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Results of 10% Thermal Model Test, Nimbus B Sensory Ring SNAP 19 Expanded Safety Program

MND-3607-94

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

MARTIN COMPANY
BALTIMORE MARYLAND 21203

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RESULTS OF 10% THERMAL MODEL
TEST, NIMBUS B SENSORY RING

MND-3607-94

January 1967

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FOREWORD

This report describes the test results obtained from a thermally scaled model of the Nimbus B spacecraft when tested in the NASA-Ames Research Center 3.5-foot Hypersonic Wind Tunnel at a Mach number of 10. These tests were conducted during the week beginning 12 September, 1966. This report was prepared under United States Atomic Energy Commission Contract AT(30-1)-3607 and covers the test portion of Sub-task 10.9 of the Expanded Safety Program for SNAP 19.

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SYMBOLS AND DEFINITIONS

M	Mach number, dimensionless
P	Pressure, psia
T	Temperature, degrees Rankine
V	Velocity, feet per second
$\dot{q}$	Stagnation heat transfer rate, $\text{BTU/ft}^2\text{-sec}$
$\dot{q}''$	Stagnation heat transfer rate, $\text{BTU/ft}^2\text{ - sec}$ (referenced to radius of flat circular disc)
α	Angle of attack, degrees (referenced to longitudinal axis of spacecraft, bottom surface of spacecraft always faces windward)
ϕ	Angle of roll, degrees (referenced to plane bisecting bays 1 and 18, $\phi = 0^\circ$ when reference plane is located at 6 o'clock looking forward, clockwise roll is positive)
r	Radius of sensory ring ($r = 2.856 \text{ in.}$, 10% model)
k	Thermal conductivity, $\text{BTU/ft - sec - }^\circ\text{R}$
c	Specific heat at constant pressure, $\text{BTU/Lb. /}^\circ\text{R.}$
t	Time, seconds
ρ	Material density, pounds mass/foot ³
L	Characteristic length, feet
d	Thickness, feet
h	Tunnel density altitude, feet
T. C.	Abbreviation for thermocouple

SYMBOLS AND DEFINITIONS (Continued)

h _j	Joint conductance, BTU/Ft ² - Hour - °R
q	Internally generated heat dissipated by conduction, BTU/Ft ³ - sec
ε	Emissivity, dimensionless
R	Scale ratio, L _m /L _p
Δ T _r	Temperature difference, reference temperature minus local temperature, degrees Rankine

Subscripts

1	refers to conditions upstream of normal shock
2	refers to conditions downstream of normal shock
t	refers to total conditions
m	refers to model
p	refers to Nimbus B prototype
χ	any model instrumentation location

SUMMARY

The 10% scale thermal model test was conducted to obtain the temperature distribution in the Nimbus B sensory ring at 32 locations in the basic structure when the model was subjected to a typical Nimbus B re-entry stagnation heating rate. The model was scaled using the temperature preservation technique. The temperature distribution will be used to verify the results obtained from a mathematical model of the re-entering Nimbus B. The tests were conducted at the NASA-Ames 3.5-foot Hypersonic Wind Tunnel Facility. The nominal test conditions were Mach 10.4, total pressures of 400, 1000 and 1800 psia, total temperature of 2100°R and model angles of attack of +30°, 0°, -30° and -60°. The only model configuration change involved in these tests was the removal of the external Nimbus B antennae. The data obtained from these tests were in the form of temperature-time histories for each of the instrumentation locations throughout the duration of the model in the stream.

There were three major parameters that were studied during these tests. They were angle of attack, total pressure and antennae removal effects. In discussing the temperature distribution in the model as a function of the test variables, a reference temperature technique was employed. This technique was applied specifically to the three instrumented separators whose instrumentation locations were geometrically identical. One thermocouple on each of the three separators was selected as a reference point and the remaining

thermocouples in each separator were compared to their respective reference temperatures. The temperatures compared in the discussion were selected at the sixth second of the temperature-time histories. Instrumentation located in the model A-frame did not lend itself to the reference temperature technique; consequently, the discussion has been limited to the actual measured temperatures at these A-frame locations as a function of the test variables.

Test results from the instrumented separators indicate several interesting features. The thermocouples located on the windward surfaces of the three instrumented separators and the A-frame are the most sensitive to changes in angle of attack. However, the temperatures at locations in the structure connecting the windward and leeward surfaces and at locations on the leeward surface are more stable with angle of attack changes. The spacecraft structure appears to average the total aerodynamic heating to its windward surface so that the internal structure and the leeward surface temperatures do not reflect the large temperature variations found on the windward surface. As far as the antennae removal is concerned, those locations on the separators adjacent to or shadowed by the antennae are most sensitive to their presence. It was concluded that flow instability was taking place on the windward face of the separators with all antennae installed. Removal of antennae in the region of separator 11-12 causes this separator temperature to decrease slightly, while the converse is true for separator 1-2. Separator 1-18 is not substantially affected by antennae removal. The A-frame temperatures did not exhibit any consistent behavior with antennae removal.

The effect of total pressure on the model temperature distribution was studied at angles of attack of 0° and -60° . In general, the temperature measured on the model were highest at $\alpha = 0^\circ$. The temperatures throughout the model increased with increasing total pressure for both angles of attack tested; however, the rate of temperature increase with increasing pressure abated at $\alpha = 0^\circ$ while it remained essentially constant for $\alpha = -60^\circ$. The trends with total pressure of the temperatures measured in the A-frame were consistent with those of the separators. A study of the temperature distribution in the separators revealed that at $\alpha = 0^\circ$ temperatures differed by as much as 1000°R in a given separator, while at $\alpha = -60^\circ$ the maximum temperature difference did not exceed 700°R .

The data realized from this test will be used in the SNAP 19 Safety Study to establish the validity of the digital computer program developed for the thermal analysis of the Nimbus B spacecraft.

I. INTRODUCTION

The SNAP-19 generator containing a radioisotope heat source is being produced for use on the NASA Nimbus B satellite. It is necessary to establish and confirm the safety of the system throughout its existence from fueling the generator to ultimate atmospheric re-entry of the nuclear material. In order to determine the ultimate disposition of the fuel, it is necessary to perform an aero-thermal analysis of the Nimbus, of the generator assembly freed from the spacecraft, and of the fuel capsules. Since these configurations are of complex shapes, theoretical methods available are difficult to apply without confirmation or establishment of basic coefficients in wind tunnel tests. This becomes very obvious when the extremely "non-aerodynamic" shape of the Nimbus satellite is considered.

Studies completed in References 1 and 2 established a number of conditions where the Nimbus would reenter the atmosphere in a stable orientation with the sensory ring facing the airstream. With the SNAP-19 still mounted on its support on the Nimbus, it is necessary that aerodynamic heating completely destroy the sensory ring before significant generator heating occurs for this stable Nimbus orientation. The complex structure of the sensory ring requires almost a complete burn-up of its members before any break-up will take place, as evidenced by calculation of the thermal destruction of a section of Nimbus sensory ring. This calculation was performed using a forty-nine-element structural heating program which accounted for the thermal properties of the material and average heat input to the face and sides of the sensory ring as determined from the heat rates given in Table 1. With an initial altitude of 400,000 feet, the first elements calculated to be ablated were the thin magnesium side plates of the sensory

ring at an altitude of 343,000 feet. The first major piece of structure (the forward-facing section of sensory ring separator material) ablated at 1076 seconds into the trajectory at an altitude of 335,000 feet. At time equals 1578 seconds at an altitude of 205,000 feet, the upper and inner structure on the sensory ring separators and the structure joining the eighteen bays are still intact. This indicated that no significant melting of the SNAP-19 will occur until well below 200,000 feet for the stable Nimbus reentry.

Any preliminary thermal analysis of the complex Nimbus sensory ring requires a number of simplifications and assumptions in the mathematical model to keep the problem within a reasonable scope. To validate these simplifications and assumptions the following experimental data are required:

- (a) The external aerodynamic heat rates to the sensory ring (Experimental Safety Program (E.S. P.) Test 4 (1) (e)).
- (b) The thermal distribution within the sensory ring structure when exposed to a typical stagnation heat rate (E.S. P. Test 4 (1) (a)).
- (c) Miscellaneous mechanical and thermal properties of magnesium near its melting temperature (E.S. P. Test 4 (1) (h)).
- (d) Ablation of magnesium exposed to reentry temperatures (E.S. P. Test 4 (1) (d)).

This report covers the results obtained from the 10% thermal model, Test 4 (1) (a).

To best obtain the required information in Test 4 (1) (a) a 10% scale model of the Nimbus B sensory ring was constructed. This thermal model

was scaled by use of the temperature preservation technique. The temperature preservation scaling technique provides a model which, when subjected to a given heating environment, will have the same temperature at homologous locations as a prototype subjected to the same heating environment. This thermal model was tested in the Ames 3.5-foot Hypersonic Wind Tunnel Facility, which was capable of providing heat transfer rates in the range of interest (Table 1). The nominal test conditions in the wind tunnel were a total pressure of 400 psia and a total temperature of 2100°R at Mach 10.4. These test conditions provided a model stagnation heating rate which approximated the heating rate encountered by the reentering Nimbus B at an altitude of 325,000 feet, for the specific trajectory referenced.

