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REPORT 375

TECHNIQUES AND INSTRUMENTATION ASSOCIATED WITH ROCKET MODEL HEAT-TRANSFER INVESTIGATIONS

by

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(6) TECHNIQUES AND INSTRUMENTATION ASSOCIATED
WITH ROCKET MODEL HEAT-TRANSFER INVESTIGATIONS,

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This Report is one in the Series 375-397, inclusive, presenting papers, with discussions, given at the AGARD Specialists' Meeting on 'The Use of Rocket Vehicles in Flight Research' at the Kurhaus Hotel, Scheveningen, Holland, 18-21 July 1961, sponsored by the AGARD Fluid Dynamics Panel

FOREWORD

The Meeting on 'The Use of Rocket Vehicles in Flight Research' held in Scheveningen, Holland during July 1961 was sponsored by the AGARD Fluid Dynamics Panel, and was intended for specialists in this subject. It was felt that the papers, together with the discussions, would contain information which would be new and of direct use to such an audience in their work.

The Meeting dealt both with research techniques and with design and operational problems.

The papers read may be grouped into eight sections, according to the subjects considered, as follows:

RESEARCH TECHNIQUES

1. Heat Transfer
2. Aerodynamic Stability and Dynamics
3. Wind, Turbulence and Meteorology
4. Space Environment

DESIGN AND OPERATIONAL PROBLEMS

5. General
6. Design and Development
7. Instrumentation

SPECIAL TOPICS

8. Pyrotechnics and Payload Recovery

Each paper, together with its discussion and authors' replies is published as a separate report, making in all twenty three papers (Reports 375-397 inclusive). Also included, at the end of each report, is an Addendum containing a list of the titles and authors of all the papers.

SUMMARY

In the study of aerodynamic heat transfer and thermal protection by use of rocket-propelled models several factors must be considered. The over-all model configuration should fly at zero angle of attack although the model can be designed to provide heat-transfer measurements on bodies and surfaces at angle of attack. Different trajectories that could be obtained with the same rocket model provide quite different test conditions and the selected trajectory must be accurately predicted for design of the heat-transfer model. The instrumentation carried within the model is generally not extensive, but design of the skin as a calorimeter and the installation of thermocouples require particular attention. To determine the heat-transfer rate on a thermally-thick skin, the previous time history of skin temperature must be considered, and rapid fluctuations of the heating rate may be obscured. The instantaneous heating rate on a thermally-thin skin can be determined directly from the corresponding time rate of change of skin temperature.

Investigations of the effectiveness of transpiration cooling can be made with rocket models carrying additional instrumentation to measure coolant flow rates. For investigations of the ablation of teflon due to aerodynamic heating a continuous-reading ablation sensor has been developed and used successfully in rocket model tests.

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NOTATION

h	heat-transfer coefficient
C_w	specific heat of skin material
C_ρ	specific heat of air
W	specific weight of skin material
q	heat flux
T	temperature
τ	skin thickness
K	conductivity of skin material
F	shape factor
σ	Stefan-Boltzmann constant
ϵ	emissivity
t	time
ρ	density of air
v	velocity of air just outside boundary layer

TECHNIQUES AND INSTRUMENTATION ASSOCIATED WITH ROCKET MODEL HEAT-TRANSFER INVESTIGATIONS

C.B. Rumsey*

1. INTRODUCTION

For several years the National Aeronautics and Space Administration has devoted a major effort to the study of convective aerodynamic heat transfer and methods for thermal protection. An important phase of that effort has been through the use of rocket-propelled, free-flight models. Heat-transfer investigations are need at high Mach numbers with the high enthalpy conditions of flight in the real atmosphere, which rocket models provide, because the viscous boundary layer causing the heat transfer is itself greatly influenced by the temperatures developed within it. Rocket model investigations are therefore needed to confirm or evaluate heat-transfer formulae obtained from theoretical analysis or from low enthalpy experimental investigations. They are also needed to obtain data from which empirical relations can be developed for problem areas, such as separated flow, where theory is not well established. Although rocket models are poorly suited for parametric studies, they are valuable to proof-check the heat-transfer predictions for a specific shape when this is necessary in the design of a hypersonic missile or airplane.

Many factors must be considered in planning and carrying out heat-transfer investigations with unguided, multistage rocket vehicles. This paper will discuss some of the techniques associated with model configuration, trajectory planning, model instrumentation, and interpretation of the basic heat-transfer data.

2. MODEL CONFIGURATION

One of the first requirements is that the rocket vehicle have a high degree of aerodynamic stability. With a multistage vehicle, the final stage plus its heat-transfer model should, in particular, be very stable, so that any disturbance due to final-stage ignition will damp out rapidly, and the model will be at zero angle of attack during the high-speed, data collecting part of the flight.

If the final-stage configuration is to fly at zero angle of attack, the heat-transfer model must be symmetrical, at least in the sense that it does not produce a resultant force normal to the longitudinal axis. A body of revolution is of course an optimum configuration and can be used in many cases. However, if the heating on a surface or body at angle of attack is being investigated, the lift of the surface must be balanced out by duplicating the surface. Figure 1 shows a model designed to investigate the heating on a highly swept delta wing at angle of attack. A three-sided pyramidal shape was used to obtain zero resultant lift on the configuration. Each face of the pyramid represented the windward surface of a 77° swept delta wing at an 8° angle of attack, and the rounded edges between the faces represented the delta wing leading edges. One face and one leading edge were instrumented as the

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principal test surface, although temperatures were of course measured at a few corresponding locations on all three faces. The model was mounted on the flare-stabilized final stage of a multistage vehicle. The importance of designing with a large margin of stability to cover the uncertainties in predicting the hypersonic stability characteristics of rather unconventional shapes is pointed out by the fact that in this test the final stage trimmed at an angle of attack. However, valuable data were obtained and the trylon technique has been used successfully in other investigations.

Figure 2 shows a configuration designed to investigate the heating on the wings and bodies of two airplane-type configurations at angle of attack. The models were mounted on a Nike rocket motor at an 8° angle to the vehicle center line, with the model lift vectors opposing each other. The two wing planforms were not identical but the areas were proportioned to produce equal lift. Note the wedge-shaped fairing which was used to eliminate the converging area between the conical stings supporting the models. Without the fairing, the lift and drag forces on that part of the configuration would have been very difficult to predict. The Nike stage was fin-stabilized, and was the second stage of a two-stage propulsion system. The configuration flew at zero trim angle without oscillations, and the desired heat-transfer data were obtained.

