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SCALE MODEL STUDY OF FLOW PATTERNS IN THE INLET MANIFOLD OF THE FUEL PUMP DRIVE TURBINE FOR THE M-1 HYDROGEN-OXYGEN ROCKET ENGINE

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SUMMARY

Flow conditions in the inlet manifold of the M-1 fuel pump-drive turbine were investigated using circumferential static pressure measurements in conjunction with smoke trace photographs. This manifold is toroidal with a single radial feedpipe. The study was prompted by reference tests which indicated a large variation in total pressure around the turbine nozzle which was attributed to manifold flow conditions. In addition, the possibility of flow asymmetry in the manifold was indicated by circumferential measurements of manifold static pressure.

The results obtained from both the static pressure measurements and smoke flow traces indicated that the flow pattern within this manifold was essentially symmetrical about the feedpipe. In addition, the large observed circumferential variation in static pressure and associated flow patterns afforded a better understanding as to why reference nozzle exit total pressure patterns occurred.

INTRODUCTION

Experimental evaluations of the aerodynamic performance of the pump-drive turbines for the M-1 engine have been included as part of the turbine research and project support programs. The M-1 is a 1.5-million-pound-thrust hydrogen-oxygen engine. Fuel and oxidizer pumps are mounted on opposite sides of the engine combustion chamber. Each is driven by a two-stage axial-flow turbine.

Details of the oxidizer pump-drive turbine design may be found in reference 1. Cold-air performance evaluations of a 0.45 scale model have been reported in references 2 to 5.

Details of the fuel-pump drive turbine design may be obtained from reference 6. Cold-air performance evaluations of a 0.646 scale model have been reported in reference 7. The inlet manifold of this axial flow turbine is toroidal with a single radial feedpipe. The results of this reference investigation indicated a large variation of total pressure around the nozzle exit which was attributed to manifold flow conditions. In addition, static pressure measurements around the inner and outer walls of the manifold indicated the possibility of flow asymmetry in the manifold which could occur because of incidence effects at the nozzle inlet.

The observations made in the reference investigation prompted an extension of the program to determine more precisely the circumferential variation in the manifold static pressure and more definitely establish whether asymmetry in flow actually existed. Accordingly, the 0.646 scale-model feedpipe-manifold-nozzle assembly, used in the performance tests of reference 7, was instrumented with additional static taps on the inner and outer walls of the manifold, and additional flow tests were conducted.

This report presents the results of these tests and includes a comparison of the circumferential variation in static pressure thus obtained with the results presented in reference 7. In addition, a flow visualization study was conducted by photographing smoke traces in a transparent manifold having the same internal dimensions as the test manifold. Results obtained from these smoke flow tests are also included and used in conjunction with the static pressure distributions to further describe the flow patterns within the manifold.