II. FACILITY DESCRIPTION

The NASA-Ames 3.5-foot Hypersonic Wind Tunnel (hereafter referred to as the 3.5-foot tunnel) is one of the facilities operated by the Hypersonic Aerodynamics Branch of NASA-Ames Research Center, Moffett Field, California. This facility is a blowdown type wind tunnel and is equipped with three interchangeable nozzles contoured for nominal Mach numbers of 7, 10 and 14. Tunnel stagnation pressures range from 50 to 1800 psia allowing a Reynolds number range of $.157 \times 10^6$ to 6.31×10^6 per foot. A schematic diagram of the tunnel circuits and a model of the 3.5-foot tunnel plant are presented in Figures 1 and 2, respectively. The operational sequence of the 3.5-foot tunnel begins with the pressurization of the cylindrical storage vessels upstream of the heater and the evacuation of the large spherical containers downstream of the test section. Thus, the necessary pressure ratio can be obtained across the nozzle and sustained long enough to establish stable hypersonic flow for model testing. Stagnation temperatures from 1160°R to about 2300°R are achieved by passing the pressurized air through a pebble bed heater shown schematically and in model form in Figures 3 and 4, respectively. The heater contains about 150 tons of aluminum oxide spheres which are heated to stagnation temperature from the top by a gas fired furnace burner. A forced draft through the heater draws the heat down through the pebble bed until the desired temperature is reached, then the burner and the forced draft are shut off and the air from the high pressure tanks is allowed to pass through the heater to the nozzle. Through the nozzle the air flow becomes supersonic and then expands into the test section where hypersonic flow is established; the flow then exhausts into the huge vacuum tanks. The run is usually terminated before the pressure ratio across

the nozzle becomes too small to maintain hypersonic flow in the test section (which would cause a spontaneous flow breakdown). At a nominal Mach number of 10, the maximum running time is about 2 minutes. The three interchangeable nozzles shown in Figure 1 require cooling at the nozzle throat. To accomplish this cooling, helium is admitted into the boundary layer next to the wall, just upstream of the nozzle throat, through an annular slot which can be seen in Figure 3. About 95 percent of the helium used in each run is recovered and stored for re-use. A plot of the operating regime at Mach 10.4 in the 3.5-foot tunnel is presented in Figure 5.

This test employed the quick-insert mechanism used for heat transfer tests. The model was mounted on a sting which, in turn, was secured to a movable strut. The horizontal strut is retractable into a large sealed container from which it is rapidly inserted into the test section. It is kept there for a prescribed time and then quickly withdrawn. Sliding doors in the test section wall opened to admit the model during insertion and closed again after the model was withdrawn. The sting used with the quick-insert mechanism could be pitched from 0° to 20° . Figure 6 is a sketch viewing the tunnel test section from the top and showing the test section geometry and the sting-mounted thermal model. A photograph of the west side of the tunnel test section and the thermal model installed in the tunnel is presented in Figure 7.

III. MODEL DESCRIPTION

There are several techniques available for obtaining thermal similitude in prototypes and models. (Ref. 3.) The temperature preservation technique was selected for the 10% thermal model of the Nimbus B. This technique scales the model so that, at homologous points, the model and prototype have the same temperature. The model-prototype relationships necessary for temperature preservation:

$$(1) \quad \frac{k_m}{k_p} = \frac{L_m}{L_p} = R$$

$$(2) \quad \frac{h_{jm}}{h_{jp}} = 1$$

$$(3) \quad t_m = \frac{c_m}{c_p} \frac{\rho_m}{\rho_p} R$$

$$(4) \quad \frac{\dot{q}_m}{\dot{q}_p} = 1$$

$$(5) \quad \frac{q_m}{q_p} = \frac{1}{R}$$

$$(6) \quad \frac{\epsilon_m}{\epsilon_p} = 1$$

Rigorous thermal scaling of a spacecraft built of different materials is practically impossible. For surfaces made of thin sheet metal, it is reasonable to consider that no temperature gradient exists in the direction normal to the surface. The heat distribution is then essentially a two-dimensional problem.

Then criterion (1) becomes

$$(6) \quad \frac{K_m}{K_p} = \left(\frac{d_m}{d_p} \right)^{-1} R^2 \quad (7)$$

and criterion (5) becomes

$$(8) \quad \frac{q_m}{q_p} = \left(\frac{d_m}{d_p} \right)^{-1} \quad (8)$$

This relationship permits more flexibility in model material selection since the thickness scale can be changed independent of the geometric scale ratio, $R = \frac{L_m}{L_p}$. Relationships (5) and (6) of those listed above have not been considered in the scaling of the 10% thermal model due to their relative insignificance when compared to the aerodynamic heating contribution. (Ref. 6.) This is the basic reason for selecting the Ames 3.5 foot-hypersonic tunnel which cannot simulate the reentry temperature, but has a more uniform flow field compared to the 10 MW arc tunnel.

The Nimbus B spacecraft structure consists primarily of magnesium and aluminum with almost twice as much magnesium, by weight, as aluminum, consequently, the thermal scaling of the magnesium structural components was given first consideration. Stainless steel was substituted in the model for all the magnesium found in the prototype. Applying relationship (1) for temperature preservation in the model and prototype to the stainless steel and magnesium, we have:

$$\frac{k_m}{k_p} = \frac{k_{SS \#310}}{k_{magnesium}} = \frac{1}{10}$$

This scale ratio was very convenient for the thermal model because a 10% scale Nimbus B spacecraft was about the largest model size that the 3.5-foot tunnel

could handle. No suitable material could be found to substitute for the aluminum structure and maintain 3-dimensional similitude in the 10% model. However, by substituting stainless steel for the aluminum and distorting the model material thickness using the 2-dimensional similitude relationship, $\frac{k_m}{k_p} = \left(\frac{d_m}{d_p}\right)^{-1} R^2$, temperature preservation could also be obtained in scaling the aluminum. This relaxation in the rigorous application of the scaling laws was permissible with the aluminum structure because the majority of the structure was thin-walled.

The basic structure of the model consists of 2 inner and 2 outer rings, 18 separators and a cross-beam structure commonly called the "A" frame. Figures 8 and 9 show the basic model assembly and the separator details, respectively. These various components are all made from stainless steel and when assembled comprise the supporting structure for housing the spacecraft experiments and attaching all pieces of spacecraft equipment. Thus far, only the application of relationship (1) dealing with material conductivity has been discussed for the 10% thermal model.

Relationship (2), $\frac{h_{j_m}}{h_{j_p}} = 1$, which deals with joint conductance, will now be considered. To satisfy the joint conductance scaling law, the contact areas at each joint must be accurately scaled geometrically and the fastening methods used on the prototype must also be followed on the model. The structural complexity of the prototype spacecraft precludes strict adherence to relationship (2) with a model scale of 10%. Sub-miniature screws, rivets, bolts and nuts of the size required for a 10% scale model of the Nimbus B spacecraft simply do not exist. In the prototype, the basic sensory ring structure, consisting of the two inner and outer rings and eighteen separators, is assembled with many screws and nuts. In an effort to

satisfy the joint conductance scaling, in the 10% scale sensory ring, sub-miniature screws and nuts (000-120 size) were used in the model. Due to the "larger-than-scale" size of these screws fewer were used in the model to approximate the properly scaled contact pressure between the surfaces. The riveted joints in the prototype aluminum "A-frame" have been replaced by spot-welded joints in the model "A-frame." Spot-welding was selected as the method of attachment most closely resembling a riveted joint. The approach used with the sensory ring screws was not applicable to the rivets due to the inaccessibility of some locations caused by the small model scale.

In assembling the Nimbus-B spacecraft, a high conductivity grease is used between contacting surfaces held together by screws and rivets to provide better heat transmission in the structure. Experimental investigation of thermal conductance of mechanical joints have indicated that for metallic joints with contacting surfaces well-covered by the grease, the thermal conductance is not affected by the metallic materials forming the joint or the type of fastening. Therefore, the special grease was applied to screw-fastened surfaces to satisfy the thermal similitude of the mechanical joints.

