = 90$ deg., $Re = 1.38 \times 10^6$ /ft.	199
179	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 56, $P_o = 755$ psia, $\alpha = 0$ deg., $Re = 0.99 \times 10^6$ /ft.	200
180	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 57, $P_o = 756$ psia, $\alpha = 7\ 1/2$ deg., $Re = 1.03 \times 10^6$ /ft.	201
181	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 58, $P_o = 756$ psia, $\alpha = 15$ deg., $Re = 1.03 \times 10^6$ /ft.	202

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
182	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 59, $P_o = 756$ psia, $\alpha = 25$ deg., $Re = 1.04 \times 10^6$ /ft.	203
183	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 60, $P_o = 755$ psia, $\alpha = 32 \frac{1}{2}$ deg., $Re = 1.00 \times 10^6$ /ft.	204
184	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 61, $P_o = 756$ psia, $\alpha = 40$ deg., $Re = 1.00 \times 10^6$ /ft.	205
185	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 72, $P_o = 753$ psia, $\alpha = 50$ deg., $Re = 1.02 \times 10^6$ /ft.	206
186	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 73, $P_o = 754$ psia, $\alpha = 65$ deg., $Re = 1.02 \times 10^6$ /ft.	207
187	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 82, $P_o = 794$ psia, $\alpha = 80$ deg., $Re = 1.24 \times 10^6$ /ft.	208
188	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 79, $P_o = 767$ psia, $\alpha = 90$ deg., $Re = 0.97 \times 10^6$ /ft.	209
189	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 62, $P_o = 501$ psia, $\alpha = 0$ deg., $Re = 0.68 \times 10^6$ /ft.	210
190	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 63, $P_o = 501$ psia, $\alpha = 7 \frac{1}{2}$ deg., $Re = 0.68 \times 10^6$ /ft.	211
191	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 64, $P_o = 501$ psia, $\alpha = 15$ deg., $Re = 0.68 \times 10^6$ /ft.	212
192	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 65, $P_o = 500$ psia, $\alpha = 25$ deg., $Re = 0.68 \times 10^6$ /ft.	213
193	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 66, $P_o = 501$ psia, $\alpha = 32 \frac{1}{2}$ deg., $Re = 0.67 \times 10^6$ /ft.	214

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
194	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 86, $P_o = 497$ psia, $\alpha = 40$ deg., $Re = 0.72 \times 10^6/\text{ft.}$	215
195	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 87, $P_o = 515$ psia, $\alpha = 40$ deg., $Re = 0.69 \times 10^6/\text{ft.}$	216
196	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 74, $P_o = 503$ psia, $\alpha = 50$ deg., $Re = 0.65 \times 10^6/\text{ft.}$	217
197	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 85, $P_o = 493$ psia, $\alpha = 65$ deg., $Re = 0.67 \times 10^6/\text{ft.}$	218
198	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 83, $P_o = 520$ psia, $\alpha = 80$ deg., $Re = 0.68 \times 10^6/\text{ft.}$	219
199	Non Dimensional Heating Rate Across the Face of the Capsule, Run No: 84, $P_o = 532$ psia, $\alpha = 90$ deg., $Re = 0.73 \times 10^6/\text{ft.}$	220
200	Comparison of Experimental Heating Rate with Theoretical Results for Thermocouple 51 ($X/L = 0.5$, $\theta = 0^\circ$)	221
201	Heat Flux Distribution on the Barrel for $\alpha = 90^\circ$ and $P_o = 750$ psia, $Re = 0.99 \times 10^6/\text{ft.}$	222
202	Non Dimensional Heating Rate Along the Barrel at $\theta = 0^\circ$ and $P_o = 1200$ psia, $Re = 1.5 \times 10^6/\text{ft.}$	223
203	Non Dimensional Heating Rate Across the Face on the Diameter $\theta = -3.5^\circ$ and 176.5° for All Angles of Attack, $P_o = 1200$ psia, $Re = 1.5 \times 10^6/\text{ft.}$	224

SYMBOLS AND DEFINITIONS

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
α	Angle of attack relative to axial centerline of model	deg.
a	Speed of sound	ft. /sec.
C_p	Pressure coefficient, $(P_L - P_\infty)/q$	---
C	Specific heat at constant pressure	Btu/lb. ° F
δ	Model wall thickness	in.
g	Acceleration of gravity	$\frac{\text{ft.}}{\text{sec.}^2}$
h	Heat Transfer coefficient, $\dot{q}/(T_o - T_w)$	$\frac{\text{BTU}}{\text{sec. ft.}^2 \text{ } ^\circ \text{ F}}$
K	Thermal conductivity	BTU/hr. ft. 2 ° F /ft.
L	Axial length of model	in.
M	Mach number	---
μ	Viscosity, coefficient of	lb. /ft. sec.
N_{st}	Stanton number	---
P	Pressure	psi
P_L/P_t	Ratio of local pressure to total pressure	---
q	Dynamic pressure	psi
$\dot{q}$	Heat transfer rate	$\frac{\text{BTU}}{\text{ft.}^2 \text{ sec.}}$
R	Radius of model	in.
$\bar{R}$	Universal gas constant	ft. 2 /sec. 2 ° R
Re	Reynolds number per foot	ft. $^{-1}$
$Re(R)$	Reynolds number based on (R)	---
r	Radius (in general)	ft.

SYMBOLS AND DEFINITIONS (Contd)

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
ρ	Density	$\frac{\text{lb.}}{\text{ft.}^3}$
T	Absolute temperature	$^{\circ}\text{R}$
t	Time	sec.
T.C.	Thermocouple	---
V	Tunnel gas velocity	$\frac{\text{ft.}}{\text{sec.}}$
X	Axial distance along model from fwd. edge	in.
Y	Radial distance to a point on the model face from axial centerline	in.
θ	Radial angle on the body, positive direction is counterclockwise in front view, zero is at the bottom of the model	deg.

SUBSCRIPTS AND SUPERSSCRIPTS

<u>Symbol</u>	<u>Description</u>
i	Run number
L	Local conditions
m	Model parameters
o	Stagnation conditions
S. L.	Sea level
t	Total condition
w	Model wall conditions
x	Number assigned to a particular orifice or thermocouple
∞	Free stream conditions
1	Conditions prior to normal shock
'	Condition behind a normal shock

I. INTRODUCTION

The SNAP 19 radioisotope fueled thermoelectric power supply 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 reentry of the fuel capsule are required.

Calculations performed at Martin Marietta 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 reentry emphasized the need for an accurate description of the aerodynamic and aerothermodynamic properties of all systems and subsystems housing the fuel.

The aerodynamic and burn-up analyses of the SNAP 19 RTG mounted in the Nimbus B spacecraft involve various configurations (the spacecraft, the generators, 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 spacecraft.

The fuel capsule was designed to withstand impact during a launch abort, which does not subject the power supply to high rates of aerodynamic heating. During normal reentry, however, the capsule is subjected to high heating rates which are dependent upon motion and average attitude with respect to the velocity vector.

These characteristics are determined by the aerodynamics and the flight path parameters, and will vary as the capsule passes through the various flow regimes from free molecular to continuum flow. Existing hypersonic test data needed to accurately predict these characteristics were very limited, and consequently a series of tests was planned to substantiate theoretical estimates.

As part of this test plan, fuel capsule pressure and heat transfer tests were conducted in the Continuous Flow Hypersonic Tunnel at Langley Research Center, Langley Field, Virginia. These tests were conducted at a nominal Mach number of 10 and Reynolds number per foot range of 0.5×10^6 to 1.7×10^6 . Pressure and heat transfer data were obtained for an angle of attack range of 0° to 90° . The pressures obtained in this test program are to be integrated to determine aerodynamic coefficients and used as the inviscid base for making the corrections due to viscous interactions. The heat transfer rate distributions are to be used to determine

appropriate surface averaging factors (as indicated by the flight motions) for use in the thermal analysis to determine capsule reentry and fuel release parameters.

This report presents the results of hypersonic pressure distribution tests performed July 13-18, 1966, and hypersonic heating distribution tests performed July 20-22, 1966.

II. FACILITY DESCRIPTION

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

A flow diagram of the system is shown in Figure 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 $M = 10$), expands through the rectangular nozzle, and passes through the 31-inch square test section, diffuser, and cooler, into the vacuum sphere. The tunnel is then transferred to the compressors for continuous operation by using shutoff valves to cut off the bottle field and vacuum sphere from the circuit.

In Figure 1 the starting circuit is shown by thin arrows and the continuous flow circuit by the heavy arrows. The tunnel, heaters, and aftercooler are shown across the middle of this figure; the blowdown circuit with 900 cu. ft. of air at 2500 psia, and a 40-foot vacuum sphere are indicated at the top of the figure, and the continuous flow path is in the lower half of the figure.

For Mach 10 five compressors are used developing an overall pressure ratio of 375:1. 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. Examples of operating conditions are as follows:

Mach number	10 - 12
Stagnation pressure	15 to 100 atm.
Stagnation temperature	1400° F (Mach 10) - 1900° F (Mach 12)
Reynolds number per foot	0.5×10^6 to 1.7×10^6 ft. ⁻¹

Variations in tunnel operating conditions are plotted in Figures 2 and 3.