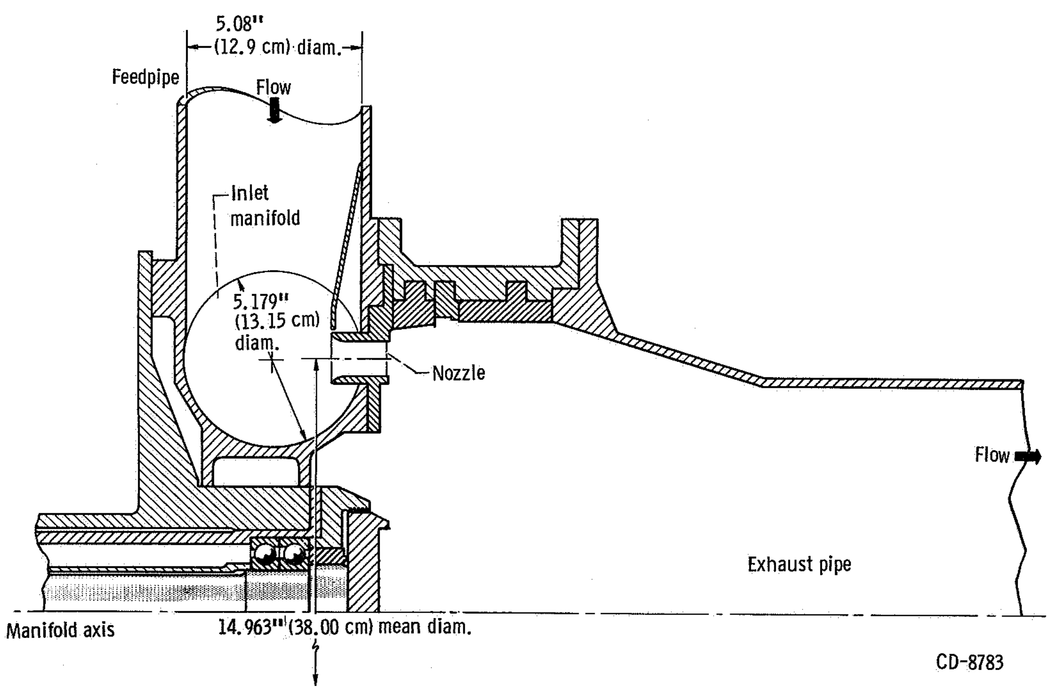

Figure 1. - Schematic of 0.646 scale-model inlet manifold-nozzle assembly.

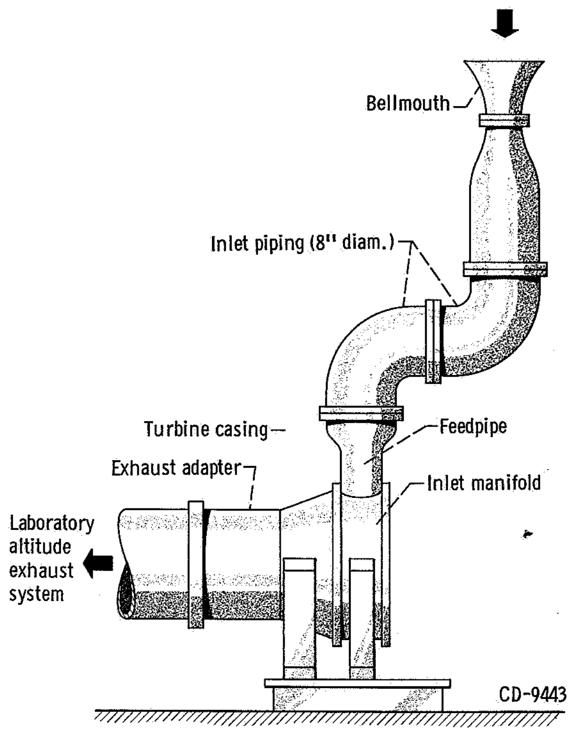

Figure 2. - Manifold test facility.

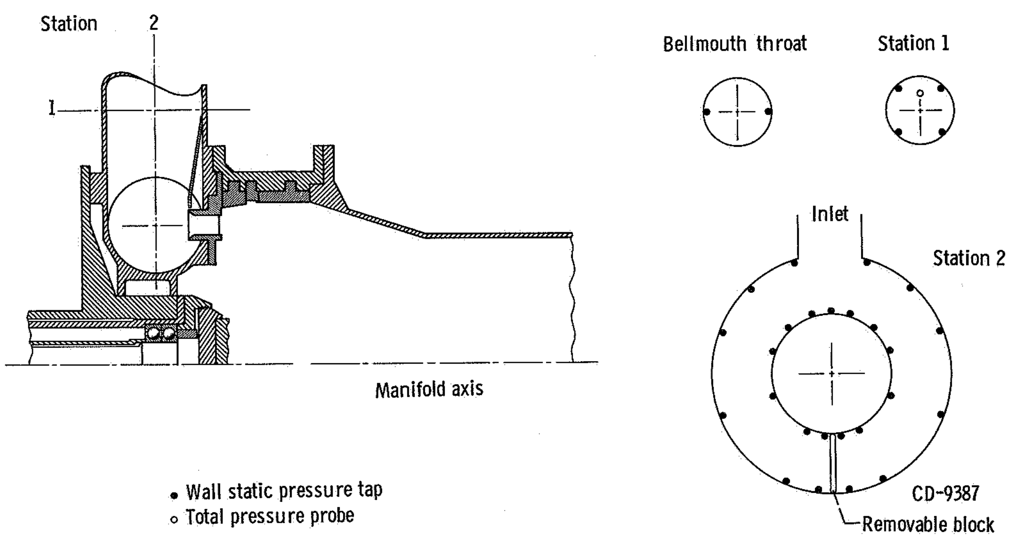

Figure 3. - Station nomenclature and location of instrumentation.

APPARATUS, INSTRUMENTATION, AND PROCEDURE

As indicated in the INTRODUCTION, the 0.646 scale-model feedpipe-manifold-nozzle assembly reported in reference 7 was used for this investigation. A sectional view of this configuration is shown in figure 1. A schematic diagram of the test facility is shown in figure 2. Atmospheric air was drawn into the inlet piping through a bellmouth and discharged to the laboratory exhaust system.