In thermally scaling the Nimbus-B spacecraft, it was also necessary to apply the scaling laws to spacecraft components other than the basic structural ones. Any portion of the spacecraft in contact with the structure will provide a conduction path that will influence the temperature distribution in the structure. Thus, the attached masses and conduction paths should be scaled to insure proper heat sink effect and temperature response. The t_m/t_p ratio was determined for the basic structure, then the prototype density and specific heat values for each component were entered into relationship (3) and

the product of model specific heat and density ascertained. Some latitude was permitted in material selection since any combination of specific heat and density giving the proper scaled product would be acceptable. It was also permissible to alter the model component density by hollowing it out. Figure 10 shows some of the scaled model components and the sub-miniature screws and nuts. This type of scaling was applied to all components and experiments mounted on the spacecraft as well as the modules that were installed in each of the bays of the sensory ring. A compromise was made in the scaling of the modules for each of the bays in that not all the modules were scaled. Only the modules located in the two bays on either side of the instrumented separators were scaled. The instrumented separators were located between bays 1 and 18, 1 and 2 and 11 and 12; therefore, the modules were scaled in bays 17, 18, 1, 2, 3, 10, 11, 12 and 13. Figures 11 through 18 document photographically the various stages of model construction. Figure 18 shows the geometry of the modules as well as the material size and manner of attachment employed in scaling the prototype modules. It was felt that scaling the two adjacent bays would provide adequate scaling for temperature preservation.

The instrumentation for the 10% thermally scaled model consisted entirely of thermocouples located in 32 places throughout the model as shown in Figure 19. The thermocouples were made from 40-gage chromel-alumel wire with high-temperature fiberglass insulation. The thermocouple junction locations in the model were obtained by spot welding the 3 mil chromel and alumel wires directly to the model structure at the desired location. The leads were routed through the model, sting, and then connected to the reference junction (150°F reference junction was maintained) and the Beckman recording system.

The bundle of 32 thermocouple wires was approximately 24 feet long from the back of the model to the connectors which plugged into the 3.5-foot tunnel instrumentation.

IV. TEST PROCEDURE

The run program listing the model attitudes, configurations and tunnel conditions tested are listed in Table 1. The run program is essentially the same as that outlined in Reference 2 with minor exceptions. The two high pressure runs, i. e. low altitude, were made with all the spacecraft antennae removed. The four runs that were left unassigned in the test plan were used to evaluate the influence of removing all antennae from the spacecraft at angles of attack of 30, 0, -30 and -60 degrees at a total pressure of 400 psia. The high pressure runs were conducted at the end of the run program because the severity of the environment could possibly cause model failure. The antennae were not re-installed on the model for these high pressure runs. A comparison using preliminary oscillograph data, was made to determine the influence of the antennae on the temperature distributions. The comparison showed a negligible effect with antennae removed. The antennae were not reinstalled because installation is a time-consuming task and the comparison showed it to be not necessary.

The test procedure employed for the thermal model test was very similar to that used in heat transfer tests (MND-3607-95). The model was sting-mounted to a door which became a portion of the test section wall when the model was inserted in the tunnel. This insertion was accomplished by a quick-insert mechanism which was adjusted to position the model on the tunnel centerline in less than one second and limit the acceleration and deceleration loads to approximately 3 g's. Figure 7 shows the 3.5-foot tunnel test section with the 10% thermal model installed on the quick-insert mechanism sting and partially inserted into the tunnel. The direction of flow is from right to left in the

picture.

For a typical run, the reservoir pressure was adjusted to the desired level and flow was established in the tunnel. Approximately one minute after flow was established, data recording was initiated, followed immediately by model insertion. The model remained on the tunnel centerline approximately 8 seconds before retraction. The 8-second duration in the stream was determined from preliminary runs made at durations of 3 and 6 seconds which indicated that the model could remain in the stream for approximately 8 seconds before reaching critical temperature, i. e. $\approx 1200^{\circ}\text{F}$ at $P_t = 400$ PSIA. Motion pictures were taken of each model run. The camera was positioned to photograph the model through the first upstream window, thereby obtaining a 3/4-frontal view of the model. The purpose of these motion pictures was to record any deformations or model failures that might occur during the testing. The Beckman data recording system at the 3.5-foot tunnel was employed to record the thermal model temperatures. Temperatures from each of the model locations were recorded at 0.05-second intervals from the time that the model was inserted into the tunnel until it was retracted.

A flash bulb, positioned in one of the test section windows, was used to correlate the motion pictures with the Beckman recording system. The triggering signal for the flash bulb was recorded on the Beckman tape while the simultaneous flashing was picked up on the movie film.

Eleven thermocouples were selected for monitoring during the test. The thermocouples were numbers 1, 2, 4, 10, 18, 25, 28, 29, 30, 31, and 32. The temperature-time histories for these thermocouple locations were recorded on both the Beckman system and a CEC oscillograph. The thermocouples

monitored on the oscillograph were selected to give a representative sampling of locations throughout the model. This data proved very useful in providing an "on-the-spot" check of the runs while the test was in progress.

Figures 20, 21, and 22 are photographs of the 10% thermal model mounted on the 3.5-foot tunnel quick-insert door. Figure 20 shows the complete model with all antennae mounted, and Figure 21 shows the model with antennae removed. Figure 22 is a rear three-quarter view of the model showing the 0° adapter. Another adapter, having a 40° bend in it, was used to obtain the angles of attack required by the test program.

V. ACCURACY OF DATA

The only quantities measured on the 10% thermal model were the thermocouple outputs from the 32 locations indicated in Figure 19. These outputs in millivolts were then converted by computer to temperatures using the standard emf-temperature curve for Chromel-Alumel thermocouples. The limits of error for the temperatures recorded by these thermocouples are $\pm 3/4\%$ in the 530° to 2300°F range. The thermocouples located on the 10% thermal model were not exposed for long periods at or near their upper temperature limit. Therefore, the instabilities in chemical composition, stress state and grain structure which affect the emf-temperature curve when thermocouples are subjected to prolonged usage can be neglected. A detailed study of surface temperature measurements with thermocouples has been reported in Reference 7 and these reported results apply to this discussion.

The measurement accuracy of the tunnel test conditions as quoted by NASA-Ames personnel are as follows: Tunnel total pressure, $P_o = \pm 5$ psi; tunnel total temperature, $T_o = \pm 30^{\circ}\text{R}$.

There are several ways of ascertaining the quality of experimental results. The method chosen for the 10% thermal model was the evaluation of the basic accuracy that can be expected from the model instrumentation. Another approach used in evaluating test results is the determination of the precision by data repeatability. To ideally determine the data repeatability, comparison is made of data from repeat runs at identical test conditions. The operational nature of the 3.5-foot hypersonic tunnel did not permit an identical reproduction of test conditions for the repeat runs; consequently, a direct comparison of data was not practical. In an effort to resolve this problem a means of normalizing the nominal replicate data was sought. The method finally selected

employed reference temperatures at specific model locations. The temperature differences (ΔT_r) between the reference temperature and the local temperature at surrounding locations were then compared to determine data repeatability. An example of data repeatability as indicated by this method can be found in the following table. A more detailed discussion of this reference temperature method is contained in Section VII of this report.

$\Delta T.C.$	Run 7 ΔT_r	Run 8 ΔT_r	Run 12 ΔT_r
3 - 1	430.5	440.2	429.3
3 - 2	188.6	192.2	211.8
3 - 4	446.0	452.0	418.9
3 - 5	294.9	304.1	300.2
3 - 6	614.3	631.5	615.4
3 - 7	343.3	357.9	314.5
3 - 8	320.1	331.9	314.7
T_r (#3)	1263.2	1286.7	1263.6

Small deviations in the nominal test conditions of total temperature, pressure and angle of attack, which were difficult to reproduce for the repeat runs, had substantial influence on the temperatures measured on separators 1 - 2 and 11 - 12 and also the "A-frame."

Therefore the above comparisons were made with locations on separator 1 - 18 only at $\alpha = 0^\circ$, $P_o = 400$ psia. This separator was obstructed the least, aerodynamically, by spacecraft components of the three instrumented separators and therefore would provide a more meaningful repeatability comparison.

One important aspect of any thermal experiment is the accuracy of the temperatures recorded. In thermometry by means of thermocouples, there is always a heat conduction loss along the thermocouple wire, the magnitude of which is a function of (1) the temperature and thermal conductivity of the surface to which the thermocouples are attached; (2) the thermal conductivity and geometry of the thermocouples; and (3) the environmental temperature the couple wires are exposed to. An estimate was made under equilibrium conditions with environment at 610°R . The maximum temperature drop across the thermocouple junction would be about 15°R for the thermal model test. Thus the actual temperature may be up to 15°R higher than the measured value. On the other hand, for locations such as the inside of a separator (with openings on both ends) which allows hot gases to circulate, the environment temperature may get to as high as 1600°R . In such cases the true surface temperature may be as much as 20°R lower than the measured value. These estimates were based on equilibrium conditions. Thermocouple errors, under transient heat transfer conditions, are much more involved and have not been included within the scope of this effort.

