Comparison of Wind-Tunnel and Flight-Test Heat-Transfer Measurements on a Pylon-Mounted Store

R. K. Matthews*
ARO, Inc., Arnold Air Force Station, Tenn.
and
J. C. Key Jr.†
Armament Development Laboratory, Eglin Air Force Base, Fla.

Flight and wind-tunnel tests were conducted on a pylon-mounted store. The purpose of these tests was to substantiate the extrapolation procedures used to determine heating rates on a full-scale Bomb Dummy Unit from those measured on a 1/15-scale model. Some substantiating evidence was obtained; however, scatter in the flight-test data prohibited any definite conclusion. The flight-test phase did produce excellent flow visualization pictures by applying phase-change paint to the store.

Nomenclature

c_p = specific heat of air at constant presssure (≈ 0.24 Btu/lbm-°R)
h = heat-transfer coefficient, Btu/ft^2-hr-°F
L = BDU length, in.
M_∞ = freestream Mach number
$\dot{q}$ = heat-transfer rate, Btu/ft^2-sec
$Re_{\infty,L}$ = freestream Reynolds number based on BDU length (118.5 in. for flight, 7.9 in. for wind tunnel)
$Re_{\infty,x}$ = Reynolds number based on freestream conditions and x
St = Stanton number, $\dot{q}/\rho_\infty V_\infty c_p (T_r - T_w)$
T_r = recovery temperature, °R or °F as noted
T_w = model wall temperature, °R or °F as noted
V_∞ = freestream velocity, ft/sec
x = longitudinal centerline distance from BDU nose, in.
ρ_∞ = freestream density, slugs/ft^3
ϕ_{inst} = circumferential position on BDU of instrumentation

Introduction

THE performance envelope of present-day aircraft can be severely limited by external stores as illustrated in Fig. 1. Unfortunately, these limitations are sometimes imposed by arbitrary temperature limits on the store.[1] Most bombs and fuses have as their explosive charge some form of TNT, which melts at about 178°F. To avoid this possibility, the aircraft speed is restricted. However, to predict the actual temperature of the TNT in flight, one must know a) the recovery temperature (Fig. 1) and the length of time at a given flight condition, b) the rate at which heat is being transferred to the store (i.e., h), and c) the thermophysical properties of the store so that a heat conduction solution can be obtained. Of these, the heat-transfer rate is the hardest to determine.

Within recent years, wind-tunnel techniques have been developed to measure heat-transfer rates on pylon-mounted stores. These techniques are described in Ref. 2. Matthews et al.[3] discussed the application of these wind-tunnel results to actual flight conditions. Figure 2 is a schematic illustrating the extrapolation procedures. Determination of the proper aerodynamic scaling law is a vital link in these procedures. In Ref. 4, theoretical considerations were used to establish the scaling relationship to extrapolate from wind-tunnel conditions to flight conditions. However, to substantiate this scaling relationship, a research project is currently in progress at the von Karman Facility (VKF) of AEDC under the sponsorship of the Armament Development Laboratory

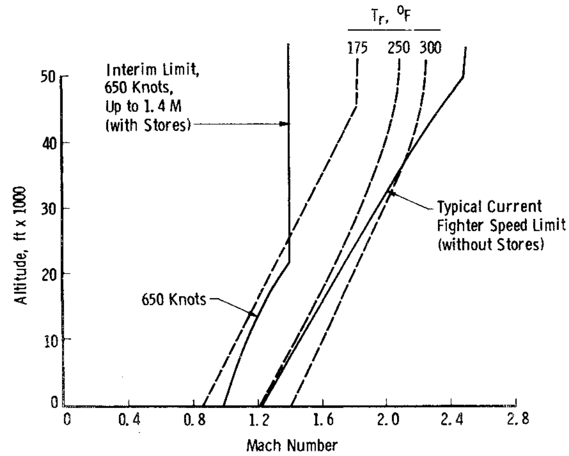


Fig. 1 Performance envelope of present-day aircraft.