3. TRAJECTORIES

With a multistage rocket vehicle a wide choice of test conditions can be obtained by changing the launch angle and the times of ignition of the stages, as indicated in Figure 3. The maximum Mach number remains approximately the same, but different trajectories produce widely different test conditions of Reynolds number and heat rate. For instance high Reynolds numbers and rapidly increasing heating rates can be obtained by using the first stages to provide altitude and firing the later stages after peak altitude along a re-entry-type trajectory. Lower heating rates which change much less rapidly can be obtained at lower Reynolds numbers by firing the later stages in a shallow climb just before peak altitude is reached. The type of trajectory chosen will of course depend on the objectives of the investigation. In any case, the trajectory used for design of the model skin thicknesses must be an accurate prediction of the actual flight. Since the skin temperatures reached during the flight depend on the time histories of altitude and velocity, the model may overheat, or heat too slowly for accurate measurement of the heating rates, if the actual flight does not follow the design trajectory quite closely. Therefore the trajectory computations must be based on accurate predictions of the weights, motor performances, and vehicle aerodynamics. Also, the effects of winds on the trajectory must be computed, so that the launch angle can be adjusted for the winds existing at the time of the test. Generally speaking, a heat-transfer test should be successful if the maximum Mach number and its altitude match the predicted values within about 10% and 10,000 ft, respectively. However, to stay within these limits requires careful preflight computations of the trajectory and wind effects, and ignition of the later stages must occur very close to the prescribed times.

4. MODEL INSTRUMENTATION

Because high velocity is generally of primary importance in a heat-transfer investigation, space and weight limitations require that only very essential instrumentation be carried in the model. The flight conditions, that is, the velocity and ambient air conditions, are obtained primarily from ground instrumentation such as tracking radar and rawinsonde sets, rather than from instrumentation in the model. However, as indicated in Figure 4, a longitudinal accelerometer should be included in the model instrumentation to aid in obtaining precise velocity data during the thrusting periods of the flight. During high acceleration, the velocity can be determined more accurately from integration of the accelerometer data than from differentiation of the tracking radar data. The model instrumentation should also include a normal and a transverse accelerometer. The magnitude of an oscillating angle of attack could be determined from these instruments alone only if they were located at the model center of gravity and the model roll rate was esstentially constant. However, the measurements will indicate the duration and frequency of oscillations in angle of attack and will provide an estimation of the magnitude of a trim angle of attack. It is also desirable to measure surface static pressures and total pressures outside the boundary layer, but the orifices and probes must be located so as not to disturb the boundary layer at the heat-transfer stations. These measurements provide the local flow conditions needed in the analysis of the heat-transfer data. If not measured, they must be computed from flight conditions and estimates of the pressure coefficients and total pressures along the model.

The basic heat-transfer data are, of course, the skin temperatures. Thermocouples are unquestionably the best available means of measuring them. In order to obtain temperature measurements at several locations on the skin, the voltages from several thermocouples are usually commutated on one telemeter channel. Along with the thermocouple voltages, a series of known voltages equivalent to temperatures spaced over the expected temperature range can also be commutated on the channel. This provides an in-flight calibration for the telemetered temperature data.

The kind of thermocouple wire used will depend on the temperature range to be covered and on the millivolts output required by the telemeter for reasonable sensitivity. Iron-constantan is generally used in NASA models for temperatures up to about 900°F and chromel-alumel is used if the temperatures are expected to approach 2,000°F. Tungten-iridium has been used in a rocket model test to measure temperatures of 3,200°F on graphite. The smaller the thermocouple wire size, the less heat it will conduct away from the skin. However, wire smaller than number 30 (0.010 in diameter) is rather impractical because it is so easily broken during model handling.

Some methods of installing the thermocouples on the skin are shown in Figure 5. Spot welding is the most desirable method since it attaches the wire firmly to the skin and does not weaken the wire in the process Each wire of the thermocouple is attached separately so that the temperature measured is that of the skin surface itself, rather than that of a bead in contact with the surface. Thermocouples can be spot welded to magnesium and aluminum if rather critical combinations of welding current, pressure, and skill are used. Spot welding to Inconel, is, of course, no problem, but spot welding to copper is apparently impossible.

The puddle-weld technique was developed a few years ago for installations on moderately thick skins. It was needed because spot welding to magnesium was not possible at that time, and because there was some question as to whether peened installations would stand the vibrational conditions during rocket motor burning. However, peened thermocouples have since been proven satisfactory in flight tests, and this is the best method for copper skins up to about 3/8 in thick.

The best thermocouple installation for thicker copper skins, from the standpoint of accurate determination of heating rate, is a technique developed by the Lockheed Aircraft Company. A hole is bored in the skin and a matching plug with a shoulder is machined from a piece of the same copper. A hole is then drilled into the plug to an accurate depth relative to the shoulder. Using copper sheathed, alumina insulated, chromel-alumel thermocouple wire, which is commercially available, a thermocouple is formed at the bottom of the hole by inserting the copper sheath, with about one diameter of the bare thermocouple wires protruding, into a small puddle of silver solder at the bottom of the hole. The plug is heated during this operation to melt the silver solder, and is X-rayed afterwards to be certain no air was trapped in the bottom of the hole. The skin is then heated and the plug cooled to overcome the negative tolerance used to insure a tight fit, and the plug is pressed into the hole until the shoulder seats on the exterior surface of the skin. This accurately positions the thermocouple at a known depth under the outside skin surface. The plug is then finished flush with the surrounding skin. Transient heating rates on thick copper skins can be measured more accurately with this type of installation than with thermocouples peened to the inside surface, because the temperatures close to the surface within a thick wall respond more rapidly than the temperatures of the inside surface.

It may be noted at this point that heat-transfer measurements should not be made by use of plugs or inserts different in thickness or material from the surrounding skin, for instance with metallic plugs in a non-metallic skin. Reference 1 has shown that the resulting discontinuities in temperature along the skin surface make heat-transfer results obtained from such installations subject to large errors.

5. DETERMINATION OF HEATING RATES

To determine the aerodynamic heating rates from the measured skin-temperature time histories, the skin is used as a calorimeter, with the heat balance essentially as shown in Figure 6. The sketch shows the cross section of a hemispherical nose and indicates the heat flows for a small section of the skin near the stagnation point. The aerodynamic heating rate per unit exposed area, minus the rates of heat lost by conduction and radiation, is equal to the rate of heat accumulation in the skin per unit area. The conduction, radiation, and heat accumulation terms in the equation are evaluated from the measured skin temperatures and the known properties of the skin.

