Table 5 Material-loss measurements

Exposure duration	No. of samples	Surface material loss[a] %	g	in.
4.2 sec	4-Tent material	100	1.5	0.045
3.0 sec	3-Tent material	65 to 78	0.97 to 1.17	0.029 to 0.035
1.3 sec	6-Tent material	13 to 29	0.19 to 0.43	0.006 to 0.013
1.3 sec	1 Dynatherm	60	0.456	0.013
1.3 sec	1 Aluminum	0	0	0

[a] The 4.2 sec. exposure also resulted in 0 to 100% loss of the fiberglass backing weave.

one of 4 samples exposed for 3.0 sec. The Fiberglass was exposed and charred over half of this sample which was closest to the nozzle centerline. A sample located on the centerline received no Fiberglass exposure during the same test. It was hypothesized that full retraction of the outer sample was delayed invalidating the condition of the sample. The material losses of the remaining 15 samples is summarized in Table 5.

The general surface condition of the 9 tent material samples from the 3.0- and 1.3-sec exposures was a clean, slightly roughened surface, with no discoloration. Three samples had single large craters (300, 600, and 750 μ). The 750-μ crater penetrated to the Fiberglass weave. The bottom of the 600- and 300-μ craters were 0.027 and 0.012 in. from the Fiberglass backing. Due to the large size and irregular shape of these particles they were believed to be particles from the rocket motor igniter or inhibitor.

The ablative sample showed a uniform material loss, and some delamination from the steel backing near the edges. The material was embrittled as indicated by cracking on one side during removal of the sample. The aluminum sample showed no deterioration. The four rubber samples instrumented for temperature attained maximum backside temperatures at 30–90 sec after the exposure. The peak temperatures were as shown in Table 6. The maximum temperature of 165°F was well below the system design thermal analysis which showed no degradation to system components at a 350°F backside temperature.

Conclusion

Silicone-rubber, Fiberglass-laminated tent material gives adequate protection to the internal components of the PBPS from the third-stage exhaust plumes, temperatures and particles during stage separation.

The Dynatherm ablative thickness of 0.022 in. is sufficient for nonload bearing parts subjected to a nominal worst-case exhaust plume exposure. However it does become brittle and caution should be taken in considering its use for load bearing applications.

Table 6 Maximum sample backside temperatures

Sample type	Thermocouple placement	Impingement duration (sec)	Peak temperature
Unsupported	Fiberglass back	3.0	165°F
Unsupported	Fiberglass back	1.3	154°F
Supported	Stainless back	1.3	144°F
Supported	Stainless back	1.3	150°F

References

[1] "PBPS Thermal Protection Requirements," Rept. S-0668-017-000, June 7, 1968, North American Rockwell, Autonetics Div. Anaheim, Calif.

[2] "Plume Analysis-PBPS Base Insulation Material Evaluation Test," Rept. D2-18825-1, March 18, 1969, Boeing Co., Seattle, Wash.

Mach Number and Reynolds Number Effect on Orbiter/Tank Interference Heating

THEODORE R. CREEL JR.*
NASA Langley Research Center, Hampton, Va.

Nomenclature

H = measured heat-transfer coefficient to tank alone configuration
H_m = measured heat-transfer coefficient to tank in mated configuration
H_S = stagnation point heat-transfer coefficient on scaled 1-ft radius sphere
H_T = calculated turbulent sonic point heat-transfer coefficient on a scaled 1-ft radius sphere
$\bar{H}$ = H_m/H
$\bar{H}_T$ = H_m/H_T
L = tank length (for model, $L = 9.83$ in.; full scale, $L = 163.8$ ft)
M_∞ = freestream Mach number
X = distance along body
$R_{\infty,L}$ = freestream Reynolds number based on tank length

THE current version of the space shuttle configuration during ascent consists of a delta wing orbiter, a tank attached parallel to the bottom of the orbiter, and two solid fuel rocket boosters along the sides of the tank. For liftoff and early ascent flight the booster solid rocket motors and the orbiter liquid fuel engines are fired. At an altitude of about 130,000 ft, the solid fuel rockets are separated from the orbiter and tank which continue ascent. A typical velocity, altitude and reference sphere heating rate trajectory is presented in Fig. 1. At booster separation there is a small peak in the heat-transfer rate. This small peak is followed by another much larger peak of 26.8 Btu/ft²sec. The maximum heat-transfer rate occurs at orbit insertion [Mach number of approximately 28 and Reynolds number ($R_{\infty,L}$) of 5.5×10^4].

