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NASA TECHNICAL MEMORANDUM

NASA TM X-71597

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TEST TECHNIQUES FOR OBTAINING OFF-NOMINAL COMPRESSOR DATA DURING ENGINE TESTS

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TECHNICAL PAPER proposed for presentation at
Aerospace Engineering and Manufacturing Meeting
sponsored by the Society of Automotive Engineers
San Diego, California, September 30 - October 3, 1974

(NASA-TM-X-71597) TEST TECHNIQUES FOR OBTAINING OFF-NOMINAL COMPRESSOR DATA DURING ENGINE TESTS (NASA) 18 p HC $3.00 CSCL 21E

N74-30250

Unclas
G3/28 54883

TEST TECHNIQUES FOR OBTAINING OFF-NOMINAL COMPRESSOR DATA DURING ENGINE TESTS

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ABSTRACT

Several unique techniques and related devices are in use at the Lewis Research Center for off-design testing of fan and compressor sections in full-scale jet engines. The devices presented not only permit a wide range of experimental conditions but also minimize downtime for hardware changes. The techniques involve use of such devices as inlet pressure distortion jets, a hydrogen burner for inlet temperature distortions, fan back pressure jets to simulate a variable area nozzle, and either an inflow-outflow bleed system or a fuel spurt system to alter compressor discharge pressure.

E-8062

INTRODUCTION

The limits imposed on jet engine operation by stalls and instabilities in the associated compressor systems have generated a need to test these systems under controlled conditions available in an altitude test chamber. A variety of techniques which involve the alteration of the compressor inlet or discharge environment have been used to explore these limits.

The most widely used of these techniques involve screens in the inlet ducting to simulate pressure distortions and tabs at the fan or core nozzle exits, independent control of a variable area exhaust nozzle, or throttle bursts to alter discharge pressure. Variation of the amplitude of inlet distortions requires a variety of screen solidity changes, a time consuming task in an altitude facility. Likewise, nozzle tabs have the same handicap. Independent control of the core exhaust nozzle and throttle bursts overcome this deficiency but are inadequate when the balance between the fan and compressor systems is to be maintained.

Compressor investigations during engine testing at the Lewis Research Center have resulted in a number of techniques which minimize these deficiencies. It is the purpose of this paper to present these techniques, their related hardware, and the results accomplished.

The techniques include a device for varying pressure distortions in the inlet ducting, another device for generating temperature distortions in the inlet, a back pressure jet system to simulate area reduction in the fan nozzle, inflow-outflow bleeds at either the high or low compressor discharge and a fuel spurt system for momentarily raising compressor discharge pressure while maintaining rotating machinery matching. The discussion will cover the purpose of each technique, a description of the hardware used, a detailed description, where necessary, of the procedures involved, and finally figures presenting generalized results.

Additional testing techniques such as a combination of fan back pressure jets and inflow bleeds, a convergent-divergent plug in the inlet ducting and rotating screens in the inlet have also been tried at Lewis. However, the data obtained were over too narrow a range to be discussed here.

DISCUSSION

INLET PRESSURE DISTORTION - The inlet pressure distortion technique is used to simulate steady-state pressure distortions that, in the past, have been simulated by inlet screens. In doing so, a quick method of change from one pattern amplitude to another is accomplished without shutdown of the altitude facility. Furthermore, variable amplitude dynamic pressure distortions and uniform pressure oscillations can also be simulated, something that was not possible even when rotating screens were employed at the Lewis Research Center.

The hardware is described in (1)* in its entirety so that only the main features will be presented here. The apparatus in the inlet duct (fig. 1) consists of jet nozzles facing upstream approximately one duct diameter from the engine face. The nozzles are equally spaced radially and circumferentially to cover the entire inlet duct. Remote control is exercised over each of six identical 60° sectors by way of high-response servo operated valves which regulate the flow to the nozzles of each 60° sector. A common air supply with a manifold acting as an accumulator feeds the six valves. Any circumferential distortion can be varied with ease in 60° sectors while valve ports or tubes can be blocked, though not remotely, to add even more versatility to the type of distortions possible. All the jets operated choked. This flow, even in the undistorted region, was sufficient to counteract any wakes off the hardware and produce uniform mixing downstream of the jets.

A six valve system was used for all engine installations but the number of jets varied from 18 to 54 depending on the diameter of the engine.