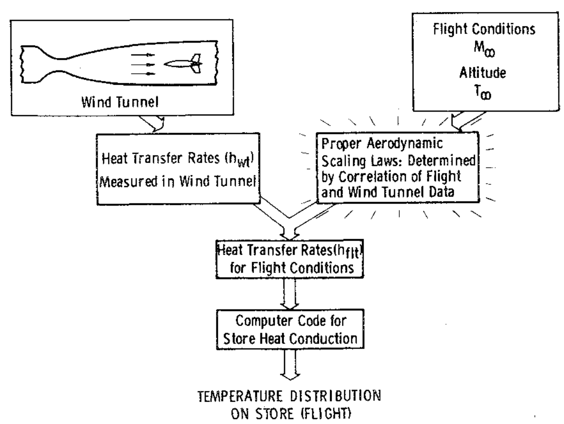


Fig. 2 Schematic showing extrapolation of wind-tunnel data to flight conditions.

Presented at the AIAA 9th Aerodynamic Testing Conference, Arlington, Texas, June 7-9, 1976 (in bound volume of Conference papers, no paper number); submitted July 13, 1976; revision received Nov. 29, 1976.

Index categories: Aircraft Testing (including Component Wind-Tunnel Testing); Boundary Layers and Convective Heat Transfer—Turbulent.

*Group Supervisor, von Karman Gas Dynamics Facility. Member AIAA.

†Major, USAF. Project Engineer.

Table 1 Approximate conditions for wind-tunnel and flight test

Parameter	Wind tunnel	Flight
M_∞	2.0	2.0
BDU length, in.	7.90(1/15 scale)	118.5
$Re_{\infty,L}$	6.32×10^6	47.2×10^6(40,000 ft)

(AFATL). The scope of this project includes both flight tests and wind-tunnel tests of a Bomb Dummy Unit (BDU) mounted on the inboard pylon on an F-111 aircraft. The wind-tunnel phase was conducted in the 40×40-in. continuous flow tunnel of the VKF (Tunnel A). The flight test was conducted at Edwards Air Force Base and was a "piggyback" effort connected with Project DAME (Determination of Aircraft Missile Environments). This paper documents the major results from both the flight and wind-tunnel phases of this project.

Theoretical Considerations

The complexity of the interference flowfield on a pylon-mounted store was illustrated by the flow visualization photographs presented in Ref. 3. As a result, theoretical calculations are extremely difficult. Conversely, the calculations of the flowfield about a store in an interference-free flowfield are relatively straightforward and can provide an insight as to the proper aerodynamic scaling law.

To investigate the significant parameters and to guide the experimental work, the Spalding-Chi turbulent heating method[5] has been utilized. Calculations of the Stanton number distribution on the BDU alone were made for conditions corresponding to those of the wind-tunnel test and for conditions corresponding to those of the flight test. The approximate conditions are summarized in Table 1.

The results of these calculations were presented in Ref. 4 where it was shown that for these specific conditions the correlation parameter has the form $St(Re_{\infty,x})^{0.17}$.

Experimental Apparatus

A photograph of the BDU-12 installed on the left inboard pylon of the 1/15-scale wind-tunnel model is presented in Fig. 3. The primary store model measurements consisted of heat-gage data obtained at several axial stations on the outboard side at an angle of 105 deg from the pylon ($\phi_{inst} = 105$ deg). Grit was used on the nose of the model to provide a turbulent boundary layer. The model is shown in the Tunnel A injection tank, which allows the model to be removed from the airflow and cooled between each run. A complete description of the tunnel may be found in Ref. 2.

As mentioned in the Introduction, the flight test phase of this project was conducted on a "piggyback" arrangement with Project DAME at Edwards AFB. Project DAME utilizes an internal data-recording system to record inert propellant stress and strain data, and the final results of this project are presented in Ref. 6.