The aerodynamic heating rate is equal to the heat-transfer coefficient, which is the parameter being investigated, multiplied by the difference between the boundary-layer temperature and the skin temperature. The boundary-layer temperature is computed from the local flow conditions and a recovery factor whose value depends on whether the boundary layer is laminar or turbulent.

The conduction along the skin is a function of the skin thickness, the conductivity, a factor depending on body shape, and the distribution of temperature along the skin. In many cases the conduction term must be approximated because the measurement locations are too widely spaced to accurately define the temperature distribution. In order to minimize the conduction, it is sometimes possible to vary the skin thickness approximately in proportion to the anticipated heat-transfer distribution as indicated in Figure 6. This reduces the temperature gradients along the skin.

The measured skin temperatures are used in the computation of the radiation term which also includes the Stefan-Boltzmann constant and the emissivity of the skin. Accurate knowledge of the skin's emissivity is needed if the radiation term is significant. Loss of heat through internal radiation can be minimized by a thin reflective radiation shield mounted inside the skin. This also shields the telemeter instruments from the hot skin

If the skin is thermally thick, that is, if there is a significant temperature gradient through the skin, the distribution of temperature through the skin will be dependent on the previous time history of the heating. To determine the rate of heat accumulation in the skin from the measured skin temperatures in this case requires the use of a thick wall transient heating analysis such as that of Reference 2. This method is the most accurate and convenient means available for analyzing thermally thick wall-temperature measurements. However, if data from many thermocouples are to be analyzed, automatic computing equipment is very desirable to reduce the computation time.

If the skin is thermally thin, that is, if the temperature gradient through it is negligible, the rate of heat accumulation per unit area can be computed directly from the time derivative of the measured temperature, the specific heat of the skin material, C_W , and the weight of the skin per unit area, $W\tau$, as indicated in Figure 6.

Since the heat accumulation term is proportional to the skin thickness, the percentage accuracy in evaluating the heating can be no better than the percentage accuracy of the skin thickness measurements. Measurements should be made at each thermocouple location, since thickness variations of several per cent sometimes occur along supposedly constant thickness material.

The specific heat of the skin material must, of course, be known over the temperature range, and it must be relatively free of anomalies. This somewhat limits the choice of skin materials since the precise measurements of specific heat needed for this purpose are not available for all materials and several materials have anomalies which make them unsuitable. The specific heat of Inconel, which is often used for heat-transfer models, is shown in Figure 7. One rather small anomaly occurs near 1,200°F. The determination of heating rates from a temperature-time curve is inherently inaccurate in a region of specific heat anomaly, but the anomaly in Inconel extends over only a small temperature range.

Inconel has another characteristic which makes it a desirable material for heat-transfer models if radiation is likely to be important. Its emissivity can be stabilized by heating to 2,000° for about 15 minutes, as described in Reference 3. This forms a thin smooth oxide coating on the surface, and thereafter the emissivity as a function of temperature does not change, regardless of further heat cycling.

If the emissivity of a skin surface is not stable in this sense, the degree of oxidation that has occurred must be estimated in order to specify the emissivity.

Some other materials that have been used extensively in heat-transfer investigations are aluminum, magnesium, and copper Copper is a good material for models which will be exposed to high heating rates because of its very high heat capacity per unit of skin thickness, its fairly high melting temperature, and its very high thermal conductivity which minimizes temperature gradients through the skin. However, for the investigation of local hot spots, as in a region of wing-body interference, it is preferable to use a low-conductivity material such as Inconel, so that variations in heating along the skin are not obscured by conduction along the skin.

As noted previously, the heating rates on a thermally thin skin can be determined by graphically reading the slopes of the measured skin-temperature time curve. Figure 8 shows some data from Reference 4 that were analyzed in this way. These temperature-time histories were measured at three locations on the thin Inconel skin of a model designed to investigate heat transfer on a slender conical nose. The time period covers thrusting of the second-stage motor and coasting flight thereafter. The measured temperatures indicate that boundary-layer transition was moving along the body over the measurement stations. Since radiation and conduction along the skin were negligible, the aerodynamic heating rates were directly proportional to the slopes of the temperature curves, which were read graphically at particular times of interest. Figure 9 shows the time histories of the experimental heat-transfer coefficients, expressed as the non-dimensional Stanton number, which is the heat-transfer coefficient h divided by the product of specific heat, density, and velocity of the air just outside the boundary layer. The theoretical laminar and turbulent Stanton numbers are also plotted. The boundary layer was laminar at the forward station, except at two times when transition moved forward over the station and the heating rates changed to the turbulent level. The laminar boundary layer extended back as far as the second station only part of the time and did not reach the third station which had turbulent heating rates at all times. The data and theory are in quite good agreement. Note that because the skin was thermally thin the heat transfer coefficient for a particular time could be determined from the temperature and rate of change of temperature at that time. If the skin had been thermally thick the history of skin temperature prior to the time of interest would have had to be considered to determine the heat transfer coefficient for that time. The required analytical procedure, as well as the thermal damping of a thick skin would have tended to obscure the rapid movement of transition location that was observed.

6. TRANSPIRATION COOLING AND ABLATION INSTRUMENTATION

Rocket model investigations of transpiration cooling and the ablation utilize most of the techniques that have been discussed. In transpiration cooling investigations additional measurements must be telemetered from the model to define the coolant flow rate. Figure 10 shows the basic details of a model designed to investigate the effectiveness of ejecting nitrogen gas through a porous skin to alleviate the aerodynamic heating. The skin is porous stainless steel on one side of the conical nose and non-porous Inconel on the other side. An internal bulkhead forms a chamber under the porous side. Nitrogen gas is released from the storage tank into this chamber through a valve which opens at a prescribed time during the test. The mass flow rate of nitrogen through the skin is determined from measurements of the pressure differential across the skin and the pressure and temperature of the gas in the chamber. A ground calibration of the coolant flow rates through the porous material is, of course, necessary. Thermocouples spotwelded to the inside of the porous skin measure the heating rates with transpiration cooling, and thermocouples spotwelded to the Inconel skin provide reference measurements of the heat transfer to the uncooled skin.