Previous Shuttle interference heating tests (for example, see Brevig et al.[1]) have been concerned primarily with fully reusable two stage concepts in which only the orbiter experienced speeds higher than Mach 10. Consequently, interference heating occurred on these mated configurations at lower Mach numbers and much lower altitudes than for the present concept. Data are now needed at higher Mach numbers and lower Reynolds numbers than previously investigated. Since data at high Mach number and low Reynolds number are presently nonexistent, the present study was undertaken to determine how these two body interference heating rates vary with Mach number and Reynolds number. Results extend the Mach number range up to 19 and the Reynolds number

Received January 10, 1973; revision received March 28, 1973.
Index category: Rocket Vehicle Aerodynamic Heating.

*Aerospace Engineer, Aerodynamics and Heat Transfer Section, Hypersonic Vehicles Division.

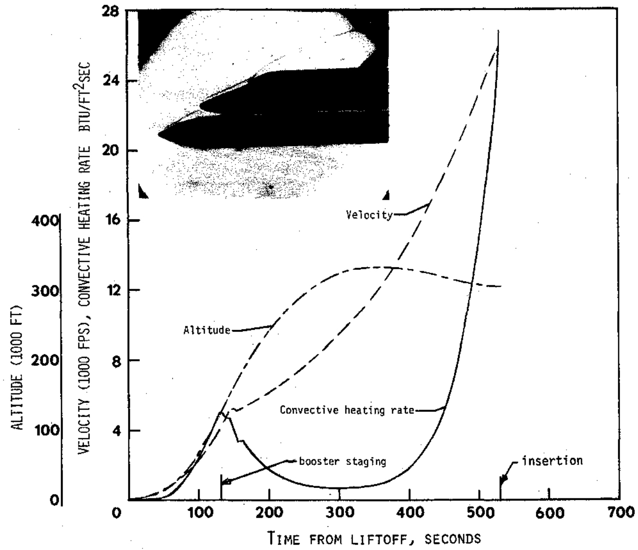

Fig. 1 Typical ascent trajectory for a space shuttle launch configuration.

range ($R_{\infty,L}$) down to 0.25×10^6. The high Mach number data were obtained in the Langley Hypersonic Nitrogen Tunnel[2] at Reynolds numbers of 0.35×10^6 to 0.57×10^6. Tests were also made at Reynolds numbers from 0.25×10^6 to 8.3×10^6 in the Langley Mach 8 Variable Density Tunnel.[3]

The schlieren picture of Fig. 1 shows the longitudinal gap that exists between the orbiter and tank which, because of vehicle contours, decreases axially as indicated. A system of multiple reflected shocks is found in the gap similar to those discussed by Thomas.[4]

All of the data were obtained by thermocouples located on the top centerline of the tank.[5] The data for the tank alone are shown in Fig. 2 as the ratio H/H_S where H is measured heat-transfer coefficient and H_S is the calculated value for a 1-ft radius sphere scaled by the same factor as the model. The distribution of these data indicates essentially laminar flow at both Mach numbers and all Reynolds numbers.

The mated configuration consisting of the orbiter and tank was tested over the same Reynolds and Mach number range as the tank alone. In this investigation the models are joined at the forward attachment point by a solid plate which completely blocks the flow. This plate is shown in Fig. 3. Interference heating factors ($\bar{H}$) were obtained by ratioing the heat-transfer coefficients of the mated configuration to the coefficients of the tank alone and are presented in Fig. 3. The data show that very high interference heating can exist just ahead of the attachment point. At a $R_{\infty,L}$ of 8.3×10^6 in air this value is about 77 times the undisturbed value. The

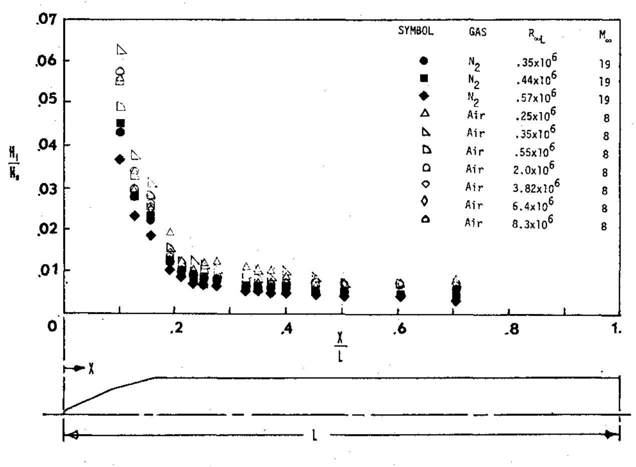

Fig. 2. Heat-transfer rate distribution on the tank alone.