VI. DATA PRESENTATION

The data obtained from the 10% thermal model tests were in the form of tabulated temperature-time histories. These data were recorded by computer from magnetic tape and printed out on standard automatic-type-writer paper at NASA-Ames. To facilitate the handling of these rather cumbersome data sheets, they have been reduced as shown in Appendix A. Data from runs 1, 2, 9, 10 and 11 were not acceptable as indicated in the run program of Table 2, consequently the print out from these runs was not included in Appendix A. The temperature at each of the thermocouple locations was recorded every twentieth of a second on magnetic tape and then printed out on the data sheets. These tabulated temperature data were then plotted versus time at one-quarter-second intervals. The plotted temperature-time histories comprise the basic results of the 10% thermal model tests and are presented in Figures 23 through 39. The data are presented in run number order with four plotted sheets per run. Each sheet contains temperature data in degrees Rankine plotted versus time in seconds for eight thermocouple locations. An example would be Figure 23a which contains data from Run 3, thermocouples 1 through 8; Figure 23b, Run 3, thermocouples 9 through 16; etc. To aid in the discussion of the test results a table was prepared and a number of data cross-plots were made.

VII. DISCUSSION OF RESULTS

To study the effects of the several test variables on the temperature distribution within the structure of the spacecraft, the temperatures in a given separator were referenced to a common thermocouple location in that separator. At no time during the test did any of these thermocouples on the model reach an equilibrium temperature while in the tunnel flow. However, the model temperatures were starting to level off at the time of retraction. Consequently, to best approximate the relative temperature distribution throughout the model, the temperatures at the sixth second after injection into the tunnel were selected for comparison. The sixth second data were chosen because they represented the last full second of temperature-time history data recorded for the majority of the runs before model retraction. Run 18 was the only run that was retracted from the stream before six seconds had elapsed. Sixth second data were obtained from Run 18 by extrapolating the temperature-time histories a tenth of a second. Table 3 lists the temperatures at the sixth second of the temperature-time history for all operating thermocouples and all valid runs. Thermocouple locations 3, 11, and 19 were selected as the reference locations on their respective separators, i. e. separators between bays 1 and 18, 1 and 2, and 11 and 12. The separator between bays 1 and 18 was examined first for a suitable reference thermocouple location because, of the the three instrumented separators, it was the only one that was not obviously shielded by some protuberance of the spacecraft for a model attitude of $\alpha = 0^\circ$. Scanning the eight thermocouple locations on this separator, hereafter referred to as separator 1 - 18, revealed that one location in particular was superior in

repeatability and was consistently higher in temperature than any other location on separator 1 - 18. This singular thermocouple, selected as the reference location for separator 1 - 18, was at location 3. The reference thermocouple locations selected on separators 1 - 2 and 11 - 12 were 11 and 19, respectively. These locations are in the same relative positions on their respective separators as thermocouple number 3 on separator 1 - 18. The algebraic differences between the temperatures at the selected reference thermocouple locations and the temperatures at locations in their respective adjacent structure (hereafter referred to as ΔT_r) are presented in tabular form for all valid runs in Tables 4, 5, and 6. The data from these tables have been utilized in several plotting schemes to illustrate the influence of the test variables on the temperature distribution in the spacecraft model.

Angle of Attack and Antennae Effects

As a basis for discussing ΔT_r as a function of angle of attack, consider the variation of the selected reference locations with α . Figure 40 is a plot of the measured reference temperatures at the sixth second in the flow versus α ; the effect of antennae removal is also apparent in this figure. As would be expected, T.C. 3 on the unshielded separator 1 - 18 recorded the highest temperature at $\alpha = 0^\circ$; increasing or decreasing α resulted in lower temperatures at this location. Removal of the antennae had little effect on T.C. 3 temperatures. Thermocouple 11, just two bays away from T.C. 3, responded to α in the same manner as T.C. 3, however being shielded by the IRLS antennae replica reduced its temperature level. Antennae removal at location 11 had a significant effect in that the temperature increased at all α 's tested. The greatest increase was noted at $\alpha = -30^\circ$, where T.C. 11

approximated T.C.3. T.C. 19, 180° around the sensory ring from T.C. 11, responded to α changes quite differently than did T.C.'s 3 and 11. The highest temperature, at T.C. 19, was measured at $\alpha = -30^\circ$. Removal of the antennae resulted in lowering the temperature for $\alpha = -30^\circ$ and resulted in an α effect for T. C. 9 similar to that observed for T. C. 3 and 11. The high temperature measured by T.C. 19 can be attributed to the S-band antennae mounted above it. The sizeable protuberance of this antennae could disturb the flow significantly. Phenomena of this type can often be anticipated with the aid of flow visualization techniques.

The discussion of the temperature distribution data in the instrumented separators as affected by angle of attack and antennae removal will be limited to the plots presented in Figures 41 through 47 where the difference between the reference temperature and local temperature, ΔT_r , is plotted versus angle of attack. Each figure presents ΔT_r data versus angle of attack for three thermocouples located identically on the three instrumented separators.

Positive values of ΔT_r indicate that the reference thermocouple temperature is hotter than the local thermocouple temperature being compared with it; the converse is true for negative values of ΔT_r . Plots of ΔT_r versus α having the same shape as the reference temperature versus α curve indicate a minimized α effect, while ΔT_r versus α curves having shapes opposite to that of the reference temperature versus α curve indicate an increased α effect. These plots show that the reference temperature location, T.C. 3, on separator 1 - 18 is hotter than all the other instrumented locations tested on that separator for all angles of attack except for T.C. 2 at $\alpha = -60^\circ$. The

ΔT_r values for separator 1 - 18 are the greatest at $\alpha = 0^\circ$ for all locations except T.C. 7 and 8. The shape of the ΔT_r versus α curve indicates a minimized α effect for T.C.'s 1, 2, 4, 5, and 6. Locations 7 and 8 are on the leeward side of the model; therefore, they receive the majority of their heat via conduction. Consequently their resultant temperatures are substantially affected by the surrounding masses and conductive paths. It was noted throughout the test that the behavior of temperatures at locations either shielded from the airflow or in close proximity to large spacecraft components was difficult to relate to the expected influence of the aerodynamic heating. Removal of the antennae generally reduced the magnitude of ΔT_r for locations 4, 5, 6, and 7, however T.C.'s 1 and 2 on the windward surface had increased ΔT_r with antennae off. Antennae removal did not significantly alter the shape of the ΔT_r versus α curves for instrumentation locations on separator 1 - 18.

The reference temperature, T.C. 11, on separator 1 - 2 is cooler than T.C.'s 9 and 10, which lie on the windward surface of the separator and T.C. 16 which lies on the leeward surface. However, T.C. 11 recorded temperatures higher than the remainder of the locations on separator 1 - 2. There are two probable reasons for T.C. 11 being cooler than 9 and 10. Firstly, with antennae on, the IRLS antennae replica shields location 11 from the air flow, thus reducing the heat input. Secondly, although with antennae off the heat input to location 11 is increased, one of the main attachments for the "A-frame" ties into the sensory ring near location 11 and serves as a heat sink to conduct away some of the heat. Thermocouple 16 falls in the same category with 7 and 8, in that its behavior is difficult to relate to the aerodynamic heating. The ΔT_r versus α curves for thermocouples 12, 13, 14 and 15 are similar in shape to their

counterparts on separator 1 - 18; however, the magnitude of ΔT_r is less. Although the ΔT_r values are lower comparing actual temperatures, we find that the temperatures in the structure receiving the majority of their heat by conduction from the aerodynamically heated portions of the model are much closer in temperature to their counterparts in separator 1 - 18 than the locations which receive the majority of their heat directly from convective aerodynamic heating. This indicates an averaging of the maximum and minimum temperature on the windward surface by the internal structure of the model. Antennae removal had the same effect on the ΔT_r values for all locations measured on separator 1 - 2; i. e. all ΔT_r values increased in the positive direction. This increase in ΔT_r is due primarily to the increase in reference temperature except for location 2 where the ΔT_r increase is approximately twice the difference in reference temperature with and without antennae.

The reference temperature, T.C. 19, on separator 11 - 12 generally is higher than the temperatures at locations 17, 18, 20, 21, 22 and 23 for $\alpha = +30^\circ, 0^\circ$ and -30° . However, at $\alpha = -60^\circ$, when the outboard edge of separator 11 - 12 is in its most forward position, the most outboard thermocouple locations become hotter than the reference temperature. T.C. 24 behaves in the same manner as T.C. 16; i. e. it remains hotter than the reference temperature even though it is located on the leeward side of the model. At $\alpha = -30^\circ$, there is a substantial peak in the ΔT_r versus α curve at locations 17 and 20 with antennae on. This peak is due to a low temperature reading at these locations accompanied by a slight increase in the reference temperature. Here, we have one of the most drastic antennae effects; when

the antennae are removed, the peak disappears completely. These drastic changes are undoubtedly due to the flow patterns resulting from the S-band antennae as the model attitude is changed.

