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SUMMARY

A stability-bleed system using relief-type mechanical valves provides large stabilizing flows more quickly than a conventional inlet control while preserving low bleed at design conditions. This report presents the transient performance of such a stability-bleed system installed in a YF-12 aircraft flight inlet while the inlet was subjected to internal and external airflow disturbances in the NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel. The stability-bleed relief valves were designed to be tolerant of the YF-12 flight environment and to fit within the cowl structure of the YF-12 aircraft inlet.

At Mach 2.47 and 2.76, the inlet unstart tolerance to an internal, triangular airflow pulse of variable period was determined. The stability-bleed system increased the inlet airflow stability by approximately 10 percent of the operating-point airflow for disturbances ranging from about 7 percent (of the operating-point value) per second to over 400 percent per second. This stability system complemented very well the inlet terminal-shock-control system, which compensated for pulse rates ranging from zero to about 10 percent per second.

The inlet was subjected to a step-type external airflow disturbance which was a combination of a decrease in Mach number and an increase in angle of attack. The stability-bleed system demonstrated its capability by keeping the inlet started longer with the valves operative than with them inoperative. Hence, the stability system provides additional time for the inlet control system to react and prevent unstart. Tests were conducted with initial spike-tip Mach numbers of 2.55 and 2.68 and the airflow at zero angle of attack.

The stability-bleed system also demonstrated its ability to provide the inlet with more angle-of-attack capability during angle-of-attack disturbance tests. The actual increases in angle-of-attack capability without unstart could not be determined because wind-tunnel mechanical-stop limits were reached. The tests were run at free-stream Mach numbers of 2.47 and 2.76.

INTRODUCTION

Usually, a mixed-compression inlet operates most efficiently when the terminal shock is just aft of the throat. In this condition, the inlet can be unstarted by a small disturbance. Preventing inlet unstart while maintaining high inlet performance is necessary for supersonic-cruise aircraft. This is especially true for commercial aircraft so that they can be economically successful.

The purpose of a stability-bleed system is to allow higher inlet performance (by having the terminal shock closer to the throat) while maintaining a substantial tolerance to inlet unstart due to internal or external disturbances. The stability-bleed system can complement the conventional inlet active control systems by providing fast-acting response without unfavorable interaction. The flight-weight active control systems usually do not provide fast-acting responses. Bleed systems can provide fast flow changes, but a high-capacity, fixed-exit bleed has excessive continuous bleed flow at on-design conditions, which penalizes inlet efficiency. A recent study at the NASA Lewis Research Center (refs. 1 and 2) has shown that a bleed system using mechanical relief-type valves can provide large stabilizing flows quickly and can also provide low bleed at design conditions. The system of reference 2 required a separate, variable reference pressure under manual control. Also, the valve mechanization was not compatible with high-temperature operation or with integration into a flight-weight inlet structure.

In a continuing investigation of mechanical bleed valves, the Lockheed Aircraft Corporation under contract to NASA designed and built a set of valves that can operate under the conditions encountered in the flight envelope of the YF-12 aircraft. They also fit within the cowl structure of a YF-12 flight inlet. This design was based on a feasibility study (ref. 3) conducted by Lockheed Aircraft Corporation. References 4 to 8 present the details of the relief stability valve design and the bench tests of the prototype valve. Reference 9 is a brief summary of results of wind-tunnel tests of the throat-bypass stability-bleed system. References 10 to 12 give a more detailed presentation of various aspects of the wind-tunnel investigation of the throat-bypass stability-bleed system.

This report presents the transient performance of the throat-bypass stability-bleed system installed in the YF-12 flight inlet while the inlet was subjected to internal and external transient airflow disturbances in the NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel.

The internal airflow disturbance was a single triangular pulse generated by high-response sliding-plate valves. The disturbance simulates an engine-corrected airflow disturbance. The sliding-plate valves were ramped closed and open at varying rates. At each rate, the pulse amplitude was increased until the inlet unstarted. This disturbance was applied at free-stream Mach numbers of 2.47 and 2.76. Two types of external disturbances were used. The first was generated by a falling plate located at the wind-tunnel throat. The resulting disturbance consisted of a simultaneous change in tunnel flow-field Mach number and flow angularity at the model. This disturbance was applied at free-stream Mach numbers of 2.55 and 2.68. The second external disturbance consisted of pitching the inlet to angle of attack and back to zero angle again. This disturbance was applied at free-stream Mach numbers of 2.47 and 2.76.

U.S. customary units were used in the design of the stability-bleed system and for recording experimental data. The units were converted to the International System of Units (SI) for presentation in this report.

SYMBOLS

DPR	YF-12 inlet duct pressure ratio signal used as the feedback signal in the aircraft terminal shock position control system
M_0	free-stream Mach number at spike tip
P_{bf}	bleed plenum forward compartment total pressure (fig. 8), N/cm^2
P_0	free-stream total pressure, N/cm^2
$p_1, p_2, p_3, \ldots, p_7$	cowl static pressures in bleed region (fig. 8), N/cm^2
α_l	inlet local angle of attack at spike tip, deg
β_l	inlet local angle of sideslip at spike tip, deg

APPARATUS

This report is part of the YF-12 inlet investigation performed at the Lewis Research Center and deals specifically with a throat-bypass stability-bleed system using relief valves to increase the transient stable airflow range of a mixed-compression inlet. However, for completeness this report also includes information on the inlet description and installation. Additional information on the inlet and its installation is given in reference 13.

Inlet and Its Installation

Figure 1 is an isometric view of the YF-12 flight inlet. The inlet is an axisymmetric, mixed-compression type. At the YF-12 aircraft cruise Mach number, 60 percent of the supersonic area contraction of the inlet occurs internally. The spike is hydraulically actuated to translate for restarting the inlet and for off-design inlet operation. Spike boundary-layer bleed is taken off through a slotted surface on the spike. This bleed is passed overboard through the spike support struts. Cowl boundary-layer bleed is taken off through a slot (shock trap) that acts like a flush slot and a ram scoop. This shock-trap flow bypasses the forward-bypass door by means of shock-trap tubes. It is then combined with the flow from the aft-bypass flow and is exhausted through the engine ejector nozzle. The forward-bypass door is used in a closed-loop control system to control terminal-shock position. The forward-bypass airflow is passed overboard. Basically, the spike bleed and shock trap are used to improve inlet performance and provide some stability, while the forward and aft bypasses are used to match inlet and engine airflow requirements. For these tests, the aft bypass was kept closed.

The shock-position control, described in reference 14, was designed to give performance similar to that of the YF-12 flight system. It used a single throat static pressure to infer shock position. The change in the static pressure was supplied to a proportional-plus-integral controller, the output of which was used to manipulate the forward-bypass door to control shock position.

Figure 2 is a schematic of the inlet and cold-pipe assembly for the 10- by 10-Foot Supersonic Wind Tunnel. The inlet was mounted on a boiler-plate nacelle, and the entire assembly was mounted on a strut. A 3.05-meter-long cold-pipe assembly was mounted inside the nacelle. The downstream airflow disturbance generator was mounted inside the cold pipe. Figure 3 shows the inlet mounted in the Lewis 10- by 10-Foot Supersonic Wind Tunnel.

Airflow Disturbance Devices

Figure 4 shows the internal disturbance generator. It was used to create the internal airflow disturbances that push the terminal shock upstream toward unstart. This upstream movement of the shock results in changes in inlet pressures which actuate the stability-bleed relief valves. This simulates an engine-corrected airflow perturbation. Figure 4(a) shows a schematic of the internal airflow disturbance generator. It expands and contracts like an umbrella to set the steady-state operating-point corrected airflow. The five sliding-plate type valves of the disturbance generator are independently controlled by hydraulic position servomechanisms to provide the transient airflow disturbance. Flow across the internal disturbance generator was choked. Additional details of the sliding-plate valves and the disturbance-generator assembly are given in reference 13. Figure 4(b) shows the internal airflow-disturbance generator installed in the cold pipe and expanded about halfway. The generator is held in the middle of the cold pipe by four support struts. The butterfly valves are used to simulate the action of the ejector nozzle.

Figure 5(a) is a schematic representation of the external airflow disturbance generator (gust generator). It was mounted on the tunnel floor at the tunnel geometric throat. The plate is hinged and falls through a 90° arc. This disturbance generator is similar to one that was used previously (ref. 15), but it has provisions to permit remote operation. The plate is initially held in the vertical position by a latching mechanism. In this position, the plate generates a shock wave that is reflected down the tunnel. When the plate is released, it falls through a 90° angle and changes the position and strength of the reflected shock.

The gust generator did not produce a uniform disturbance in front of the inlet. The disturbance was a nonuniform, simultaneous decrease in Mach number and increase in angle of attack. Conditions were determined only at the inlet spike tip and were found to be as follows: for one case, dropping the plate changed the free-stream Mach number from 2.55 to 2.43 and the angle of attack from 0° to 1.3°; for a second case, the free-stream Mach number changed from 2.55 to 2.50, while the angle of attack changed from 0° to 0.3°; and for a third case, free-stream Mach number changed from 2.68 to 2.64, and the angle of attack from 0° to 0.4°.

Figure 5(b) is a photograph of the external gust generator installed at the tunnel geometric throat. The latching mechanism holds the plate at the middle of the top edge. The strut which holds the inlet was also used to subject the inlet to an external disturbance. This was done by rotating the support strut at its maximum rate to the angle of attack at which the inlet would just remain started, and then back again. In some cases, the inlet did not unstart before it reached the physical constraint of the wind tunnel at $\pm 5.5^\circ$ angle of attack.

Throat-Bypass Stability-Bleed System

Figures 6 and 7 show the schematic and actual inlet installation of the throat-bypass stability-bleed system. The system was located just forward of the existing shock trap in the YF-12 flight inlet. The YF-12 flight inlet used in this investigation was the same inlet that was used for tests reported in references 9 to 14 and is referred to as the "unmodified" inlet. For the investigation reported herein, the inlet was equipped with the throat-bypass stability-bleed system and is referred to as the "modified" inlet.

Flight-test safety requirements dictated that a fail-safe system be provided that would allow the pilot to select an inlet configuration that is as nearly as possible like the original (unmodified) inlet. Because of this requirement, the stability-bleed region could not be placed in the ideal location, at the throat, since in the original (unmodified) inlet configuration the shock trap is there. Consequently, the test emphasis was on determining a throat-bypass stability-bleed-system configuration that would allow an adequate demonstration of the concept in flight rather than trying to optimize the system.

Figure 6(b) is a sketch of the throat-bypass stability-bleed system installed in the inlet. A portion of the solid skin ahead of the shock trap on the cowl of the unmodified flight inlet was replaced with a porous skin as shown in the figure. The holes were normal to the surface, and uniformly spaced, with a porosity of 40 percent. The entire cowl skin was porous in the region of the forward relief valves, while only the aft half of the cowl skin was porous in the region of the aft relief valves (figs. 6(b) and 7(a)). Additional details of the bleed performance study, which preceded the transient testing of the stability-bleed system presented in this report, may be found in references 11 and 12.

The stability-bleed system has two circumferential rows of 25 compartments located just forward of the shock trap (see fig. 6(c) for compartment identification). Each of the 50 compartments is isolated by bulkheads from the compartments around it. Each compartment houses a self-acting, relief-type mechanical valve which controls the bleed-plenum exit area and hence stability-bleed airflow. In general, the forward row of relief valves is intended to open in response to external disturbances, and the aft row in response to internal disturbances.

The valves, unlike the ones tested previously (refs. 1 and 2), do not require an externally supplied reference pressure for the pressure above the piston. A reference pressure is produced by using a reference orifice in each piston (fig. 6(b)). This allows the spring plenum pressure above this piston to slowly change until it equals that below the piston. The spring preload then is enough to keep the valve closed when the pressure on the bottom of the relief valve is constant or when it is changing slowly. Thus, the relief valves do not open for steady or slowly varying disturbances. The reference orifice diameter determines how fast the disturbance must change before the piston will move. The reference orifice used was 0.127 centimeter in diameter. The spring plenum of each valve was connected to a separate reference plenum in order to decrease the effect of pressure change due to valve stroking. The aft valve compartments also had a small, continuous bleed flow in parallel with the stability-relief valves as shown in figure 6(b). The function of this continuous bleed was to remove part of the boundary layer to improve the inlet angle-of-attack capability and peak pressure-recovery characteristics. The increased inlet pressure-recovery characteristics provided an increase in pressure that ensured more than adequate pressure to actuate the relief valves. The amount of this flow was determined during the study reported in reference 11.

The shields and sensing ducts were used so that the pressure under the piston would not be affected by the flow through the bleed plenums. As seen in figure 6(b), the sensing duct for the aft relief valve went from the manifolded set of ports located just forward of the shock trap to the relief-valve shield. The metal-tube sensing duct slipped over the short tube extending from the shield. For the aft relief valves, the sensing duct was placed at the downstream end of the bleed plenum. This location was used so that the highest possible pressure in the bleed region could be used to actuate the relief valve. The terminal shock can only move part way onto the aft bleed region before the inlet unstarts. Thus, as the terminal shock moves forward past the sensing tap onto the downstream end of the bleed surface for the aft relief valves, a larger pressure differential is available to actuate the relief valves than is available in the bleed plenum itself. It should be noted that, if the stability bleed could have been located at the desired location, the pressure in the bleed plenum would more nearly correspond to the sensing-duct pressure.

The sensing duct for the forward valve was a tight-fitting rubber tube as shown in figure 7(a). This sensing duct connected the bleed holes in the cowl skin directly to the shield of the forward relief valves. The forward relief valves were used to provide stabilizing airflow for transient external disturbances. These disturbances might be changes in Mach number, angle of attack, or temperature. These disturbances create pressure rises on the cowl which can lead to local choking of the throat. The bleed airflow reduces these pressures and thus prevents the inlet from unstarting.

As mentioned previously, flight-test safety requirements dictated that a fail-safe system be provided that would allow the pilot to select the original, unmodified inlet configuration. This was accomplished by a pressurizing manifold which was connected to each reference plenum. It was used to port higher pressure air to the top sides of the pistons to lock the valves closed when the pilot wanted to return the inlet to its unmodified configuration. The higher pressure air was obtained from four total-pressure tubes placed near the shock trap in the inlet. A check valve allows the higher pressure air to be ported between the pressurizing manifold and the reference plenum but stops recirculation of air among the individual reference plenums if the pressure in the reference plenum becomes higher than that in the pressurizing manifold.