The 31-inch square test section is normally equipped with two fused quartz windows for optical viewing. However, when a cooling chamber and retractable side panel are used, as in this test, one window is removed to accommodate the installation. In this optional arrangement the cooling chamber is adjacent to the test section as shown in Figure 4. A sliding

door separates the cooling chamber from the test section when the model is not under test. The model and sting were mounted to the panel such that the model could be injected into the tunnel core to obtain test data, and retracted from the hot stream between tests. Injection into the core took approximately 1 second while retraction time was 5 to 7 seconds.

In the heat transfer test it was necessary to cool the model to a uniform temperature near 100° F before each run. This was accomplished using an air jet system in the cooling chamber. The angle of attack was continuously controllable over the 90° range by a pneumatic system which rotated the panel and attached model.

The tunnel instrumentation for both tests is discussed in the next chapter of this report.

All hypersonic tunnel components are stainless-clad, water-cooled sections using a closed circuit distilled water system operated at 150 psi. The contoured nozzle is constructed of beryllium copper and is cooled by a separate distilled water system operating at 1500 psi.

III. MODEL DESCRIPTION AND INSTRUMENTATION

Two full scale models of the fuel capsule were required for these tests; one for measuring pressures and the other for measuring heat transfer rates.

The pressure model was constructed of type 321 stainless steel with 48 monel tubes (.083-inch O.D.) installed for pressure measurements. The face of each tube was flush with the surface at the orifice locations shown in Figure 5.

The heat transfer model had a .030-inch shell constructed of Inconel X-750 with Inconel -600 end caps. Chromel-alumel thermocouples were welded flush with the surface of the shell at the 67 locations shown in Figure 6.

Detailed drawings of the pressure model, heat transfer model, and sting-adaptor are reproduced in Figures 7, 8, and 9, respectively. In Table I the physical properties of both models are presented.

The instrumentation associated with the two tests is described in the following paragraphs.

Immediately outside of the tunnel test section the 48 pressure tubes were separated into four bundles of 12 each, and each bundle was routed into Datex SP-101 12-point rotary selector valves. Each scanner valve, at the test conductor's selection, allows 1 of the 12 pressures to be sensed by three transducers connected in parallel. Three transducers were employed due to the expected range of pressures and accuracy required over this range. An Alphatron, radiation type transducer was used for pressures less than 30 mm Hg. Above 30 mm Hg two strain gage type transducers were available, one for 0-3 psia and the other for 3-10 psia. The data in the form of four electrical signals were transmitted to the data center, separate from the test facility, and changed to voltage ratios which were referenced to a predetermined value. These conditioned signals were then sent back to the test facility where they were displayed visually on a Sanborn recorder. The purpose of this recorder was to assure the test conductor that steady state conditions were attained prior to the initiation of data acquisition. When steady state conditions were observed information from the four channels on the recorder was transmitted to the data center as input to a digital program used in obtaining the desired format of results. This procedure was then repeated with each of the valves set to monitor a different orifice.

In the heat transfer tests the 67 thermocouple wires were connected to a junction panel, in the immediate vicinity of the tunnel test section, where they joined standard tunnel instrumentation. From the junction panel the 67 leads, larger in cross-section than the thermocouple wires, entered a 125° F controlled reference temperature area. The electrical output of

each of the thermocouples was transmitted to the data center where the 67 signals were conditioned and changed to voltage ratios based on pre-determined reference voltage. The conditioned signals were then transmitted back to the test facility where they were viewed on a Beckman 210 system console, which has the capability of handling 99 analog and 21 digital channels.

Whereas in the pressure tests only 4 of the 48 orifices were sampled and the results displayed by the instrumentation at one time, all 67 of the thermocouples were sampled and the results displayed simultaneously.

IV. TEST PROCEDURE

Hypersonic pressure and heating distributions on the fuel capsule were obtained by injecting the full-scale capsule models into the tunnel flow at incremental angles of attack from 0° (flat face normal to airstream) to 90° . These tests were performed for three tunnel total pressures: 500, 750, and 1200 psia. A more significant selection of incidence angles than those selected in early test planning, Reference 1, was made based on the results of the capsule force tests, Reference 2. The test sequence is shown in the run schedules of Tables II and III.

Prior to the tunnel testing, the instrumentation of both models was checked to insure that all sensors, 67 temperature and 48 pressure, were indicating properly. The thermocouples and their recording devices were tested by immersing the model in hot water and noting that all data channels responded and approximately indicated the uniformity of the heat distribution. The pressure model was tested by subjecting each tube to a vacuum of 50 microns (abs.) for 30 seconds. Leakage was limited to pressure increases less than 50 microns.

Test procedures for both test series were similar. In the basic sequence the angle of attack was set with the model in the cooling chamber, the model was injected into the continuous flow, and the required measurements were made. Subsequently, the model was retracted into the cooling chamber and prepared for the next test run. However, the flow requirements and the tunnel capabilities were such that all runs could not be made using this exact procedure, and certain optional runs were shown to be unfeasible. Although difficulties in maintaining hypersonic flow conditions were anticipated, a sequence of runs was tentatively planned at a total tunnel pressure of 250 psia. These tests were abandoned when hypersonic flow could not be maintained with the model in the tunnel.

For those model attitudes at which the frontal area presented to the airstream created significant tunnel blockage, the disturbance of the tunnel wall boundary layer during injection caused the tunnel to break flow (hypersonic conditions could not be maintained) and a different injection procedure had to be devised, as explained later in this text.

Pressure tests were made at nine angles of attack, 0° , $7\frac{1}{2}^\circ$, 15° , 25° , 40° , 50° , 65° , 80° , and 90° at the three obtainable pressures for a total of 27 runs. For the smaller angles of attack, 50° and less, it was possible to set the model to the desired angle while in the cooling chamber. For those angles above 50° the model was injected at a setting near 0° and rotated in the core of the tunnel to the desired angle, thus minimizing the blockage and disturbances associated with high incidence injection. A photograph of the model in a test position in the core of the tunnel is shown in Figure 10.

Acquisition of data was initiated only when the four pressures monitored on Sanborn recorders indicated that steady-state conditions had been reached in the pressure lines. Due to the low free-stream pressures an appreciable amount of time, on the order of 30 seconds, was necessary for stabilization. The data were recorded on magnetic tape at a data center separated from the wind tunnel and later were passed through a standard data reduction computer program at the Langley complex.

Heat transfer tests were scheduled at the same angles of attack as in the pressure tests. However, visual monitoring of the 67 thermocouple readings, displayed on the Beckman data conditioning console, indicated a sharp increase in the heating rates on the forward face of the capsule at angles of attack from 25° to 40° . An intermediate test at 32.5° angle of attack was therefore added to the run schedule to decrease the interval between data points in the range, making a total of ten angles of attack which were tested at each of the three pressure conditions. A duplicate run was made at 40° angle of attack and 500 psia total pressure, at the request of tunnel personnel, making a total of 31 runs.

As in the pressure tests, the smaller angles of attack ($\alpha = 40^\circ$ and less for 1200 and 750 psia, $\alpha = 32.5^\circ$ and less for 500 psia) presented no problems of breaking flow upon injection. The angles of attack were established while the model was in the cooling chamber, the model was injected into the tunnel, the data were acquired, and the model was retracted for cooling prior to another run. The method employed in the pressure tests to avoid the problem of blocking and disturbances resulting from injection at high incidence angles could not be used due to the length of time the model would have been exposed to the hypersonic flow. The thin shell of the heat transfer model would have responded too quickly to the high temperature for valid test measurements to be made after this added exposure time. An attempt was made to reduce the disturbances during injection by placing a 30° wedge fairing on the sting to reduce blockage effects (Figure 11). In order that more than one run could be made at a given fairing position, the wedge was set at an angle to the flow which was a compromise of two or more test angles. With the fairing at a 55° angle to the model axis, this method was successful in obtaining data for 50° and 65° angles of attack at the 750 psia and 1200 psia total pressures, and the 50° angle for 500 psia total pressure. At 90° angle of attack and 1200 psia total pressure the hypersonic conditions were broken on injection, with the fairing at 90° , and another means of obtaining higher incident angle conditions was needed.

To increase the capability of injection without interrupting flow, a higher pressure ratio across the expansion nozzle and test section was required. The mode of operation of the tunnel was changed from continuous recirculating flow to an extended blowdown configuration in which the compressors were exhausted to the atmosphere. This arrangement was unsatisfactory; flow conditions were broken on the initial injection, and no data runs were made.

To obtain an even higher pressure ratio the facility operation was further modified to a straight blowdown into the vacuum sphere. This permitted approximately 40 seconds of operation time which was in excess of the few seconds needed for injection and data acquisition. Successful injection was made with the fairing in place and the remainder of the runs (80° and 90° incidence for the three pressures, 40° and 65° angles for the 500 psia, and the duplicate of the 40° angle at 500 psia) were made.

With the exception of the thermocouple visual monitor and three channels of pressure information, all data were transmitted directly to the data center. These data were recorded on magnetic tape for future processing through standard data reduction programs.

Model pressures were recorded, after stabilization, along with the necessary tunnel flow parameters for the computer program to yield the pressure coefficient at each orifice. The tabulated output of the computer program is presented, with further explanation, in Appendix B.