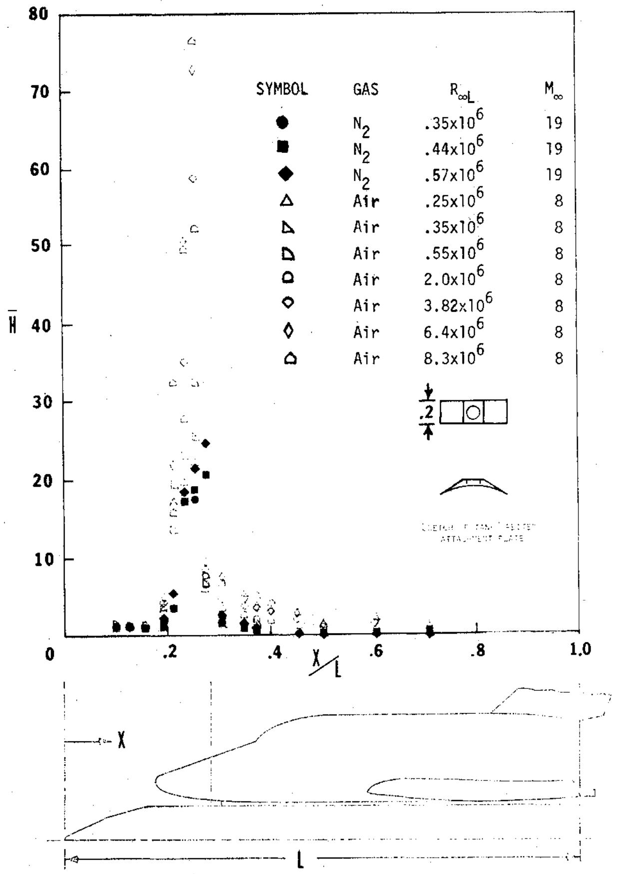

Fig. 3 Orbiter induced interference heat-transfer ($\bar{H}$) factors on the tank.

magnitude of the peak interference heating rate is much more strongly affected by Reynolds number than Mach number; higher heating is associated with higher Reynolds numbers. The Reynolds number effect is better illustrated in Fig. 4a

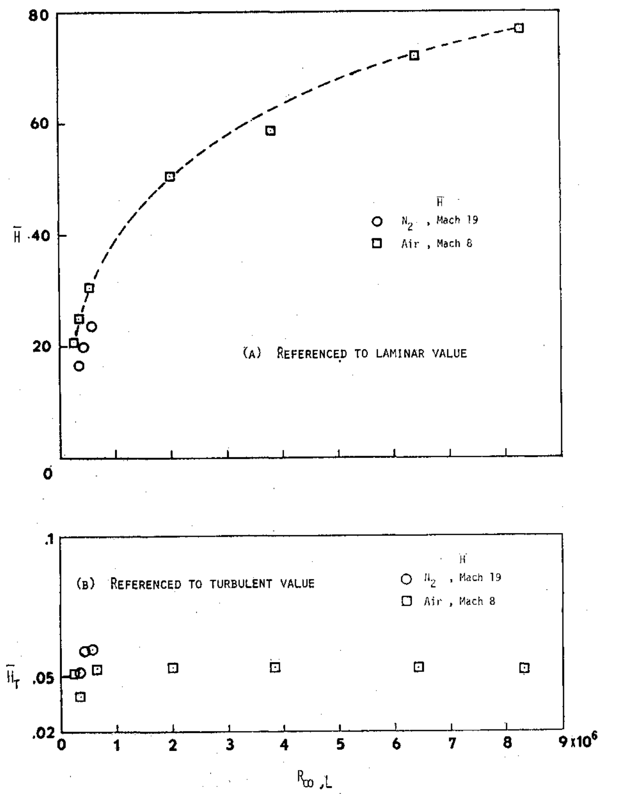

Fig. 4 Peak interference heating.

which shows only the peak heating factors from Fig. 3. The strong dependence of $\bar{H}$ on Reynolds number suggests that the interference may be tripping the boundary layer to turbulent flow. The data of Fig. 3 are also plotted in Fig. 4b in terms of the ratio of the measured peak interference heating to a reference turbulent value, $\bar{H}_T$. The reference turbulent value is taken as the turbulent heat-transfer coefficient calculated at the sonic point of a scaled 1-ft radius sphere. The interference heating data when referenced to a turbulent value are essentially independent of Reynolds number. This is a strong indication that the primary effect of interference in the present tests was to cause transition to fully developed turbulent flow, and emphasizes the necessity of checking all interference data for transitional effects.

References

[1] Brevig, O. and Young, C., "Shock Interference Heating on the Space Shuttle Booster During Ascent," TM X-2272, April 1971, NASA.

[2] Beckwith, I. E., Harvey, W. D., and Clark, F. L., "Comparisons of Turbulent-Boundary-Layer Measurements at Mach Number 19.5 with Theory and an Assessment of Probe Errors," TN D-6192, June 1971, NASA.

[3] Stainback, P. C., "Heat-Transfer Measurements at a Mach Number of 8 in the Vicinity of a 90° Interior Corner Alined with the Free-Stream Velocity," TN D-2417, Aug. 1964, NASA.