Simple illustrations of how the system works are presented for the case of a 180° circumferential distortion in figure 2 and a tip radial distortion in figure 3. Increasing the secondary flow in three of the 60° sectors results in a lower than average pressure in those sectors at the engine face (fig. 2). Also seen in figure 2 is the definition between the distorted and undistorted sectors. The results of a tip radial distortion caused by blocking inner circumferential jets are seen in figure 3. The number of jets used is important in controlling the shape of the profiles. For example, in one particular installation with only three jets active in the hub section,

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*Numbers in parentheses designate References at end of paper.

out of a total of 18 for the entire duct, the results were unsatisfactory.

An analog computer and frequency generator were also linked to the valve input signals to permit uniform sinusoidal patterns, pulses of varying amplitude and duration and 60° out of phase clockwise and counterclockwise rotating distortion waves. Taped signals of actual pressure variations measured in the inlet of an engine in flight were also used to drive the valves. Not all the techniques were equally successful but they do illustrate the versatility of the apparatus.

The designed frequency capability of the valves is 200 hertz. Because of the dynamics of the piston valve-tube arrangement and the inlet duct, however, the system is most effective to 20 hertz with declining but still acceptable amplitudes to 80 hertz (fig. 4). This range was useful enough for inlet pressure distortion investigations for a variety of turbofan and turbojet engines.

INLET TEMPERATURE DISTORTION - The second of the inlet distortion techniques developed at the Lewis Research Center involves a temperature distortion device described in detail in (2), (3), and (4). The purpose of this hardware is to generate temperature distortions which may result from air exiting a previous compressor or from hot gases ingested from an external source.

The device shown in figure 5 consists of a hydrogen burner, located upstream of the inlet duct bellmouth, that is designed to produce circumferential temperature distortion in any or all of four 90° quadrants both spatially (potential rise of 450 K) and transiently (up to 11 000 K/sec). Each of the quadrants is occupied by a system of tubes, in annular and radial gutters, to distribute the gaseous hydrogen. Ignition is provided by several swirl cans in each quadrant. The eventual distortion is dependent on the release through slow acting control valves for spatial temperature distortions and the release of a trapped volume of hydrogen through high speed valves for the transient temperature distortions.

An example of the circumferential steady state temperature distortion resulting at the engine face for hydrogen burning in various quadrants is shown in figure 6. The boundaries between the sectors were not as sharply defined as the pressure distortions cited above and, in addition, radial gradients were superimposed on the circumferential distortions.

The transient temperature distortion pattern is presented in figure 7, a profile at one instant in time during a 360° extent excursion. The prominent feature of the figure is the concentration of high temperatures in the center or hub region due to the design of this hydrogen burner.

FAN BACK PRESSURE VARIATION - The fan back pressure jet system was introduced to simulate a variable area fan nozzle blocking or restricting the fan duct flow-path. The hardware used for this technique, shown in figure 8, consists of a manifold or accumulator supplied by high pressure air and pipes from this manifold terminating in nozzles that uniformly direct the flow counter to the fan exit flow. Control of the back pressure is exercised by facility valves upstream of the manifold.

The system operates on two basic principles - both related to a constant total pressure from nozzle inlet to nozzle exit. First, added mass flow from the jets requires a higher nozzle exit pressure and thus a higher back pressure on the fan. Second, the forward facing jets cancel momentum thus causing a higher upstream pressure (i. e., fan back pressure).

The procedure used with this equipment can best be illustrated with the aid of figure 9, a fan map obtained for a high bypass ratio engine at low and high altitude conditions. The back pressure is slowly increased as given corrected fan speed and engine inlet and exhaust conditions are held constant. The pressure increase is continued as the fan moves along a speed line until stall or some other limit, such as stress, is reached. The end result of a number of these excursions plus tests without the back pressure jets operating is a fan map complete with operating line, constant corrected speed lines and stall line constructed in a relatively short amount of time. The facility at which some of these tests were performed is equipped with an on-line digital computer with the capability of updating the desired parameters each second. Engine and facility operators thus were able to easily maintain constant settings as the back pressure was varied and thereby assist in minimizing the time between data points.

Caution should be exercised in the use of this method. Determination of how the areas of the fan will be affected by the jet counterflow may not be a straightforward matter. If the fan duct-core splitter is too close to the fan blades, instabilities in this region in both the fan duct and core may occur resulting in nonsteady conditions. If the splitter is far enough away from the fan blades, the resulting volume permits the back pressure to influence both the fan tip and hub regions as desired.

COMPRESSOR DISCHARGE - There are two techniques for varying compressor discharge pressure, inflow-outflow bleeds and fuel spurts.