Thermocouple data from the heat transfer model were acquired with samples taken at 50 millisecond intervals. The method of least squares was used in a digitally programmed curve-fitting technique to calculate the best line through the temperature-time data for each thermocouple. From this line the heating rate and standard and maximum deviations of temperature were obtained and recorded as part of the digital program output.

Calculations for the best fairings and resulting heating rates were based on a 1-second data sample (21 points from each thermocouple). The best 1-second period in each run was selected by a test engineer, based on his review of the data in plotted form. In general the time period was correlated to the most linear portion of the data from the most active thermocouples.

In the standard LRC computer program, the calculations were repeated for the next 1-second period immediately after the primary data sample. This second set of results is included in the computer program output reproduced in Appendix C; however, it is of little interest in this test program. Corrections for conduction and radiation effects are partially based on these quantities in other programs.

The computer program for continuous flow heat transfer was limited to homogeneous models, but as mentioned in the preceding chapter of this report, the heat transfer model end caps were of a different material with slightly different thermal properties than the sleeve (Table I). Compensation for this difference was made by inputting only the heat transfer properties of the sleeve material, and analytically adjusting the end cap thickness (also a program input) such that the results were those of the non-homogeneous model. A more detailed description of this program, with the necessary inputs, appears in Appendix C of this report.

V. ACCURACY OF DATA

Previous calibrations of the wind tunnel facility indicate the variation of Mach number across the test section is reasonably flat. The accuracy of Mach number for a given test point in this series was considered to be within $\pm .02$ of the tabulated value. The angle of attack could be set within $.05^\circ$ of the desired value.

The accuracy of the stagnation temperature was $+ 2^\circ \text{ F}$ from 0° F to 530° F and $+ 3/8\%$ from 530° F to 2300° F . The stagnation pressure was considered to be accurate within $1/10$ of 1% . The recording devices for both of these measurements were accurate to within 5 parts in 8000 for both the heat and pressure tests.

The thermocouple wire was accurate within $+ 2^\circ \text{ F}$ for 0° F - 530° F and within $+ 3/8\%$ of the temperature above 530° F . The thermocouple reference junction was within $\pm 1/2^\circ \text{ F}$ of 125° F .

The accuracy of the pressure transducers was:

1 to 5 mm Hg. absolute	5% of indication
5 to 30 mm Hg. absolute	2% of indication
30 mm to 3 psi	.015 psi
above 3 psi	.035 psi

The maximum local pressure was 3.83 psia with an accuracy associated with the transducer of .035 psia in this range, and negligible error in the recording device. This yields pressure data with an accuracy of approximately 1% .

The non-dimensional heat transfer rates, although not as accurate as the pressure data due to the intermediate operations necessary in transforming the temperature histories into heating rates, are accurate within 3% .

The one attempt to duplicate a heat transfer test condition ($\alpha = 40^\circ$, $P_o = 500 \text{ psia}$) yielded excellent agreement between the two sets of data. The analogous figures for the two tests are Figures 163 and 164, and Figures 194 and 195. Differences in the data are not noticeable except for two samples from Thermocouple No. 6; average differences are less than 3% .

VI. DATA PRESENTATION AND DISCUSSION

Most of the data graphs were plotted on the Benson-Lehner S. T. E. plotter using multiple graphs on the same abscissa while offsetting the multiple ordinates. Care should be exercised when reading the data; the graph symbol is noted at the origin of the corresponding ordinate.

The results of the hypersonic pressure tests are presented in Figures 12 through 70. Examination of the data obtained from the 48 orifices indicate that all pressure channels performed properly.

In Figures 12 through 38 the pressure coefficients, defined as $C_p = (P_L - P_\infty)/q$, for a given X/L , are plotted versus meridian angle (θ) for each of the five positions along the capsule. These 27 plots, each representing a certain run, yield the C_p at each of the 26 orifices along the sleeve of the capsule for all test conditions.

Figures 39 through 65 present the pressure coefficient for a given meridian angle on the end cap of the capsule versus radial distance from the centerline (Y/R) for each of the 6 meridian angles. The 27 plots render the C_p at each of the 22 orifices on the end cap for all conditions.

While all the pressure test data are available in Figures 12 through 65, Figures 66 through 70 present certain data in a somewhat different manner. Figure 66 shows the variation of pressure coefficient with angle of attack for two significant orifices. The pressure coefficient data for the curved capsule surface, orifice 38, closely approaches the modified Newtonian ideal of $1.84 \sin^2 \alpha$. Orifice 1 located at the center of the recessed end cap is seen to differ markedly from the modified Newtonian ideal of $1.84 \cos^2 \alpha$ in the 25° to 70° range of angle of attack. This difference is an indication of the effect the recess has on capsule aerodynamics.

Another significance of this figure is the unvarying pressure coefficient with Reynolds number (total pressure). Having shown the magnitude of data scatter with varying Reynolds number to be small, the succeeding three figures present only one of the three total pressures.

Figure 67 shows the pressure coefficient profile along the sleeve of the capsule on the windward side. No peculiarities are observed; the profile is symmetric at $\alpha = 90^\circ$ as expected, and the magnitude changes regularly with the angle of attack.

In Figures 68 and 69 the pressure coefficient across the facial diameter 5° from the vertical (i. e., $\theta = -5^\circ$ and 175°) is shown as a function of angle of attack. Neglecting the data at $Y/R = .954$ where the edge effects

can be seen, the greatest radial variation in pressure coefficient occurs in the range $25^\circ < \alpha < 70^\circ$, and is significantly higher over the leeward radius. Figure 17 of Reference 2 presents the capsule moment coefficient, both theoretical (incorporated with previous test data on a flat face cylinder) and present test data, as a function of attack angle. In the same range of angle of attack where the wide spread of data occurred in the pressure test, the force test data greatly exceeded theoretical expectations, again indicating that the contoured face effects on capsule aerodynamics increase markedly in this range of α . This same diametrical pressure distribution is presented in Figure 70 in such a manner that it can be compared to Figure 71 (extracted from Reference 3, which is a similar plot for the flat face of a cylinder at $M = 8$). There is no agreement between the two whatsoever, again indicating the significance of the recesses. In Appendix A a discussion of the flow across the recessed face of the fuel capsule and that across a flat face explains the differences between Figure 70 and Figure 71.

The results of the hypersonic heat distribution tests are presented in Figures 72 through 203. Data from thermocouple (T.C.) 41 was considered non-valid after comparisons with neighboring thermocouples, and noting its lack of response to various tunnel conditions. This thermocouple was later found to be inadequately attached. The data obtained at the higher angles of attack for T.C. 49 and T.C. 50 were also questionable due to the lack of trend consistency at the pressures tested. No explanation is available for this occurrence but it must be assumed that the thermocouple installations at these points were deficient.

The non-dimensional heat transfer rate (the capsule heating characteristic presented in Figures 72 through 203) is the ratio of the local capsule heat transfer rate to the stagnation point heat transfer rate of a 1-foot-radius sphere at tunnel flow conditions and having a wall temperature of 540°R . The local heat transfer rates are calculated from the thermocouple data using the digital program described in Appendix C. Each local heating rate is presented in the program output also in Appendix C. The stagnation point heating rate of the sphere is obtained from the following equation, Reference 4:

$$(1) \quad \dot{q}_{o(\text{sphere})} = 0.94 (\rho\mu)_w^{0.1} (\rho'\mu')_o^{0.4} C (T_o - T_w)$$

$$\frac{1}{r} \left[2\bar{R}T_o' \left(\frac{1 - P_1'}{P_0'} \right)^{0.5} \right]^{0.5} g$$

Calculation of $\dot{q}_{o(\text{sphere})}$ for a specific condition (including data sources) is presented in Appendix C, and the results for the 31 run conditions are listed in Table IV. The condensed version of this equation presented in Reference 3

$$(2) \quad \dot{q}_{o(\text{sphere})} = \frac{17600}{r} \left(\frac{\rho}{\rho_{S.L.}} \right)^{0.5} \left(\frac{V_{\infty}}{26,000} \right)^{3.15}$$

was originally intended for use in the sphere calculation but it did not produce results in agreement with those from Equation (1) and the measured test data, therefore it was not used. A possible reason for this disagreement is that Equation (2) is based on assumptions valid for atmospheric re-entry conditions which may not be valid for forced flow because of dissociation effects and others.

Figures 72 through 137 present the local non-dimensional heating rate versus angle of attack for each thermocouple. In the first 25 of these plots, which represent data from the thermocouples on the end cap of the capsule, the maximum heating rate is in the 40° to 50° angle of attack range. Here the closest theoretical approximation to determining heat transfer rates is for a flat disk. With appropriate shape factors and size relationships, the ratio for a theoretical disk should vary smoothly from 1.55 at $\alpha = 0^\circ$ to zero at $\alpha = 90^\circ$. For thermocouple 1, located in the center of the end cap (Figure 72), the test curve differs markedly from the flat face theoretical values. At $\alpha = 0^\circ$ the recessed surface is farther from the shock wave than a flat face would have been and the heat transfer rate is therefore reduced. At $\alpha = 40^\circ$ the heat transfer rate is drastically increased because the flow tends to enter the recess; a similar effect was previously observed in force model tests of the capsule. Finally, near $\alpha = 90^\circ$ the heat transfer rate approaches zero as expected.