Figure 7 shows the installation of the throat-bypass stability-bleed system in the YF-12 flight inlet. One of the relief valves was replaced by an orifice plate to illustrate a method of bleed-system calibration done during another phase of the experimental program (refs. 11 and 12).

Figure 7(b) shows the reference plenums as viewed from the exterior of the inlet. The airflow from the stability-bleed valves was passed overboard through louvered exits. Also shown is the connection between the stability relief valve spring plenum and the valve reference plenum.

High-Response Pressure Instrumentation

The relative positions of the high-response pressure taps located in the region of the throat-bypass stability-bleed system are shown in figure 8. The pressures were measured with strain-gage type pressure transducers. The transducers were mounted essentially flush to the taps to ensure high dynamic response (-3 dB point at 10, 000 Hz). Most of the taps were located at the $\theta = 353^{\circ}$ position (see fig. 2 for inlet orientation), while two were located at the 163° position. Pressures p_1 to p_7 are cowl-surface static pressures located in the region where the stability bleed occurs for the throat-bypass stability system. Pressure p_1 is located at the same station as the tap for the sensing duct for the aft valves; thus, it is a measure of the pressure that actuates the aft valves. Pressure p_2 is a measure of the average cowl-surface pressure (since it is located near the middle of the aft bleed region) that supplies stability-bleed flow to the aft relief valves. Pressures p_3 to p_6 are static pressures located along the portion of cowl surface that supplies stability-bleed flow to the forward set of relief valves. These pressures are used to determine whether local choking occurs in the forward stability-bleed region for the external type disturbances. Pressure p_7 is a static pressure measured about 180° opposite from pressures p_3 to p_6 and is intended to show how the inlet pressure varies on the opposite side of the inlet.

Stability-Bleed Relief Valve

A cross-sectional view of the relief valve and a photo of a disassembled valve are shown in figure 9. The relief valve is constructed mainly of titanium and weighs about 1 kilogram. The piston is closely guided on the housing centerpost. To prevent interference, a relatively loose clearance is maintained between the piston outer diameter and the housing. Piston rings, which are made of a carbon compound, are used to minimize the leakage from the spring plenum. A hole drilled in the piston between the two rings connects the volume between the two rings to that between the piston and the shield. This was done to minimize the leakage from the spring plenum to atmosphere. Leakage around the top piston ring has the same effect as flow in parallel with the reference orifice. Thus, by minimizing the leakage from the spring plenum past the top piston ring, the transient response is determined principally by the size of the reference orifice.

For development purposes, it was necessary to measure the position of the piston in some of the relief valves. The piston position-measuring transducer had to be small and light so that it would not affect relief-valve response. Piston position was measured by two strain gages mounted on fingers of a specially designed washer as shown in figure 9. As the piston opens, the force from the spring deflects the fingers, and the strain gages produce a signal proportional to piston position. All of the relief valves were identical, so they would respond the same. However, about one-third of the relief valves had position-measuring strain gages added to them; these were located as shown in figure 6(c).

PROCEDURE

The transient response of the inlet with the throat-bypass stability-bleed system was measured for internal and external disturbances. The transient data were recorded on an analog-multiplex tape recorder and were played back later for analysis.

Response to Internal Disturbances

The internal diffuser-exit disturbance airflow transients were obtained by pulsing the airflow disturbance generator closed from the open position. The sliding-plate valves were ramped closed and then back open again, thus generating a single, triangular-wave pulse. Ramp rates were varied from slower than that required to actuate the stability relief valves to the maximum rate of the disturbance sliding-plate valves. At each rate, the pulse amplitude was increased until the inlet unstarted. The maximum decrease in sliding-plate valve area that the inlet would tolerate without unstarting was thus obtained. The area change was related to a corrected airflow change, using steady-state data. The pulse data were obtained with both the unmodified inlet and the modified inlet. Unmodified-inlet data were taken with the forward-bypass shock-position control both operative and inoperative. Modified-inlet data were taken with the stability-relief valves locked and unlocked and with the shock-position control operative and inoperative.

Response to External Disturbances

The external disturbance caused by the tunnel gust generator consisted of a simultaneous change in tunnel flow-field Mach number and flow angularity. From an initial spike-tip Mach number of 2.55, the simultaneous change occurred in 0.025 second. From an initial spike-tip Mach number of 2.68, the simultaneous change occurred in 0.03 second. The inlet was subjected to this disturbance with the relief valves both operative and inoperative. Since the relief valves do not work for steady-state disturbances, the inlet would eventually unstart after the change was made, because the inlet spike control was not operative for these tests. A comparison was made of the transients with the relief valves operative and inoperative. It was then determined whether the relief valves kept the inlet started long enough so that the inlet spike-control system could have moved the spike far enough to have prevented the inlet from unstarting.

Steady-state and transient data were also taken that showed the ability of the inlet to withstand angle-of-attack variations without unstarting. For the steady-state data, the inlet was pitched slowly to angle of attack to determine the maximum angle of attack the inlet could tolerate without unstarting. For the transient data, the inlet was ramped up to some maximum angle of attack and then ramped back to its operating-point position. These data were compared to determine whether the relief valves allowed the inlet to tolerate transient angles of attack exceeding the steady-state unstart values. In flight, angle-of-attack variations due to gusts could be rapid enough to actuate the valves. However, the wind-tunnel hardware was not capable of moving the inlet to angle of attack fast enough to simulate these disturbances. Therefore, the relief valves were modified by plugging the reference orifice in the valve piston so that they could respond to the slower angle-of-attack variations in the wind tunnel. Thus, it was possible to determine whether the valves do respond to inlet angle-of-attack variations.

RESULTS AND DISCUSSION

The data shown in this report are given as a percent of change from the operating-point value. The operating-point values of inlet duct pressure ratio (DPR) and spike position, along with the actual steady-state unstart angles of attack, are given in reference 12, which is a classified report.

Response to Internal Disturbances

A typical transient response of the throat-bypass stability-bleed system for an internal airflow disturbance is shown in figure 10. This transient is typical of the data which were taken. Transients shown are for a slow and a fast ramp rate, with the forward-bypass-door shock-position control operational. The transient traces for a slow ramp rate at Mach 2.47 (fig. 10(a)) show that not all the relief valves opened fully nor at the same rate. Only the valves in compartments 1, 4, and 7 opened fully, as indicated by the flat spots on the open part of the traces. Since the inlet was at zero angles of attack and sideslip, all the relief valves might have been expected to open equally. Nonuniform valve response could be caused by any of the following conditions: nonuniform pressures (due to terminal-shock skew or the shock being nonplanar) in the inlet during the disturbance transient; inequality of valve characteristics such as piston friction, spring preload, spring rate, or internal valve leakage; or leakage from parts of the stability-bleed system other than the valve. These items are discussed in more detail in reference 9.

Pressure p_1 is a cowl static pressure located at approximately the same axial distance from the cowl lip as are the relief-valve sensing-duct pressure taps. The increase in this pressure has to become large enough to overcome the relief-valve spring preload and friction before the valve piston will move. The delay between when the disturbance begins and when the piston moves is a result of two factors: one is the time required to build up a large enough pressure differential as just mentioned; the other is the pneumatic delay time. The pneumatic delay time is more evident in figure 10(b) than in figure 10(a).

Pressure p_2 is a cowl static pressure in the region where stability airflow is being bled off for the aft relief valves. Because it is further upstream than p_1 is, it does not change as much as p_1 does.

The position trace for the valve in compartment 1 shows that the valve overshoots the fully open and the fully closed positions. Since these are physical stops, the valve piston could not be overshooting as the trace indicates. The seeming overshoot results from sensitivity of the position transducer to the vibration from the impact of the piston against the physical stops. This "ringing" effect is more clearly seen at the faster chart speed used in figure 10(b).

The transient shown in figure 10(a) is slow enough so that the terminal-shock-position control can also react and help compensate for the disturbance. This is evidenced by the relatively large motion of the forward-bypass door.

Figure 10(b) shows transient traces for a fast ramp rate at Mach 2.47. The pneumatic delay time is more evident at this faster disturbance rate and shows up better because of the higher chart speed. The "ringing" on the valve-position traces is more evident here than in figure 10(a). For this faster disturbance rate, the shock-position control system is much less effective. This is illustrated by the small motion of the forward-bypass door. These traces show how the stability valves complement the terminal-shock-position control, because the valves are still capable of moving and thus acting to prevent unstart.

Shock-position control inoperative. - The unstart tolerance of the inlet to a decreasing, single, triangular wave pulse in downstream airflow is shown in figure 11. These data are for Mach 2.47, with zero angles of attack and sideslip, with the aft-bypass door closed, and with the forward-bypass door either closed or initially closed when the forward-bypass control is operative. The solid-line curves represent the data obtained with the shock-position control inoperative.

For the unmodified inlet, the increase in stability as the disturbance rate increases is due to the volume of the inlet being better able to absorb higher-frequency disturbances. The addition of locked-closed stability-relief valves increases the tolerance of the inlet by 3 to 4 percent relative to that of the unmodified inlet. The reason for this is the previously discussed bleed in parallel with the aft stability-relief valves. Allowing the stability-relief valves to operate results in additional inlet stability for disturbance rates greater than about 7 percent per second. (The stability relief valves are dynamic devices and function only for a changing condition. For the tested configuration, the valves functioned only for airflow-disturbance rates above 7 percent per second.) The additional stability tolerance is about 10 percent up to disturbance rates of 200 percent per second, beyond which the dynamic response of the relief valves starts to diminish.

Shock-position control operative. - The data obtained with the inlet shock-position control are represented by the dashed-line curves in figure 11. These data show how the shock-position control system and the stability-bleed system work together to increase the ability of the inlet to tolerate an internal airflow disturbance. The shock-position control system compensates for disturbance rates below about 15 percent per second, and the stability-bleed system compensates for disturbance rates above 15 percent per second. The overlapping region over which the shock-position control and the stability-relief valves are effective can be adjusted by changing the bandwidth of the shock-position control or by changing the size of the reference orifice in the stability relief-valve piston.

Data similar to those presented in figures 10 and 11 for two other operating conditions at Mach 2.47 and for two operating conditions at Mach 2.76 are given in figures 12 to 16 and are discussed in the appendix. The operating conditions for all of the figures showing responses of the inlet to disturbances are summarized in table I. The results shown in figures 12 to 16 are very similar to those of figure 11. One additional curve, that of the unmodified inlet with shock-position control, has been included in figures 12, 15, and 16. The conclusion to be drawn from comparing the data in figure 11 with those of figures 12 to 16 is that performance of the stability system is quite consistent, even when the inlet operates at various steady-state angles of attack. Also, when the Mach number is changed from 2.47 to 2.76, the curves retain the same general shape and exhibit only a small shift.

Figure 17 shows estimated unstart tolerance data for both the modified and the unmodified inlet with the terminal-shock-position control active for an actual flight condition. The angle of sideslip remains zero, but the angle of attack has been changed from zero to the value for flight as given in the classified report of reference 12. These curves start out around -20 percent instead of the -30 percent shown in figure 11 because the forward-bypass door is normally partially open for the actual flight conditions at Mach 2.47. The forward-bypass door opening cannot increase as much to compensate for the disturbance as it did for the data shown in figure 11. Thus, the effectiveness of the forward-bypass door to compensate for low-frequency decreases in airflow depends on its initial opening.

Response to External Disturbances

Tunnel gust-generator transient data. - Figures 18 and 19 show the transient response of the inlet to the disturbance by the tunnel gust generator for initial spike-tip conditions of Mach 2.55 and zero angle of attack.

Figure 18 shows the response of the inlet to the falling-plate gust-generator disturbance when all the relief valves are locked closed. The inlet unstarts about 0.3 second after the disturbance occurs. The inlet unstart is indicated by the sharp drop in bleed-plenum pressure and cowl-surface static pressure which is pointed out in the figure. The relief-valve piston-position trace shows a lot of noise after the inlet unstarts; however, the piston is not actually moving. The position-transducer sensor is sensitive to vibration. When the inlet unstarts, the vibration level of the inlet increases enough to cause the noise shown in the relief-valve position trace.

Figure 19 shows the response of the inlet to the disturbance with the relief valves free to operate. The relief valve shown opened to about 25 percent of its maximum area. The ability of the relief valve to handle only transient type disturbances is demonstrated by the closing action of the valve while the disturbance is still present. Only one other instrumented upstream stability relief valve and no instrumented downstream relief valves opened during this transient. It should be remembered that only about one-third of the relief valves had position transducers. The inlet unstarted about 1.25 seconds after the disturbance occurred. The inlet unstart is pointed out by the sharp drop in bleed-plenum pressure and cowl static pressure. Again, the noise level increased for the piston-position trace when the inlet unstarted.

The response of the inlet to the disturbance both with the relief valves locked closed and with the valves free to operate was also tested for initial spike-tip conditions of Mach 2.68 and zero angle of attack. The transient traces are shown in figures 20 and 21 and are discussed in the appendix. Table II summarizes the unstart times for the two Mach numbers.

The table shows that the inlet remains started 4 to 28 times longer with the valves operative than with them inoperative. The response of the unmodified inlet is expected to be about the same as that of the modified inlet with valves inoperative. No data were obtained for this disturbance with the inlet control system operative. (The hardware associated with sensing changes in angle of attack and Mach number, necessary for the spike control, were unavailable.) Thus, it is not known if the inlet control could have prevented unstart. However, it was concluded that without the valves being operative, the control could not have prevented unstart at Mach 2.68 and probably not at Mach 2.55. These conclusions are based on knowledge of the spike extensions required to prevent unstart, the spike slew rate, and the lag times associated with the sensing hardware. The stability system with valves operative does provide additional time for the inlet control system to react to prevent unstart.

Inlet angle-of-attack transient data. - As was mentioned in the PROCEDURE section, the relief valves were modified for the angle-of-attack tests. Because the strut cannot move very fast (it acts almost like a steady-state disturbance to the inlet), the reference orifices in the stability-valve pistons were plugged. Thus, the relief valves could respond to more slowly varying pressures. However, because of some small leakage across the piston, the relief valves still will not actuate for steady-state or very slowly changing disturbances.

