N91-24335

HEAT-TRANSFER AND SURFACE-PRESSURE MEASUREMENTS FOR THE SSME FUEL-SIDE TURBOPUMP TURBINE*

by

Michael G. Dunn

Calspan-UB Research Center
Buffalo, New York 14225

S28-37
19885

INTRODUCTION

An experimental research program is currently underway at the Calspan-UB Research Center (CUBRC) that is designed to obtain detailed heat-flux and surface-pressure distribution on the first-stage vane and first-stage blade of the SSME fuel-side turbopump turbine. This particular turbine is a two-stage machine and both stages will be in use. However, at the present time, the first-stage vane, the first-stage blade, and the second stage vane will be instrumented. The specific turbine being utilized is a combination of actual engine hardware and reproduced hardware consistent with that being used at NASA Marshall Space Flight Center for the initial measurements in their newly constructed blow-down turbine test facility.

The facility being used at CUBRC is also a blow-down type facility, but it is of the short-duration shock-tunnel variety. The short-duration nature of the shock-tunnel facility permits use of thin-film thermometers which are used to measure the surface temperature histories at prescribed locations on the turbine component parts. Heat-flux values are then inferred from the temperature histories using standard data reduction procedures. Miniature surface mounted pressure transducers are also used on both the vane and the rotating blade to obtain the desired pressure distributions.

*The research described in this paper was supported by NASA Lewis Research Center under Grant No. NAG 3-581.

EXPERIMENTAL APPARATUS

The experimental apparatus sketched in Figure 1 consists of a 0.47-m (18.5-in) i.d. helium-driven shock tube with a 12.2-m (40-ft.) long driver tube and an 18.2-m (60-ft.) long driven tube as a short-duration source of heated air, supplying the test section device located near the exit of the primary shock-tunnel nozzle. The 2.7-m (9-ft.) i.d. receiver tank is initially evacuated to a pressure on the order of 1 torr in order to minimize the flow establishment characteristics of the model. The useful test time in this facility for the test conditions to be used for the SSME measurements is on the order of 35 ms, which is nearly two times greater than the test time available for the facility used in the previous CUBRC full-stage turbine studies (References 1-6). A more detailed photograph of the test section device housing the two-stage turbine is shown in Figure 2. This device consists of a forward transition section with a circular opening facing the supersonic primary nozzle flow. This transition section is followed by the 360 deg. annular passage containing the turbine stages. Downstream of the second rotor exit is an annular passage with a contoured nozzle at the exit. This nozzle is used to establish the desired pressure ratio across the turbine. The internal model configuration duplicates the SSME turbopump configuration including the twelve upstream struts and the protruding bolt head on the dome. In our configuration, this forward dome houses an air motor that is used to accelerate the turbine from test to the desired speed just prior to initiation of the experiment and prior to arrival of the test gas. The aft internal cavity houses a 200-channel slip ring that is used to transfer the pressure and heat-transfer data from the rotor blade to the laboratory data recorders.

Figures 3 and 4 are front and rear photographs of the first stage nozzle guide vane ring. A contoured leading-edge insert containing ten thin-film heat-flux gages will be installed at midspan on vane No. 32. Button-type thin-fim gages will be installed on vane No. 16 (pressure surface) and vane No. 17 (suction surface) at 10%, 50%, and 90% span. Miniature surface mounted pressure transducers will be installed at 10% span on vane No. 13 (pressure surface) and vane No. 14 (suction surface), at 50% on vane No. 23 (pressure surface) and vane No. 24 (suction surface), and at 90%span on vane No. 29 (pressure surface) and vane No. 30 (suction surface). The specific vanes and instrumenttion locations on those vanes at which pressure measurements will be performed are consistent with the Marshall instrumentation plan. The heat-flux measurements will be performed at locations such that direct comparisons can be made between the heat-flux and surface-pressure results.

ORIGINAL PAGE IS OF POOR QUALITY

Figure 4 illustrates removal of a portion of the vane near the hub wall. This cut in vane profile is consistent with flight engine hardware. Several heat-flux gages have been placed near this cut on both the pressure and suction surfaces and on the hub endwall in order to investigate the influence of the cut on the flow field.

Figure 5 is a photograph of one of the first-stage rotor blades that will be instrumented with flush-mounted miniature pressure transducers and thin-film heat-flux gages. Both heat-flux and pressure instrumentation will be placed at selected chordwise locations at 10%, 50% and 90% spans. The heat-flux instrumentation will be composed of button-type gages and a leading-edge insert.