Figures 97 through 137 are representative of the thermocouples on the sleeve of the capsule. Thermocouple 51, located at the midpoint of the capsule sleeve and at $\theta = 0^\circ$ (Figure 121), shows close correlation between theoretical and experimental results. At $\alpha = 0^\circ$ the heat transfer ratio is near zero and smoothly approaches the theoretical stagnation point ideal of 2.0 at $\alpha = 90^\circ$. The theoretical stagnation point ideal is again obtained by applying shape factors and size relationships.

As in the pressure tests the variances of the non-dimensional heating with total pressure was less on the sleeve than on the end cap.

All of the heating rate data is available from Figures 72 through 137 but, as in the pressure data presentation, Figures 138 through 168 present the data in a different manner. For a given X/L the non-dimensional heating rate is plotted versus meridian angle. Thermocouple 41 has been removed from this presentation as have T.C. 49 and T.C. 50, where applicable. These 31 plots, each representing a specific tunnel configuration, present the data for the sleeve of the capsule.

Figures 169 through 199 present the heat transfer data for a given meridian angle on the end cap of the capsule versus radial distance from the centerline. Each page represents a certain tunnel configuration with the six plots per page each depicting one of the six test meridians.

Figures 200 through 203 are representative plots which are shown either because a correlation with theory is possible or as a more illustrative way of presenting the data. Figure 200 shows a correlation between the heating rate at $X/L = 0.5$, $\theta = 0^\circ$, and the theory for an infinite cylinder, Reference 5. There is good agreement between the test and theory from 0° to approximately 45° angles of attack, but for angles above this the test data for the three pressures are lower than the theoretical curve.

Figure 201 is another theoretical comparison. The theoretical curve, Reference 5, is representative of the heat rate distribution around the circumference of an infinitely long cylinder. The data are plotted for six of the available seven X/L 's; $X/L = .258$ was not plotted because T.C. 41 was the reference thermocouple ($\theta = 0^\circ$). Theoretical agreement with each of the X/L 's shown was fair when realizing that end effects contribute to the results. Averaging the data for a given meridian angle over the length of the capsule produced results in excellent agreement with the theory.

Figure 202 presents the non-dimensional heating rate versus the windward capsule length, ($\theta = 0^\circ$). Over the midportion of the capsule the heating rate is fairly smooth. The small deviations in this area may be due to local conduction, or slight physical peculiarities such as internal weld beads which might be noted if the capsule were to be dissected. At the 90° angle of attack condition, the heating rate at $X/L = .984$ is approximately twice that at $X/L = .016$. The profile was expected to be symmetric, and a possible reason for its non-symmetry might be sting interference affecting the heating rate at $X/L = .984$.

Figure 203 is the heating profile analogous to the pressure profile of Figure 70. Without going into detail for each curve, the effects of the recessed end cap can be immediately seen by the many abrupt changes of heating rate across the diameter for a given angle of attack.

The ability to reconstruct the data at a tunnel flow condition can be seen by a comparison between Figures 163 and 164, and between Figures 194 and 195, the analogous figures for the one duplication of tunnel flow conditions ($\alpha = 40^\circ$, $P_0 = 500$ psia). The agreement is excellent.

VII. CONCLUSIONS

The test objectives were fulfilled in that fuel capsule hypersonic pressure and heat transfer rates were determined for a Reynolds number range of 0.5×10^6 to 1.7×10^6 per foot, and over an angle of attack range of 0° to 90° .

In the pressure tests significant effects of the recessed capsule face were observed which were not predictable by theoretical calculations. The results did, however, agree with, and help explain, the results obtained in force model testing. The deviation from expectation was most marked in the $25^\circ < \alpha < 70^\circ$ range.

The pressure coefficient at the center of the capsule face closely approached the modified Newtonian value of $1.84 \cos^2 \alpha$ at $\alpha = 0^\circ$, exceeded this value throughout the midrange of α , and approached zero as expected as α approached 90° .

On the barrel of the capsule the windward side pressure coefficient variation with angle of attack closely approached the modified Newtonian value ($1.84 \sin^2 \alpha$) throughout the 90° range of α .

Along the capsule sleeve at a given meridian angle the pressure coefficient was relatively flat as expected, and on the windward side increased with the angle of attack.

The pressure coefficient was relatively invariant with Reynolds number.

In the heat transfer tests there was generally good agreement between theory, where applicable, and experimental results.

The heat transfer rate on the face of the capsule peaked in the $40^\circ \leq \alpha \leq 50^\circ$ region, and showed a marked difference from flat face theory in the same $25^\circ < \alpha < 70^\circ$ range noted in the pressure tests. Outside of this range there was again good agreement between theory and experimental results.

On the midpoint of the capsule sleeve facing the flow, the non-dimensional heat transfer ratio was in close agreement with the theoretical expectations of zero at $\alpha = 0^\circ$ and two at $\alpha = 90^\circ$.

The non-dimensional heat transfer rate was relatively invariant with changes in Reynolds number.

VIII. REFERENCES

1. Lambert, W. , "Test Plan Report SNAP 19 Capsule Pressure and Heat Transfer - Mach 10," MND-3607-60R, February 1966, Revised May 1966 (U).
2. Stouffer, C. G. , "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.
3. Cullota, A. J. , Fernandex, I. , "RFD-2 Flight Test Program Supplementary Analysis Report," MND-3283, January 1966.
4. Fay, J. A. , Riddell, F. R. , Kemp, N. H. , "Stagnation Point Heat Transfer in Dissociated Air Flow," Jet Propulsion, June 1957.
5. Hags, W. , "SNAP Programs - Upper Atmosphere Experimental Reentry Study Final Summary Report," MND-P-2953, April 1966.

TABLES

TABLE I
Physical Properties of Models

Property	Heat Transfer Model		Pressure Model
	Inconel X-750 Sleeve	Inconel 600 End Cap	Cres Bar
Density (lb/in ³)	0.298	0.307	0.29
Specific heat (Btu/lb° F)	0.105 (32° -212° F)	0.109 (77° -212° F)	0.12 (32° -212° F)
Conductivity (Btu/hr ft ² ° F/ft)	8.5 (32° -212° F)	8.6 (80° -212° F)	9.4 (212° F)
Mean linear coefficient of thermal expansion (in/in/° F)	6.7×10^{-6} (80° -200° F)	6.4×10^{-6} (68° -212° F)	9.2×10^{-6} (68° -212° F)
Melting range (° F)	2540-2600	2540	2500-2600

TABLE II

SNAP 19 Fuel Capsule Hypersonic Pressures Run Schedule

Run No.	Angle of Attack (deg.)	Stagnation		Reynolds No. per ft. (10^6 /ft.)	Mach Number
		Press. (psia)	Temp. (°R)		
19	0	1205	1795	1.53	10.46
20	7 1/2	1205	1785	1.55	10.46
22	15	1204	1780	1.56	10.46
23	25	1204	1785	1.55	10.46
24	40	1205	1790	1.54	10.46
25	0	753	1740	1.03	10.40
26	7 1/2	753	1760	1.00	10.40
28	40	753	1795	0.96	10.40
29	15	756	1820	0.94	10.40
30	25	755	1770	1.00	10.40
31	0	499	1760	0.67	10.33
33	7 1/2	499	1775	0.66	10.33
34	15	499	1775	0.66	10.33
35	25	499	1765	0.67	10.33
36	40	498	1770	0.67	10.33
38	50	1206	1785	1.55	10.46
39	65	1197	1780	1.55	10.46
40	80	1197	1790	1.54	10.46
41	90	1197	1795	1.52	10.46
42	50	758	1805	0.96	10.40
43	65	760	1770	1.00	10.40
44	80	754	1780	0.98	10.40
45	90	754	1785	0.99	10.40
46	50	498	1785	0.66	10.33
47	65	499	1785	0.66	10.33
48	80	504	1775	0.67	10.33
49	90	504	1780	0.67	10.33

TABLE III

SNAP 19 Fuel Capsule Hypersonic Heating Rates Run Schedule

Run No.	Angle of Attack (deg.)	Stagnation		Reynolds No. per ft. (10 ⁶ /ft.)	Mach Number
		Press. (psia)	Temp. (°R)		
50	0	1205	1783	1.582	10.46
51	7 1/2	1207	1758	1.630	10.46
52	15	1207	1756	1.633	10.46
53	25	1206	1761	1.623	10.46
54	40	1207	1762	1.622	10.46
55	32 1/2	1203	1767	1.608	10.46
56	0	755	1791	0.990	10.40
57	7 1/2	756	1758	1.028	10.40
58	15	756	1757	1.029	10.40
59	25	756	1746	1.042	10.40
60	32 1/2	755	1783	0.999	10.40
61	40	756	1785	0.996	10.40
62	0	501	1775	0.676	10.33
63	7 1/2	501	1775	0.676	10.33
64	15	501	1773	0.677	10.33
65	25	500	1773	0.676	10.33
66	32 1/2	501	1779	0.673	10.33
69	50	1204	1801	1.549	10.46
70	65	1200	1786	1.571	10.46
72	50	753	1761	1.019	10.40
73	65	754	1761	1.021	10.40
74	50	503	1795	0.652	10.40
79*	90	767	1820	0.974	10.40
80*	90	1006	1743	1.383	10.44
81*	80	1004	1717	1.422	10.44
82*	80	794	1641	1.236	10.40
83*	80	520	1803	0.678	10.34
84*	90	532	1761	0.727	10.34
85*	65	493	1770	0.669	10.33
86*	40	497	1707	0.724	10.33
87*	40	515	1785	0.685	10.34