[4] Thomas, A. C., "Interference and Radiation Blockage Effects of Surface Temperatures of Composite Flight Vehicles," *Space Transportation System Technology Symposium/Aerothermodynamics and Configurations*, Vol. I, NASA Lewis Research Center, Cleveland, Ohio, 1970.

[5] Osonitsch, C., D'Errico, A., and Creel, T., "Heat Transfer Study of the Grumman H-33/HO Orbiter," Contract NAS 8-4016, SADSAC Space Shuttle Aerothermodynamics Data Management Systems, NASA Marshall Space Flight Center, Huntsville, Ala.

A Study of Satellite Television Broadcasting Systems for India

B. S. RAO,* K. S. KARNIK,† AND V. D. GUPTA†
Indian Space Research Organization, Ahmedabad, India

Introduction

BROADCASTING of television signals to cover large areas appears to be feasible through the use of high-power transponders and large antennas mounted on geostationary satellites. These satellite systems appear to be very important, particularly for the new, developing, and large countries because they provide a base for education and information dissemination to achieve rapid national development. The first test of direct satellite broadcast of television is planned to be tried out in India during 1974 using a NASA launched ATS-F satellite. During this experiment the cities, large and small, would be provided TV reception through receive-transmit terminals, the villages and the remote and inaccessible areas through direct reception. Principles of operation with respect to receive-transmit terminals is fairly well established, whereas the problems relating to direct reception from satellites in the hostile environmental conditions of remote and inaccessible villages are yet to be solved. In addition, from considerations of interference to existing terrestrial systems, various technical constraints have been imposed on the mode of satellite TV transmission, type of reception and other parameters. Because of the technical and environmental constraints, the conventional TV receiver in its regular form is unsuitable for direct reception of satellite signals. Therefore, what is required is an augmented receiver which would meet all the technical specifications as well as operate efficiently in remote areas.

Presented as Paper 72-524 at the AIAA 4th Communications Satellite Systems Conference, Washington, D.C., April 24–26, 1972; submitted January 22, 1973; revision received April 10, 1973.
Index category: Earth Satellite Systems, Unmanned.

* Director, Electronic Systems Division.
† Scientist.

Satellite Instructional Television Experiment

As a first step to the use of television for a large area coverage in a short period of time, and based on the joint study groups recommendations,[1] the Department of Atomic Energy (India) entered into an agreement with NASA to conduct a joint satellite television experiment using the ATS-F satellite to be launched by NASA around 1973.

The space segment of this system would consist of the ATS-F satellite positioned within effective operational view of India, for the purpose of this experiment, in synchronous equatorial orbit, with a 30-ft parabolic antenna pointed generally toward the center of India with an accuracy of $\pm 0.1°$. A FM transmitter operating in the 800–900 MHz frequency range, with a rf bandwidth of approximately 30 MHz, will provide adequate power (80 w) for transmitting TV program material and two audio channels to augmented conventional TV recievers. In this experiment the up-link transmission to the ATS-F satellite would be in the 6 GHz band. The Experimental Satellite Communication Earth Station (ESCES) at Ahmedabad will be used for transmitting Indian ITV program material to the satellite and for monitoring these transmissions and performance of the satellite during the duration of the experiment. Augmented conventional TV receivers would be capable of receiving monochrome TV transmission from the satellite and one of the two audio channels transmitted. For this purpose the conventional receivers would be augmented by a front-end, viz a small parabolic receiving antenna (7–10 ft in diameter) and a preamplifier FM to AM converter of sufficient quality, to receive transmisssions from the satellite. In high village density areas, transmission from the satellite could be received by cheap "mini earth stations" for rediffusion by VHF TV transmitters to conventional TV receivers located in nearby villages. A receive only facility, using a 20–30 ft parabolic antenna is required near the VHF TV transmitter. The experiment envisages the test of a hybrid system involving both direct reception by augmented TV receivers as well as rebroadcast to conventional TV receivers. About 2000 direct reception sets and 3000 conventional sets will be located in 5000 villages. The direct reception sets will be located in clusters of about 400 sets each in various parts of the country, while the conventional sets will be located in villages around the existing and planned terrestrial TV transmitters in the larger cities. The TV sets will be located in different cultural, linguistic, socio-economic, and environmental regions of India. This will provide the wide range of experience which is so necessary before a diverse country like India can embark on a large nationwide hybrid TV system. This experiment will provide invaluable experience for setting up an ongoing operational system. The full responsibility for the TV programs and the ground segment hardware will be that of India, and this includes the task of developing the required hardware also.

Operational Environment

To test out the concepts of community reception in villages, India provides an excellent experimental situation. It has almost all types of environmental conditions. Therefore, the community receivers should be designed to operate in all these conditions. The climates and physical environments that must be endured by these receivers are severe. The range of these environments extend from the extreme cold of winter