In ablation investigations, accelerometer measurements to aid in determining the flight conditions are usually the only data telemetered in addition to the ablation measurements. Various types of sensors for measuring the ablation of the skin have been devised. One type, known as a break-wire system, utilizes a fragile wire embedded at a known depth in the skin and its destruction, when the skin ablates to that depth, breaks an electric circuit. This type of sensor is usable in principle in a variety of ablating materials. In another type devised for use in charring ablators, the charred layer which is electrically conducting completes the circuit between two wires embedded a known depth in the skin when the charred layer reaches that depth. Neither of these types has been completely satisfactory in tests to date. The break wires have sometimes failed to break immediately upon becoming exposed, and, in the other type, contact between the char layer and the wires has not always been good enough to complete the electrical circuit. However, development work is continuing. One objection to these types of sensors is that multiple make- (or break-) circuits must be built into the sensor to determine the ablation time history, that is, the ablation rates.

A sensor has been developed for use in an ablating teflon skin which provides a continuous measurement of the ablation. It is described in Reference 5 and is shown schematically in Figure 11. In principle it is an electrical capacitor that changes capacitance as ablation of the skin reduces the size of the plates. The condenser plates are two areas of aluminum plating about five one-hundred-thousandth of an inch thick deposited on a sheet of teflon approximately one-thousandth inch thick. The two areas of aluminum coating are separated electrically by an uncoated area, as shown in the sketch, and each has a tab for an electrical connection. With this sheet wrapped twice around a teflon rod, the teflon sheet forms the dielectric between the two sections of aluminum coating, which overlap one another to form the capacitor. The wrapped rod, with wires connected to the tabs, is pressed into a teflon plug, and the assembly is fitted into a hole in the thick teflon skin on which the ablation rates are to be measured. As the skin ablates, the length of the capacitor plates is reduced, and a continuous measurement of the ablation is obtained. The instrument has been used successfully over a variety of heating rates in both ground and flight investigations.

7. CONCLUDING REMARKS

Rocket model heat-transfer and thermal-protection investigations have unique value because the test conditions are those of high-speed flight in the real atmosphere. Some of the methods and techniques associated with these investigations have been discussed, and factors which must be considered have been pointed out. Although much effort has been devoted to development of these techniques in many organizations in addition to NASA, there is doubtless still room for ingenuity in most of the areas mentioned.

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Fig.1 Model simulating a delta wing at angle of attack