*(Blowdown Operation)

TABLE IV

Stagnation Point Heating Rates of a 1-Foot Radius Sphere For
Tunnel Flow Conditions and a 540°R Wall Temperature

<u>Run Number</u>	<u>$\dot{q}_0(\text{sphere})(\text{BTU}/\text{ft.}^2\text{sec.})$</u>
50	5.189
51	5.086
52	5.077
53	5.097
54	5.104
55	5.115
56	4.169
57	4.059
58	4.055
59	4.018
60	4.141
61	4.150
62	3.393
63	3.390
64	3.388
65	3.385
66	3.405
69	5.265
70	5.190
72	4.062
73	4.064
74	3.398
79	4.301
80	4.599
81	4.489
82	3.754
83	3.530
84	3.450
85	3.353
86	3.192
87	3.459

FIGURES

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

Fig. 2. Tunnel Operating Conditions - M, T_0 , Core

(COPIED FROM BLACKSTOCK'S CURVE OF 3-66)

Fig. 3. Tunnel Operating Pressure Conditions

Fig. 4. Tunnel Installation

Fig. 5. Pressure Model Instrumentation

Fig. 6. Heat Rate Model Instrumentation

FIG. 7 SNAP 19 CAPSULE
FULL SCALE PRESSURE
MODEL DRAWING

[illegible]

Fig. 10: Model Installation At The Langley Facility

Fig. 11: Model Installation With 30° Wedge Fairing In Place

Fig-12
Run 19

FORM 800000
K-34
JANUARY 1964
NAVY

1-1

Fig. 12 Pressure Coefficient Along The Capsule Barrel, Run No: 19, $P_0 = 1205$ psia, $\alpha = 0$ deg., $Re = 1.53 \times 10^6/ft$

#20

fig 13

© 1964 KODAK SAFETY FILM

3-1

Fig. 13 Pressure Coefficient Along The Capsule Barrel, Run No: 20 , $P_0 = 1205$ psia, $\alpha = 7.5$ deg., $Re = 1.55 \times 10^6/ft$

34

Fig. 14 Pressure Coefficient Along The Capsule Barrel, Run No: 22, $P_0 = 1204$ psia, $\alpha = 15$ deg., $Re = 1.56 \times 10^6/ft$

Fig. 15 Pressure Coefficient Along The Capsule Barrel, Run No: 23, $P_0 = 1204$ psia, $\alpha = 25$ deg., $Re = 1.55 \times 10^6/ft$

24

Fig 16

REAR VIEW
 REAR ORIGINARY
 REAR ORIGINARY
 REAR ORIGINARY

9-1

Fig. 16 Pressure Coefficient Along The Capsule Barrel, Run No: 24 , $P_0 = 1205$ psia, $\alpha = 40$ deg., $Re = 1.54 \times 10^6/ft$

Fig. 18 Pressure Coefficient Along The Capsule Barrel, Run No: 39, $P_0 = 1197$ psia, $\alpha = 65$ deg., $Re = 1.55 \times 10^6/ft$

Fig. 19 Pressure Coefficient Along The Capsule Barrel, Run No: 40, $P_0 = 1197$ psia, $\alpha = 80$ deg., $Re = 1.54 \times 10^6/ft$

Fig. 20 Pressure Coefficient Along The Capsule Barrel, Run No: 41, $P_0 = 1197$ psia, $\alpha = 90$ deg., $Re = 1.52 \times 10^6/ft$

Fig 21

FORM 5-03000
REPLACES FORM 5-03000
1-64

11-1

Fig. 21 Pressure Coefficient Along The Capsule Barrel, Run No: 25, $P_0 = 753$ psia, $\alpha = 0$ deg., $Re = 1.03 \times 10^6/ft$

Fig 22

FORM 10-00000
K-2 ALBANY
ESSEX

13-1

Fig. 22 Pressure Coefficient Along The Capsule Barrel, Run No: 26 , $P_0 = 753$ psia, $\alpha = 7.5$ deg., $Re = 1.00 \times 10^6/ft$

Fig. 23 Pressure Coefficient Along The Capsule Barrel, Run No: 29 , $P_0 = 756$ psia, $\alpha = 15$ deg., $Re = 0.94 \times 10^6$ /ft

Fig. 24 Pressure Coefficient Along The Capsule Barrel, Run No: 30 , $P_o = 755$ psia, $\alpha = 25$ deg., $Re = 1.00 \times 10^6/ft$

Fig. 25 Pressure Coefficient Along The Capsule Barrel, Run No: 28, $P_0 = 753$ psia, $\alpha = 40$ deg., $Re = 0.96 \times 10^6$ /ft

Fig 26

FORM 03000 K&E ALBANY, N.Y. 12207

39-1

Fig. 26 Pressure Coefficient Along The Capsule Barrel, Run No: 42, $P_0 = 758$ psia, $\alpha = 50$ deg., $Re = 0.96 \times 10^6/ft$

Fig 27

Fig. 27 Pressure Coefficient Along The Capsule Barrel, Run No: 43 , $P_0 = 760$ psia, $\alpha = 65$ deg., $Re = 1.00 \times 10^6/ft$

Fig 28

REPORT MEMORANDUM
RESEARCH BRIGADE
NATIONAL BUREAU OF AERONAUTICS

43-1

Fig. 28 Pressure Coefficient Along The Capsule Barrel, Run No: 44, $P_o = 754$ psia, $\alpha = 80$ deg., $Re = 0.98 \times 10^6/ft$

Fig 29

FORM 9-00000 K&E ALUMINUM 3483

45-1

Fig. 29 Pressure Coefficient Along The Capsule Barrel, Run No: 45, $P_0 = 754$ psia, $\alpha = 90$ deg., $Re = 0.99 \times 10^6/ft$

Fig 30

FORM 8-00000 KE ALPHABETIC 2828

21-1

Fig. 30 Pressure Coefficient Along The Capsule Barrel, Run No: 31, $P_0 = 499$ psia, $\alpha = 0$ deg., $Re = 0.67 \times 10^6/ft$

Fig 31

FORM 00000
K&E
K&E
K&E

23-1

Fig. 31 Pressure Coefficient Along The Capsule Barrel, Run No: 33 , $P_0 = 499$ psia, $\alpha = 7.5$ deg., $Re = 0.66 \times 10^6/ft$

Fig 32

FORM 10-0000 H.E. ALBANY, N.Y. 12208

25-1

Fig. 32 Pressure Coefficient Along The Capsule Barrel, Run No: 34, $P_0 = 499$ psia, $\alpha = 15$ deg., $Re = 0.66 \times 10^6/ft$

fig 33

SEANTY 021212121212 050000 11 MRO7

27-1

Fig. 33 Pressure Coefficient Along The Capsule Barrel, Run No: 35, $P_0 = 499$ psia, $\alpha = 25$ deg., $Re = 0.67 \times 10^6/ft$

fig 34

FORM 8-00000
RESEARCH
NAVY

29-1

Fig. 34 Pressure Coefficient Along The Capsule Barrel, Run No: 36, $P_0 = 498$ psia, $\alpha = 40$ deg., $Re = 0.67 \times 10^6/ft$

Fig 35

REAR K&E FORM 010050

47-1

Fig. 35 Pressure Coefficient Along The Capsule Barrel, Run No: 46, $P_o = 498$ psia, $\alpha = 50$ deg., $Re = 0.66 \times 10^6/ft$

fig 36

FORM 4-00000
ALPHABETIC
LITHOGRAPH
2-55

49-1

Fig. 36 Pressure Coefficient Along The Capsule Barrel, Run No: 47, $P_0 = 499$ psia, $\alpha = 65$ deg., $Re = 0.66 \times 10^6/ft$

Fig 37

RESEARCH AIRCRAFT
K-15
L-10000

51-1

Fig. 37 Pressure Coefficient Along The Capsule Barrel, Run No: 48 , $P_0 = 504$ psia, $\alpha = 80$ deg., $Re = 0.67 \times 10^6/ft$

Fig. 38 Pressure Coefficient Along The Capsule Barrel, Run No: 49 , $P_0 = 504$ psia, $\alpha = 90$ deg., $Re = 0.67 \times 10^6$ /ft

Fig 39

CELEST 3-11 050010 4 MROV

1-1

Fig. 39. Pressure Coefficient On The Capsule Face, Run No: 19, P_o 1205 psia, $\alpha = 0$ deg., $Re = 1.53 \times 10^6/ft$

fig 40

FORM 100000
K-2
K-2
K-2

4-1

Fig. 40 Pressure Coefficient On The Capsule Face, Run No: 20 , P_0 1205 psia, $\alpha = 7.5$ deg., $Re = 1.55 \times 10^6/ft$

fig 41

© 1964 K&E ENGINEERING CO. 050000-0000

7-1

Fig. 41 Pressure Coefficient On The Capsule Face, Run No:22 , P_0 1204 psia, $\alpha = 15$ deg., $Re = 1.56 \times 10^6/ft$

fig 42

FORM 10-10050
K-E
ALUMINUM
REPAIR
TAPES

10-1

Fig. 42 Pressure Coefficient On The Capsule Face, Run No:23 , P_0 1204 psia, $\alpha = 25^\circ$, $Re = 1.55 \times 10^6/ft$

fig 43

FORM 600000
K.E. ALBRIGHT
JAN 64

13-1

Fig. 43 Pressure Coefficient On The Capsule Face, Run No:24 , P_0 1205 psia, $\alpha = 40$ deg., $Re = 1.54 \times 10^6/ft$