The radial and circumferential location of the instrumentation taps is shown in figure 3. The station 1 and station 2 instrumentation of reference 7 was used. Four additional taps were installed in the outer wall of the manifold and five in the inner wall. Wall static pressure taps were located at the bellmouth throat to provide an indication of flow rate. Pressures were indicated on a bank of water-fluid manometers. All pressures were recorded simultaneously by photographing the manometer bank.

During one phase of the test program, a removal block to prevent recirculation of flow was fitted in the manifold diametrically opposite the feedpipe. The location of this partition is also shown in figure 3.

A transparent manifold having the exact internal dimensions of the scale-model manifold was built for visual studies. Sectional views of this manifold are presented in

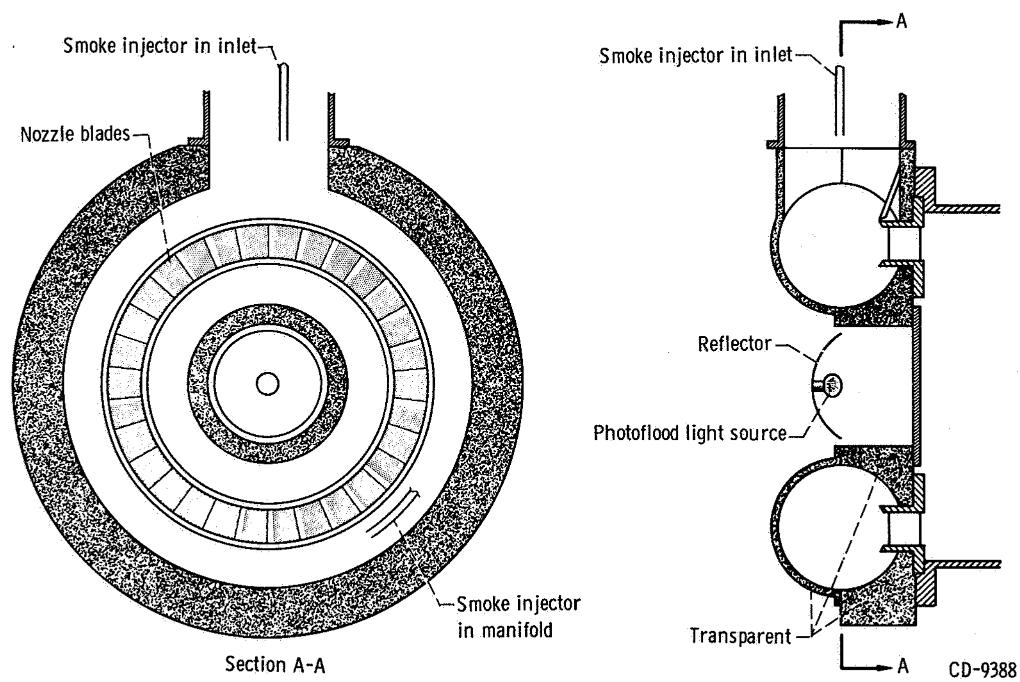

Figure 4. - Schematic of transparent manifold.

figure 4. Smoke for flow visualization was generated by burning tobacco soaked with oil in a glass tube "pipe". The "pipe" was pressurized to provide the differential required to obtain the desired smoke flow rate through the injector. The two smoke injection positions are shown in figure 4. The nozzle assembly and the back side of the manifold were painted dull black to reduce reflections and to provide background contrast for the white smoke. Photoflood illumination was positioned at the axis and aimed directly away from the camera by a reflector as shown in figure 4. Exposure was first adjusted to stop motion. The smoke formations thus revealed gave no indication of flow direction. Exposure was then lengthened to the time required for the smoke to move several inches with the flow. Smoke concentrations then produced "streaks" which showed flow direction and indicated relative velocity.

Manifold static pressure data were taken for the blocked and unblocked manifold configuration with choked flow through the nozzle and with one-fourth choked flow and for the unblocked configuration with choked flow. With one-fourth choked flow in the transparent manifold configuration, smoke was injected at several radial positions in the feedpipe and manifold. Several photographs were made of the smoke streak pattern for each injection position.

RESULTS AND DISCUSSION

The results of the subject investigation will be divided into two sections. The first section will present the circumferential distribution of manifold static pressure as obtained from the choked nozzle tests. The second part will then describe the results of the smoke flow study and, using these traces in conjunction with the static pressure results, will discuss the indicated internal flow patterns.