Inflow-Outflow Bleeds - The inflow-outflow bleed system operates on a principle similar to that of the fan back pressure jets to alter either low or high compressor discharge pressure. That is, the inflow bleed to the exit of the compressor raises the discharge pressure producing intermediate speed line data between the operating line and stall while outflow bleed of compressor exit air lowers the pressure permitting extension of these speed lines below the normal operating line (5). The bleed ports, in turn, are attached to pipes with remotely controlled valves which either allow high pressure air to enter the engine or compressor discharge air to bleed to the facility exhaust system. The compressor map constructed by this method is similar to the fan map (fig. 9) mentioned in the back pressure jet section.

The procedure of holding compressor speed and facility conditions constant during pressure changes is also followed. An analog computer can be used in place of a real time digital computer to assist in maintaining test conditions. This computer can be linked to an electric throttle and then to a null meter to ease the engine operator's task of holding constant corrected speed. The analog computer, in addition, is particularly important for the high pressure compressor if the inlet temperature is a function of back pressure.

Care should be taken, though, in using this technique with existing bleed ports to insure that flow maldistributions do not occur because of the bleed system hardware and that the resulting temperature pattern does not cause mechanical interference problems. That is, with compressor bleed ports designed only for a small amount of outflow bleed, a large amount of inflow bleed may not necessarily be delivered uniformly to the compressor discharge plane.

Fuel Spurt - Back pressure jets and inflow-outflow bleeds are useful for one component (i.e., fan, low compressor, or high compressor) analysis. The fuel spurt technique is used to study the interaction of several units. It is particularly suited to the study of interactions in compressor units to a stall because the match in the rotating components is maintained, a condition not found in the other techniques.

The fuel spurt system used at the Lewis Research Center produces the desired result because of fuel insertion location (between the controller and the engine) and spurt duration so brief (approximately 0.5 sec) that the controller does not respond to it. The system, shown in figure 10, contains the conventional fuel accumulator pressurized by a nitrogen source. But, in addition, it includes a valve with a timer that permits independent control of spurt amplitude and duration. The system produces a step rise in pressure, a rise only high enough to cause stall, a step shut off fast enough to minimize overtemperature and results which are repeatable.

Figures 11(a) and (b) indicate what some of the consequences would be if spurt duration were long enough that the engine fuel controller could react. A fuel spurt could be overridden by the controller and a meaningful change in compressor discharge pressure prevented (fig. 11(a)). Another possibility is an abrupt abnormal loss in compressor discharge pressure as spurt pressure is cancelled while the fuel controller is in the process of responding to the previous fuel pressure increase (fig. 11(b)). Furthermore, if the fuel spurt pressure is not properly regulated, the engine could accelerate and overtemperature the turbine.

The spurt produced by the Lewis system (fig. 11(c)) is so sudden that speed matches are maintained and the effect of a high compressor stall on an entire compressor system can be investigated (6). However, it should be noted that for a given condition, only two points on the compressor map, the operating line point and the stall point, are possible. Additionally, because of the transient nature of the data, this technique is completely dependent on the availability of high response instrumentation and data reduction systems.

SUMMARY

Five techniques employed at Lewis Research Center for investigating compressor systems during engine tests under altitude conditions have been presented. They are inlet pressure distortion, inlet temperature distortion, fan nozzle area reduction and compressor discharge variation by either inflow-outflow bleed or fuel spurts.

The inlet pressure distortion technique, using a system of jets, permits versatility in the application of steady state and dynamic pressure distortions. The steady state distortions are sufficiently well defined and the dynamic distortions acceptable, in terms of amplitude and frequency (to 80 Hz) over a large enough range to replace conventional screens.

The inlet temperature distortion technique uses a hydrogen burner. It allows the effects of temperature induced distortions on a compressor system to be studied for steady state circumferential distortions (potential rise of 450 K) and transient distortions up to 11 000 K/sec.

The fan back pressure technique utilizes a system of uniformly spaced jets in counterflow to the fan flow while the compressor discharge variation technique employs an inflow-outflow bleed system. Both permit the mapping of constant corrected speed lines from the normal operating line to the stall line for any one compressor or fan unit.

The fuel spurt technique in conjunction with high response pressure instrumentation permits the study of the effects of high compressor stall on an entire compressor system. This is possible because of the inclusion of a timed release valve that delivers a fuel step of such short duration down-

stream of the engine fuel controller that component matching can be maintained up to the stall condition.