Figure 22 shows the transient response for a ramp variation in inlet angle of attack for Mach 2.47. The inlet was initially at the flight operating point, which included having the inlet initally at angle of attack. The angle of attack was increased 1.3° from the flight angle without the inlet unstarting. At this point the wind-tunnel hardware limits were reached. Thus, the unstart angle of attack could not be determined with the stability-relief valves operating. However, the relief valves did allow the inlet to exceed the steady-state unstart angle of attack at Mach 2.47 without unstarting.

Figure 23 shows the transient response for a ramp variation in angle of attack for Mach 2.76. The initial angle of attack was zero. The two relief valves shown opened about 25 percent of their maximum. The inlet exceeded the steady-state unstart angle of attack by approximately 2.6° without unstarting. The actual unstart angle could not be determined because of physical limits of the wind-tunnel hardware.

Tests were also conducted at Mach 2.47 and 2.76 with an initial angle of attack of zero, but the spike was extended 1.78 centimeters more than it had been for figures 22 and 23. These traces are shown in figures 24 and 25, respectively, and are discussed in the appendix. Again, the inlet did not unstart before the wind-tunnel hardware limits were reached. Thus, the inlet angle of attack disturbance transients have demonstrated the ability of the stability-bleed system to keep the inlet started for variation in inlet angle of attack.

SUMMARY OF RESULTS

A throat-bypass stability-bleed system installed in a YF-12 aircraft flight inlet was tested in the Lewis 10- by 10-Foot Supersonic Wind Tunnel. The stability-bleed system allows higher inlet performance (by permitting the terminal shock to operate closer to the inlet throat) while maintaining a substantial tolerance to inlet unstart due to internal and external disturbances. The valves that bleed the airflow are a flight-type design that are able to withstand the flight environment of the YF-12 aircraft and also fit within the inlet structure. The valves are relief-type mechanical valves.

The tests demonstrated that the stability-bleed system could compensate for internal disturbances from about 7 percent (of the operating-point value) per second to over 400 percent per second. An additional stability airflow of about 10 percent (of the operating-point value) was achieved out to rates of 200 percent per second, where the dynamic response of the relief valves starts to diminish. The tests were conducted at Mach 2.47 and 2.76.

The stability-bleed system and the terminal-shock-position control worked well together. The terminal-shock-position control compensated for internal disturbance rates from zero to about 10 percent per second, while the stability-bleed system compensated for internal disturbances from just below 10 percent per second to above 600 percent per second.

The inlet was subjected to a step-type external disturbance which was a combination of a decrease in Mach number and an increase in angle of attack. The stability-bleed system demonstrated its capability to keep the inlet started 4 to 28 times longer than the unmodified inlet. Thus, the stability system provides additional time for the inlet control system to react to prevent unstart. Tests were conducted with initial spike-tip Mach numbers of 2.55 and 2.68, at zero angle of attack.

The stability-bleed system also demonstrated its ability to provide the inlet with more angle-of-attack capability during tests in which the inlet angle of attack was varied. The actual increases in unstart angle-of-attack capability could not be determined because of wind-tunnel hardware limits. The tests were run at free-stream Mach numbers of 2.47 and 2.76.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 9, 1979,
743-03.

APPENDIX - ADDITIONAL DYNAMIC DATA OF A STABILITY-BLEED SYSTEM

The data in the main body of the report demonstrated the ability of the stability-bleed system to extend the range of frequency of disturbances that the inlet could withstand without unstarting. These included both internal and external disturbances. The data included in this appendix are additional data that were taken. They are included here to give information at other operating conditions even though the results are, in general, the same.

Figures 12 and 13 show the transient response of the inlet to a single triangular pulse in diffuser-exit corrected airflow for Mach 2.47 with the inlet angle of attack equal to the scheduled value. The forward-bypass door was closed for the data shown in figure 12 and at its flight-scheduled opening for figure 13. Comparing the data of figures 12 and 13 indicates that with the bypass control inactive the inlet has a little more unstart tolerance with the forward bypass open. This is true for all three curves. There are two factors which contribute to the increase in stability. One results from the fact that the inlet is at about 1.3° less angle of attack for the data shown in figure 13 than it was for the data shown in figure 12. This gives a more uniform shock pattern (less skewed) in the inlet which in turn allows more of the relief valves to be activated. The other factor accounting for the increased stability is that the forward bypass door is open at the operating point. The stationary bypass door can bypass more airflow (thus more stability), when compared to a closed door, as the pressure inside the inlet builds up when the disturbance causes the inlet to get closer to unstart.

Figures 14 to 16 show data of inlet transient stability for a single triangular pulse in diffuser-exit corrected airflow. It is similar to that discussed in the main body of the report and for figures 12 and 14 in the appendix except that the free-stream Mach number was 2.76 instead of 2.47. Thus, Mach number, angle of attack, and small spike variations did not greatly affect the general nature of the results. Comparing figures 15 and 16 indicates that the standard inlet unstart tolerance (solid line with solid circular symbols) is increased a little for the angle-of-attack data. The principal reason for this is that the spike was extended more for the data of figure 16 than it was for the data shown in figure 15. The stability relief valves were slightly less effective at increasing the inlet's unstart tolerance at angle of attack than they were at zero angle. The reason for this is that with the inlet at angle of attack not all the valves are effective. The stability relief valves still do increase the inlet's unstart tolerance significantly, however.

Figures 20 and 21 show the inlet response to the gust generator with the relief valves free to operate and locked up, respectively. The initial spike-tip Mach number was 2.68. The data in the main body of the report were for Mach 2.55. The data of figures 20 and 21 again show that the stability-bleed system keeps the inlet started longer when the valves are operative. This provides additional time for the inlet control system to react to prevent unstart.

Figures 24 and 25 show additional data for inlet strut angle-of-attack disturbances. It again demonstrates that the stability-bleed system allows the inlet to transiently exceed the steady-state unstart angles without unstarting. The actual transient unstart angles could not be determined since the inlet reached the tunnel physical limits. In figure 24 there are some high-frequency oscillations on the cowl static pressures and on the position trace for the relief valve in compartment 11. These pressure fluctuations are probably the result of flow separation and reattachment along the inlet. This same phenomenon was observed when the inlet was slowly taken to an unstart angle of attack. In that case, just before the inlet unstarted, these same higher frequency pressure fluctuations were observed, which probably means the inlet is closer to unstart for the transient shown in figure 24 than for the strut angle-of-attack transients shown elsewhere in this report.

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TABLE I. - INLET OPERATING CONDITIONS

Figure	Source of disturbance	Initial Mach number at spike tip	Initial angle of attack	Initial angle of sideslip	Initial forward-bypass door position	Initial aft-bypass door position	Shock-position control	Spike position	Condition of stability-bleed valves
10	Disturbance generator	2.47	Zero	Zero	Closed	Closed	Operative	Flight position	Operative
11	↓	↓	Zero	↓	Closed	↓	Operative; also inoperative	↓	Locked closed; also operative
12			Flight angle		Closed		Operative; also inoperative		Locked closed; also operative
13			Flight angle		Flight opening		Inoperative		Locked closed; also operative
14		2.76	Zero		Closed		Operative		Operative
15		2.76	Zero		Closed		Operative; also inoperative		Locked closed; also operative
16		2.76	Flight angle		Closed		Operative; also inoperative		Locked closed; also operative
17		2.47	Flight angle		Flight opening	Flight opening	Operative; also inoperative		Locked closed; also operative
18	Gust generator	2.55	Zero	Zero	Closed	Closed	Inoperative	Flight position	Locked closed
19	↓	2.55	↓	↓	↓	↓	↓	↓	Operative
20		2.68							Operative
21		2.68							Locked closed
22	Strut angle of attack	2.47	Flight angle	Zero	Closed	Closed	Inoperative	Flight position	Operative
23	↓	2.76	Zero	↓	↓	↓	↓	Flight position	↓
24		2.47	Zero					1.78 cm forward of flight position	
25		2.76	Flight angle					1.78 cm forward of flight position	

TABLE II. - TIME TO INLET UNSTART AFTER START

OF GUST-GENERATOR DISTURBANCE

Mach number at spike tip before start of disturbance	Condition of stability-bleed valves	Time to unstart, sec
2.55	Operative Locked closed	1.25 .3
2.68	Operative Locked closed	1.7 .06

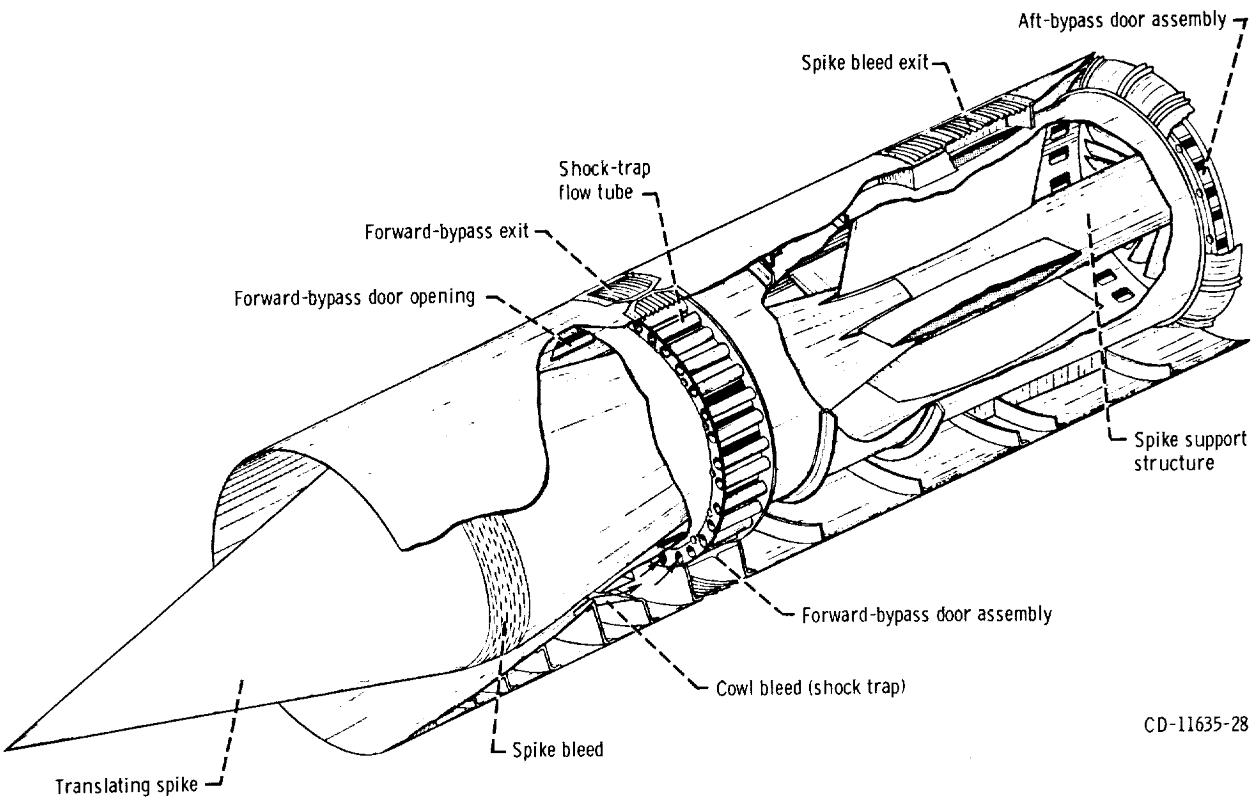


Figure 1. - Isometric view of flight inlet of YF-12 aircraft.

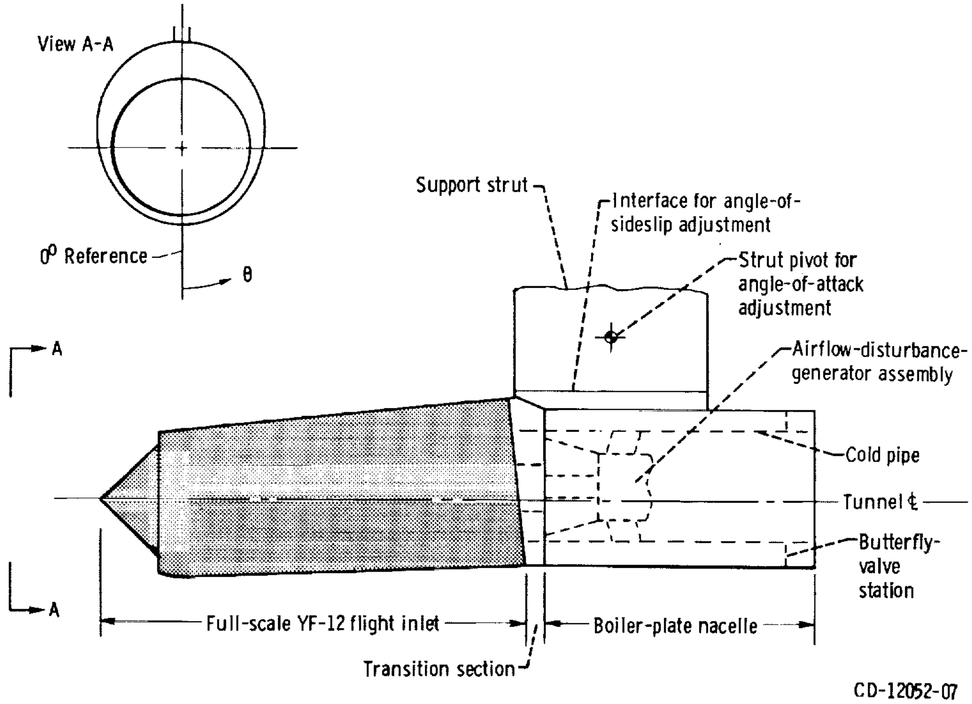


Figure 2. - Schematic diagram of the inlet and cold-pipe assembly for the 10- by 10-Foot Supersonic Wind Tunnel.