The reference temperature technique was not applied to the thermocouples located in the "A-frame" because the trends in these data could be best presented in terms of actual temperature. Figure 48 is a plot of "A-frame" temperatures versus angle of attack, with and without antennae. Of the five locations on the "A-frame" only three of them are on the windward surface of the model; however, all locations but 28 and 31 (midway between the windward and leeward surface) exhibit a similar trend with angle of attack. The maximum temperatures for locations 29 through 32 occur at either 0° or $+30^\circ$ angle of attack. The 0° attitude would be expected to provide the highest temperatures on the windward "A-frame" locations were it not for the presence of the antennae and the SIRS can in the midst of the structure. These components protrude from the "A-frame" in such a manner that they shield portions of the "A-frame" in varying degrees, depending on model attitude, as evidenced by the plots of Figure 48. The general temperature level through the "A-frame" structure is of the same order of magnitude as that of the reference temperature locations on the separators as shown when comparing Figures 40 and 48.

Total Pressure Effect

The reference temperature technique was also used to evaluate the temperature distribution in the model as a function of total pressure. However, the plotted data shown in Figures 50 through 55 were grouped differently. Tunnel

total pressure was varied at angles of attack of 0° and -60° . The nominal total pressures tested were 400, 1000 and 1800 psia. Each figure has all the ΔT_r data, from a single separator at one angle of attack, plotted versus total pressure in psia. The ΔT_r data plotted versus total pressure have the same properties as mentioned in the previous discussion on angle of attack effects; i. e. positive values of ΔT_r indicate that the reference thermocouple temperature is hotter than the local thermocouple temperature being compared with it. The converse is true for negative values of ΔT_r . It should be noted that ΔT_r versus P_o curves having the same shape as the reference temperature versus P_o curves indicate a minimized P_o effect while ΔT_r versus α curves having shapes opposite to that of the reference temperature versus P_o curve indicate an increased P_o effect.

A plot of the temperatures at the reference locations versus total pressure is presented in Figure 49 for angles of attack of 0° and -60° . Data points were not taken at the highest total pressure (≈ 1800 psia) with the antennae installed; the dashed fairings of Figure 49 are the result. The data from the antennae-installed and antennae-removed configurations (obtained at $P_o = 400$ psia) were used to estimate the curve through the antennae-installed data. Although the temperatures indicated by these curves are not quantitatively accurate at $P_o = 1800$ psia, it is valid to accept the qualitative trends indicated by the fairings. The difference in temperature level for the two angles of attack tested, as well as the relationship between the reference temperatures on the three separators, has been established in the previous discussion on angle of attack effects. The significance of Figure 49 is found in comparing the change in slope with increasing total pressure for $\alpha = 0^\circ$ and -60° . At $\alpha = 0^\circ$, the slope of the temperature versus total pressure curve decreases with increasing total pressure while at $\alpha = -60^\circ$, the temperature versus total

pressure curve slope is constant or increases slightly with increasing total pressure.

The temperature difference in the separators as a function of total pressure at $\alpha = 0^\circ$ as shown in Figures 50 through 52, has some interesting characteristics. In separator 1 - 18 the reference temperature is always hotter than the rest of the separator locations and of the three instrumented separators, the ΔT_r values in separator 1 - 18 are least sensitive to total pressure. The ΔT_r values in separator 1 - 2 differ greatly throughout the separator with locations on both the windward and leeward surfaces reaching higher temperatures than the reference location. These ΔT_r values generally increase with increasing total pressure, indicating that the actual temperature levels in the separator are not greatly affected by changing total pressure. The ΔT_r data in Figure 52 from separator 11 - 12 are not consistent with increasing total pressure and its sensitivity to total pressure is disguised by the surrounding structure.

The temperature difference data for the three instrumented separators at $\alpha = -60^\circ$ is presented in Figures 53 through 55. These plots show that there is little difference in the ΔT_r data from separators 1 - 18 and 1 - 2. The temperatures at locations on the windward surface are the closest in magnitude to the reference temperatures (except for location 16, on the leeward surface). Also, increased total pressure causes the difference between temperatures throughout the separator to increase. The temperature data from separator 11 - 12 is grouped closely to the reference temperature as indicated by the ΔT_r data. Only two thermocouple locations, 21 and 23, are cooler than the reference temperature for separator 11 - 12. These locations are well shielded from the airflow and should be cooler. However, location 24 is similarly located

and is as hot as the windward surface locations. The relatively high temperatures recorded for location 24 and its counterpart, location 16 on separator 1 - 2, have been characteristic of their behavior throughout the test and must be attributed to the influence of the surrounding structure.

The temperature data for the "A-frame" locations is plotted versus total pressure in Figure 56. The reference temperature technique for handling the "A-frame" data was not used in determining the effect of total pressure on "A-frame" temperatures for the same reason as stated in the previous discussion on angle of attack effects. The same technique used in fitting the curves of Figure 49 was used in fairing the "A-frame" versus total pressure curves. There is great similarity in the "A-frame" and separator reference temperature distributions plotted in Figures 49 and 56. The highest temperatures resulted at the $\alpha = 0^\circ$ attitude; antennae removal had a very small effect. The difference in temperature level for the two angles of attack tested as well as the relationship between the various locations on the "A-frame" was previously established in the discussion on angle of attack effects.

VIII CONCLUSIONS AND RECOMMENDATIONS

The objective of the thermal model test was to use the experimental results as a tool for verifying or improving the analytical computer program being used in SNAP-19 thermal analysis and to establish the temperature distribution history of the Nimbus-B under one typical re-entry environment. The experimental results are presented here. The following conclusions can be drawn from the test data obtained:

- 1) The data obtained from these tests are considered to be reliable and accurate for the model tested. The influence of instrumentation mass on model temperatures was not excluded.
- 2) As would be expected, the removal of antennae had no effect on sensory ring surface not covered or shadowed by antennae. However, it was also revealed that removal of antennae reduced temperature at certain locations, evidently influenced by the flow pattern change. It would be a mistake to assume the removal of antennae would automatically increase the temperature everywhere.
- 3) The location of maximum temperature changes with change of angle of attack; however, the maximum absolute temperature and the maximum temperature difference recorded always happened at angle of attack $\alpha = 0$.
- 4) Flow instability was probably taking place on the windward face of the separators with all antennae installed. This was exemplified by the erratic temperature fluctuation at certain locations in tests with antennae on. Removal of antennae greatly reduced these variations.

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TABLE I

Variation of Nimbus Stagnation Heat Rate
vs. Time for a Typical Reentry

<u>Time</u>	<u>Altitude</u>	<u>$\dot{q}_{\text{Stag}}$</u>	<u>Ref. Radius</u>
0	121 km	.452 watts/cm ²	None
200	117.5	.680
300		.906	
400	114.5	1.134	
500		1.470	
600	111.2	1.705	
700		2.38	
800	107.2	3.18	
900	105.2	4.32	
950		5.22	
1000	103	6.35	
1051		7.95	
1100	100.8	10.00	
1150	98.7	13.08	
1200	97.2	15.34	
1250	95.5	17.60	
1300	93.5	22.50	30.5 cm, spherical
1325		25.00	
1350	91.2	27.80	
1375	90	31.40	

TABLE I (continued)Variation of Nimbus Stagnation Heat Rate
vs. Time for a Typical Reentry

<u>Time</u>	<u>Altitude</u>	<u>$\dot{q}_{\text{Stag}}$</u>	<u>Ref. Radius</u>
1400	88.5	35.80	None
1410		37.40	↓
1420		39.70	30.5 cm, spherical
1425	86.7	41.20	↓
1430		42.60	↓
1440		45.40	↓
1450	85	48.80	↓

TABLE 2 RUN PROGRAM
NIMBUS-B, SNAP-19 10% THERMAL MODEL TEST
NASA - AMES 3.5-FOOT HYPERSONIC TUNNEL

<u>Run No.</u>	<u>α m (Deg.)</u>	<u>Pt (Psia)</u>	<u>Tt (°R)</u>	<u>$\dot{q}$ Btu/ft²/sec.</u>	<u>Remarks</u>
1	0	400 ^	2100 ↑	5.53 ↑	1st Trial Run, Short Duration, Approx. 3 sec.
2	0				2nd Trial Run, Short Duration, Approx. 6 sec.
3	0				1st Production Run, Will Try to Limit Time in Stream to Approx. 8 sec.
4	+30				T. C. #26 Lost
5	-30				
6	-60				
7	0				Repeat of Run 1
8	0				Repeat of Run 1
9	-60				Repeat of Run 6, Short Duration Approx. 4 sec., Need Longer Repeat
10	-60				Repeat of Run 6, Sensory Ring Came Loose, T. C. #28 Lost
11	0				Repeat of Run 1 With Repaired Model to Check Effects of Repairs, T. C. Output Slightly Low, Need Repeat
12	0				Repeat of Run 1, Good Repeat
13	-60	✓		↓	Repeat of Run 6
14	-60	400	↓	5.53	Repeat or Run 6
15	-60	1000	2100	8.76	Repeat of Run 6 at Higher Pressure

TABLE 2 (continued)