The measurements in and along the flowpath are important for determining the gas dynamics into and out of the turbine stage. The turbine model shown in Figure 2 has approximately twenty static pressure measurements distributed between the inner and outer portions of the model flow path. Static pressure measurements of particular importance are those at the inlet to the guide vane row, the intra stage measurements, and the static pressure measurements downstream of the second rotor. A spanwise total pressure rake is placed downstream of the second rotor and an attempt is being made to fit such a rake into the flow just downstream of the first rotor. Further, an attempt is being made to install a spanwise rake of total temperature probes downstream of the first rotor. The rakes just described may result in excessive flow blockage at the location of interest, and if so would be moved to a station downstream of the second rotor.

EXPERIMENTAL CONDITIONS

The SSME turbopump operates with a test gas composed of hydrogen plus steam. The facility to be used at CUBRC will operate with air as the test gas, but the appropriate scaling has been done to achieve the corrected conditions at the turbine inlet. It is important that the experiment duplicate the design flow function ($\dot{w}\sqrt{\theta}/\delta$), the corrected speed ($N_{phy}/\sqrt{\theta}$), the wall to total temperature ratio (T_w/T_0), and the stage total to static pressure ratio ($(P_0)_{in}/(P_s)_{out}$). It is also important to produce a turbine inlet Reynolds number sufficiently close to the operating value that the inlet boundary-layer characteristics are representative.

The SSME turbopump turbine measurements will be performed in a large turbine test facility at the Calspan Corporation. Because of the large dimensions of this facility it is possible to place the inlet to the model housing the two-stage turbine at a couple of different locations in the nozzle expansion (see Figure 1), and in this manner, change the turbine inlet total pressure and Reynolds number while holding the turbine inlet total temperature constant.

The nominal flow conditions for the SSME fuel side turbopump are; T_o = 1890°R, P_o = 5526 psia, inlet Mach No. = 0.14, inlet density = 4.29 lbm/ft^3 (H_2 + steam), Flow Function = 2.28, and overall total to static pressure ratio = 1.52.

For the proposed measurements, air would be used as the test gas instead of hydrogen plus steam. Two experimental test conditions will be run, both at a total temperature of the turbine inlet gas equal to 1000°R and both at the appropriate flow function, overall total to static pressure ratio, and corrected speed. The two test conditions would provide two different turbine inlet total pressure values and Reynolds number values as noted in Table 1.

Table 1
TEST CONDITIONS WITH AIR AS TEST GAS

Test Condition	Shock-Tube Conditions			Model Conditions Ahead of Vane			Turbine Conditions		
	P_o psia	T_o °R	$\dot{W}_*)_{throat}$ lbm/sec	P_o psia	T_o °R	Re /ft	$\dot{W}$ lbm/sec	Rotor Speed rpm	T_w/T_o
#1	1100	1000	523	270	1000	1×10^7	31.6	9731	0.53
#2	2500	1000	1188	615	1000	2×10^7	71.7	9731	0.53

CONCLUSIONS

The current status of the measurement program described herein is as follows: (a) The model to house the two stage turbine has been designed and detailed engineering drawings have been prepared. Construction of the model has been initiated and is planned for completion in July 1989, (b) the pressure and heat-flux gages have been constructed and calibrated. Installation of this instrumentation in the components shown in Figures 3 and 5 is scheduled for completion in June 1989, and (c) upon delivery of the model components, the instrumented vanes and blades will be installed and the measurement program will begin in the Summer of 1989.

REFERENCES

1. Dunn, M.G., "Experimental Measurements of Heat-Flux Distributions in a Turbine Stage with Upstream Disturbances," paper presented at the 1986 Advanced Earth to Orbit Propulsion Technology Conf., Huntsville, Alabama, 13-15 May 1986.

2. Dunn, M.G., "Heat-Flux Measurements for the Rotor of a Full-Stage Turbine: Part I - Time-Averaged Results," ASME Journal of Turbomachinery, vol. 108, pp. 90-97, July 1986 (also presented at the 31st International Gas Turbine Conf. June 8-12, 1986, paper no. 86-GT-77).

3. Dunn, M.G., George, W.K., Rae, W.J., Woodward, S.H., Moller, J.C., and Seymour, P.J., "Heat-Flux Measurements for the Rotor of a Full-Stage Turbine: Part II - Description of Analysis Technique and Typical Time-Resolved Measurements," ASME Journal of Turbomachinery, Vol. 108, pp. 98-107, July 1986. (Also Presented at the 31st International Gas Turbine Conf., June 8-12, 1986, Paper No. 86-GT-78.)