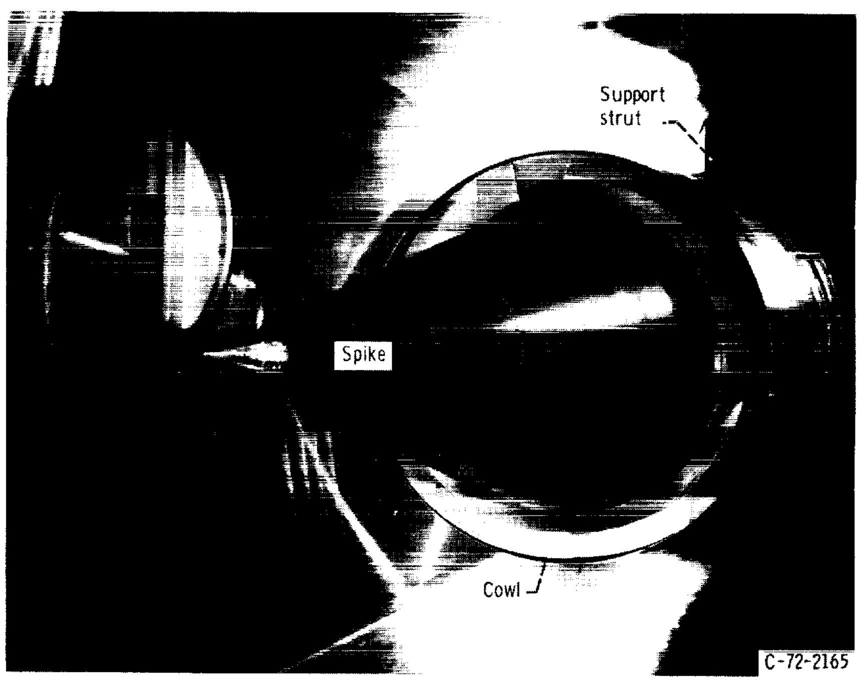
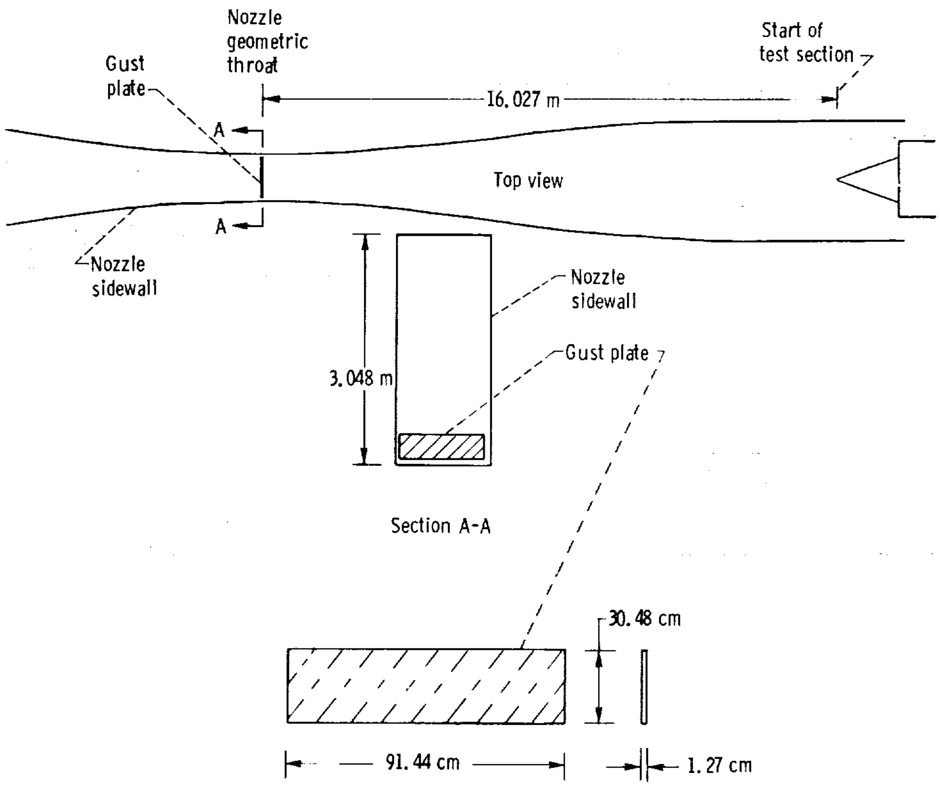
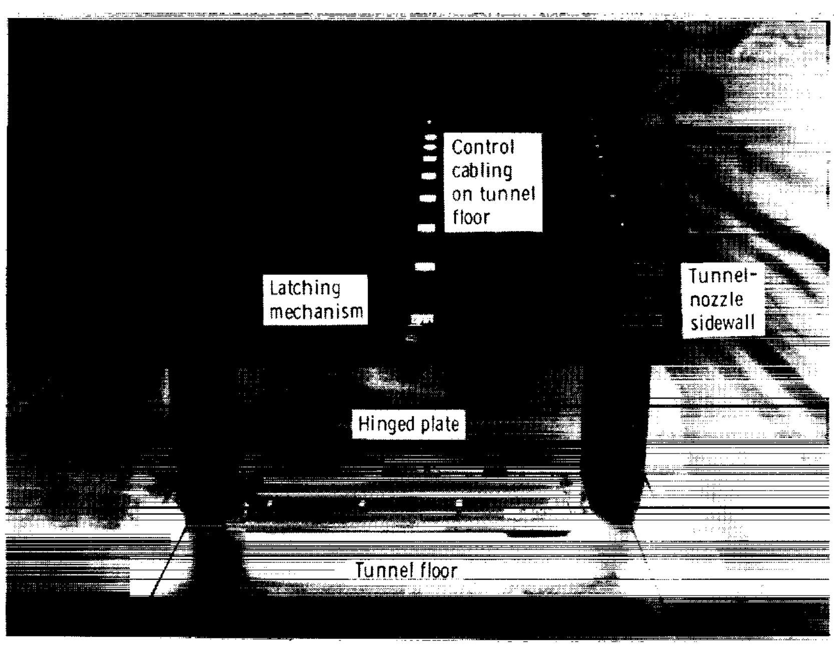


Figure 3. - Supersonic inlet used for stability valve studies, shown mounted in test section of wind tunnel.

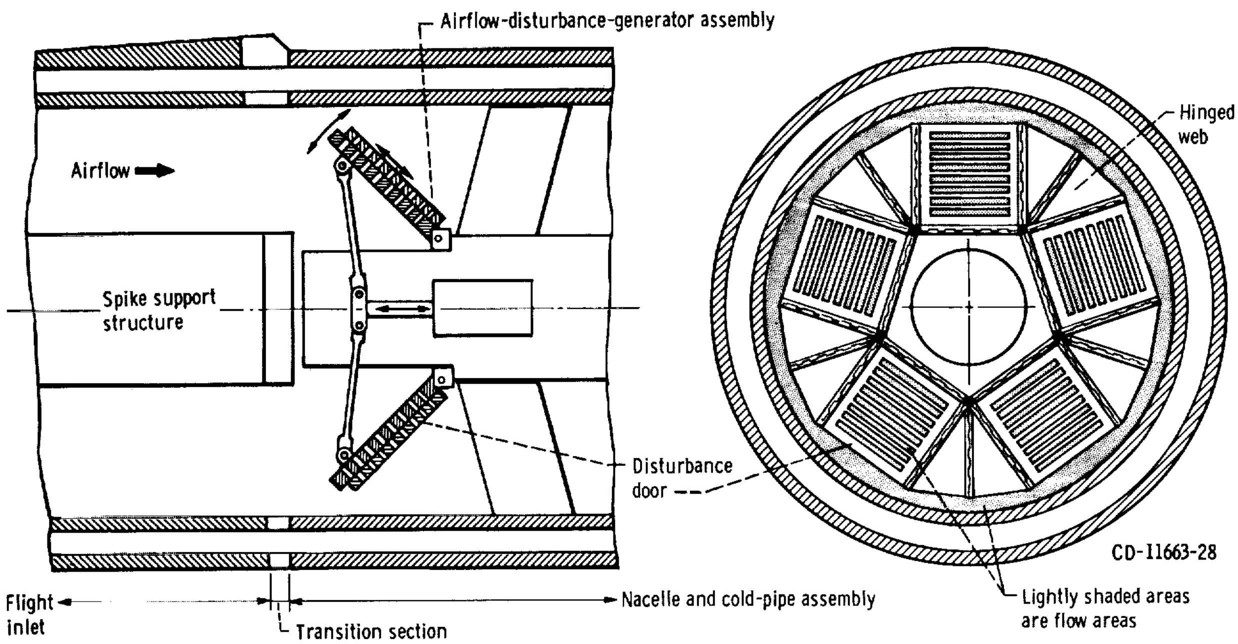


(a) Schematic.

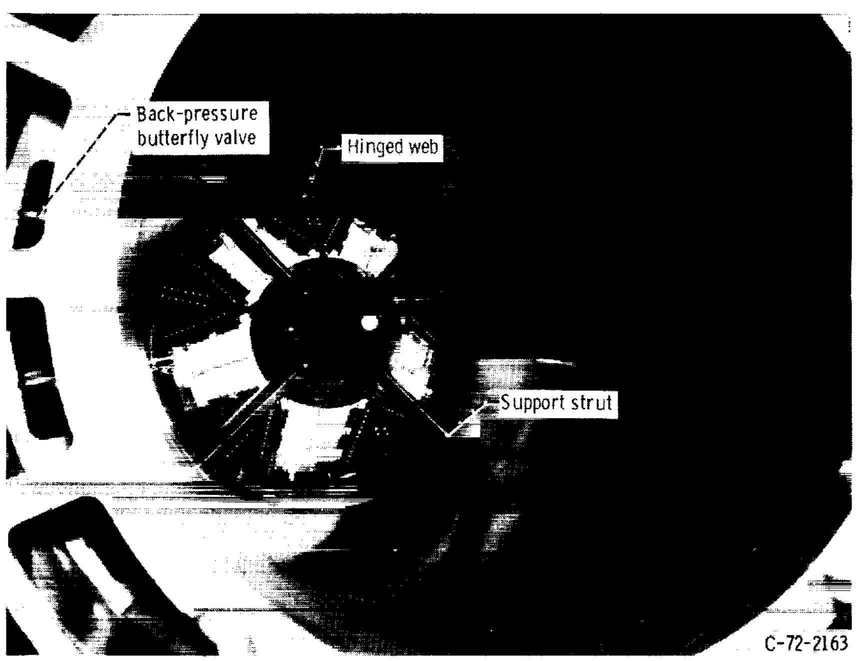


(b) View looking upstream.

Figure 5. - External airflow disturbance (gust) generator.

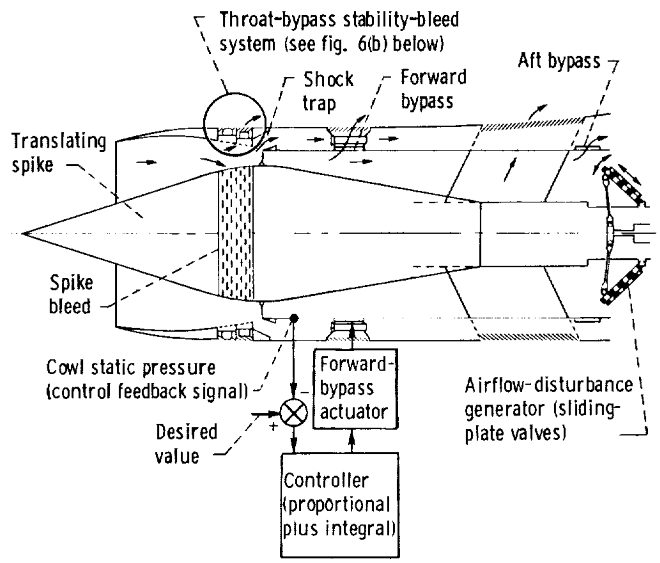


(a) Schematic diagram of internal airflow disturbance generator.

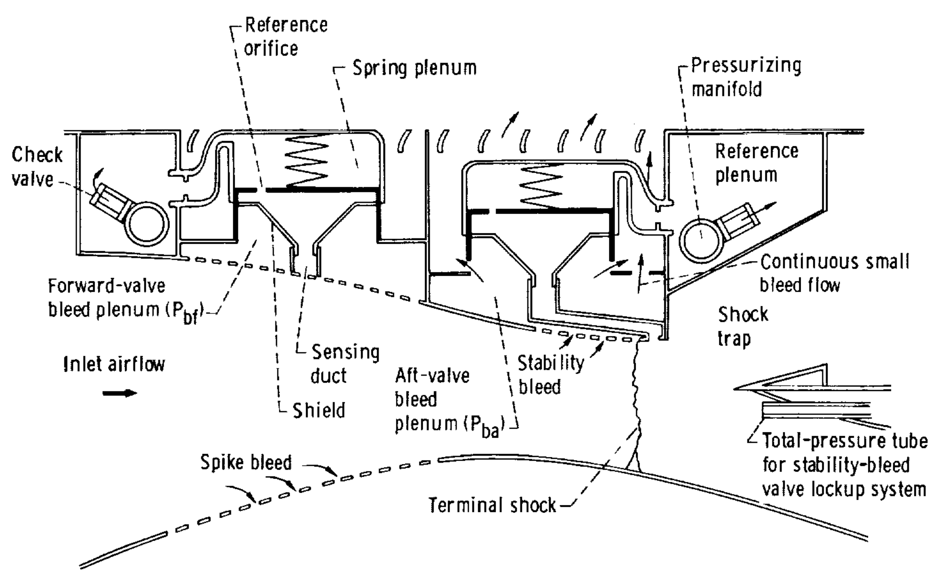


(b) Airflow-disturbance-generator assembly installed in cold pipe and expanded about halfway. (View looking upstream from aft end of cold pipe.)

Figure 4. - Internal airflow disturbance generator.

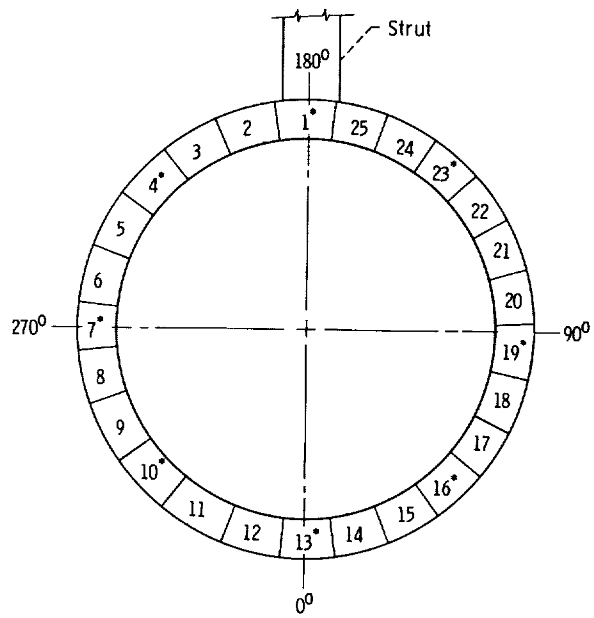


(a) Schematic of inlet, bleeds, bypasses, and throat-bypass stability-bleed system.