Static Pressure Distribution

The wall static pressure distribution produced by choked flow through the manifold-nozzle configuration is shown in figure 5. The data from the initial test (ref. 7) are also shown (open symbols).

The individual pressure readings of the initial test are effectively substantiated by the new data. The inner wall static pressure distribution indicated by the initial readings is, however, revised by the information supplied by the additional taps. The circumferential variation of static pressure and the pressure gradients near the feedpipe are much larger than those indicated by the initial data. In addition, the curves shown in figure 5 indicate that the flow conditions in the manifold are essentially symmetrical

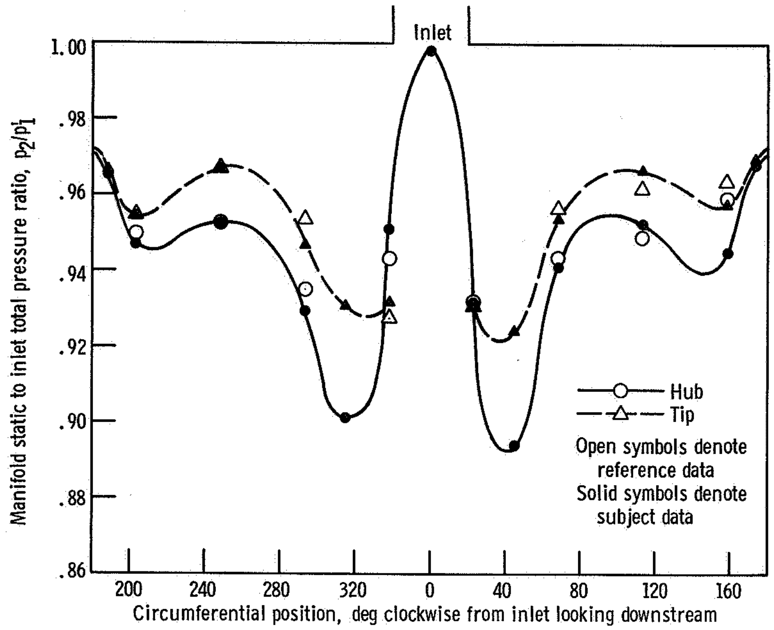

Figure 5. - Static pressure distribution around inlet manifold with choked nozzle flow: comparison with reference data.

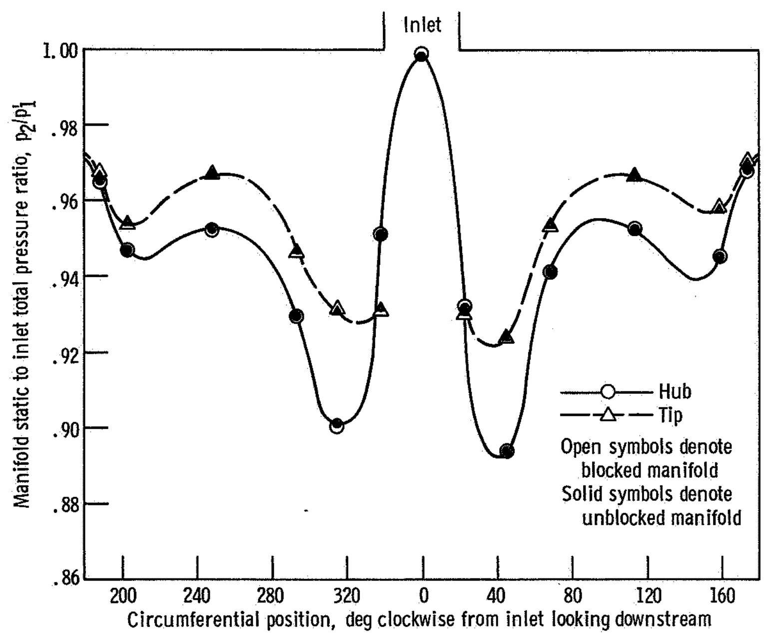

Figure 6. - Static pressure distribution around inlet manifold with choked nozzle flow: comparison with blocked manifold distribution.

about the feedpipe. It is of interest to note that the circumferential variation of manifold static pressure shown in figure 5 is very similar to the circumferential variation in nozzle exit total pressure reported in reference 7.

Further discussion of these circumferential trends will be made in conjunction with the smoke flow test results.

The effect of the block against circumferential flow at the 180° position (see fig. 3) is presented in figure 6, where static pressure distributions produced by choked flow in the blocked and unblocked configurations are compared. The readings are substantially the same at every static tap location, indicating that the block had no apparent effect on the flow pattern and therefore that there was no appreciable flow past the 180° position in the unblocked manifold.