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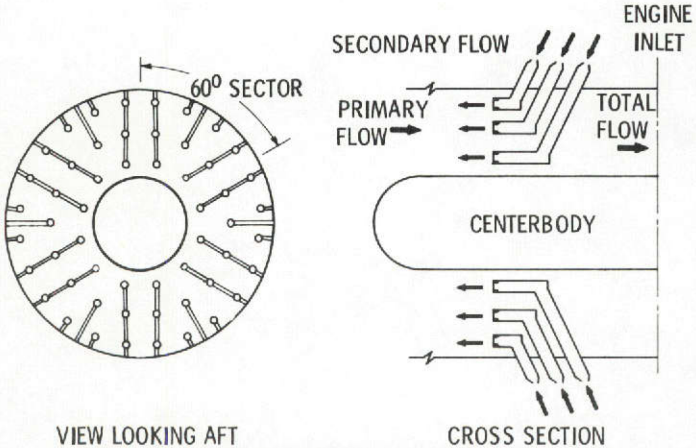
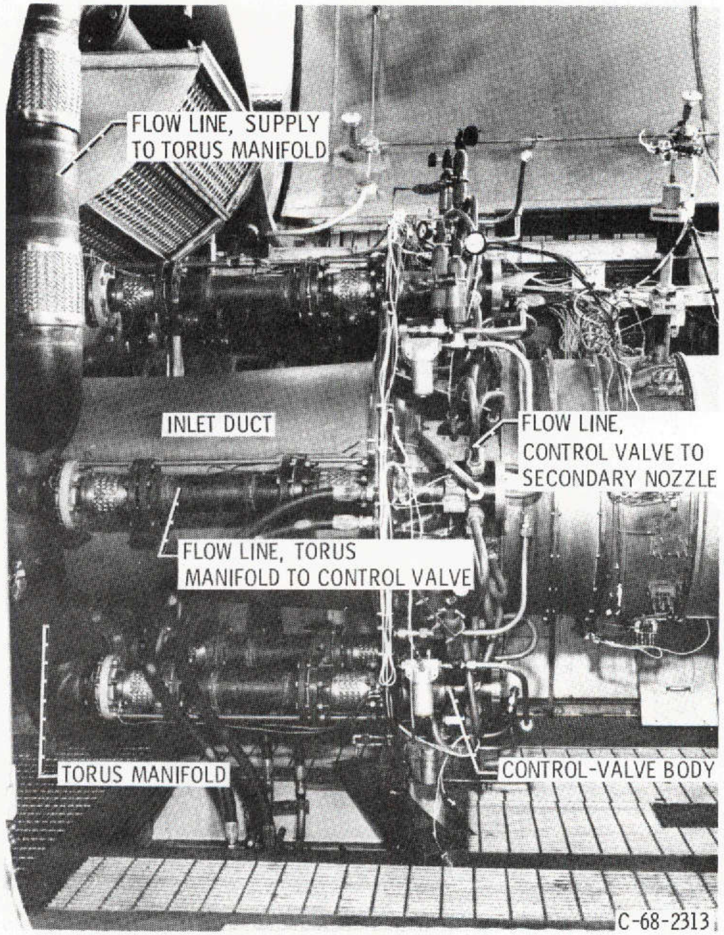


(a) SCHEMATIC DRAWING OF JET ARRAY.

Figure 1. - Secondary-air jet array assembly.



(b) SECONDARY-AIR SUPPLY SYSTEM.

Figure 1. - Concluded.