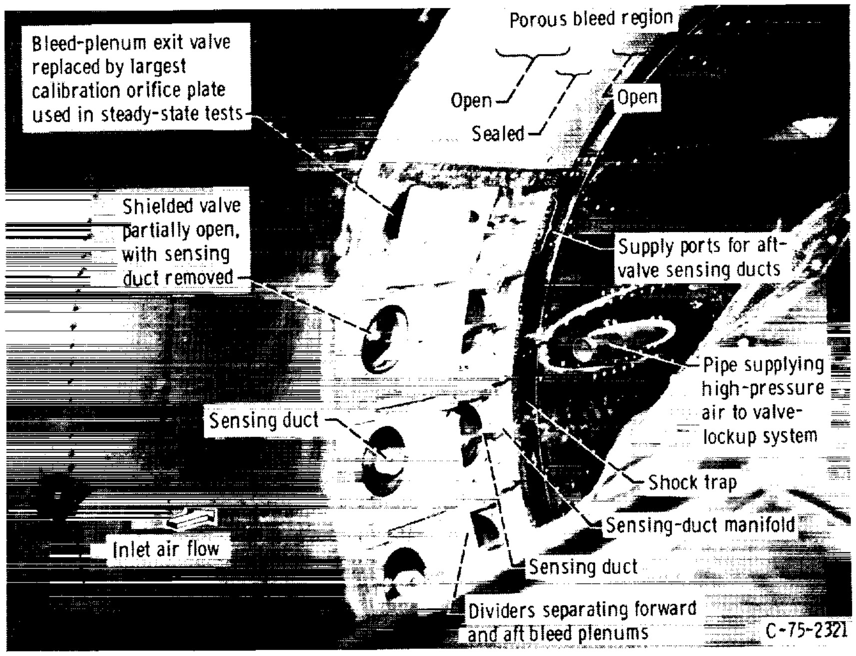
(b) Detailed schematic of throat-bypass stability-bleed system.

Figure 6. - Throat-bypass stability-bleed system in the YF-12 aircraft flight inlet.

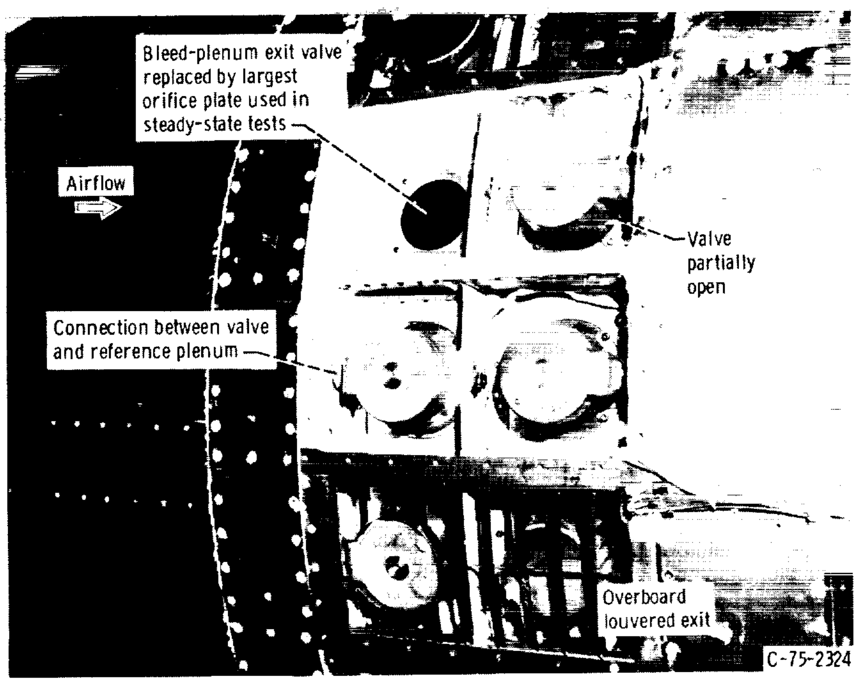


(c) Stability-bleed valve compartment identification (view looking downstream). Asterisks denote compartments wherein valves with position transducers are located.

Figure 6. - Concluded.



(a) Internal view. (Spike and portion of porous wall removed for clarity.)



(b) External view. (Some overboard exit louvers removed for clarity.)

Figure 7. - Installation of throat-bypass stability-bleed system in cowl of inlet.

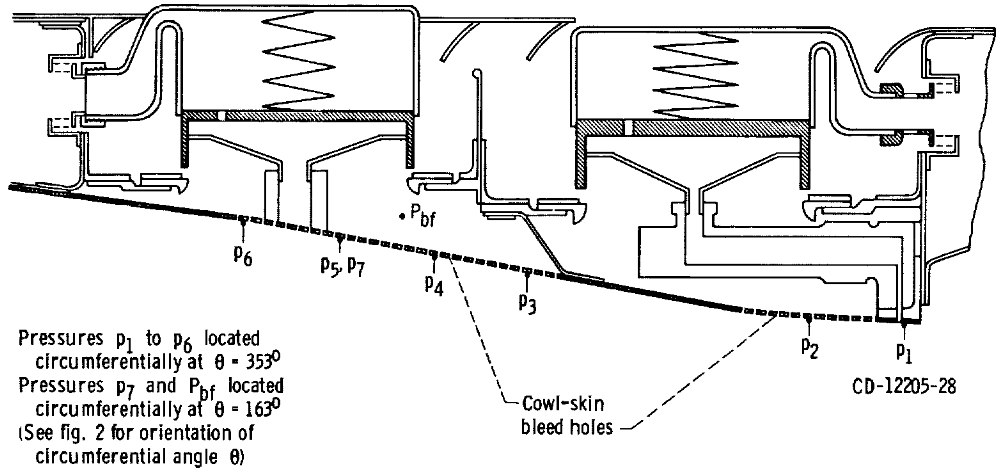
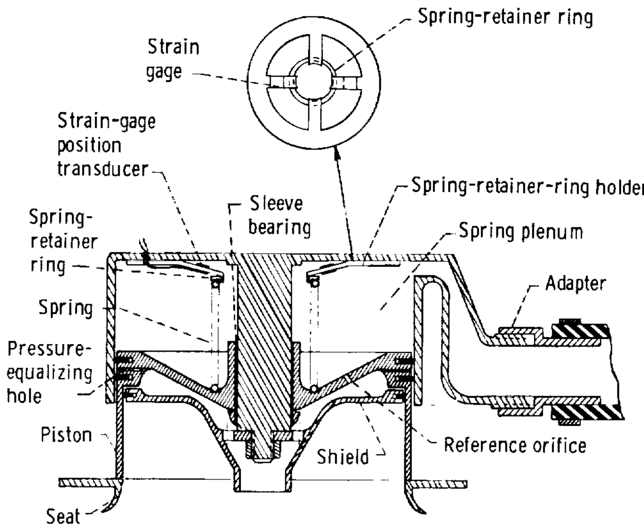
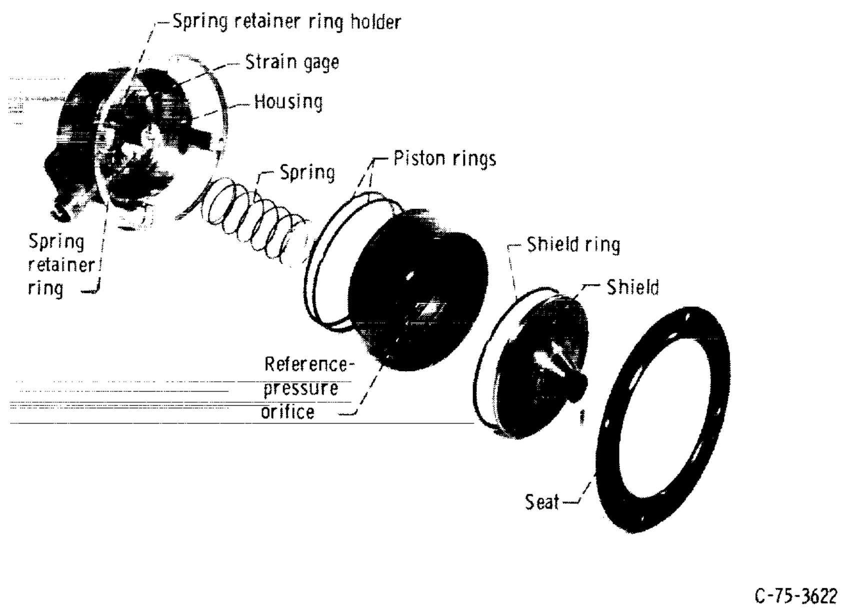


Figure 8. - Location of high-response pressure instrumentation in the region of the throat-bypass stability-bleed system.

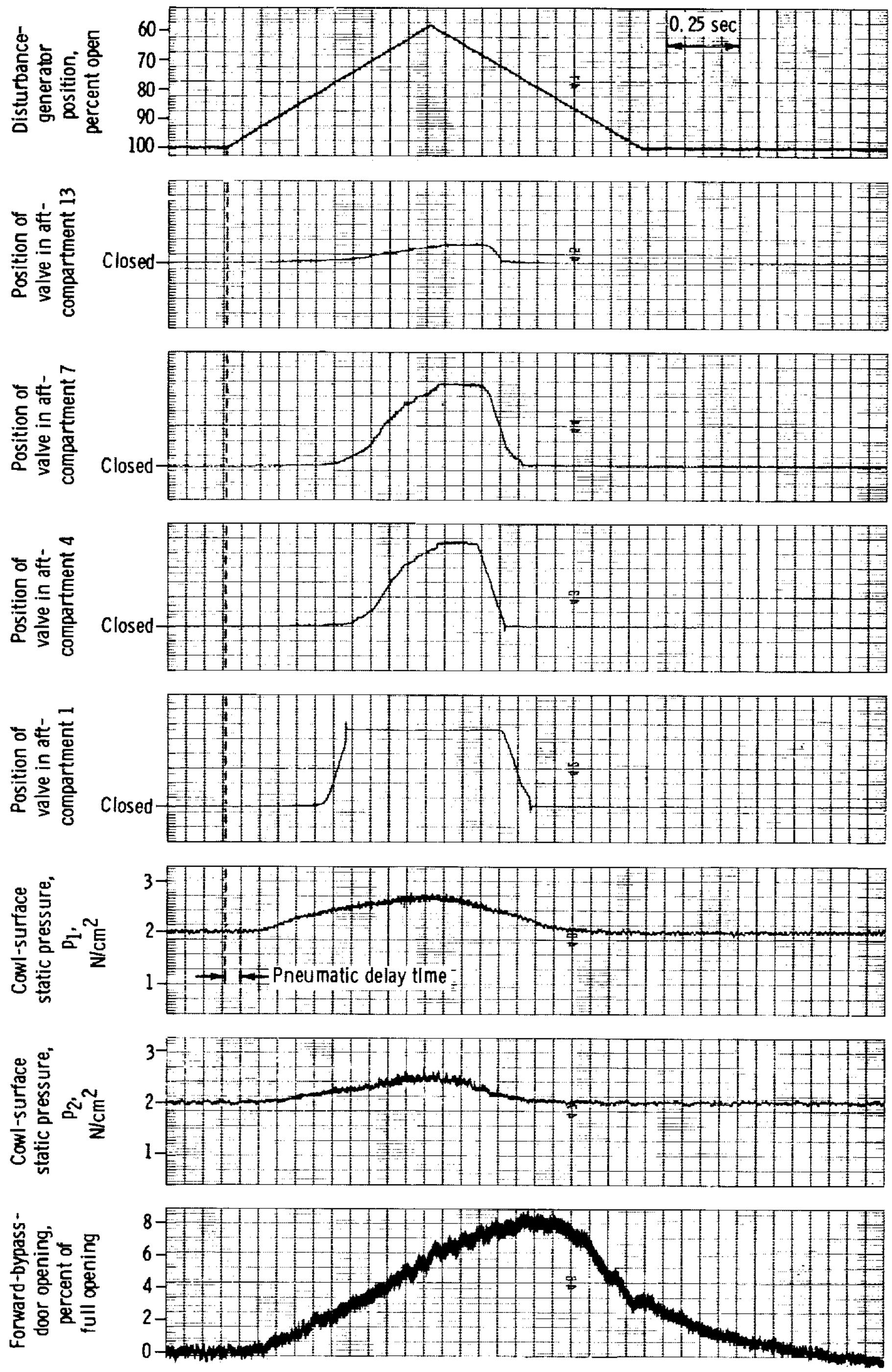


(a) Cross section.