Fig 44

K-2 ALUMINUM
FORM 010030
JAN 64

46-1

Fig. 44 Pressure Coefficient On The Capsule Face, Run No: 38 , P_o 1206 psia, $\alpha = 50$ deg., $Re = 1.55 \times 10^6/ft$

fig 45

FORM 8-00000 K-2 JANUARY 1954

49-1

Fig. 45 Pressure Coefficient On The Capsule Face, Run No: 39 , P_0 1197 psia, $\alpha = 65$ deg., $Re = 1.55 \times 10^6/ft$

fig 46

CEAAT 234822 24 000000 11000

52-1

Fig. 46 Pressure Coefficient On The Capsule Face, Run No: 40 , P_0 1197 psia, $\alpha = 80$ deg., $Re = 1.54 \times 10^6/ft$

fig 47

55-1

Fig. 47 Pressure Coefficient On The Capsule Face, Run No: 41, P_0 1197 psia, $\alpha = 90$ deg., $Re = 1.52 \times 10^6/ft$

fig 48

FORM 8-03000 H-3 ALBANY, N.Y.

16-1

Fig. 48 Pressure Coefficient On The Capsule Face, Run No: 25 , P_0 753 psia, $\alpha = 0$ deg., $Re = 1.03 \times 10^6/ft$

Fig. 49 Pressure Coefficient On The Capsule Face, Run No: 26 , P_o 753 psia, $\alpha = 7.5$ deg., $Re = 1.00 \times 10^6$ /ft

fig 50

FORM 10-00000 1-10-54

25-1

Fig. 50 Pressure Coefficient On The Capsule Face, Run No: 29 , P_0 756 psia, $\alpha = 15$ deg., $Re = 0.94 \times 10^6/ft$

fig 51

FORM # 010020 K&E ENGINEERING LABORATORY

23-1

Fig. 51 Pressure Coefficient On The Capsule Face, Run No: 30 , P_o 755 psia, $\alpha = 25$ deg., $Re = 1.00 \times 10^6/ft$

Fig 52

FORM # 010030 K-E ALBANY, N.Y. 12207

22-1

Fig. 52 Pressure Coefficient On The Capsule Face, Run No: 28 , P_0 753 psia, $\alpha = 40$ deg., $Re = 0.96 \times 10^6/ft$

fig 53

GRAPH BY THE MARINE CORPS ENGINEERING SCHOOL

53-1

Fig. 53 Pressure Coefficient On The Capsule Face, Run No: 42 , P_o 758 psia, $\alpha = 50$ deg., $Re = 0.96 \times 10^6/ft$

fig 54

SECRET 3-11 050000 11001

61-1

Fig. 54 Pressure Coefficient On The Capsule Face, Run No: 43 , P_0 760 psia, $\alpha = 65$ deg., $Re = 1.00 \times 10^6/ft$

Fig. 55 Pressure Coefficient On The Capsule Face, Run No: 44 , P_0 754 psia, $\alpha = 80$. deg., $Re = 0.98 \times 10^6$ /ft

f1456

FORM 6-60000
SURFACE BATTERY

67-1

Fig. 56 Pressure Coefficient On The Capsule Face, Run No: 45 , P_o 754 psia, $\alpha = 90$ deg., $Re = 0.99 \times 10^6/ft$

fig 57

REAR © 1964 NASA 34 000000-1

31-1

Fig. 57 Pressure Coefficient On The Capsule Face, Run No: 31 , P_0 499 psia, $\alpha = 0$ deg., $Re = 0.67 \times 10^6/ft$

fig 58

RELAT. HUMIDITY 34-1

34-1

Fig. 58 Pressure Coefficient On The Capsule Face, Run No: 33 , P_0 499 psia, $\alpha = 7.5$ deg., $Re = 0.66 \times 10^6/ft$

fig 59

K-E ALBANY, N.Y. 12206

37-1

Fig. 59 Pressure Coefficient On The Capsule Face, Run No: 34 , P_0 499 psia, $\alpha = 15$ deg., $Re = 0.66 \times 10^6/ft$

Fig 60

FORM 8-50000 K2

40-1

Fig. 61 Pressure Coefficient On The Capsule Face, Run No: 36 , P_o 498 psia, $\alpha = 40$ deg., $Re = 0.67 \times 10^6/ft$

fig 62

FORM 400000-1 MROB
REPLACES FORM 400000-1
JAN 64

70-1

Fig. 62 Pressure Coefficient On The Capsule Face, Run No: 46 , P_o 498 psia, $\alpha = 50$ deg., $Re = 0.66 \times 10^6/ft$

fig 63

REPORT 34 000000-4 1000000

73-1

Fig. 63 Pressure Coefficient On The Capsule Face, Run No: 47, P_0 499 psia, $\alpha = 65^\circ$, $Re = 0.66 \times 10^6/ft$

fig 64

FORM # 00000 K-E ALUMINUM 7000

76-1

Fig. 64 Pressure Coefficient On The Capsule Face, Run No: 48 , P_0 504 psia, $\alpha = 80$ deg., $Re = 0.67 \times 10^6/ft$

Fig 65

FORM 10000-1
K&E ALUMINUM
TAPES

79-1

Fig. 65 Pressure Coefficient On The Capsule Face, Run No: 49 , P_0 504 psia, $\alpha = 90$ deg., $Re = 0.67 \times 10^6/ft$

Fig. 66 Variation of Pressure Coefficient With Angle of Attack for Two Significant Orifices, Numbers 1 and 38

Fig. 67 Pressure Coefficient Along the Barrel at $\theta = 0^\circ$ and $P_0 = 1200$ psia

Fig. 68 Pressure Coefficient on the Face at $\theta = -5^\circ$, and $P_o = 1200$ psia vs. Angle of Attack

Fig. 71 Flat Face Pressure Distribution Along the 0° , 180° Meridians (Reference 3)

fig 72

FORM NO. 000000
 K-1
 VERIFICATION
 000000

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Fig. 72 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 1

fig 73

RESEARCH
 REPORT
 68-1000

Fig. 73 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 2

Fig. 74 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 3

ROBERT ROSEN
JANUARY 1964
NEW YORK
NEW YORK

RESEARCH REPORT
 K-1
 RESEARCH REPORT
 K-1

Fig. 76 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 5

Fig. 77 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 6

fig 78

PHOTOGRAPH
K-2
REPRODUCED FROM
REPORT NO. 100

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Δ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Angle Of Attack, α (degrees)

Fig. 78 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 7

fig 79

NO. 5 010780
K.E. JENSEN
JANUARY 1968

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Δ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Angle Of Attack, α (degrees)

Fig. 79 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 8

Fig. 80 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 9

RESEARCH REPORT
 RESEARCH REPORT
 RESEARCH REPORT

Fig. 82 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 11

Fig 83

K&E
 AIRCRAFT
 ALIGNMENT
 1980

Non-Dimensional Heat Transfer Rate, $\dot{q}/q_0$ (sphere)

Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

Angle Of Attack, α (degrees)

Fig. 83 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 12

fig 84

GENERAL ELECTRIC
RESEARCH & DEVELOPMENT
DIVISION
Schenectady, New York

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

$\triangle$ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

Angle Of Attack, α (degrees)

Fig. 84 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 13

Fig. 85 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 14

fig 86

RESEARCH & DEVELOPMENT
K. E. JOHNSON
CORPORATION

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Δ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Angle of Attack, α (degrees)

Fig. 86 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 15

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

5
4
3
2
1
0

0

30

60

90

Angle Of Attack, α (degrees)

$\triangle$ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Fig. 87 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 16

fig 88

RESEARCH & ANALYSIS
K&M
PASCAGO, MISSISSIPPI

Fig. 88 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 17

Fig. 89 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 18

fig 90

 K&M
 LABORATORY
 1000 1000000

 Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

 Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

 Angle Of Attack, α (degrees)

Fig. 90 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 19

Fig 91

 K&E
 JACOBS DATA
 SYSTEMS
 08880

 Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Fig. 91 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 20

Fig 92

NON SOLID K-E
GENERAL AIRCRAFT
DIRECT

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

5
4
3
2
1
0

0

30

60

90

Angle of Attack, α (degrees)

Δ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Fig. 92 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 21

Fig 93

 K&E
 JETTING SYSTEMS
 15880

 Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

 Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

Fig. 93 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 22

fig 94

ORBITAL
K&E
RESEARCH & DEVELOPMENT
CORPORATION

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Fig. 94 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 23

fig 95

 KODAK SAFETY FILM
 KODAK SAFETY FILM
 KODAK SAFETY FILM

 Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

 Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

 Angle Of Attack, α (degrees)

Fig. 95 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 24

Fig. 96 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 25

fig 97

NO. 4 01050
K.E. JENNINGS
RESEARCH
CORP.