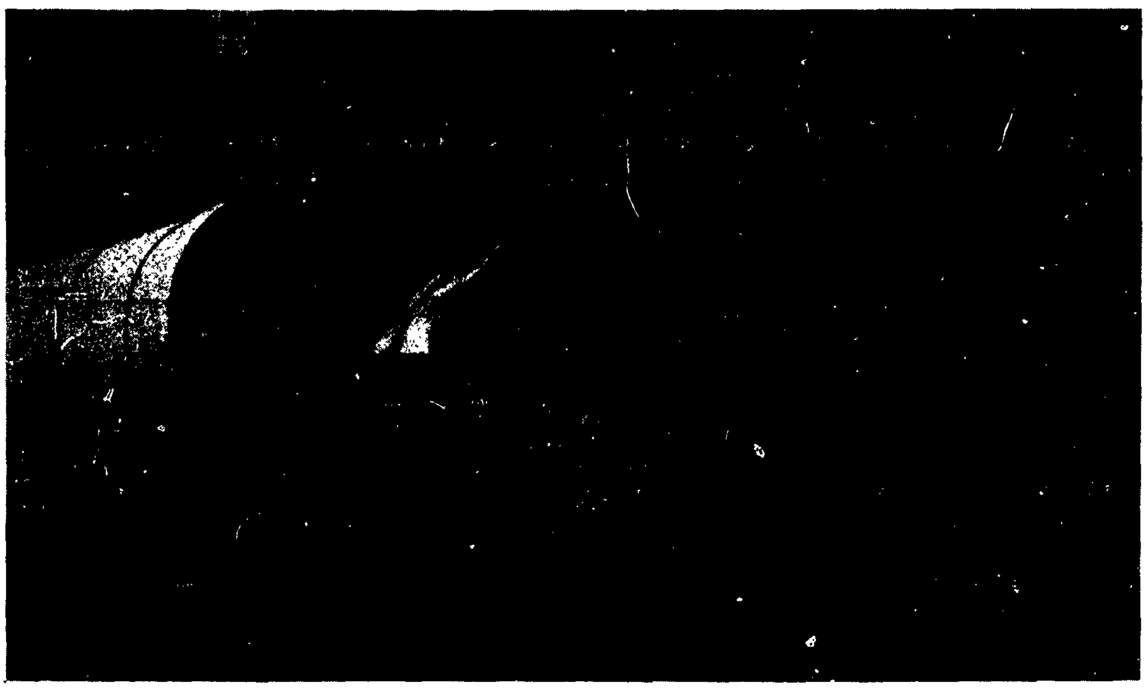


Fig.2 Airplane configurations at angle of attack

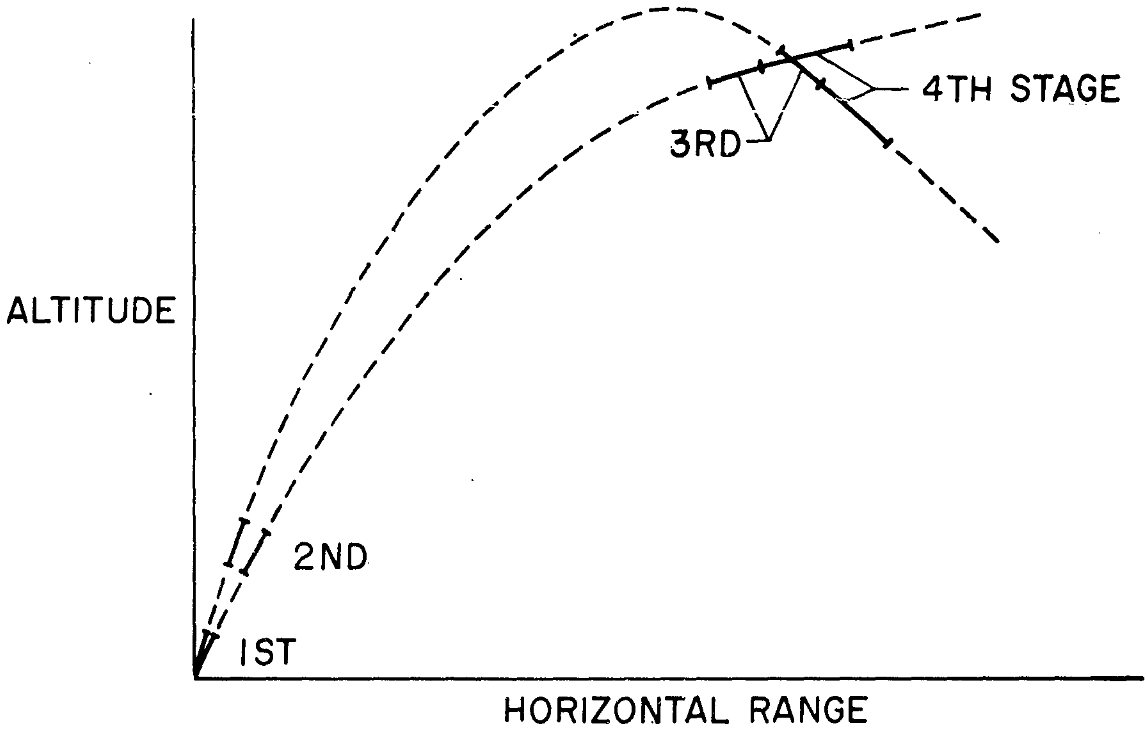


Fig.3 Types of multistage vehicle trajectories