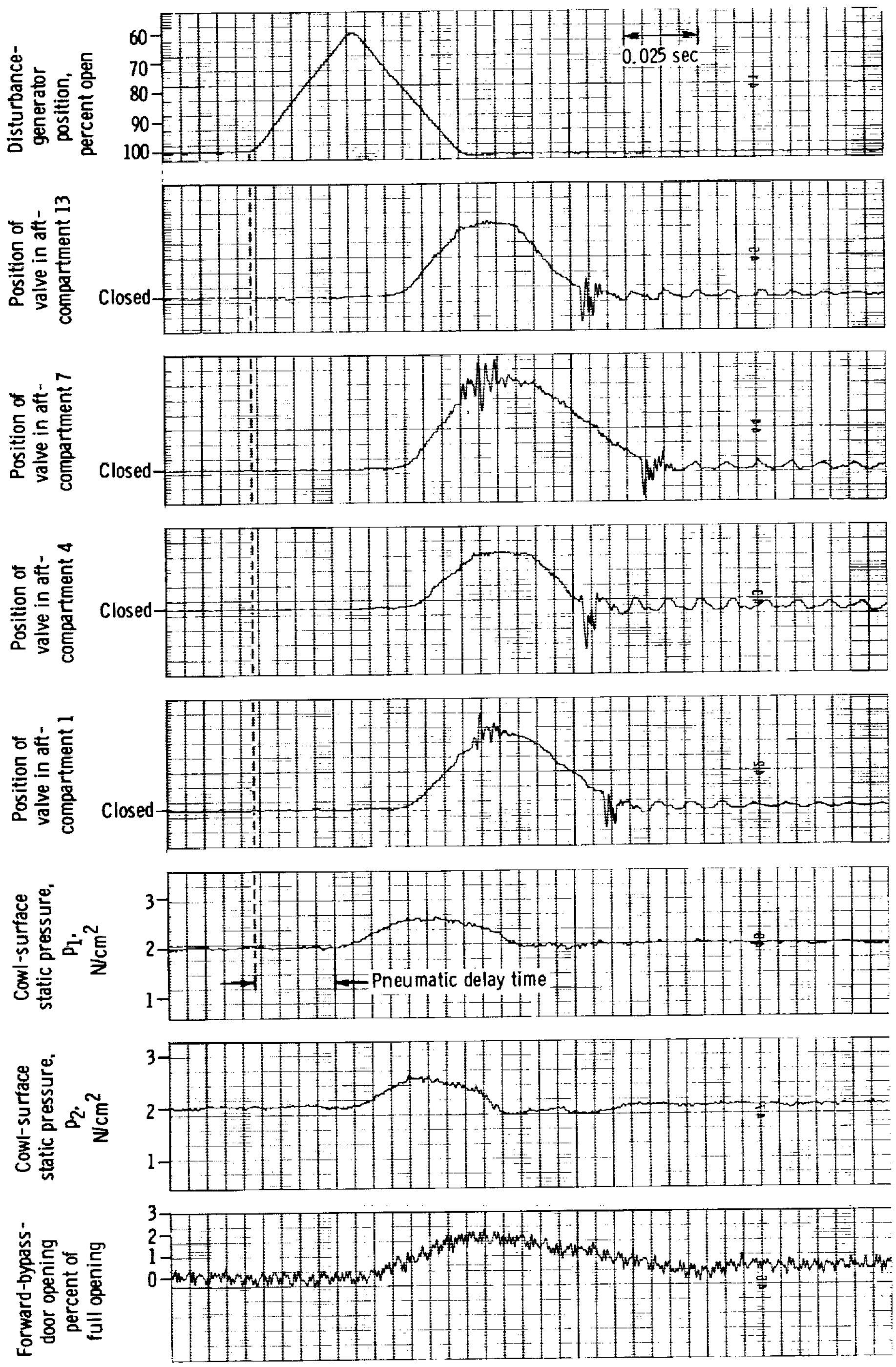
(b) Exploded view.

Figure 9. - Stability-bleed-system relief valve.



(a) Slow disturbance. Amplitude, 13.3 percent of operating-point value; rate, 19.2 percent/sec of operating-point value.

Figure 10. - Response of throat-bypass stability-bleed system to downstream internal airflow disturbances produced by the airflow disturbance generator. Inlet local angles of attack and sideslip, α_l and β_l, both zero; free-stream Mach number at spike tip, M_0, 2.47.



(b) Fast disturbance. Amplitude, 13.0 percent of operating-point value; rate, 385.3 percent/sec of operating-point value.

Figure 10. - Concluded.

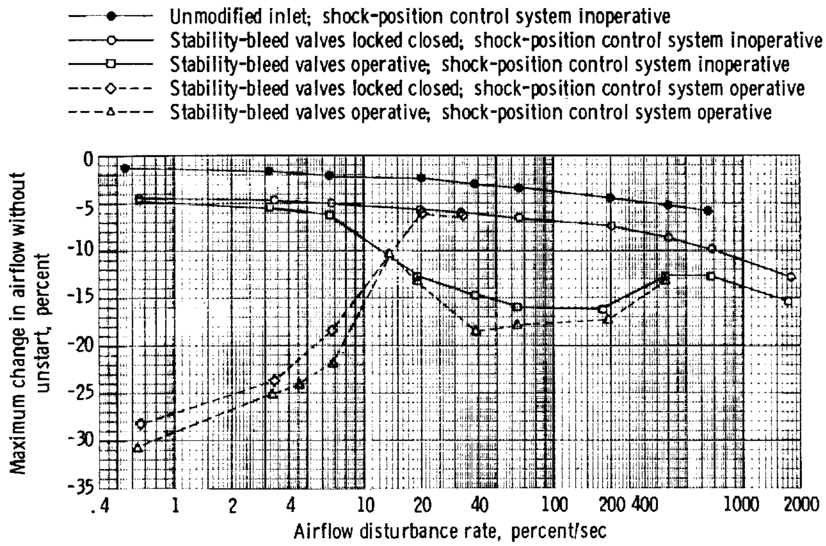


Figure 11. - Transient stability of inlet when subjected to a single triangular pulse in diffuser corrected airflow. Inlet at Mach 2.47 and zero angles of attack and sideslip; forward- and aft-bypass doors closed.

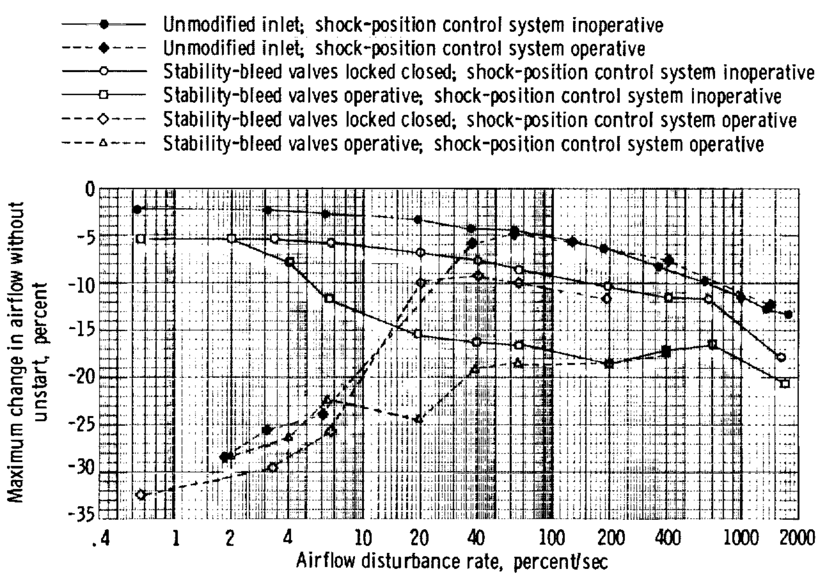


Figure 12. - Transient stability of inlet when subjected to a single triangular pulse in diffuser corrected airflow. Inlet at Mach 2.47 and equivalent flight angle of attack, with zero angle of sideslip; forward- and aft-bypass doors closed before start of disturbance.

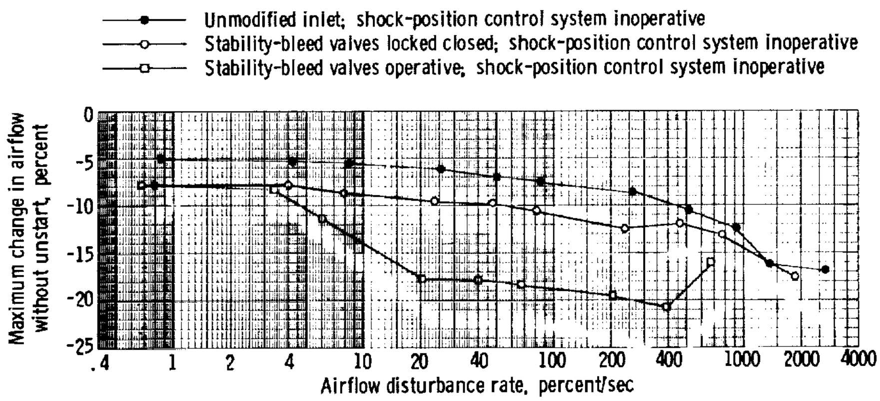
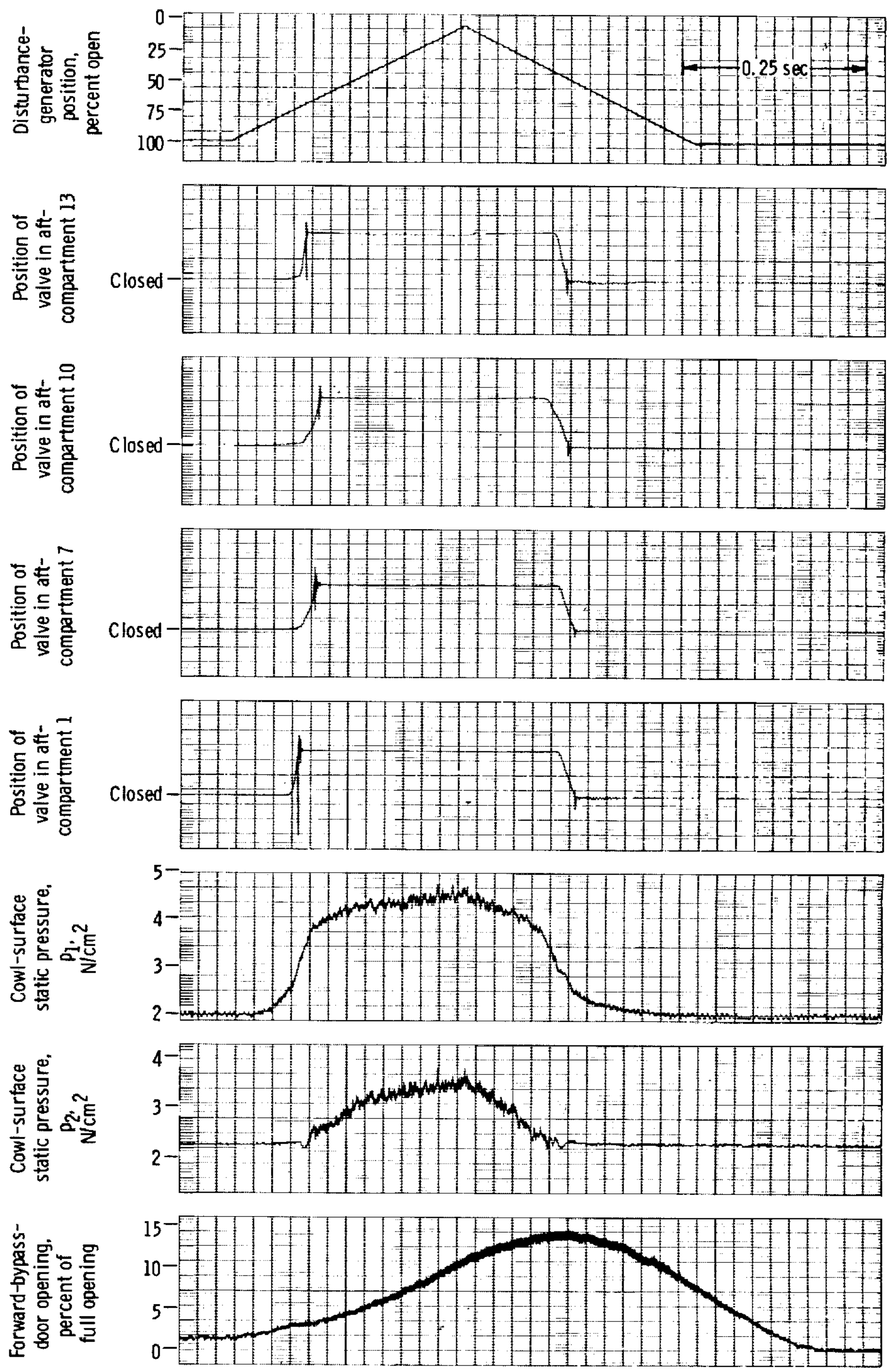
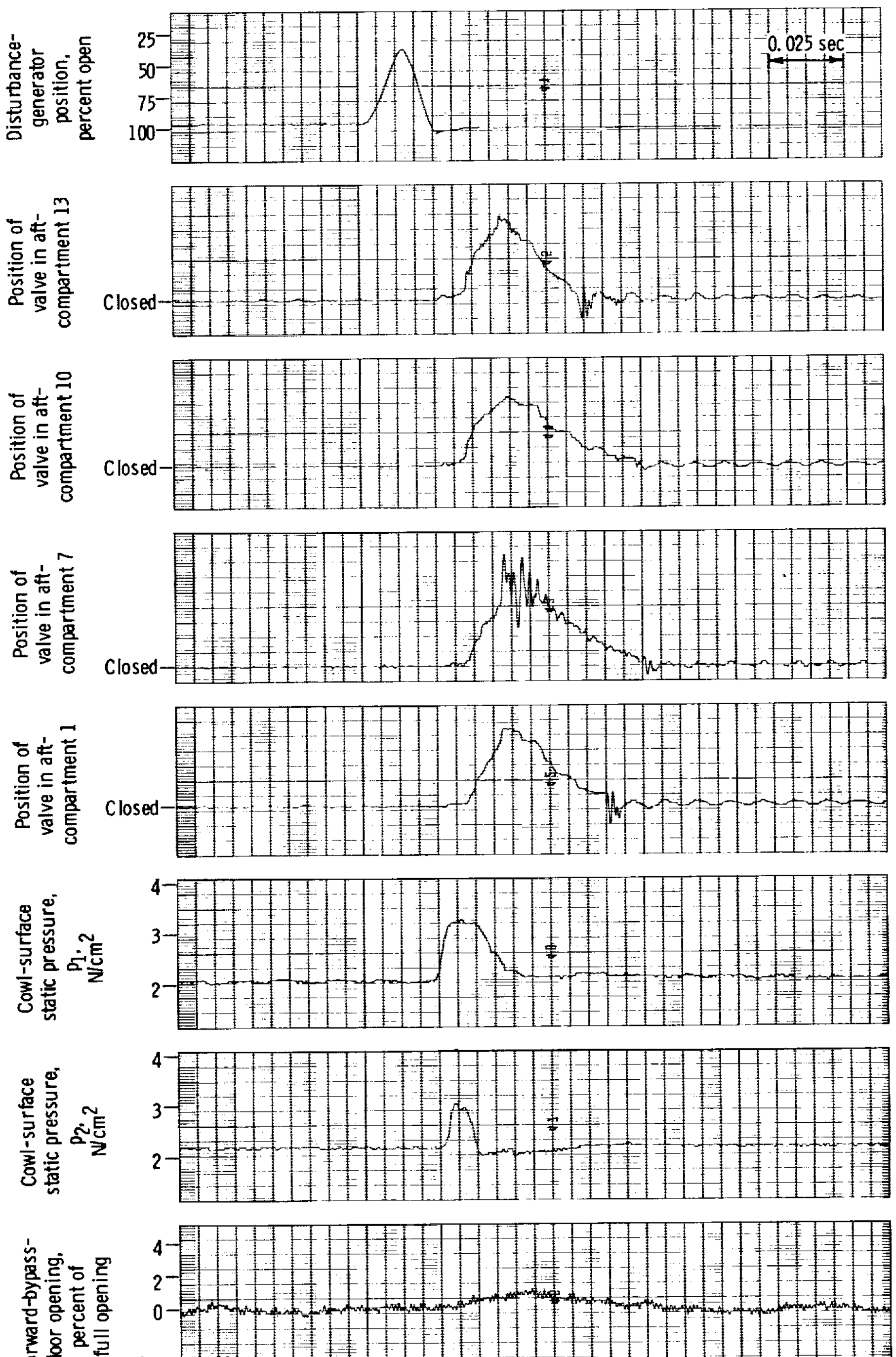


Figure 13. - Transient stability of inlet when subjected to a single triangular pulse in diffuser corrected airflow. Inlet at Mach 2.47 and equivalent flight angle of attack, with zero angle of sideslip; forward-bypass door open to flight match opening; aft-bypass door closed.