4. Dunn, M.G., "Phase and Time-Resolved Measurements of Unsteady Heat Transfer and Pressure in a Full-Stage Rotating Turbine," Paper Presented at the 1988 Conference on Advanced Earth-to-Orbit Propulsion Technology, 10-12 May 1988.

5. Dunn, M.G., Seymour, P.J., Woodward, S.H., George, W.K., and Chupp, R.E., "Phase-Resolved Heat-Flux Measurements on the Blade of a Full-Scale Rotating Turbine," ASME Journal of Turbomachinery, Vol. III, pp. 8-18, January 1989. (Also Presented at the 33rd International Gas Turbine Conference Paper No. ASME 88-GT-173, 5-9 June 1988.)

6. Dunn, M.G., "Phase and Time-Resolved Measurements of Unsteady Heat Transfer and Pressure in a Full-Stage Rotating Turbine," Paper to be Presented at the 34th ASME International Gas Turbine Conference, 4-9 June 1989. (Also accepted for publication in the ASMĖ Journal of Turbomachinery.)

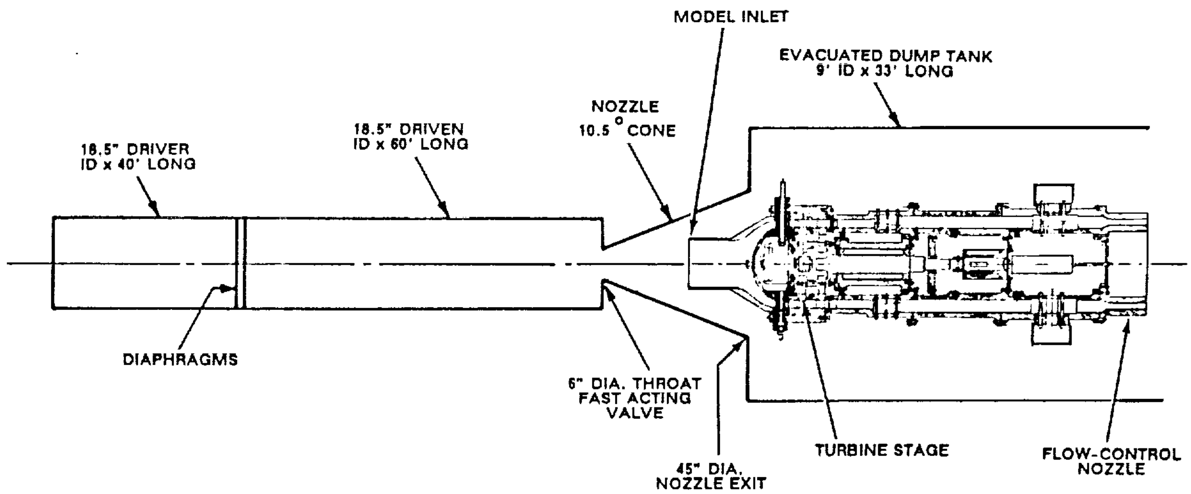