<u>Run No.</u>	<u>α m (Deg.)</u>	<u>Pt (Psia)</u>	<u>Tt (°R)</u>	<u>$\dot{q}$ Btu/ft²/sec.</u>	<u>Remarks</u>
16	0	1000	2100	8.76	
17	0	400	↑	5.53	T.C. #8 Lost, No Antennae
18	+30	↑	↑	↑	No Antennae
19	-30	↓	↑	↓	No Antennae
20	-60	400	↑	5.53	No Antennae
21	-60	1850	↓	11.85	T.C. #2 Lost, No Antennae
22	0	1835	2100	11.80	No Antennae

TABLE 3

6TH SECOND TEMPERATURE DATA - 10% THERMAL MODEL TEST

RUN	3	4	5	6	7	8	12	13	14	15	16	17	*18	19	20	21	22
T. C.	$\alpha = 0^\circ$ Po=400	$\alpha = +30^\circ$ Po=400	$\alpha = -30^\circ$ Po=400	$\alpha = -60^\circ$ Po=400	$\alpha = 0^\circ$ Po=400	$\alpha = 0^\circ$ Po=400	$\alpha = 0^\circ$ Po=400	$\alpha = -60^\circ$ Po=400	$\alpha = -60^\circ$ Po=400	$\alpha = -60^\circ$ Po=1000	$\alpha = 0^\circ$ Po=1000	$\alpha = 0^\circ$ Po=400	$\alpha = +30^\circ$ Po=400	$\alpha = -30^\circ$ Po=400	$\alpha = -60^\circ$ Po=400	$\alpha = -60^\circ$ Po=1850	$\alpha = 0^\circ$ Po=1835
1	960.0	810.2	762.9	674.5	832.7	846.5	834.3	694.4	686.7	795.9	1027.9	807.4	841.2	718.9	687.4	925.6	1208.9
2	1251.0	1132.0	1027.6	846.1	1074.6	1094.5	1051.8	903.5	891.3	1083.7	1257.3	1038.1	1245.6	935.0	883.2		
3	1260.9	1128.5	1044.1	760.6	1263.2	1286.7	1263.6	735.4	726.6	896.6	1533.7	1203.0	1150.4	1022.6	761.1	1137.2	1693.1
4	818.6	920.3	719.6	584.4	817.2	834.7	844.7	611.0	605.2	679.4	1156.8	841.5	941.5	722.2	619.1	832.4	1347.1
5	948.4	946.1	775.7	611.4	968.3	982.6	963.4	601.3	595.0	667.5	1253.7	944.2	931.7	768.7	610.5	831.7	1434.7
6	644.0	838.4	571.6	558.9	648.9	655.2	648.2	559.8	554.5	564.5	761.1	614.2	825.8	576.7	553.6	592.0	831.0
7	839.4	827.8	671.3	570.5	919.9	928.8	949.1	572.0	566.3	610.3	1170.6	930.5	890.3	693.9	575.9	725.4	1357.7
8	933.7	1027.2	741.2	579.8	943.1	954.8	948.9	584.6	580.3	661.5	1265.0						
9	1233.7	1326.7	1149.2	827.1	1210.2	1304.0	1144.8	825.1	867.3	1093.7	1489.1	1220.5	1331.9	1058.8	882.7	1277.5	1605.3
10	1220.2	1493.5	1085.1	707.7	1225.7	1277.2	1051.8	677.6	673.4	807.9	1288.9	994.5	1258.0	981.6	751.9	1122.8	1444.5
11	982.5	926.8	835.0	667.5	989.2	999.4	975.2	682.2	673.3	803.5	1308.1	1037.1	1029.1	999.9	700.4	1003.8	1617.2
12	733.5	884.4	621.6	576.2	782.7	791.4	781.5	587.2	581.5	633.3	980.7	775.7	804.8	719.1	575.5	675.9	1134.8
13	696.2	809.5	641.6	580.1	718.7	725.7	718.2	575.5	569.3	607.7	917.3	706.5	758.0	664.7	581.2	710.9	1185.5
14	608.4	785.0	580.8	557.0	618.4	620.3	601.7	558.2	554.3	563.8	677.3	594.8	818.5	572.0	551.2	583.7	756.1
15	864.7	1012.4	719.3	584.0	873.7	891.0	829.2	592.2	586.5	652.4	1105.9	919.4	1017.5	812.3	590.7	747.3	1449.6
16	1247.2	1274.7	1039.5	652.8	1266.1	1288.2	1276.2	632.6	621.8	771.0	1545.9	1186.5	1396.3	1081.1	700.9	1021.1	1685.9
17	835.0	774.1	748.9	865.0	842.1	851.1	852.8	918.4	902.3	1131.8	1170.1	869.6	760.2	881.6	846.3	1279.6	1569.2
18	902.6	931.3	888.8	850.0	909.0	922.4	918.2	875.8	860.6	1084.7	1191.3	957.4	873.3	831.3	837.0	1243.5	1553.3
19	928.6	909.2	1025.8	832.4	938.3	952.3	942.4	792.6	781.7	961.3	1195.1	926.0	871.9	894.9	867.3	1280.3	1391.2
20	697.7	578.0	685.3	831.1	698.4	707.0	729.4	848.9	848.9	1124.0	1107.1	630.2	555.6	829.7	850.4	1425.9	1145.0
21	687.8	671.7	750.3	679.6	694.8	699.7	686.7	644.0	638.2	761.9	874.5	680.1	672.7	703.3	658.9	1042.7	1121.5
22	624.7	560.2	799.6	889.0	634.9	638.4	622.5	876.8	864.8	1091.9	733.6	568.4	551.3	813.3	923.7	1382.3	784.5
23	621.2	565.9	632.5	723.1	628.6	631.2	603.5	689.9	685.3	866.2	699.0	610.0	561.7	621.1	728.5	1110.9	845.4
24	1082.6	1110.9	1070.7	875.8	1088.9	1105.2	1216.2	903.0	882.1	1081.6	1462.9	1031.4	1176.3	1080.9	848.9	1266.3	1453.7
25	694.3	732.9	665.2	596.6	697.6	702.1	692.7	586.3	579.4	608.7	795.8	674.1	746.8	662.2	599.6	699.7	887.4
26	1401.7																
27	755.2	651.6	808.1	885.7	761.7	785.6	795.2	1035.3	922.2	1223.3	1079.1	698.8	637.4	748.2	778.5	1415.6	1171.3
28	856.2	781.3	888.8	853.5	867.7	879.3											
29	926.3	881.4	900.9	827.3	938.3	952.5	962.0	916.1	910.8	1178.7	1331.7	1033.2	846.3	901.6	799.6	1331.7	1485.0
30	1207.8	1178.2	1098.0	933.7	1213.0	1234.6	1225.7	900.5	883.7	1092.1	1524.1	1175.3	1219.5	1107.1	935.5	1415.1	1684.7
31	1240.7	1285.2	984.9	1008.2	1237.5	1261.0	1278.6	1106.6	1092.4	1386.5	1635.5	1252.3	1184.9	1114.2	1079.5	1528.0	1786.5
32	1049.0	951.4	849.7	788.0	1051.8	1066.2	1041.3	773.3	760.6	934.3	1355.2	1011.7	986.0	910.4	798.6	1202.2	1502.2

* Denotes Extrapolated Temperatures

TABLE 4

6th Second T_r Data

= 0°

no

antennae

no

antennae

 $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$
 $P_0=400$ $P_0=400$ $P_0=400$ $P_0=400$ $P_0=1000$ $P_0=400$ $P_0=1835$
 $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$ $\alpha=0$
 $P_0=400$ $P_0=400$ $P_0=400$ $P_0=400$ $P_0=1000$ $P_0=400$ $P_0=1835$