Flow Visualization Results

Preliminary tests with the transparent manifold used for the smoke flow studies indicated that the maximum flow velocity at which smoke streak photographs are feasible occurs in the manifold at approximately one-fourth choked flow. In order to determine if the flow distribution in the manifold is similar at this reduced velocity, the static pres-

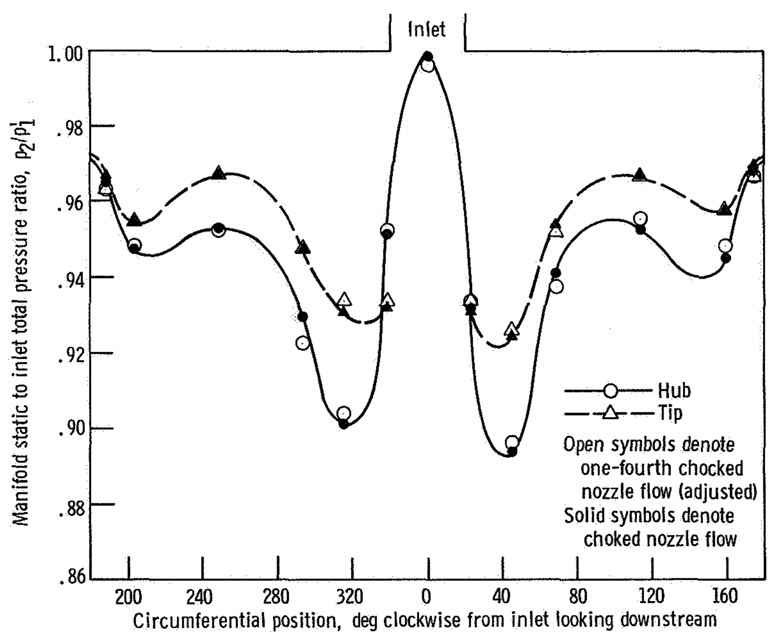

Figure 7. - Static pressure distribution around inlet manifold: comparison with low flow distribution.

sure distribution measured at this one-fourth choked point was adjusted for the difference in dynamic head, and the distributions were plotted together in figure 7. These pressure distributions are essentially similar, which indicates that the flow patterns are also similar.

From this it was concluded that the smoke patterns obtained at the reduced flow are representative of the flow pattern which occurs in the manifold with choked flow.

Figure 8 is a composite photograph of the smoke traces produced by injection at the two locations shown in figure 4. This figure illustrates the flow patterns in one-half of the inlet manifold. The manifold hub and tip static pressure distributions, from figure 5, are also replotted in polar coordinates in figure 8. An outline of the inlet manifold is superimposed on this figure to aid in visualizing the relationship between the smoke traces and the pressure distribution. Figure 8 is viewed looking downstream.