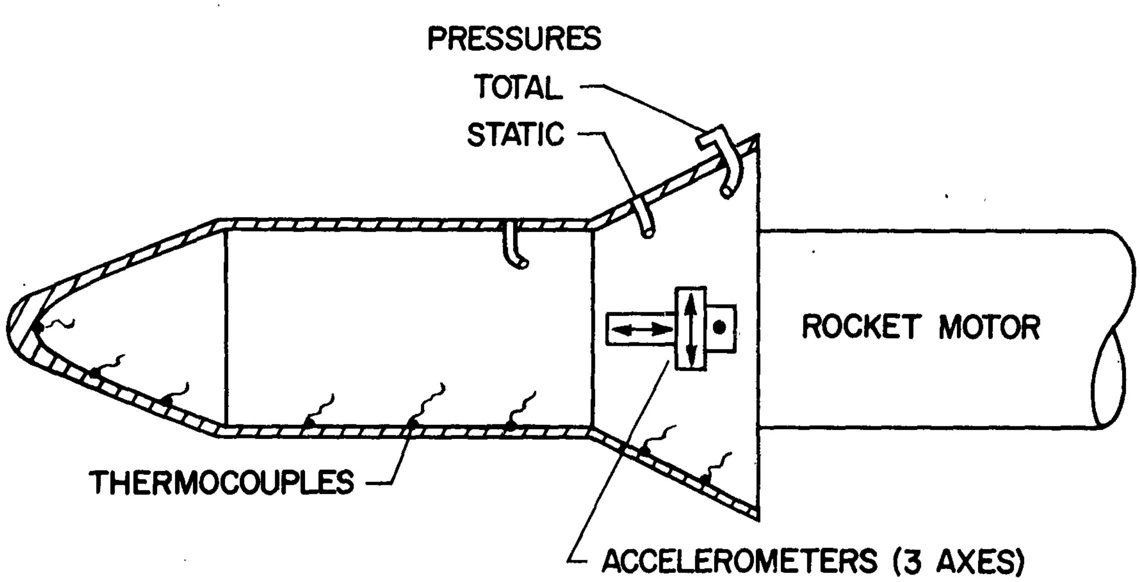


Fig.4 Telemetered measurements

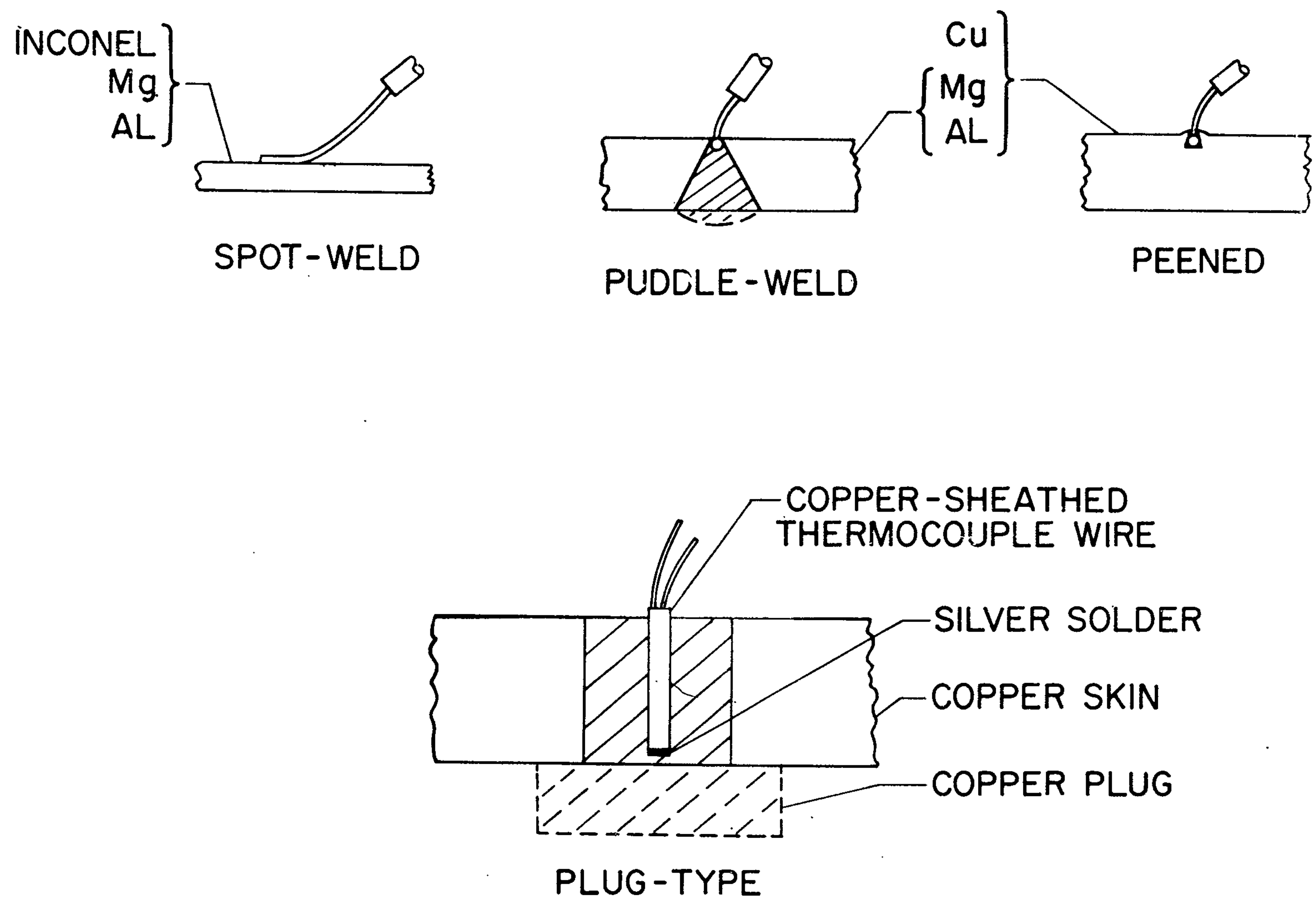
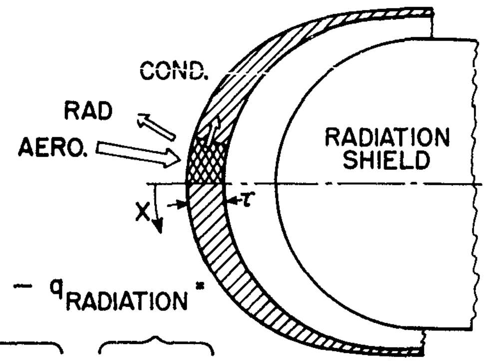