T.C.	Run 3 ΔT_r	Run 7 ΔT_r	Run 8 ΔT_r	Run 12 ΔT_r	Run 16 ΔT_r	Run 17 ΔT_r	Run 22 ΔT_r	T.C.	Run 3 ΔT_r	Run 7 ΔT_r	Run 8 ΔT_r	Run 12 ΔT_r	Run 16 ΔT_r	Run 17 ΔT_r	Run 22 ΔT_r
3-1	300.9	430.5	440.2	429.3	505.8	395.6	484.2	19-17	93.6	96.2	101.2	89.6	25.0	56.4	-178.0
3-2	9.9	188.6	192.2	211.8	276.4	164.9	--	19-18	26.0	29.3	29.9	24.2	3.8	-31.4	-162.1
3-4	442.3	446.0	452.0	418.9	376.9	361.5	346.0	19-20	230.9	239.9	245.3	213.0	88.0	295.8	246.2
3-5	312.5	294.9	304.1	300.2	280.0	258.8	258.4	19-21	240.8	243.5	252.6	255.7	320.6	245.9	269.7
3-6	616.9	614.3	631.5	615.4	772.6	588.8	862.1	19-22	303.9	303.4	313.9	319.7	461.5	357.6	606.7
3-7	421.5	343.3	357.9	314.5	363.1	272.5	335.4	19-23	307.4	309.7	321.1	338.9	496.1	316.0	545.8
3-8	327.2	320.1	331.9	314.7	268.7	--	--	19-24	-154.0	-150.6	-152.9	-273.8	-267.8	-105.4	-62.5
3-25	566.6	565.6	584.6	570.9	737.9	528.9	805.7	19-27	173.4	176.6	166.7	147.2	116.0	227.2	219.9
T @ 3	1260.9	1263.2	1286.7	1263.6	1533.7	1203.0	1693.1	T @ 19	928.6	938.3	952.3	942.4	1195.1	926.0	1391.2
11-9	-251.2	-221.0	-304.6	-169.6	-181.0	-183.4	+11.9	31-28	384.5	369.8	381.7	--	--	--	--
11-10	-237.7	-236.5	-277.8	-76.6	19.2	42.6	172.7	31-29	314.4	299.2	308.5	316.6	303.8	219.1	301.5
11-12	249.0	206.5	208.0	193.7	327.4	261.4	482.4	31-30	32.9	24.5	26.4	52.9	111.4	77.0	101.8
11-13	286.3	270.5	273.7	257.0	390.8	330.6	431.7	31-32	191.7	185.7	194.8	237.3	280.2	240.6	284.3
11-14	374.1	370.8	379.1	373.5	630.8	442.3	861.1	T @ 31	1240.7	1237.5	1261.0	1278.6	1635.5	1252.3	1786.5
11-15	117.8	115.5	108.4	146.0	202.2	117.7	167.6								
11-16	-264.7	-276.9	-288.8	-301.0	-237.8	-149.4	-68.7								
11-26	-419.2	--	--	--	--	--	--								
T @ 11	982.5	989.2	999.4	975.2	1308.1	1037.1	1617.2								

ENG. REP. NO.

PAGE

35.

TABLE 5

6th Second T_r Data $\alpha = +30^\circ$ $\alpha = -30^\circ$

no antennae

 $\alpha = +30^\circ$ $\alpha = -30^\circ$ $\alpha = +30^\circ$ $\alpha = -30^\circ$
 $P_0=400$ $P_0=400$ $P_0=400$ $P=400$

T.C.	Run 4 ΔT_r	Run 5 ΔT_r	Run 18 ΔT_r	Run 19 ΔT_r				T.C.	Run 4 ΔT_r	Run 5 ΔT_r	Run 18 ΔT_r	Run 19 ΔT_r			
3-1	318.3	281.2	309.2	303.7				19-17	135.1	276.9	111.7	13.3			
3-2	-3.5	16.5	-95.2	87.6				19-18	-22.1	137.0	-1.4	63.6			
3-4	208.2	324.5	208.9	300.4				19-20	331.2	340.5	316.3	65.2			
3-5	182.4	268.4	218.7	253.9				19-21	237.5	275.5	199.2	191.6			
3-6	290.1	472.5	324.6	445.9				19-22	349.0	226.2	320.6	81.6			
3-7	300.7	372.8	260.1	328.7				19-23	343.3	393.3	310.2	273.8			
3-8	101.3	302.9	--	--				19-24	-201.7	-44.9	-304.4	-186.0			
3-25	395.6	378.9	403.6	360.4				19-27	257.6	217.7	234.5	146.7			
T @ 3	1128.5	1044.1	1150.4	1122.6				T @ 19	909.2	1025.8	871.9	894.9			
11-9	-399.9	-314.2	-302.8	-58.9				31-28	503.9	96.1	--	--			
11-10	-566.7	-250.1	-228.9	18.3				31-29	403.8	84.0	338.6	212.6			
11-12	42.4	213.4	224.3	280.8				31-30	107.0	-113.1	-34.6	7.1			
11-13	117.3	193.4	271.1	335.2				31-32	333.8	135.2	198.9	203.8			
11-14	141.8	254.2	210.6	427.9				T @ 31	1285.2	984.9	1184.9	1114.2			
11-15	-85.6	115.7	11.6	187.6											
11-16	-347.9	-204.5	-367.2	-82.2											
11-26	--	--	--	--											
T @ 11	926.8	835.0	1029.1	999.9											

TABLE

6th Second T_r Data $= -60^\circ$

no antennae							= -60°	no antennae								
$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 1850$	$\alpha = -60$ $P_0 = 1000$		$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 400$	$\alpha = -60$ $P_0 = 1850$	$\alpha = -60$ $P_0 = 1000$				
T.C.	Run 6 ΔT_r	Run 13 ΔT_r	Run 14 ΔT_r	Run 20 ΔT_r	Run 21 ΔT_r	Run 15 ΔT_r	T.C.	Run 6 ΔT_r	Run 13 ΔT_r	Run 14 ΔT_r	Run 20 ΔT_r	Run 21 ΔT_r	Run 15 ΔT_r			
3-1	86.1	41.0	39.9	73.7	211.6	100.7	19-17	-32.6	-125.8	-120.6	21.0	0.7	-170.5			
3-2	-85.5	-168.1	-164.7	-122.1	--	-137.1	19-18	-17.6	-83.2	-78.9	30.3	36.8	-123.4			
3-4	176.2	124.4	121.4	142.0	304.8	217.2	19-20	1.3	-56.3	-67.2	16.9	-145.6	-162.7			
3-5	149.2	134.1	131.6	150.6	305.5	229.1	19-21	152.8	148.6	143.5	208.4	237.6	199.4			
3-6	201.7	175.6	172.1	207.5	545.2	332.1	19-22	-56.6	-84.2	-83.1	-56.4	-102.0	-130.6			
3-7	190.1	163.4	160.3	185.2	411.8	286.3	19-23	109.3	102.7	96.4	138.8	169.4	95.1			
3-8	180.8	150.8	146.3	--	--	235.1	19-24	-43.4	-110.4	-100.4	18.4	14.0	-120.3			
3-25	164.0	149.1	147.2	161.5	437.5	287.9	19-27	-53.3	-242.7	-140.5	88.8	-135.3	-262.0			
T @ 3	760.6	735.4	726.6	761.1	1137.2	896.6	T @ 19	832.4	792.6	781.7	867.3	1280.3	961.3			
11-9	-159.6	-142.9	-194.0	-182.3	-273.7	-290.2	31-28	154.7	--	--	--	--	--			
11-10	-40.2	+4.6	-0.1	-51.5	-119.0	-4.4	31-29	180.9	190.5	181.6	279.9	196.3	207.8			
11-12	91.3	95.0	91.8	124.9	327.9	170.2	31-30	74.5	206.1	208.7	144.0	112.9	294.4			
11-13	87.4	106.7	104.0	119.2	292.9	195.8	31-32	220.2	346.0	331.8	280.9	325.8	452.2			
11-14	110.5	124.0	119.0	149.2	420.1	239.7	T @ 31	1008.2	1106.6	1092.4	1079.5	1528.0	1386.5			
11-15	83.5	90.0	86.8	109.7	256.5	151.1										
11-16	14.7	49.6	51.5	-.5	-17.3	32.5										
11-26	--	--	--	--	--	--										
T @ 11	667.5	682.2	673.3	700.4	1003.8	803.5										

TUNNEL CIRCUITRY SCHEMATIC DIAGRAM

Fig. 1 NASA Ames 3.5-foot Tunnel
Circuitry-Schematic Diagram

Fig. 2 Photograph of 3.5-foot Tunnel Plant Model

Fig. 3 NASA Ames 3.5-foot Tunnel Pebble Bed Heater-Schematic Diagram

Fig. 4 Photograph of 3.5-foot
Tunnel Pebble Bed Heater Model

AMES 3.5 FT. HYPERSONIC TUNNEL

OPERATING REGIME @ $M_\infty 10.4$

Fig. NASA Ames 3.5-foot Hypersonic Tunnel
 - Operating Regime @ $M_\infty 10.4$

Fig. 6 Plan View of 10% Nimbus B
Thermal Model Installed in 3.5-foot Tunnel Test Section

Fig. 7. NASA-Ames 3.5-Foot Hypersonic Tunnel Test Section
with 10% Thermal Model Installed

Fig. 8 10% Thermal Model of Nimbus B
Sensory Ring - Assembly Drawing

ALL WELDS MUST HAVE
FULL PENETRATION

SIDE PLATE - .004 THICK
SCALE 2:1

SEPARATOR
MADE FROM .012 THICK SHEET
SCALE 2:1

DETAIL	HOLE "A"		HOLE "B"		QUANT.
	T	B	T	B	
-1	X	X	X	X	7
-3	X		X		8
-5	X	X		X	3

Fig. 9 10% Thermal Model of Nimbus B
Sensory Ring-Separator Details

Fig. 10. Ten Percent Thermal Model Components

Fig. 11. Frontal View of Partially Assembled Model--Thermocouple Wire Routing

Fig. 12. Side View of Partially Assembled Model--Thermocouple Wire Routing

Fig. 13. Frontal View of Partially Assembled Model--SIRS
Can Installed

Fig. 14. Rear View of Partially Assembled Model--SIRS Can Installed

Fig. 15. Front View of Completed 10% Thermal Model

Fig. 16. Rear Three-Quarter View of Completed 10% Thermal Model

Fig. 17. Side View Close-up of Completed 10% Thermal Model

55.