Figure 1 SKETCH OF MODEL HOUSING TURBINE STAGE LOCATED IN FACILITY

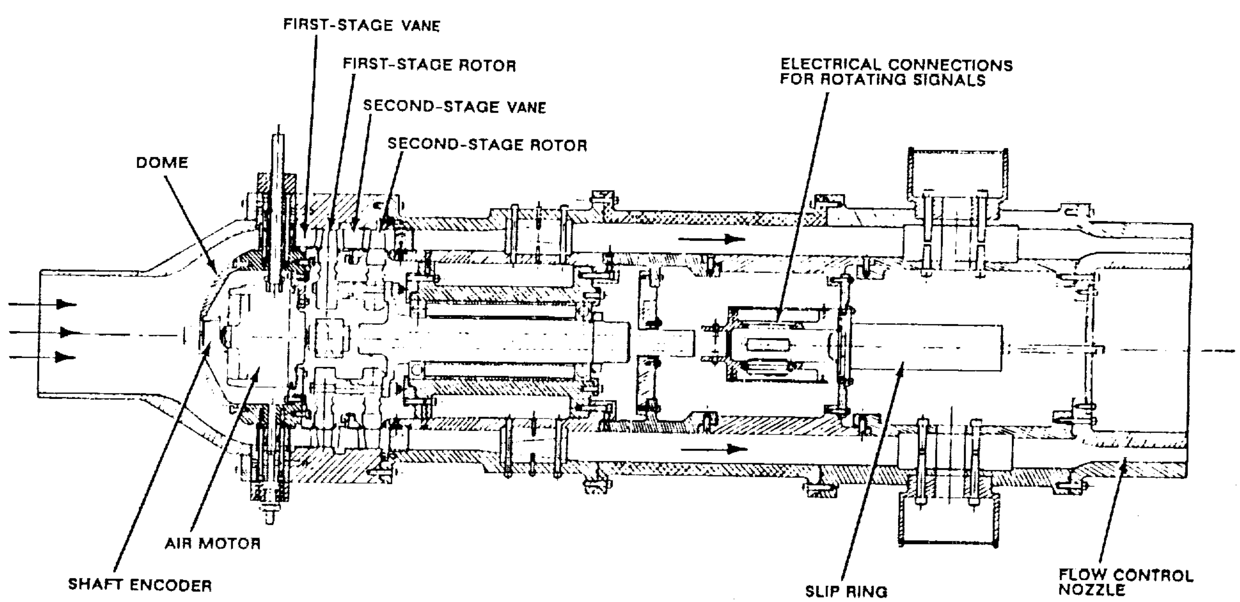

Figure 2 SKETCH OF MODEL TO HOUSE TURBINE STAGE

ORIGINAL PAGE IS
OF POOR QUALITY

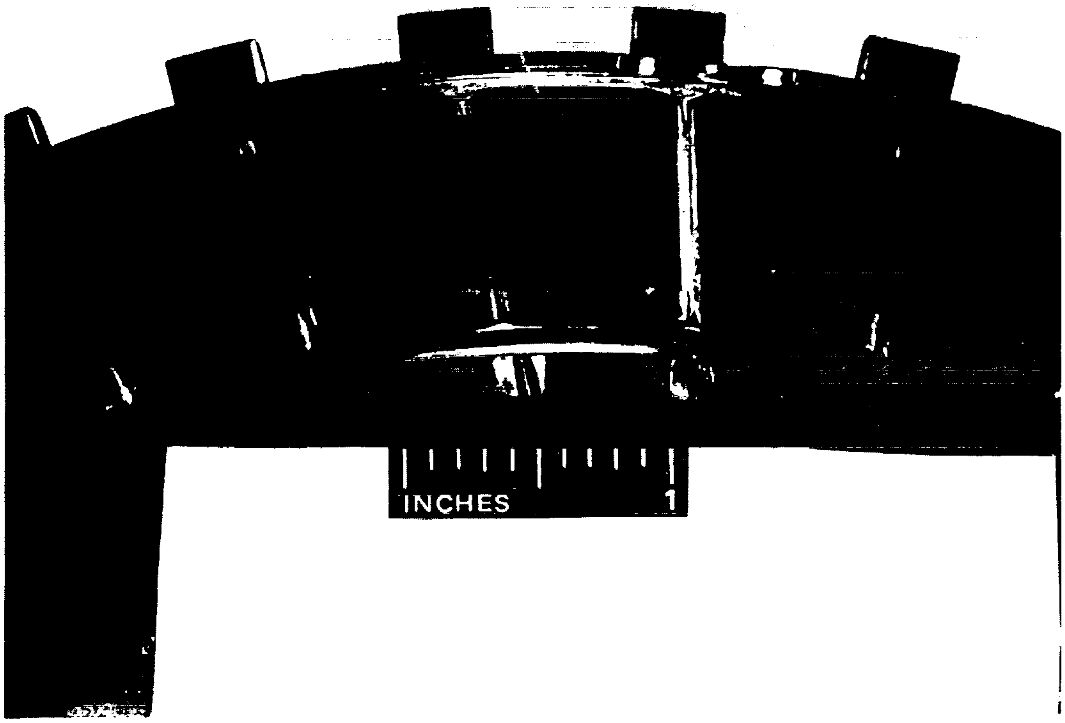

Figure 3 FRONT-VIEW PHOTOGRAPH OF FIRST-STAGE VANE

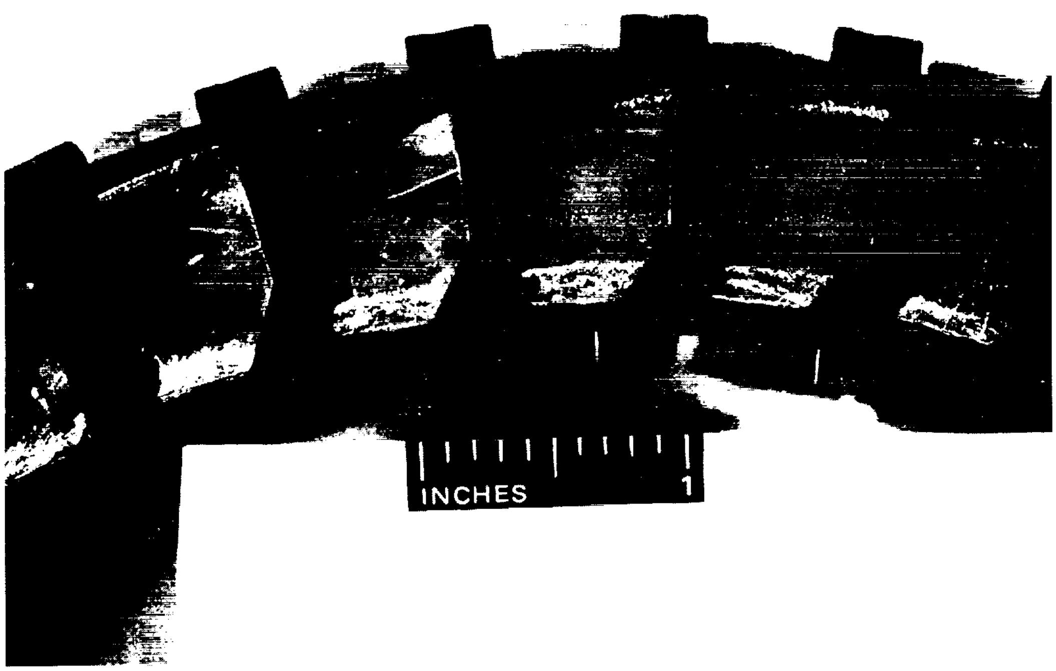

Figure 4 REAR-VIEW PHOTOGRAPH OF FIRST-STAGE VANE

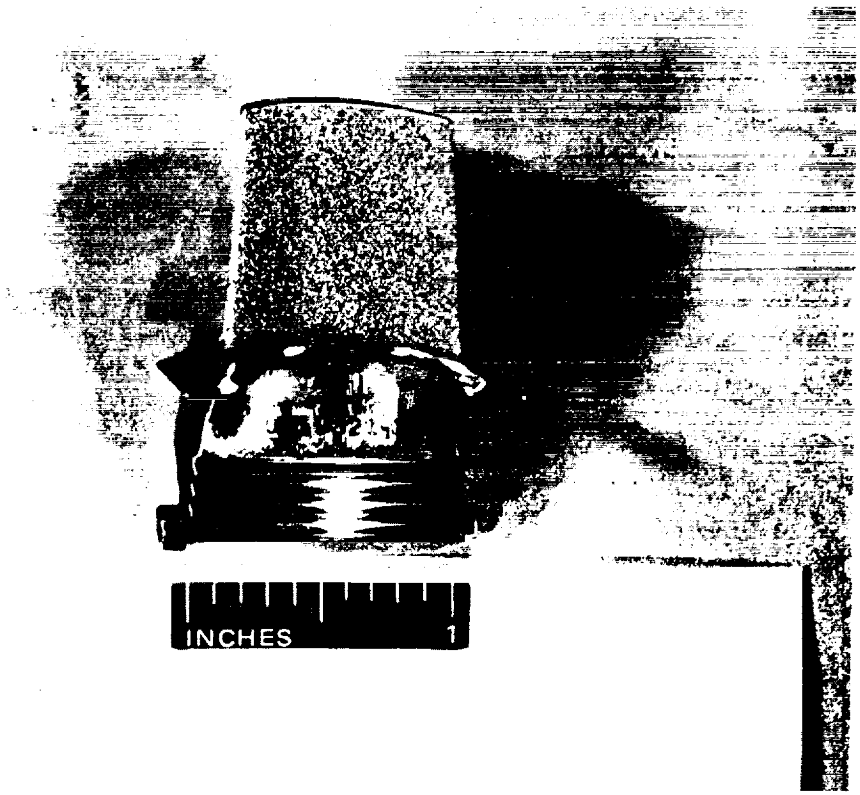

Figure 5 PHOTOGRAPH OF FIRST-STAGE BLADE