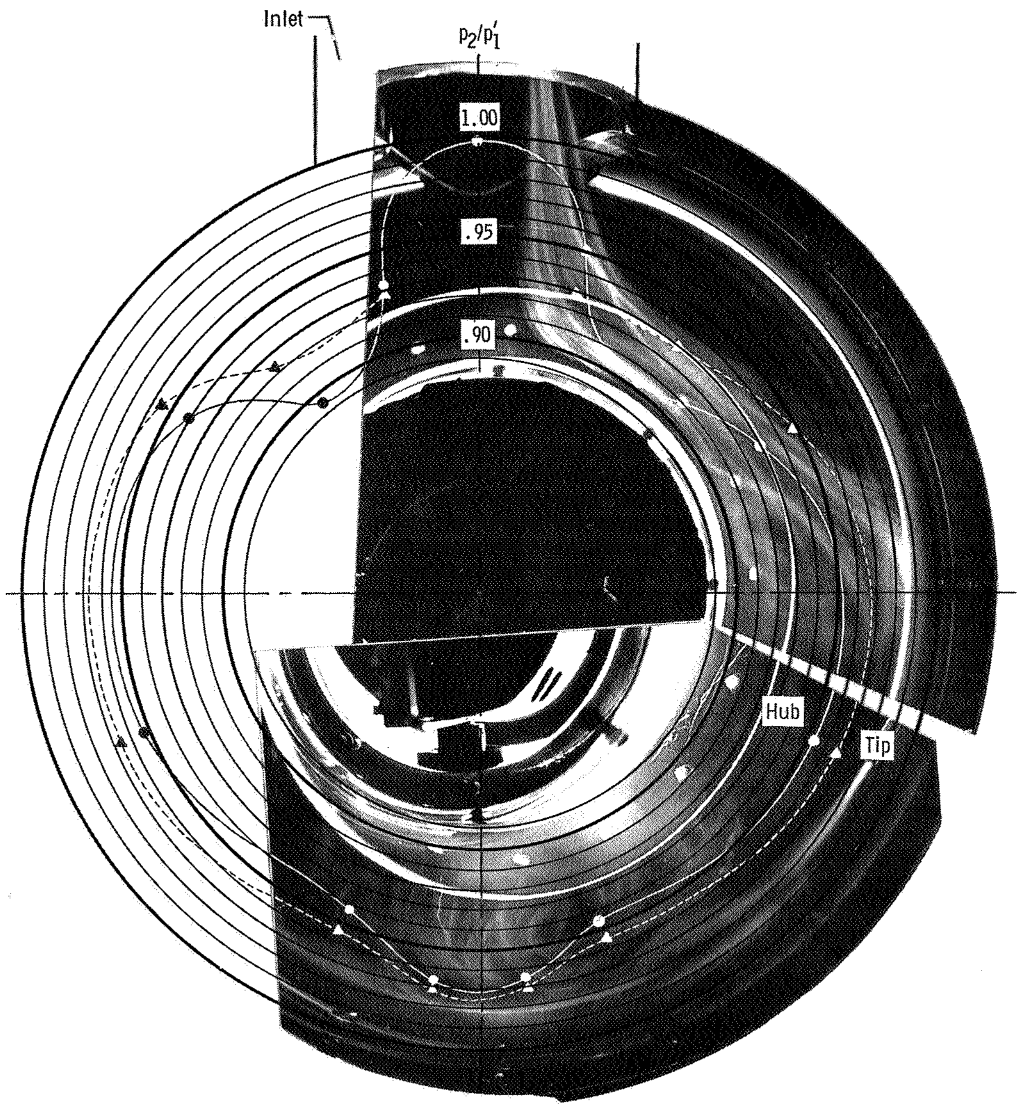

Figure 8. - Correlation of manifold static pressure distribution with smoke photographs.

The composite photograph of the smoke traces shows the flow entering the manifold through the radial feedpipe, turning, and flowing around the manifold to the 180° point. The flow entering the manifold from the right side (looking downstream) of the feedpipe all flows around the right branch of the manifold. This, together with the symmetry of the manifold inner and outer wall static pressures about the manifold vertical centerline, indicates an even distribution of the flow between the right and left branches of the manifold.

Figure 8 also shows that the manifold static pressures increase near the bottom-center of the manifold. At the 180° point the static pressures reach a maximum and the inner and outer wall static pressures are equal. This further indicates that the flow stagnates at the bottom of the manifold and does not recirculate. The accumulation of smoke at the 180° point also substantiates this indication that the flow does not recirculate.

The static pressure distribution curves in figure 8 indicate another stagnation region on the inner surface of the manifold at the 0° point (static pressure at this point equal to inlet total pressure). The flow then appears to accelerate to a fairly high velocity as the static pressure is seen to drop sharply in the region next to the feedpipe. The photograph of the smoke traces also shows the flow impinging on the manifold inner surface. The flow then accelerates and appears to impinge on the outer surface at approximately 70° to 90°. From this point to the region near the bottom of the manifold the inner and outer surface static pressures are fairly uniform.

The highest total pressures measured downstream of the nozzle, as reported in reference 7, were found to occur at the feedpipe location (0° point) where the flow was observed in the subject investigation to stagnate at the manifold inner wall. In addition, the lowest total pressures were found to occur in the region next to the feedpipe. In these regions, the subject study indicated the flow in the manifold to be accelerating to a fairly high tangential velocity. Therefore, the low total pressures observed in the reference tests could have been caused by high incidence losses or by low flow in the nozzle channels next to the feedpipe.

SUMMARY OF RESULTS

Flow conditions in the inlet manifold of the M-1 fuel pump-drive turbine were investigated using circumferential static pressure measurements in conjunction with smoke trace photographs. The results obtained from both the static pressure measurements and smoke flow traces indicated that the flow pattern within this manifold was essentially symmetrically around the feedpipe. In addition, the large observed circumferential variation in static pressure and associated flow patterns afforded a better understanding as to why reference nozzle exit total pressure patterns occurred.

Lewis Research Center,
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