Fig.5 Skin thermocouple installations

HEAT BALANCE IN SKIN



$$\underbrace{q_{AERO}}_{h(T_{BL}-T_{SKIN})} - \underbrace{q_{CONDUCTION}}_{f\,(\tau,\ K,\ F,\ T_{SKIN})} - \underbrace{q_{RADIATION}}_{\sigma \epsilon T^4_{SKIN}} =$$

RATE OF ACCUMULATION OF HEAT PER UNIT SURFACE AREA =

$$W \tau C_W \frac{dT_{SKIN}}{dt} \quad \text{(FOR THIN SKIN)}$$

Fig.6 Heat balance in skin

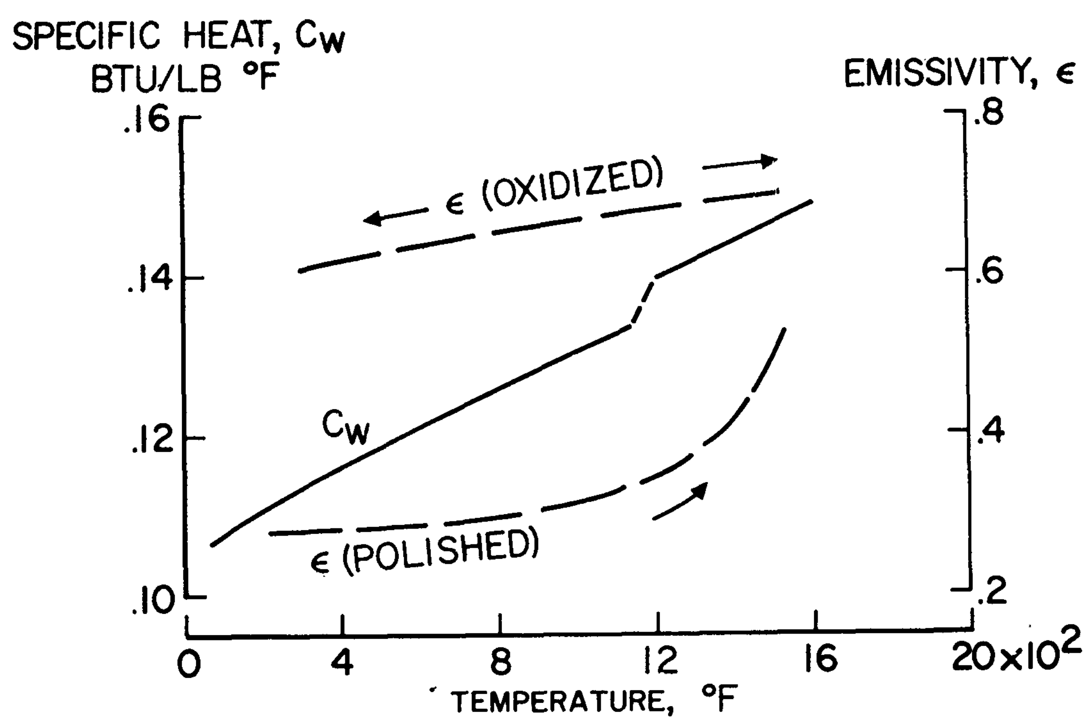


Fig.7 Specific heat and emissivity of Inconel

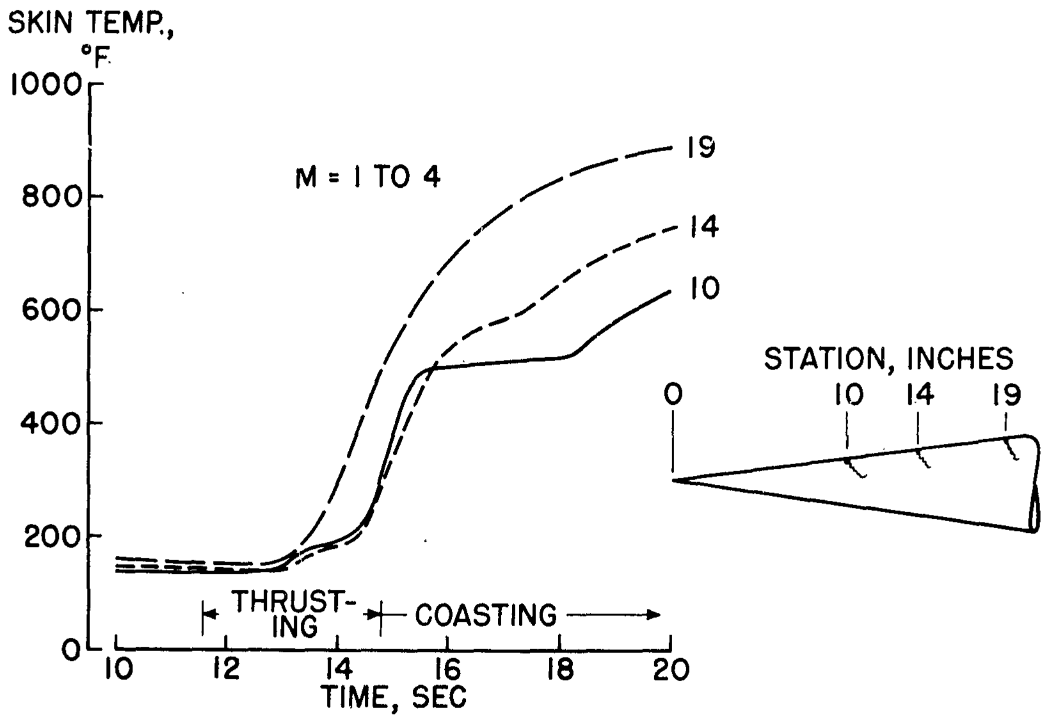


Fig.8 Temperatures measured on a thermally thin skin

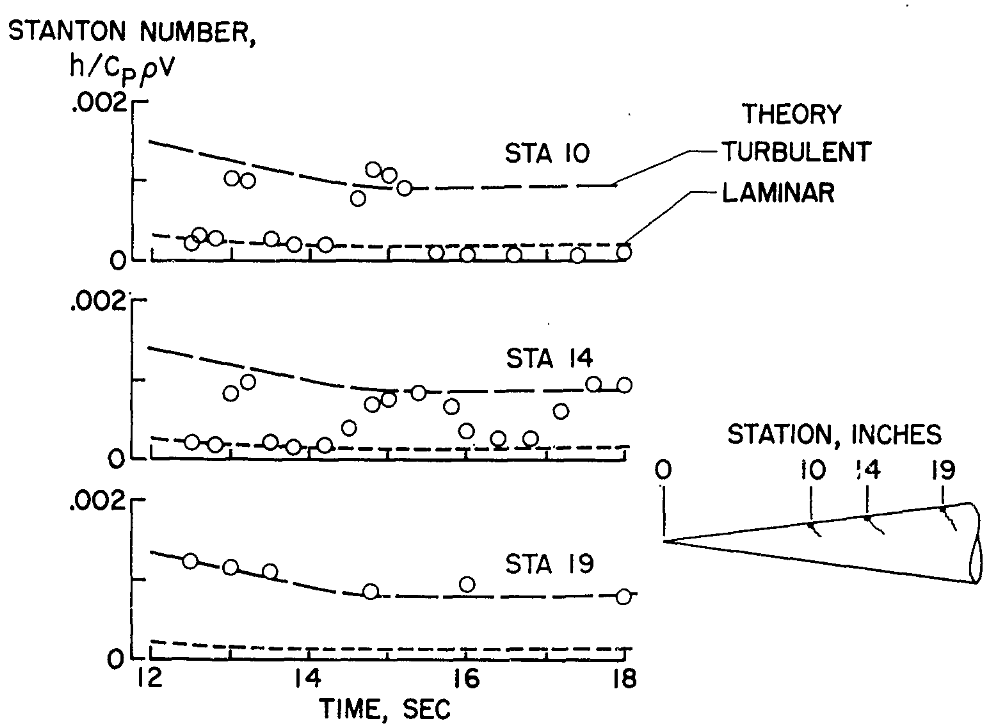


Fig.9 Results from thin-skin temperature measurements

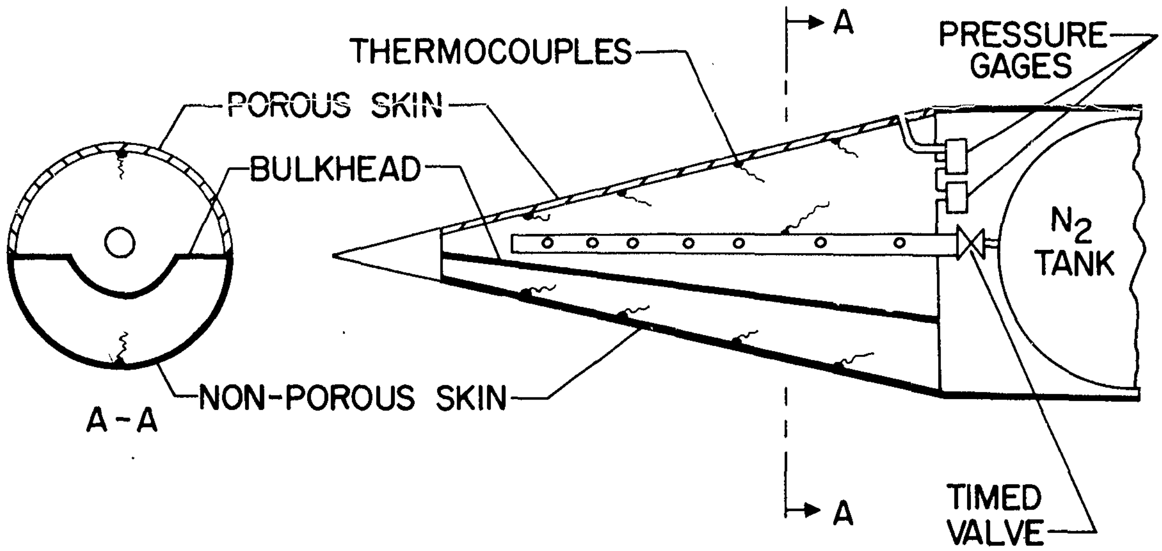


Fig.10 Transpiration cooling model

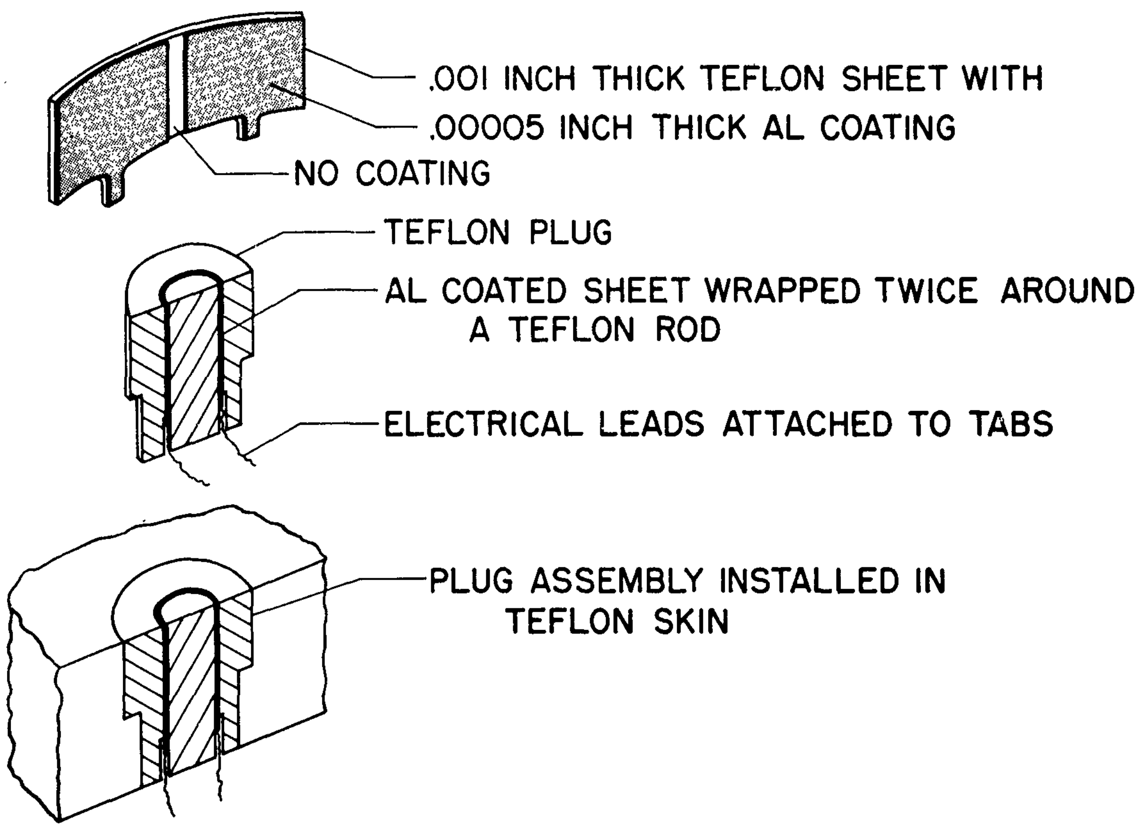


Fig. 11 Ablation sensor

DISCUSSION

J.A. Hamilton (U.K.): I have two points to raise, both arising from the use of the 'pyramid' technique for simulating narrow-delta wings at incidence (Figure 1 of the paper). First, has Mr. Rumsey made any auxiliary investigations to check the degree to which the flow over the pyramid does truly simulate that of a delta wing? One feels that there may be significant differences, particularly in the region of the leading edge. Second, has Mr. Rumsey made use of similar techniques to investigate the distribution of heat transfer over the upper surface of narrow delta wings where the flow is much more complex because of the separated flows which occur there?

Author's reply: No, we have not made the wind tunnel flow studies required to check the degree to which the flow on the trylon configuration actually represents that on a delta wing at angle of attack. The question was considered in a speculative sense and it is believed that the flow representation is fairly good at hypersonic Mach numbers, at least close to the stagnation line.

The technique indicated by Figure 2 (two models sting-mounted in opposition to each other) should be applicable to this problem, although we have not made such an investigation, using that technique.

Some references associated with these questions have been made available to your government through appropriate channels.

A.J. Marx (Netherlands): In the paper the use of stainless steel for model material was only mentioned in the case of the porous skin for transpiration. Why is stainless steel not more often used in the tests, as it might be an important structural material for future aircraft?

How are thermocouples attached to stainless steel?

Author's reply: Thermocouples can be spot-welded to stainless steel However, stainless steel is not a desirable material to use in a heat-transfer investigation because there are anomalies in its specific heat-temperature relation.

Porous stainless steel is used in the investigation referred to because of the porous properties available with that particular material. The significant skin temperature measurements are obtained in temperature ranges other than those where anomalies exist.