Additional instrumentation consisting primarily of heat gages and thermocouples was installed by AEDC/VKF

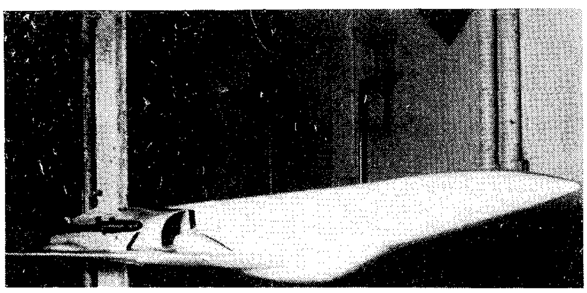


Fig. 3 Photograph of 1/15-scale wind-tunnel model of F-111/BDU-12.

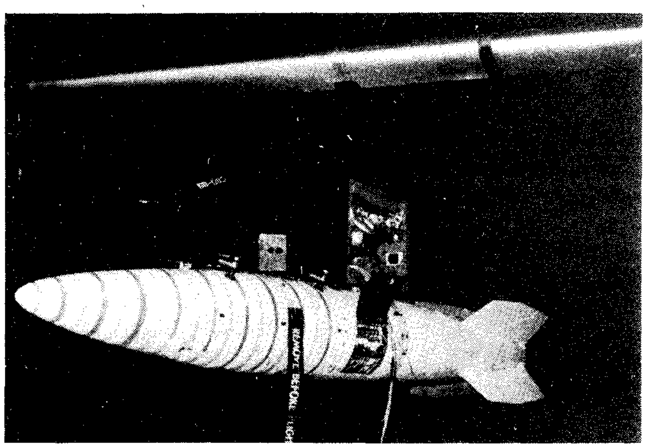


Fig. 4 Preflight photograph of BDU with phase-change paint applied.

personnel so that the heat-transfer scaling law shown in the previous section could be substantiated. The relative location of the primary instrumentation was essentially identical to that of the wind-tunnel model.

A photograph of the BDU-12 installed on the left inboard pylon of an F-111D aircraft is presented in Fig. 4. The peculiar looking circumferential strips on the front half of the BDU are Tempilaq® paint strips. These paints, which melt at a specific temperature, are commonly used in wind-tunnel testing to obtain heat-transfer data.[7] Perhaps one of the more important results of this project has been the application of wind-tunnel technology, such as the phase-change paint and the heat gages, to the aircraft/store compatibility field.

Results and Discussion

By far the most dramatic results of these tests were obtained with the Tempilaq paint. The postflight photograph presented in Fig. 5 vividly shows the flow patterns produced by the pylon shock and by the sway-brace hardware. These patterns correspond to local streamlines and are produced as the paint melts and the local shear forces cause the melted paint to flow. The paint melts when the wall temperature reaches the specific temperature (i.e., 150°F), which, of course, does not occur until the aircraft accelerates significantly above Mach 1, producing recovery temperatures greater than 150°F. It is also important to note that the Mach number reached during this flight was 2.5. Of course, this particular store did not contain TNT and was in no way restricted by the temperature limitations previously discussed. This Mach 2.5 flight does demonstrate that present-day aircraft do have the required thrust for supersonic carriage of large stores.

Before discussing the quantitative results from the heat gages, a few comments concerning the instrumentation and the data reduction are required. The gages used in both phases of this project are classified as high-sensitivity Gardon

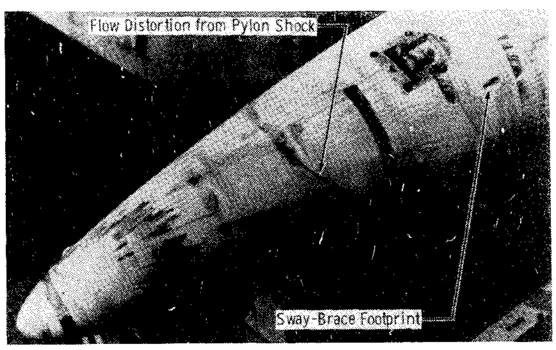


Fig. 5 Postflight photograph of phase-change paint after Mach 2.5 flight.

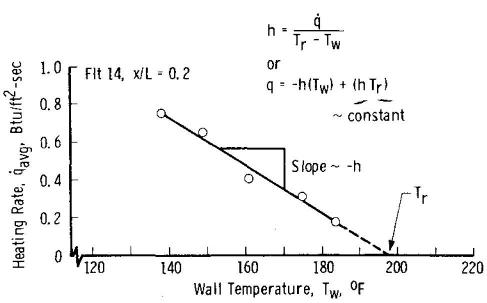


Fig. 6 Illustration of data reduction technique.