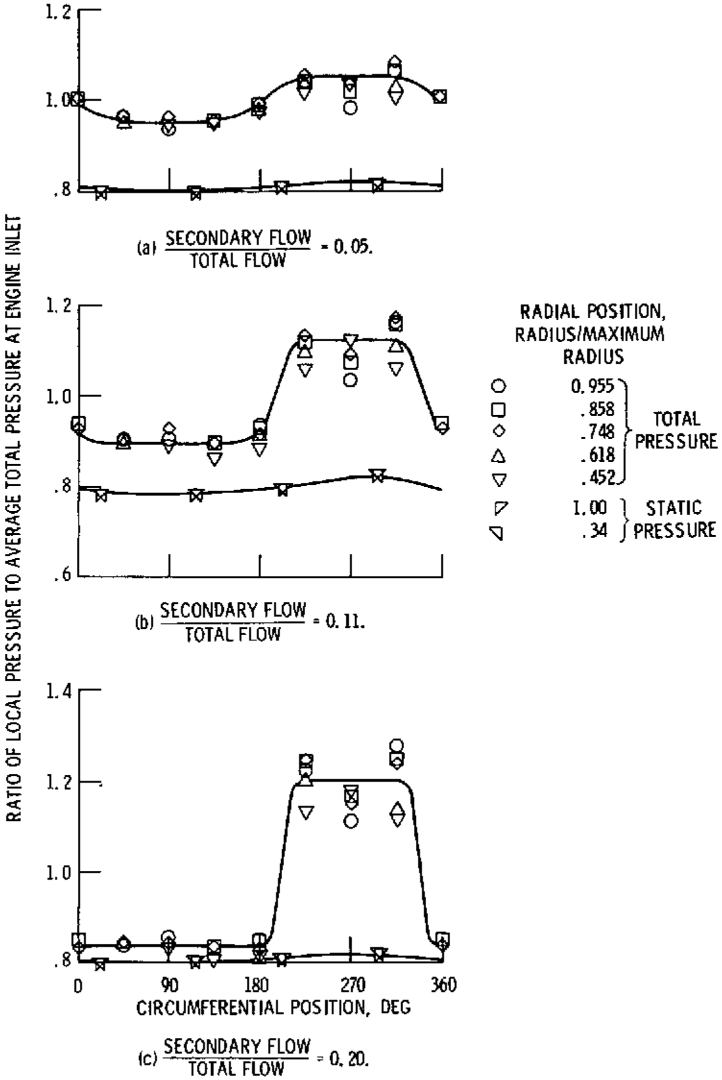


Figure 2. - Circumferential pressure distortion; secondary flow from three adjacent 60° sectors.

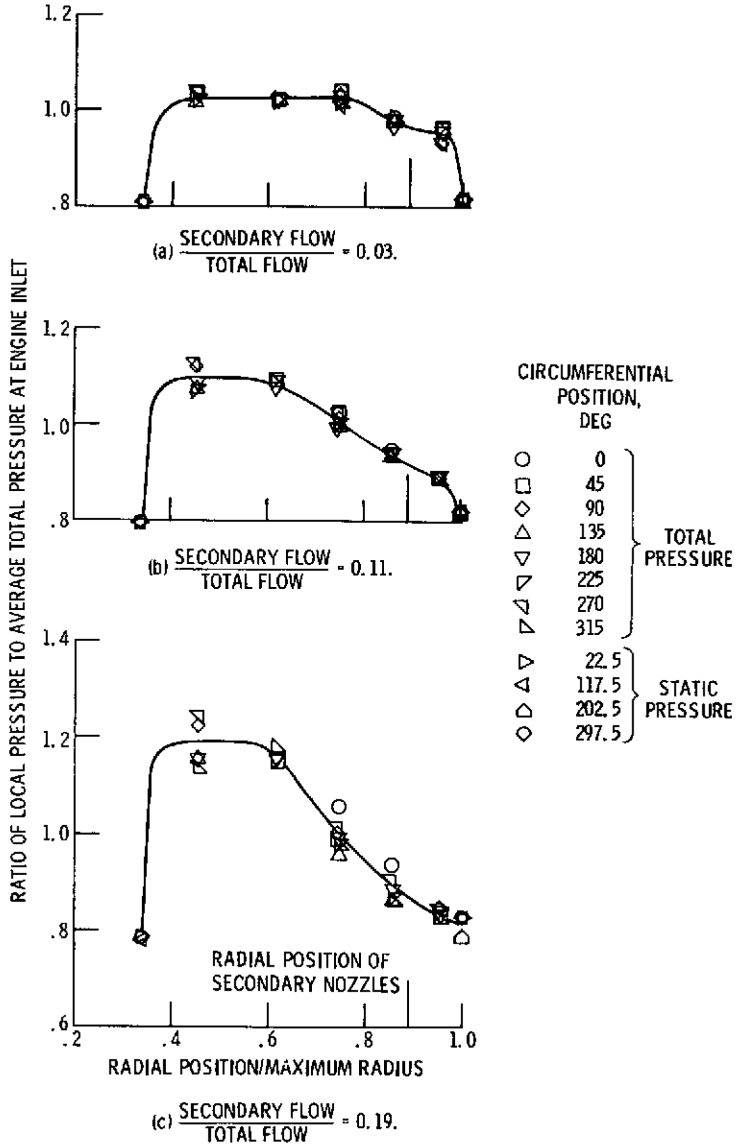


Figure 3. - Tip-radial pressure distortion; secondary flow from outer circumferential ring.