Anthony M. Smith (U.S.): In the way of augmenting Mr. Rumsay's comment on his capacitor type ablation sensor used in teflon, I would like to point out that a number of ablation materials used in the U.S. are of the charring type, quite unlike pure subliming teflon. For these charring materials, the General Electric Company has developed a type of printed circuit ablation sensor to measure ablation histories. A thin sliver of the ablation material is simply scribed with a printed circuit and then embedded directly in the heat shield. As ablation occurs, the circuits are broken and a step-function time history of ablation is recorded. This history, and a knowledge of the trajectory flown, thus permit a complete analysis of the ablation process for a given type of material. This technique has been successfully used on a number of occasions.

H.L. de l'Estoile (France): Avec quelle précision fait-on mesurer la vitesse sur trajectoire, car une erreur sur la vitesse entraine une erreur à la troisième puissance sur les flux du chaleur?

En ce qui concerne les essais d'ablation, nous pensons, en France, qu'une méthode intéressante est la mesure directe aux profil des températures dans le corps solide qui permet de remonter à la vitesse d'ablation. Que pense M. Rumsey de cette méthode?

Author's reply: Velocities during the coasting period of flight can be measured by the tracking radar with an accuracy of better than ±50 ft/sec. Telemetered accelerometer data have an accuracy of about ±2% of full scale range of the instrument. With a 100g accelerometer, the accuracy in velocity would be the sum of the ±50 ft/sec initial value plus about ±60 ft/sec for each second of thrust acceleration integrated.

Satisfactory installation of the thermocouples would be difficult, and I am not sure that the ablating characteristics, that is the heat-absorbing mechanism, of the material can be studied from these data alone.

ADDENDUM

AGARD SPECIALISTS' MEETING

ON

"THE USE OF ROCKET VEHICLES IN FLIGHT RESEARCH"

List of Papers Presented

Following is a list of the titles and authors, together with the AGARD Report number, of twenty three papers presented at the above Meeting held at Scheveningen, Holland, in July 1961.

ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT
Organisation du Traite de l'Atlantique Nord
64, rue de Varenne — Paris 7 eme

July 1962

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Investigations of the effectiveness of transpiration cooling can be made with rocket models carrying additional instrumentation to measure coolant flow rates. For investigations of the ablation of teflon due to aerodynamic heating a continuous-reading ablation sensor has been developed and used successfully in rocket model tests.

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TECHNIQUES AND INSTRUMENTATION ASSOCIATED WITH ROCKET MODEL HEAT-TRANSFER INVESTIGATIONS
C.B. Rumsey
1961
14 pages incl. 5 refs., 11 figs; plus discussion and bibliography of papers presented at the Stability and Control Meeting

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