Technical drawing showing a cross-section of a wall and module assembly.

Dimensions and labels:

- Overall width: .650
- Module diameter: .060 (TYR)
- Module spacing: .100
- Module width: .600
- Wall thickness: .012
- Module height: .650 ("B" DIM.)
- Module 1 width: .200
- Module 2 width: .400
- Module 3 width: .600
- Module 4 width: .800
- Module spacing: .200 (TYR)
- Label: WALL THICKNESS

The image contains two technical drawings. The left drawing, titled "TRANSITE INSTALLATION", shows a cross-section of a module with a Transite material inside. Labels include "MODULE", "TRANSITE", and "CONTACT WIDTH". The right drawing, titled "DETAIL OF NICKEL SLUG", shows a cross-section of a nickel slug with dimensions: .540, .460, .740, .015, and .221. A label "LAND BRAZED TO TOP OF MODULE" points to a specific feature on the slug.

BAY	1	2	3	10	11	12	13	17	18	-169 CROSS BEAM	-179 CROSS BEAM
MODULE SIZE	0 4	1 4	4 4	4 4	4 4	4 4	2 4	3 4	4 2	3 3	2 2
WALL THICK.	— .025	.025 .010	.012 .025	.012 .012	.018 .035	.018 .035	.025 .025	.025 .025	.025 .025	.012 .012	.012 .012
"B" DIM.	.650	.650	.650	.650	.650	.650	.650	.650	.650	1.300	1.300
SIMU- LATION MAT'L	NICKEL 200	TRAN- SITE	TRAN- SITE NICKEL 200	TRAN- SITE	— TRAN- SITE	TRAN- SITE NICKEL 200	TRAN- SITE NICKEL 200	TRAN- SITE NICKEL 200	SS- 321 TRAN- SITE	TRAN- SITE	TRAN- SITE
CONTACT WIDTH	.460	.086 .067	.097 .460	.073 .073	— .075	.054 .460	.190 .460	.130 .460	.078 0.122 0.14	.073	.100

Fig. 18 10% Thermal Model - Module Details and Materials

SEPARATOR LOCATIONS SHOWN ON SEPARATOR (1-18) ARE IDENTICAL FOR ALL INSTRUMENTED SEPARATORS, SEE TABLE BELOW FOR CORRESPONDING THERMOCOUPLE NUMBERS.

SEPARATOR		
(1-18)	(1-2)	(11-12)
1	9	17
2	10	18
3	11	19
4 *	12 *	20 *
5 *	13 *	21 *
6	14	22
7	15	23
8	16	24

* DENOTES LOCATIONS MIDWAY BETWEEN TOP AND BOTTOM SURFACE OF SENSORY RING

Fig. 19 10% Thermal Model -
Instrumentation Location Sketch

Fig. 20. Frontal Installation View of 10% Thermal Model
Without Antennae

Fig. 21. Frontal Installation View of 10% Thermal Model Without Antennae

Fig. 22. Rear Three-Quarter View of 10% Thermal Model
with 0-deg Adapter

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	◊
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 23. Temperature-Time Histories - Run 3, $\alpha = 0^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	▽
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 24. Temperature-Time Histories - Run 4, $\alpha = +30^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	△
6	14	22	30	○
7	15	23	31	◇
8	16	24	32	▽

Fig. 25. Temperature-Time Histories - Run 5, $\alpha = -30^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	◁
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 26. Temperature-Time Histories - Run 6, $\alpha = -60^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	◁
5	13	21	29	△
6	14	22	30	○
7	15	23	31	▽
8	16	24	32	▽

Fig. 27. Temperature-Time Histories - Run 7, $\alpha=0^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▤
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 28. Temperature-Time Histories - Run 8, $\alpha = 0^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▤
5	13	21	29	△
6	14	22	30	○
7	15	23	31	◇
8	16	24	32	▽

Fig. 29. Temperature-Time Histories - Run 12, $\alpha_c = 0^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▵
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 30. Temperature-Time Histories - Run 13, $\alpha = -60^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	▽
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 31. Temperature-Time Histories - Run 14, $\alpha = -60^\circ$, $P_o = 400$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▵
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 32. Temperature-Time Histories - Run 15, $\phi = -60^\circ$, $P_o = 1000$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▢
5	13	21	29	△
6	14	22	30	○
7	15	23	31	◊
8	16	24	32	▽

Fig. 33a. Temperature-Time Histories - Run 16, $\theta = 0^\circ$, $P_o = 1000$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	△
6	14	22	30	○
7	15	23	31	◇
8	16	24	32	▽

Fig. 33b. Temperature-Time Histories - Run 16, $\theta = 0^\circ$, $P_o = 1000$ PSIA

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	◁
5	13	21	29	△
6	14	22	30	○
7	15	23	31	◻
8	16	24	32	▽

Fig. 34. Temperature-Time Histories - Run 17, $\alpha = 0^\circ$, $P_o = 400$ PSIA
Antennae Removed

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	▽
6	14	22	30	○
7	15	23	31	◇
8	16	24	32	▽

Fig 35 Temperature-Time Histories - Run 18, $\alpha = +30^\circ$, $P_o = 400$ PSIA
Antennae Removed

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 36. Temperature-Time Histories - Run 19, $\alpha = -30^\circ$, $P_o = 400$ PSIA
Antennae Removed

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▵
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig. 37. Temperature-Time Histories, Run 20 $\alpha = -60^\circ$, $P_o = 400$ PSIA, Antennae Removed

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig 38 Temperature-Time Histories - Run 21, $\alpha = -60^\circ$, $P_o = 1850$ PSIA
Antennae Removed

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	▤
5	13	21	29	△
6	14	22	30	○
7	15	23	31	◇
8	16	24	32	▽

Fig 39a Temperature-Time Histories - Run 22A, $\alpha = 0^\circ$, $P_o = 1835$ PSIA, Antennae Removed

Thermocouple No.				Symbol
1	9	17	25	○
2	10	18	26	□
3	11	19	27	◇
4	12	20	28	△
5	13	21	29	△
6	14	22	30	○
7	15	23	31	☆
8	16	24	32	▽

Fig 39b Temperature-Time Histories Run 22-B, $\alpha = 0^\circ$, $P_o = 1835$ PSIA, Antennae Removed

Fig. 40 Separator Reference Temperatures
vs. Angle of Attack, $P_0 = 400 \text{ PSIA}$

SW ΔT_c

○ 5-1

□ 11-9

△ 19-17

FLAG DENOTES
ANTENNAE OFF $P_0 = 400$

Fig. 41 Separator ΔT_r Values vs. Angle of Attack, Locations 1, 9 and 17, $P_0 = 400$ PSIA

Fig. 42 Separator ΔTr Values vs.
Angle of Attack, Locations 2, 10 and 18, $P_0 = 400$ PSIA

Fig. 43 Separator ΔTr Values vs.
Angle of Attack, Locations 4, 12 and 20, $P_0 = 400$ PSIA

Fig. 44 Separator ΔTr Values vs.
Angle of Attack, Locations 5, 13 and 21, $P_0 = 400$ PSIA

ΔTr ΔTr
 ○ 3-6
 □ 11-14
 △ 19-22
 FLAG DENOTES
 ANTENNAE OFF
 $P_0 = 400$

Fig. 45 Separator ΔTr Values vs. Angle of Attack, Locations 6, 14 and 22, $P_0 = 400$ PSIA

Fig. 46 Separator ΔTr Values vs. Angle of Attack, Locations 7, 15 and 23, $P_0 = 400$ PSIA

Fig. 47 Separator ΔT_r Values vs.
Angle of Attack, Locations 8, 16 and 24, $P_0 = 400$ PSIA

Fig. 48 A-frame Temperatures vs. Angle of Attack, $P_0 = 400 \text{ PSIA}$

Fig. 49 Separator Reference Temperatures vs. Total Pressure, $\alpha = 0^\circ$ and -60°

Fig. 50 Separator 1-18 ΔT_r Values vs. Total Pressure, $\alpha = 0^\circ$

Fig. 51 Separator 1-2 ΔTr Values vs. Total Pressure, $\phi = 0^{\circ}$

Fig. 52 Separator 11-12 ΔTr Values vs. Total Pressure, $\alpha = 0^\circ$

Fig. 53 Separator 1d8 $\Delta T Tr$ Values vs. Total Pressure, $\lambda = -60^\circ$

Fig. 54 Separator 1-2 ΔTr Values vs. Total Pressure, $\phi = -60^\circ$

Fig. 55 Separator 11-12 ΔTr Values vs. Total Pressure, $\phi = -60^{\circ}$

Fig. 56 A-frame Temperatures vs. Total Pressure, $\alpha = 0^\circ$ and -60°