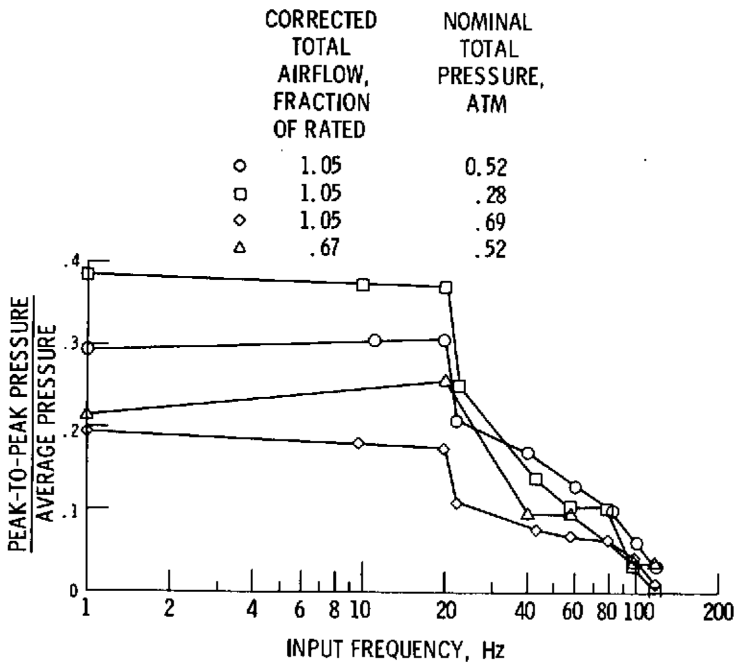
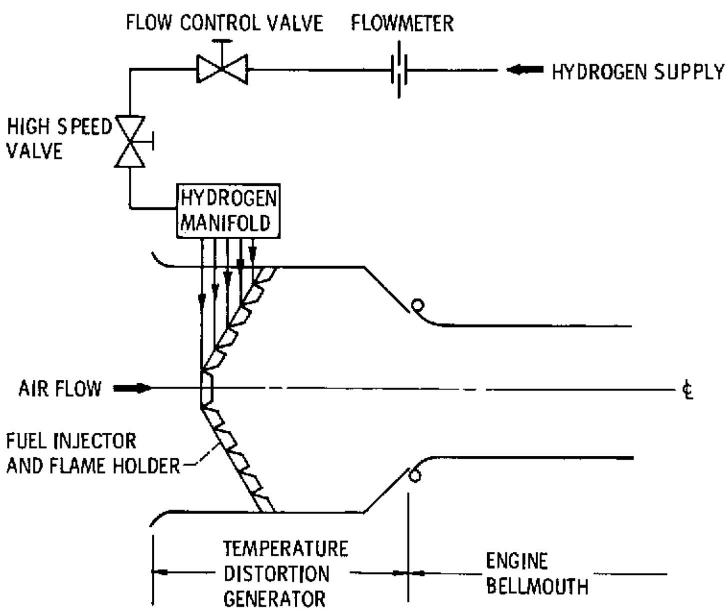


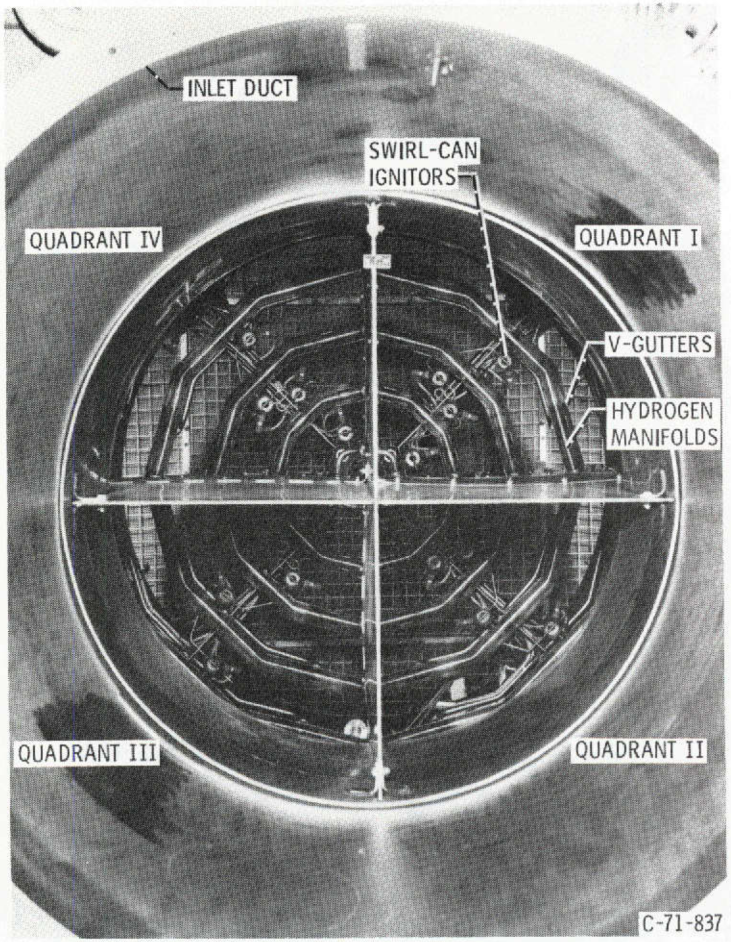
Figure 4. - Inlet-pressure amplitude characteristics.