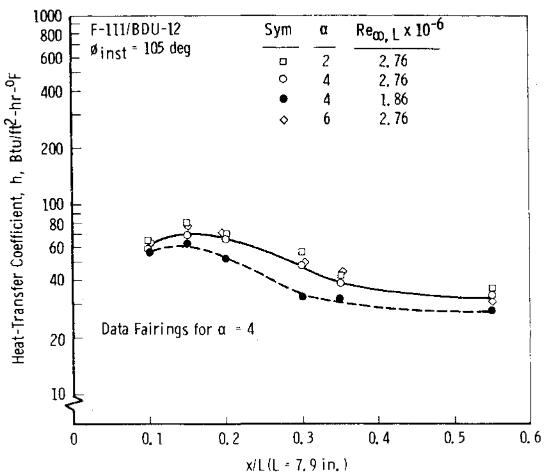


Fig. 7 Heat-transfer results from wind tunnel (VKF/Tunnel A).

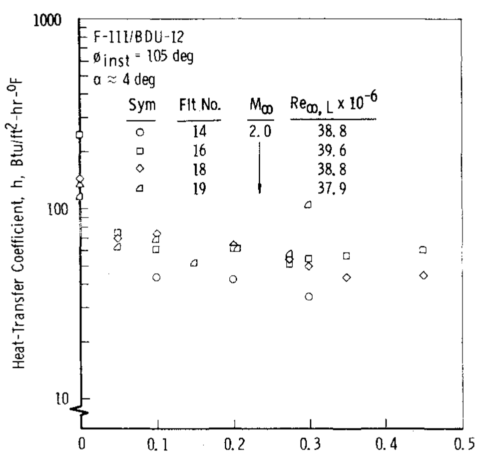


Fig. 8 Heat-transfer results from flight test.

gages.[7] These gages provide a heating rate $\dot{q}$ as well as a measurement of wall temperature T_w.

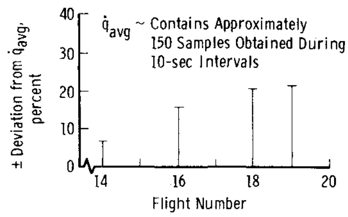
Of course, the parameter of interest is the Stanton number, which is defined as

$$St \equiv \frac{h}{\rho_\infty V_\infty c_p} \quad \text{where} \quad h = \frac{\dot{q}(3600)}{T_r - T_w}$$

As illustrated in Fig. 6, the heat-transfer coefficient h was determined from the slope of $\dot{q}$ versus T_w, while the freestream conditions were constant (i.e., flight at fixed altitude and Mach number). This technique, which assumes that h and T_r are constant, is particularly useful when the driving potential $(T_r - T_w)$ is relatively small, as is the case for the lower supersonic Mach numbers.

Heat-transfer distributions measured on the BDU wind-tunnel model and using this data reduction technique are presented in Fig. 7. The data fairings are for $\alpha = 4$ deg, which corresponds to the nominal angle of attack for the Mach 2 portion of the flight test. Data are also presented that illustrate that the distribution is relatively insensitive to changes in angle of attack. Based on these data and on the uncertainties in the gage calibration factors, the estimated precision of the wind-tunnel data is $\pm 10\%$.

Fig. 9 Illustration of relative "noise-level" for flights.



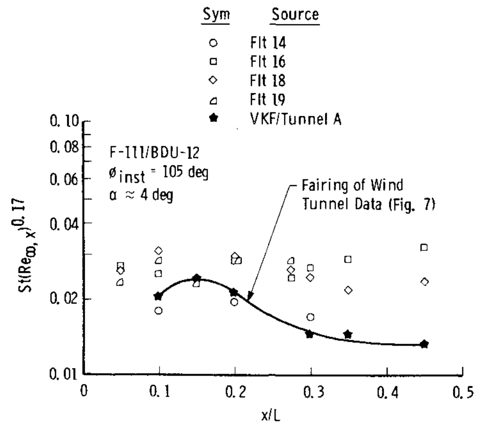


Fig. 10 Comparison of flight-test and wind tunnel results.