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Δ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Angle Of Attack, α (degrees)

Fig. 97 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 26

Fig 98

 FORM 8-010700
 K&E
 JANUARY 1970
 04280

 Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

 Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

Fig. 98 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 27

fig 100

RESEARCH
K.E. ENGINEERING
SERIES 1000

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Fig. 100 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 29

fig 102

K&E
 K&E ENGINEERING
 RESEARCH & DESIGN
 CORP.

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Fig. 102 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 31

Fig. 104 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 33

Fig. 105 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 34

Fig. 106 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 35

fig 107

DESOTO MFG CO
K&E
VERMONT
MADE IN U.S.A.
1988

Fig. 107 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 36

Fig 113

RESEARCH TRIANGLE INSTITUTE
 RESEARCH TRIANGLE INSTITUTE
 RESEARCH TRIANGLE INSTITUTE

Fig. 113 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 43

Fig. 114 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 44

Fig. 115 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 45

Fig 116

ORBITAL ENGINEERING
 241
 241
 241

Fig. 116 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 46

Fig. 119 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 49

Fig. 120 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 50

fig 123

Fig. 123 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 53

fig 125

RESEARCH
 DIVISION
 NATIONAL BUREAU OF STANDARDS
 WASHINGTON, D. C. 20535

Fig. 125 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 55

Fig. 126 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 56

RECEIVED
 NATIONAL AERONAUTICS
 AND SPACE ADMINISTRATION
 12/12/67

Fig. 127 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 57

Fig 128

© 1964 K. E. JENSEN
 K. E. JENSEN
 3000 N. 10TH AVE.
 DENVER, CO 80202

Fig. 128 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 58

Fig. 129 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 59

Fig 130

RESEARCH
K&E
OBSOLETE
MROV

Fig. 130 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 60

fig 131

 FORM 010550
 KE
 @31MABJJA
 17687

 Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

 Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

 Angle Of Attack, α (degrees)

Fig. 131 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 61

Fig 132

K&E
 K&E ENGINEERING
 1700 N. 17th St.
 Phoenix, AZ 85016

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

5

4

3

2

1

0

0

30

60

90

Angle Of Attack, α (degrees)

Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

Fig. 132 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 62

fig 133

ITCAY ©1975 MAGJIA DUBOITO MHO 3
KAM
REMA BRIGADY

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

5
4
3
2
1
0

0 30 60 90

Angle Of Attack, α (degrees)

Δ = 1200 psia
X = 750 psia
 $\square$ = 500 psia

Fig. 133 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 63

fig 134

1124X
 020724823-1
 2805070
 1124X

Fig. 134 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 64

Fig. 135 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 65

Fig. 136 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 66

fig. 137

HEAT © 1964 NASA
 K&E
 RESEARCH & ENGINEERING

Non-Dimensional Heat Transfer Rate, $\dot{q}/\dot{q}_0$ (sphere)

Δ = 1200 psia
 $\times$ = 750 psia
 $\square$ = 500 psia

Angle Of Attack, α (degrees)

Fig. 137 Non-Dimensional Heating Rate Vs. Angle Of Attack For Thermocouple 67

Fig. 138 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 50 , $P_0 = 1205$ psia, $\alpha = 0$ Deg., $Re = 1.58 \times 10^6/ft$

fig 139

GENERAL ELECTRIC COMPANY
RESEARCH AND DEVELOPMENT DIVISION

3-1

Fig. 139 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 51, $P_0 = 1207$ psia, $\alpha = 7.5$ Deg., $Re = 1.63 \times 10^6/\text{ft}$

$\Delta: \frac{x}{L} = .984$ $\times: \frac{x}{L} = .742$ $\square: \frac{x}{L} = .500$ $\circ: \frac{x}{L} = .379$ $\Delta: \frac{x}{L} = .258$ $\times: \frac{x}{L} = .137$ $\square: \frac{x}{L} = .076$ $\circ: \frac{x}{L} = .016$

Non-Dimensional Heat Transfer Rate

 $\dot{q}/\dot{q}_0$ (sphere)

Fig. 140 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 52, $P_0 = 1207$ psia, $\alpha = 15$ Deg., $Re = 1.63 \times 10^6/ft$

fig 141

FORM 10000 K-E ALABAMA READING TABLE

7-1

$\Delta: \frac{x}{L} = .984$

$\times: \frac{x}{L} = .742$

$\square: \frac{x}{L} = .500$

$\circ: \frac{x}{L} = .379$

$\Delta: \frac{x}{L} = .258$

$\times: \frac{x}{L} = .137$

$\square: \frac{x}{L} = .076$

$\circ: \frac{x}{L} = .016$

Non-Dimensional Heat Transfer Rate

$\dot{q}/\dot{q}_0$ (sphere)

Fig. 141 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 53, $P_0 = 1206$ psia, $\alpha = 25$ Deg., $Re = 1.62 \times 10^6/ft$

Fig 142

FORM 8-60050 K-M ALUMINUM 2024-T3

11-1

Fig. 142 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 55 , $P_0 = 1203$ psia, $\alpha = 32.5$ Deg., $Re = 1.61 \times 10^6$ /ft

$\Delta: \frac{x}{L} = .984$ $\times: \frac{x}{L} = .742$ $\square: \frac{x}{L} = .500$ $\circ: \frac{x}{L} = .379$ $\Delta: \frac{x}{L} = .258$ $\times: \frac{x}{L} = .137$ $\square: \frac{x}{L} = .076$ $\circ: \frac{x}{L} = .016$

Non-Dimensional Heat Transfer Rate

 $\dot{q}/\dot{q}_0$ (sphere)Radial Angle, θ (degrees)

Fig. 143 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 54 , $P_0 = 1207$ psia,
 $\alpha = 40$ Deg., $Re = 1.62 \times 10^6$ /ft

Fig. 144 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 69 , $P_0 = 1204$ psia, $\alpha = 50$ Deg., $Re = 1.55 \times 10^6/ft$

Fig. 145 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 70 , $P_0 = 1200$ psia,
 $\alpha = 65$ Deg., $Re = 1.57 \times 10^6/ft$

$\Delta: \frac{x}{L} = .984$
 $x: \frac{x}{L} = .742$
 $\square: \frac{x}{L} = .500$
 $\circ: \frac{x}{L} = .379$
 $\Delta: \frac{x}{L} = .258$
 $x: \frac{x}{L} = .137$
 $\square: \frac{x}{L} = .076$
 $\circ: \frac{x}{L} = .016$

Non-Dimensional Heat Transfer Rate

 $\dot{q}/\dot{q}_0$ (sphere)

Fig. 146 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No:81 , $P_0 = 1004$ psia, $\alpha = 80$ Deg., $Re = 1.42 \times 10^6/\text{ft}$

Fig. 147 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 80 , $P_0 = 1006$ psia,
 $\alpha = 90$ Deg., $Re = 1.38 \times 10^6$ /ft

fig 148

FORM 8 070000
KZ
ALBANY
MASS
JAN 62

13-1

$\Delta: \frac{x}{L} = .984$

$\times: \frac{x}{L} = .742$

$\square: \frac{x}{L} = .500$

$\circ: \frac{x}{L} = .379$

$\Delta: \frac{x}{L} = .258$

$\times: \frac{x}{L} = .137$

$\square: \frac{x}{L} = .076$

$\circ: \frac{x}{L} = .016$

Non-Dimensional Heat Transfer Rate

$\dot{q}/\dot{q}_0$ (sphere)

Fig. 148 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 56 , $P_0 = 755$ psia, $\alpha = 0$ Deg., $Re = 0.99 \times 10^6/\text{ft}$

Fig. 149 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 57, $P_0 = 756$ psia, $\alpha = 7.5$ Deg., $Re = 1.03 \times 10^6$ /ft

fig 150

CC-BY-SA 4.0
BY-SA 4.0
BY-SA 4.0

17-1

Fig. 150 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 58 , $P_0 = 756$ psia, $\alpha = 15$ Deg., $Re = 1.03 \times 10^6/\text{ft}$

Fig. 151 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 59 , $P_0 = 756$ psia, $\alpha = 25$ Deg., $Re = 1.04 \times 10^6/ft$

fig 52

FORM 8-520000 H-10

21-1

$\Delta: \frac{X}{L} = .984$

$X: \frac{X}{L} = .742$

$\square: \frac{X}{L} = .500$

$O: \frac{X}{L} = .379$

$\Delta: \frac{X}{L} = .258$

$X: \frac{X}{L} = .137$

$\square: \frac{X}{L} = .076$

$O: \frac{X}{L} = .016$

Non-Dimensional Heat Transfer Rate

$\dot{q}/\dot{q}_0$ (sphere)

Fig. 152 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 60 , $P_0 = 755$ psia, $\alpha = 32.5$ Deg., $Re = 1.00 \times 10^6$ /ft

Fig. 154 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 72 , $P_0 = 753$ psia, $\alpha = 50$ Deg., $Re = 1.02 \times 10^6/\text{ft}$

fig 155

FORM 000000
K-2
STANDARD
1955

41-1

Fig. 155 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 73 , $P_0 = 754$ psia, $\alpha = 65$ Deg., $Re = 1.02 \times 10^6$ /ft