E-8062



(a) SCHEMATIC OF INSTALLATION.

Figure 5. - Hydrogen fueled temperature distortion generator.



(b) INTERNAL VIEW LOOKING FORWARD.
Figure 5. - Concluded.

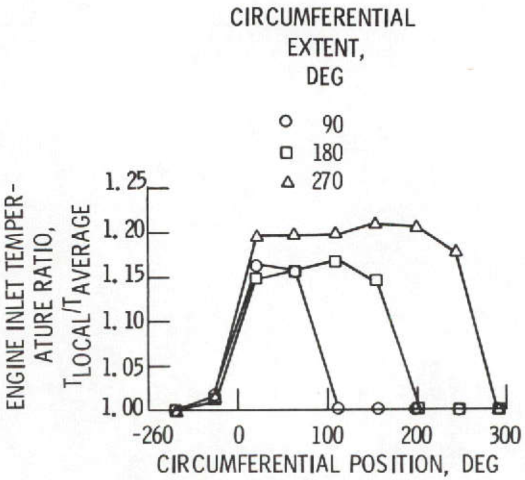


Figure 6. - Typical temperature profiles at engine inlet for spatial temperature distortions.

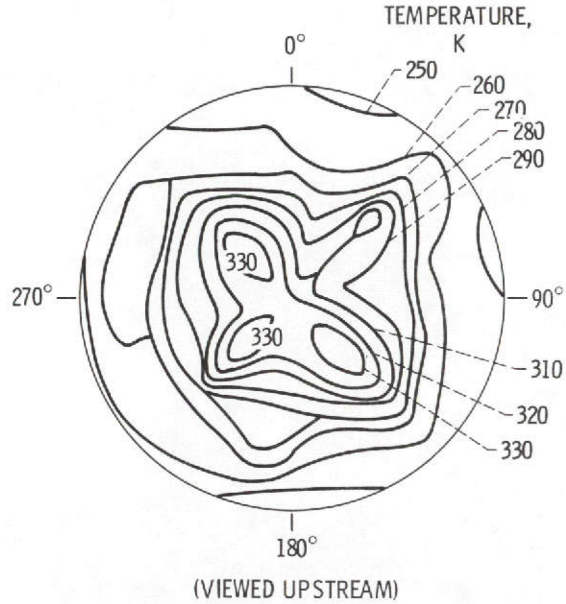


Figure 7. - Instantaneous temperature profiles during a 360° transient just prior to engine stall.

E-8062

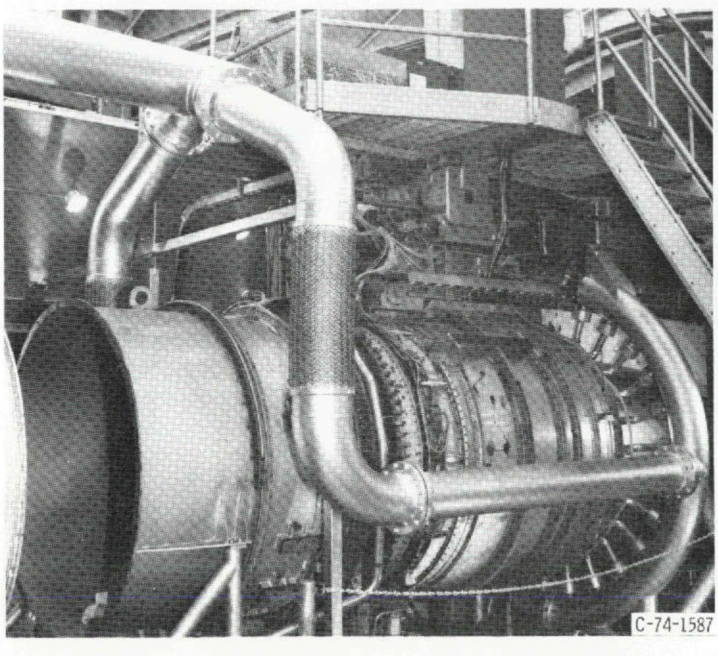


Figure 8. - Fan back pressure jet assembly.