Unfortunately, considerable difficulty was experienced with the flight data recording system and, as illustrated in Fig. 8, the repeatability of the flight test data was very poor. More specifically, the deviation from the average heating rate ($\dot{q}_{avg}$) for a typical channel is illustrated in Fig. 9 for the flights of current interest. Note that the smallest percentage deviation occurred in the data from flight 14, which are the data that were previously shown in Fig. 6. Each data point in Fig. 6 corresponds to the average of approximately 150 readings obtained over a 10-sec interval. No timewise trends were observed during this 10-sec interval, and the implications are that the scatter is attributable to system "noise."

A direct comparison of the flight and wind-tunnel data is presented in Fig. 10 in terms of the correlation parameter $St(Re_{\infty,x})^{0.17}$. Unfortunately, the scatter of the flight-test data prohibits any definite conclusion regarding the substantiation of this correlation parameter. However, it is interesting to note that the data that show best agreement with the wind-tunnel data are the data from flight 14 which also exhibited the lowest "noise level" (see Fig. 9). Therefore, there is some evidence to substantiate the correlation parameter $St(Re_{\infty,x})^{0.17}$; however, better quality flight data are needed.

Concluding Remarks

Flight and wind-tunnel heat-transfer measurements have been made on a pylon-mounted store on an F-111. The flight test data were obtained during constant altitude and Mach-number flights at Edwards AFB. The 1/15-scale wind-tunnel tests were conducted in the 40×40-in. Tunnel A of AEDC. The purpose of these tests was to substantiate wind-tunnel-to-flight extrapolation procedures. Some substantiating evidence was obtained; however, scatter in the flight-test data prohibited any definite conclusion. Excellent flight-test flow visualization photographs were obtained. Data reduction was accomplished using wind-tunnel techniques.

Acknowledgment

The research reported herein was conducted by the Arnold Engineering Development Center, Air Force Systems Command and sponsored by the Air Force Armament Development Laboratory. Research results were obtained by personnel of ARO, Inc., contract operator at AEDC.

References

[1]Epstein, C. S., "Supersonic Delivery of Conventional Weapons—Fact or Fancy?," Aircraft/Stores Compatibility Symposium, AFFDL-TR-72-67, Vol. 1, Aug. 1972, pp. 51-72.

[2]Baker, S. S. and Matthews, R. K., "Demonstration of the Thermographic Phosphor Heat-Transfer Technique as Applied to Aerodynamic Heating of External Stores," Arnold Engineering Development Center, Arnold AFS, Tenn. AEDC-TR-73-128 (AD769306), Aug. 1973.

[3]Matthews, R. K., Baker, S. S., and Key, J. C. Jr., "Wind Tunnel Heating Test of Aircraft Stores," *Aircraft/Stores Compatibility Symposium Proceedings*, JTCG/ALNNO WP-12-2, Vol. 4, Sept. 1973.

[4]Matthews, R. K. and Key, J. C. Jr., "Flight Test Heat Transfer Measurements on a Pylon Mounted Store," *Aircraft/Stores Compatibility Symposium Proceedings*, JTCG/MD WP-12, Vol. 2, Sept. 1975.

[5]Spalding, D. B. and Chi, S. W., "The Drag of a Compressible Turbulent Boundary Layer on a Smooth Flat Plate with and without Heat Transfer," *Journal of Fluid Mechanics*, Vol. 18, Jan. 1964, pp. 117-143.

[6]Burton, J. D., "Project DAME Flight and Simulation Testing of a Modified Bomb Dummy Unit," AFRPL-TR 76-60, Oct. 1976.

[7]Trimmer, L. L., Matthews, R. K., and Buchanan, T. O., "Measurement of Aerodynamic Heat Rates at the AEDC von Karman Facility," *International Congress on Instrumentation in Aerospace Simulation Facilities*, IEEE Publication CHO 784-9 AES, Sept. 1973.