(a) Slow disturbance. Amplitude, 32.0 percent of operating-point value; rate, 41.2 percent/sec of operating-point value.

Figure 14. - Response of throat-bypass stability-bleed system to downstream internal airflow disturbances produced by the airflow disturbance generator. Inlet local angles of attack and sideslip, α_l and β_l, both zero; free-stream Mach number at spike tip, M_0, 2.76.



(b) Fast disturbance. Amplitude, 20.3 percent of operating-point value; rate, 2118.8 percent/sec of operating-point value.

Figure 14. - Concluded.

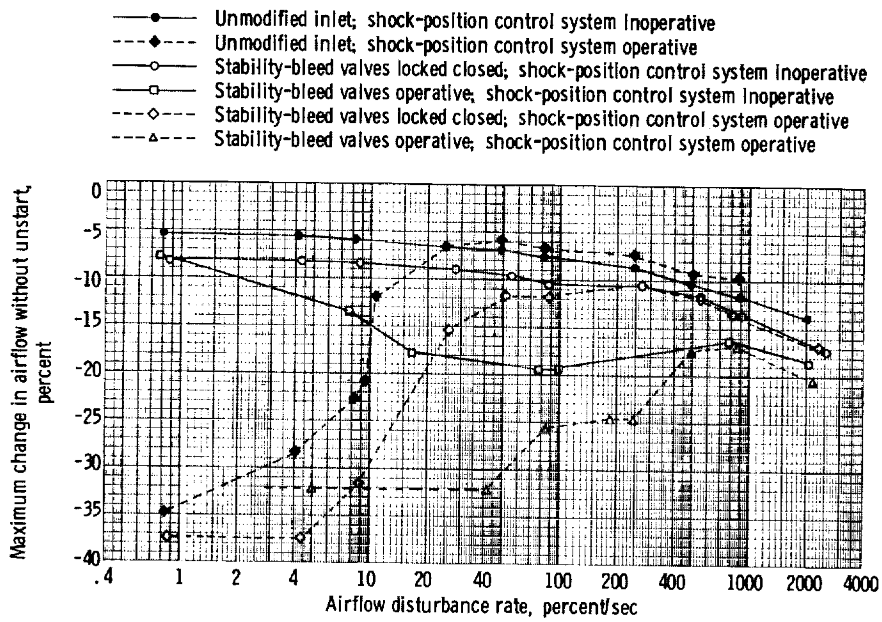


Figure 15. - Transient stability of inlet when subjected to a single triangular pulse in diffuser corrected airflow. Inlet at Mach 2.76 and zero angles of attack and sideslip; forward- and aft-bypass doors closed.

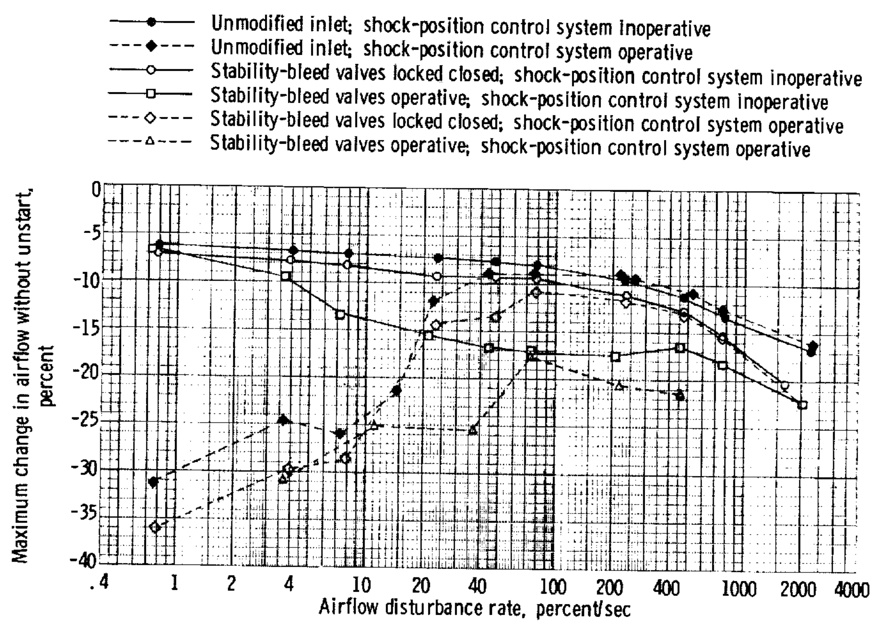


Figure 16. - Transient stability of inlet when subjected to a single triangular pulse in diffuser corrected airflow. Inlet at Mach 2.76 and equivalent flight angle of attack, with zero angle of sideslip; forward- and aft-bypass doors closed.

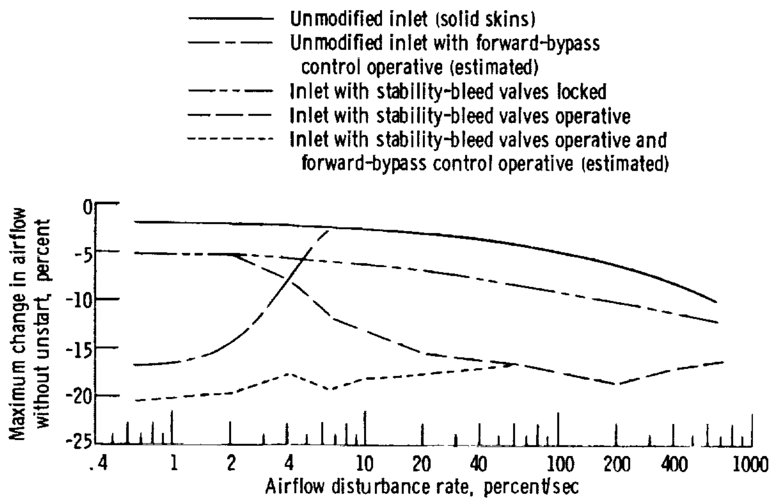


Figure 17. - Comparison of estimated unstart tolerance of modified and unmodified inlet to internal airflow transients for actual aircraft flight. Inlet at Mach 2.47 and at equivalent flight angle of attack, with zero angle of sideslip. Data corrected for flight positions of forward- and aft-bypass doors, flight DPR, and flight spike position.

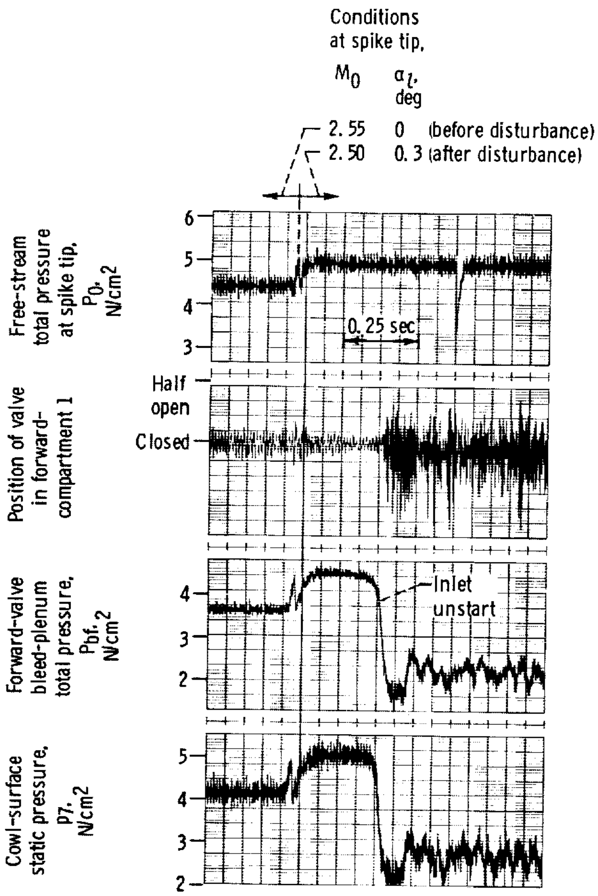


Figure 18. - Response of throat-bypass stability-bleed system to an upstream external airflow disturbance produced by the gust generator. Stability-bleed valves locked closed; free-stream Mach number before disturbance, 2.55; forward- and aft-bypass doors closed.

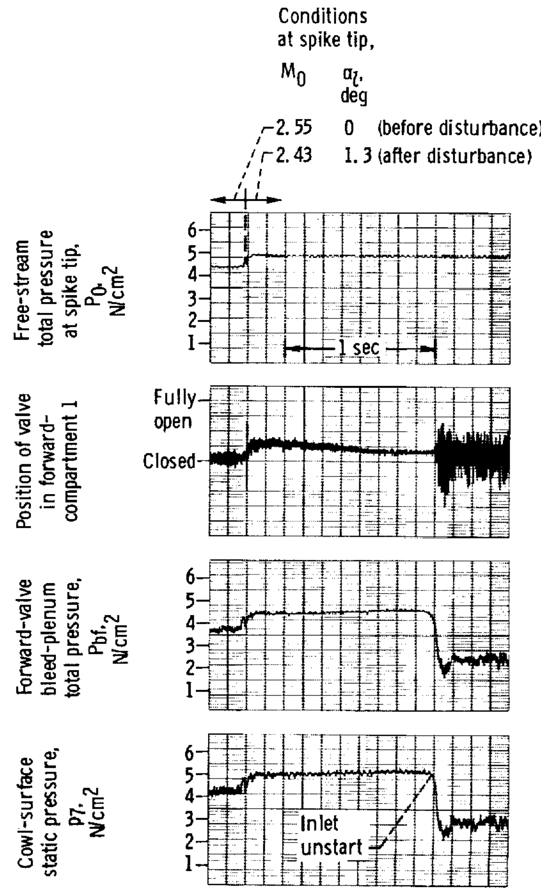


Figure 19. - Response of throat-bypass stability-bleed system to an upstream external airflow disturbance produced by the gust generator. Stability-bleed valves free to operate; free-stream Mach number before disturbance, 2.55; forward- and aft-bypass doors closed.

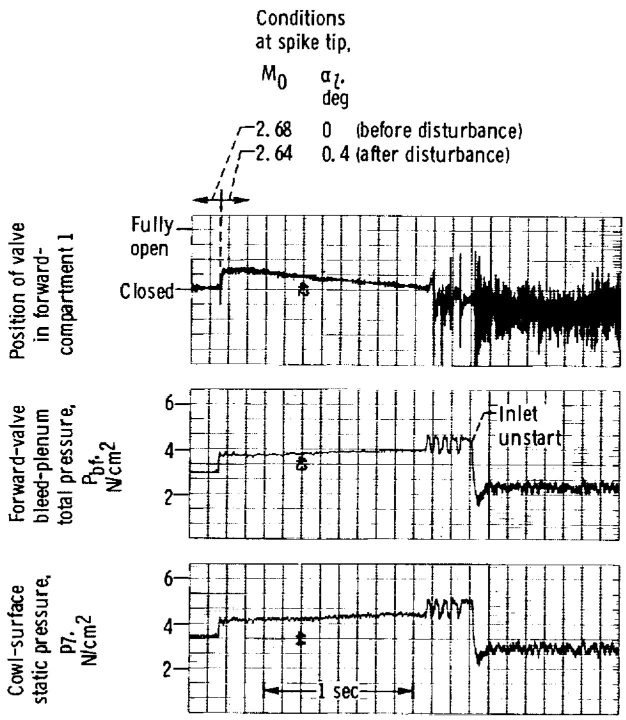


Figure 20. - Response of throat-bypass stability-bleed system to an upstream external airflow disturbance produced by the gust generator. Stability-bleed valves free to operate; free-stream Mach number before disturbance, 2.68; forward- and aft-bypass doors closed.

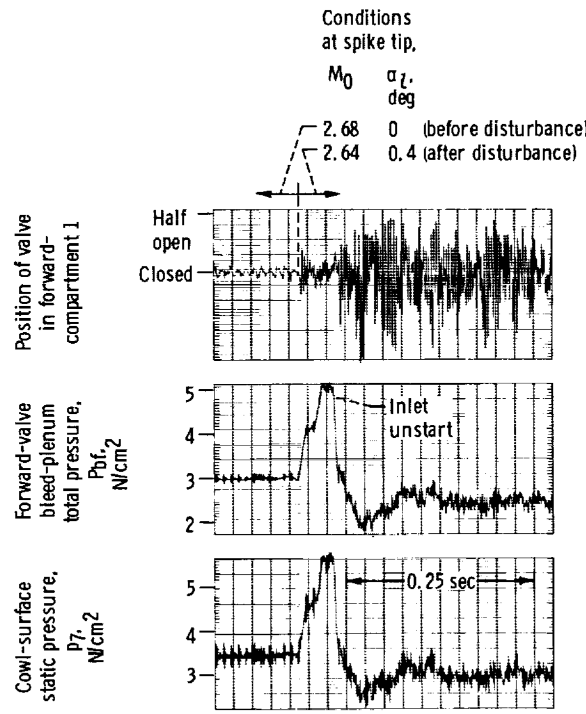


Figure 21. - Response of throat-bypass stability-bleed system to an upstream external airflow disturbance produced by the gust generator. Stability-bleed valves locked closed; free-stream Mach number before disturbance, 2.68; forward- and aft-bypass doors closed.