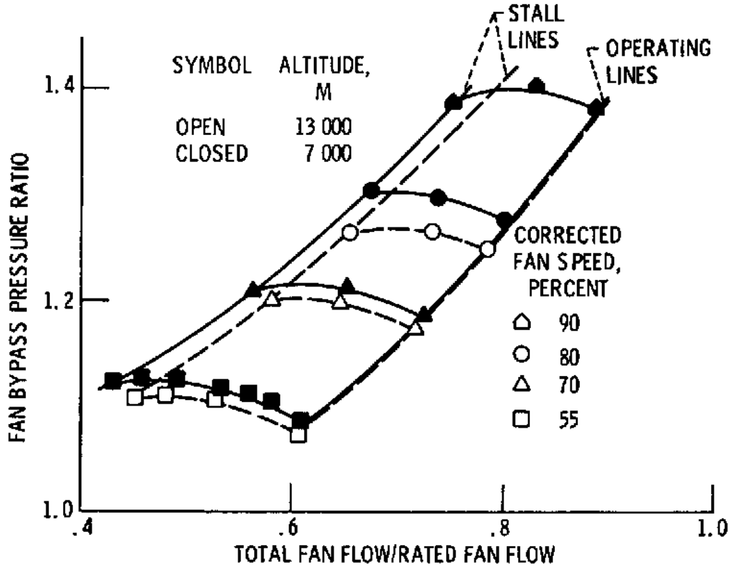


Figure 9. - Typical fan performance map.

E-8062

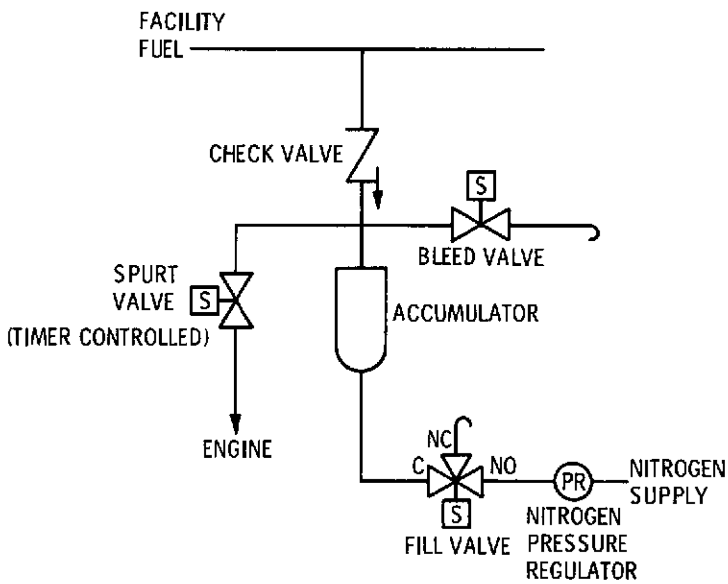
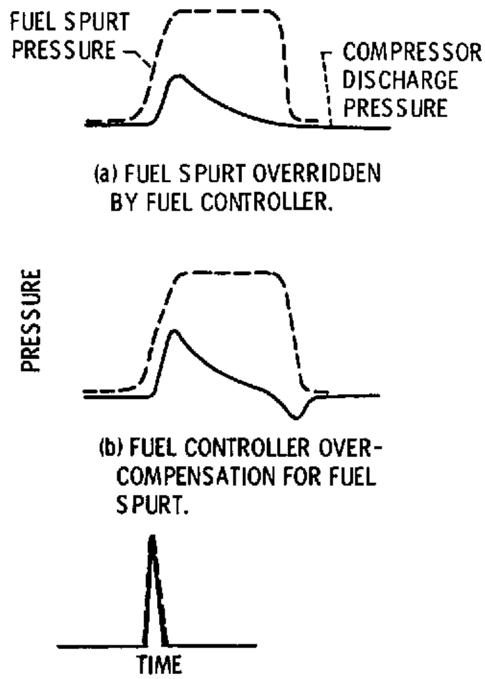


Figure 10. - Fuel spurt system schematic.

E-8062



(a) FUEL SPURT OVERRIDDEN BY FUEL CONTROLLER.

(b) FUEL CONTROLLER OVER-COMPENSATION FOR FUEL SPURT.

(c) DESIRED RESULT.

Figure 11. - Possible compressor discharge pressure responses to a fuel spurt.