Fig. 156 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 82 , $P_0 = 794$ psia, $\alpha = 80$ Deg., $Re = 1.24 \times 10^6/ft$

fig 157

KEEAT 3H31AG A M C 67 U MHOY

45-1

Fig. 157 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 79 , $P_0 = 767$ psia, $\alpha = 90$ Deg., $Re = 0.97 \times 10^6/\text{ft}$

Fig. 158 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 62, $P_0 = 501$ psia, $\alpha = 0$ Deg., $Re = 0.68 \times 10^6$ /ft

Fig 159

FORM 00000
K-2
REPLACES
FORM 00000
K-2
REPLACES

27-1

Fig. 159 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 63 , $P_0 = 501$ psia, $\alpha = 7.5$ Deg., $Re = 0.68 \times 10^6/\text{ft}$

Fig. 160 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 64, $P_0 = 501$ psia, $\alpha = 15$ Deg., $Re = 0.68 \times 10^6/ft$

fig 161

FORM 1000000
K&E ENGINEERING
ASTAR DIVISION

31-1

Fig. 161 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 65 , $P_0 = 500$ psia, $\alpha = 25$ Deg., $Re = 0.68 \times 10^6/\text{ft}$

Fig. 162 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 66 , $P_0 = 501$ psia,
 $\alpha = 32.5$ Deg., $Re = 0.67 \times 10^6/\text{ft}$

Fig. 163 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 86 , $P_0 = 497$ psia, $\alpha = 40$ Deg., $Re = 0.72 \times 10^6$ /ft

fig 164

FORM 8-00000
K-E
JANUARY 1955

61-1

Fig. 164 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 87, $P_0 = 515$ psia, $\alpha = 40$ Deg., $Re = 0.69 \times 10^6/\text{ft}$

fig 165

FORM 000000 K&E ALUMINUM T&E

43-1

Fig. 165 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 74 , $P_0 = 503$ psia, $\alpha = 50$ Deg., $Re = 0.65 \times 10^6/ft$

Fig 166

FORM 8-57000
REPLACES FORM 8-57000
1-57

57-1

Fig. 166 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 85 , $P_0 = 493$ psia, $\alpha = 65$ Deg., $Re = 0.67 \times 10^6/\text{ft}$

Fig. 167 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 83, $P_0 = 520$ psia, $\alpha = 80$ Deg., $Re = 0.68 \times 10^6/\text{ft}$

Fig. 168 Non-Dimensional Heating Rate Along The Barrel Of The Capsule, Run No: 84 , $P_0 = 532$ psia, $\alpha = 90$ Deg., $Re = 0.73 \times 10^6/\text{ft}$

FORM 4-73030 3-10-74

Fig. 169 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 50 , $P_0 = 1205$ psia,
 $\alpha = 0$ Deg., $Re = 1.58 \times 10^6/ft$

fig 170

FORM 03000 KZ ALBANY, N.Y.

2-1

Fig. 170 Non-Dimensional heating Rate Across The Face Of The Capsule, Run No: 51 , $P_0 = 1207$ psia, $\alpha = 7.5$ Deg., $Re = 1.63 \times 10^6/ft$

Fig 171

FORM 3-1
RESEARCH REPORT
A-100000

3-1

Fig. 171 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 52 , $P_0 = 1207$ psia, $\alpha = 15$ Deg., $Re = 1.63 \times 10^6/ft$

fig 172

REPRODUCED FROM THE JPL LIBRARY

41

Fig. 172 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 53 , $P_0 = 1206$ psia, $\alpha = 25$ Deg., $Re = 1.62 \times 10^6/ft$

Fig.173 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 55 , $P_0 = 1203$ psia, $\alpha = 32.5^\circ$ Deg., $Re = 1.61 \times 10^6/ft$

Fig 175

FORM 105000
ROTARY ENGINE
H. E. ALLEN

13-1

Fig. 175 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 69 , $P_0 = 1204$ psia, $\alpha = 50$ Deg., $Re = 1.55 \times 10^6/ft$

SECRET THIRPARAJA 020070 Z APR 68

197

fig 177

FORM 8-00000 H-3
RESEARCH DIVISION
AUGUST 1954

25-1

Fig. 177 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 81 , $P_0 = 1004$ psia, $\alpha = 80$ Deg., $Re = 1.42 \times 10^6/ft$

Fig. 178 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 80 , $P_0 = 1006$ psia, $\alpha = 90$ Deg., $Re = 1.38 \times 10^6/ft$

Fig. 179 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 56 , $P_0 = 755$ psia, $\alpha = 0$ Deg., $Re = 0.99 \times 10^6/ft$

Fig 180

ECBAT MEMORANDUM 3-51

8-1

Fig. 180 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 57 , $P_0 = 756$ psia, $\alpha = 7.5$ Deg., $Re = 1.03 \times 10^6/ft$

fig 181

9-1

Fig. 181 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 58 , $P_0 = 756$ psia, $\alpha = 15$ Deg., $Re = 1.03 \times 10^6/ft$

Fig. 182 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 59 , $P_0 = 756$ psia, $\alpha = 25$ Deg., $Re = 1.04 \times 10^6/ft$

Fig. 183 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 60 , $P_0 = 755$ psia, $\alpha = 32.5^\circ$, $Re = 1.00 \times 10^6/ft$

Fig 184

SEALY 3-11 050000 MROH

12-1

Fig. 184 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 61, $P_0 = 756$ psia, $\alpha = 40$ Deg., $Re = 1.00 \times 10^6/ft$

Fig 185

REPORT © 1954 JAN 1954 3-4 050000 RM 0001

20-1

Fig. 185 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 72 , $P_0 = 753$ psia, $\alpha = 50$ Deg., $Re = 1.02 \times 10^6/ft$

Fig 186

FORM 10-00000 K-24

21-1

Fig. 186 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 73 , $P_0 = 754$ psia, $\alpha = 65$ Deg., $Re = 1.02 \times 10^6/ft$

Fig. 187 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 82, $P_0 = 794$ psia, $\alpha = 80$ Deg., $Re = 1.24 \times 10^6/ft$

fig 188

СЕРИЯ 2431482А 241 000000 000000

23-1

Fig. 188 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 79 , $P_0 = 767$ psia, $\alpha = 90$ Deg., $Re = 0.97 \times 10^6/ft$

Fig 189

CPDAR L. THUMASIA 0502 0 4409

13-1

Fig. 189 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 62 , $P_0 = 501$ psia, $\alpha = 0$ Deg., $Re = 0.68 \times 10^6/ft$

Fig 190

FORM 000000
RESEARCH
NAVY

14-1

Fig. 190 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 63 , $P_0 = 501$ psia, $\alpha = 7.5$ Deg., $Re = 0.68 \times 10^6/ft$

Fig 192

FORM 030000-1
RESEARCH
NAVY

16-1

Fig. 192 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 65 , $P_0 = 500$ psia, $\alpha = 25$ Deg., $Re = 0.68 \times 10^6/ft$

Fig 193

SECRET © 1974 NASA 3-1 000000 MRO 7

17-1

Fig. 193 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 66 , $P_0 = 501$ psia, $\alpha = 32.5$ Deg., $Re = 0.67 \times 10^6/ft$

Fig 194

FORM 8-00000 H. E. CLOONEY

30-1

Fig. 194 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 86 , $P_0 = 497$ psia, $\alpha = 40$ Deg., $Re = 0.72 \times 10^6/ft$

Fig 196

22-1

Fig. 196 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 74 , $P_0 = 503$ psia, $\alpha = 50^\circ$ Deg., $Re = 0.65 \times 10^6$ /ft

fig 197

FORM 6-520000
RESEARCH REPORT
AERONAUTICAL ENGINEERING

29-1

Fig. 197 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 85 , $P_0 = 493$ psia, $\alpha = 65$ Deg., $Re = 0.67 \times 10^6/ft$

Fig. 198

FORM 30000
K&M
RESEARCH DIVISION

27-1

Fig. 198 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 83 , $P_0 = 520$ psia, $\alpha = 80$ Deg., $Re = 0.68 \times 10^6/ft$

Fig 199

KEBAT 371 050000 5 MR 07

28-1

Fig. 199 Non-Dimensional Heating Rate Across The Face Of The Capsule, Run No: 84 , $P_0 = 532$ psia, $\alpha = 90$ Deg., $Re = 0.73 \times 10^6/ft$

Fig. 200 Comparison of Experimental Heating Rate With Theoretical Results for Thermocouple 51 ($X/L = 0.5, \theta = 0^\circ$)

Fig. 201 Heat Flux Distribution on The Barrel for $\alpha = 90^\circ$ and $P_0 = 750$ psia, $Re = 1.0 \times 10^6/\text{ft}$.

Fig. 202 Non-Dimensional Heating Rate Along the Barrel at $\theta = 0^\circ$ and $P_0 = 1200$ psia, $Re = 1.5 \times 10^6$ /ft.

Fig. 203 Non-Dimensional Heating Rate Across the Face on the Diameter $\theta = -3.5^\circ$ and 176.5° for All Angles of Attack, $P_0 = 1200$ psia, $Re = 1.5 \times 10^6/\text{ft}$.