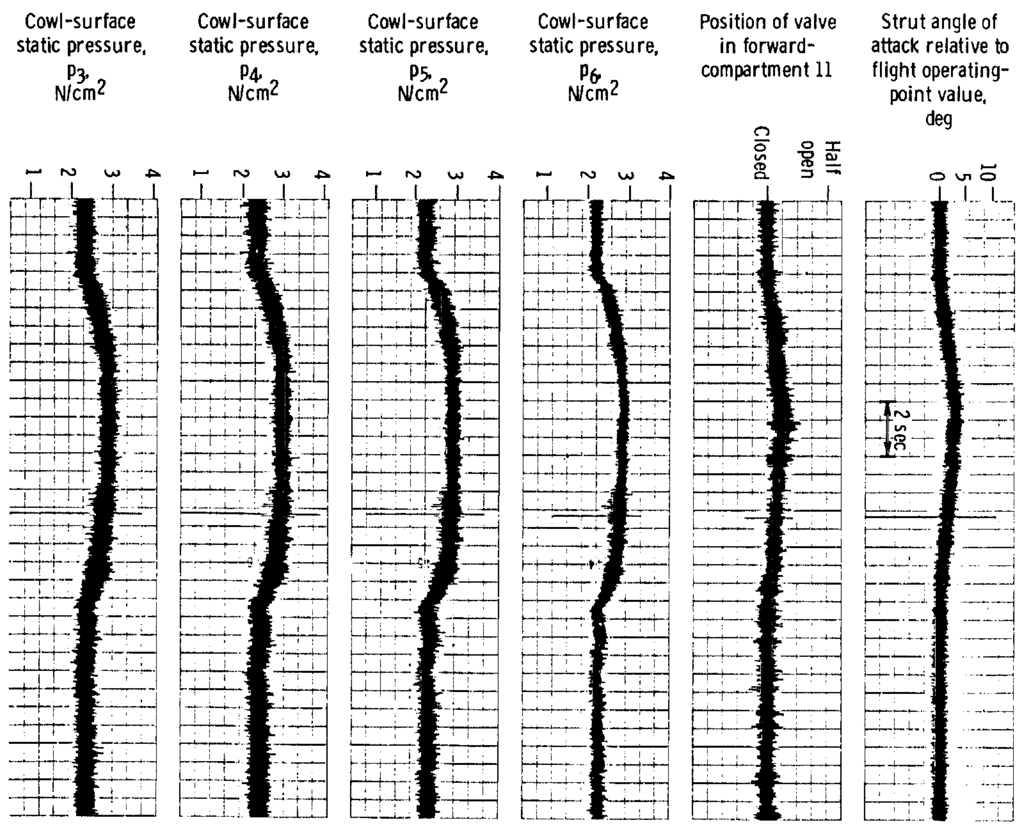


Figure 22. - Response of throat-bypass stability-bleed system to an angle-of-attack disturbance. Free-stream Mach number at spike tip, M_p, 2.47; forward- and aft-bypass doors closed; inlet initially at flight operating-point conditions.

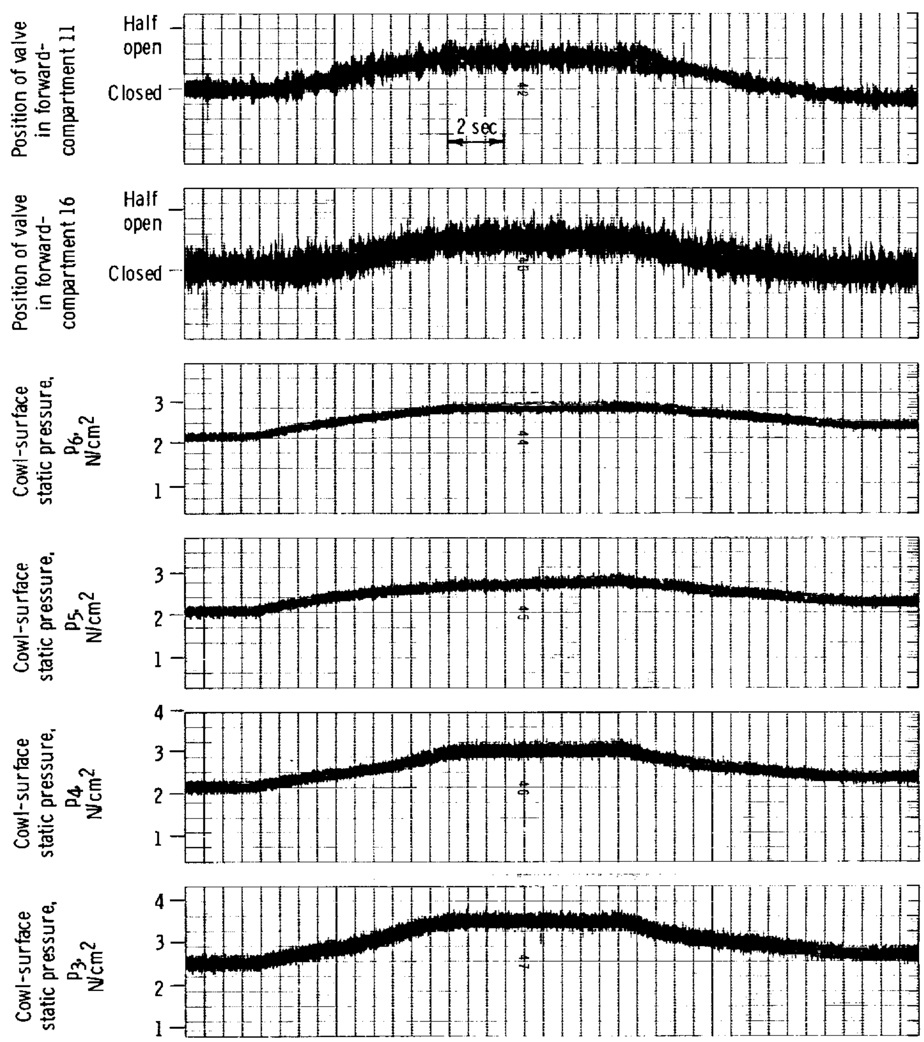


Figure 23. - Response of throat-bypass stability-bleed system to an angle-of-attack disturbance. Free-stream Mach number at spike tip, M_0, 2.76; forward- and aft-bypass doors closed; initial angle of attack, zero.

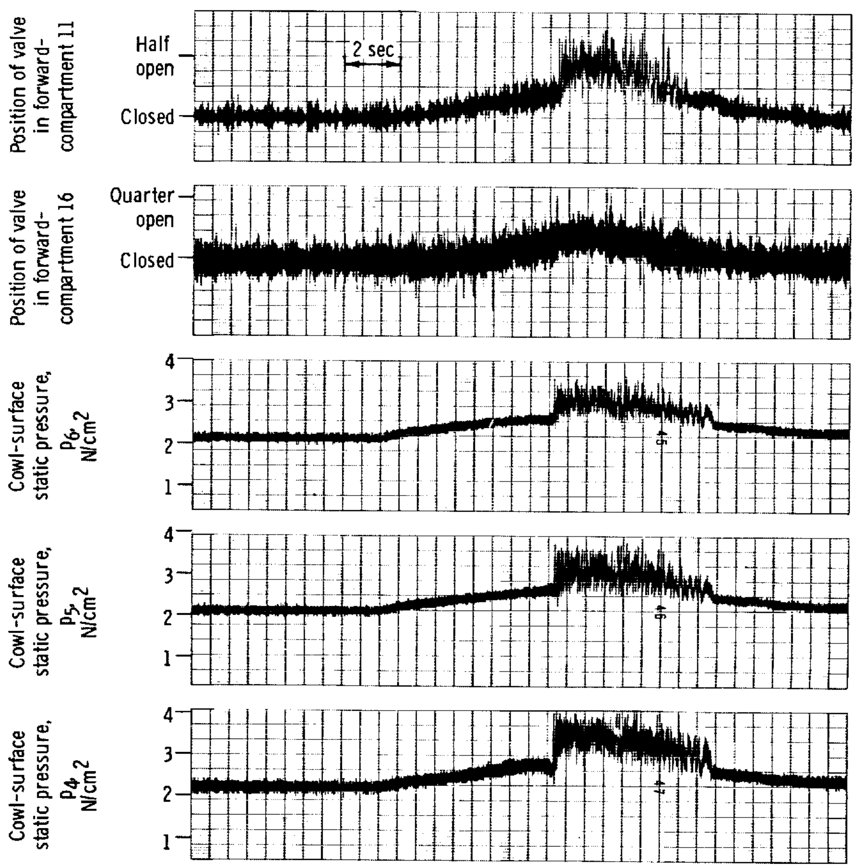


Figure 24. - Response of throat-bypass stability-bleed system to an angle-of-attack disturbance. Free-stream Mach number at spike tip, M_0, 2.47; forward- and aft-bypass doors closed; initial angle of attack, zero; spike extended 1.78 centimeters from normally scheduled flight position.

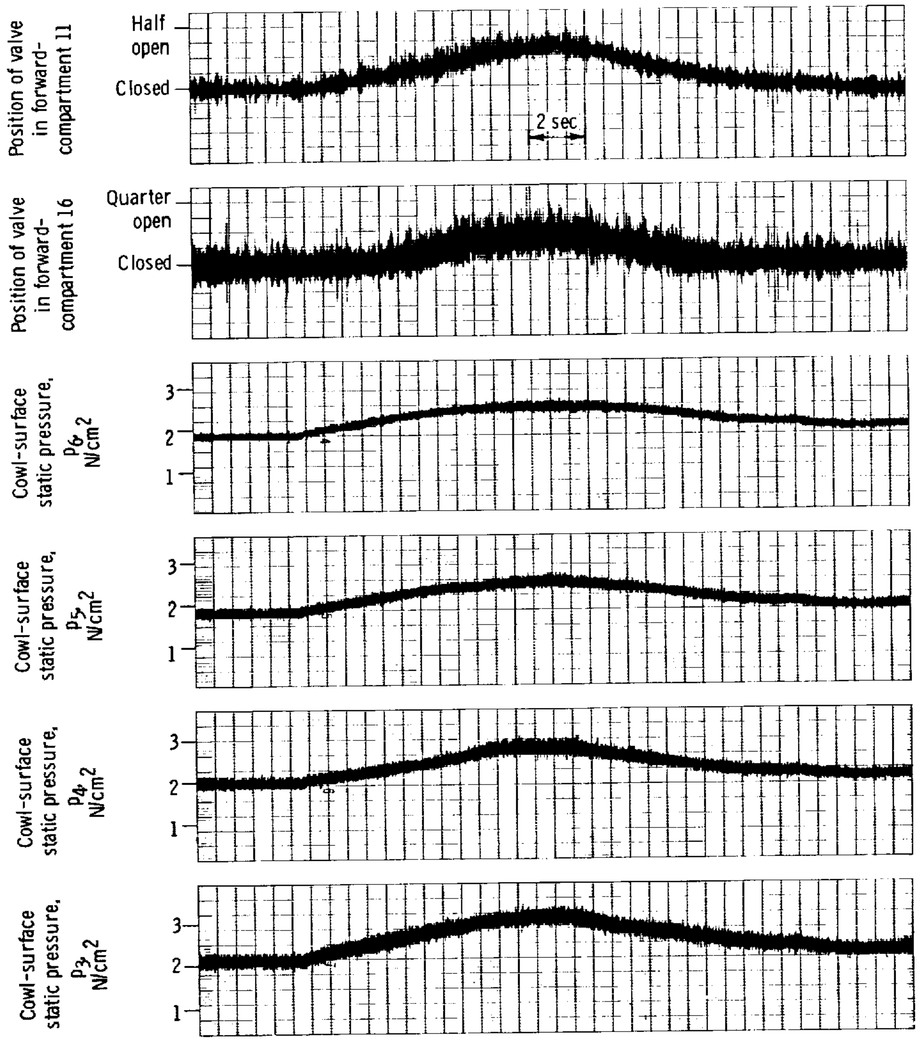


Figure 25. - Response of throat-bypass stability-bleed system to an angle-of-attack disturbance. Free-stream Mach number at spike tip, M_0, 2.76; forward- and aft-bypass doors closed; inlet initially at flight scheduled angle of attack; spike extended 1.78 cm from normally scheduled flight position.

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7. Author(s) George H. Neiner, Miles O. Dustin, and Gary L. Cole	8. Performing Organization Report No. E-8950
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15. Supplementary Notes

16. Abstract

This report presents the transient performance of a stability-bleed system installed in a YF-12 flight inlet that was subjected to internal and external airflow disturbances in the NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel. This stability-bleed system could actually be flown on the YF-12 aircraft, because it was designed to fit within the YF-12 inlet structure and to withstand the YF-12 flight environment. The purpose of the system is to allow higher inlet performance while maintaining a substantial tolerance (without unstart) to internal and external disturbances. At Mach numbers of 2.47 and 2.76, the stability-bleed system increased the inlet tolerance to decreases in diffuser-exit corrected airflow by approximately 10 percent of the operating-point airflow. The stability-bleed system complemented the terminal-shock-control system of the inlet and did not show interaction problems. For disturbances which caused a combined decrease in Mach number and increase in angle of attack, the stability-bleed system with valves operative kept the inlet started 4 to 28 times longer than with the valves inoperative. Hence, the stability system provides additional time for the inlet control system to react and prevent unstart. This was observed for initial Mach numbers of 2.55 and 2.68. For slow increases in angle of attack at Mach 2.47 and 2.76, the stability-bleed system kept the inlet started beyond the steady-state unstart angle. However, the maximum transient angles of attack without unstart could not be determined because wind-tunnel mechanical-stop limits for angle of attack were reached.

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