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A THROAT-BYPASS STABILITY SYSTEM FOR A YF-12 AIRCRAFT RESEARCH INLET USING SELF-ACTING MECHANICAL VALVES

by Gary L. Cole, Miles O. Dustin, and George H. Neiner
Lewis Research Center
Cleveland, Ohio 44135

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Gary L. Cole,* Miles O. Dustin, and George H. Neiner
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

Abstract

Results of a wind tunnel investigation are presented. The inlet was modified so that airflow can be removed through a porous cowl-bleed region in the vicinity of the throat. Bleed plenum exit flow area is controlled by relief type mechanical valves. Unlike valves in previous systems, these are made for use in a high Mach flight environment and include refinements so that the system could be tested on a NASA YF-12 aircraft. The valves were designed to provide their own reference pressure; hence, do not respond to slowly varying disturbances. However, the results show that the system can absorb internal-airflow-transients that are too fast for a conventional bypass door control system and that the two systems complement each other quite well. Increased tolerance to angle of attack and Mach number changes is indicated. The valves should provide sufficient time for the inlet control system to make geometry changes required to keep the inlet started.

Introduction

Efficient performance with minimum cowl drag at cruise Mach numbers of about 2.0 and above, requires the use of a mixed-compression inlet. The performance of a conventional mixed-compression inlet is best when the terminal shock is just downstream of the inlet throat. Unfortunately at this operating condition the inlet is most vulnerable to an undesirable characteristic known as unstart. Perturbations in flow either upstream or downstream of the terminal shock could cause the shock to move ahead of the throat. The shock is unstable there and is abruptly expelled forward of the cowl lip (inlet unstart). The unstart is accompanied by a sharp reduction in inlet mass-flow and total pressure recovery, increased distortion at the compressor face, and increased drag. This may result in large rolling and yawing moments on the aircraft. In addition, the unstart may have serious effects on the engine such as compressor stall and combustor flameout. The shock could be moved back to a less efficient operating point as a safeguard. However, efficient operation is imperative, especially for a commercial aircraft, and becomes more important as cruise Mach number increases. Therefore, it is necessary for the inlet to have a stability margin - the capability to absorb disturbances without unstarting, while operating near peak performance. Typically, this is accomplished by providing a fixed-exit bleed system in the throat region. This allows additional airflow to be spilled as the terminal shock moves upstream toward unstart. However, the fixed exit must be small to avoid large bleed airflows when the terminal shock is supercritical. Obviously, this limits the size of the disturbance that can be tolerated. In addition, inlets are generally provided with control systems which vary inlet geometry. But these are usually slow. To improve their response would increase complexity.

One means of providing a greater stability margin for fast disturbances is to make the throat bleed function as a throat bypass by regulating the bleed plenum exit area. Such a system, using mechanical valves to maintain a constant bleed plenum pressure, was patented[1] by Sanders and Mitchell of the Lewis Research Center. A technique using vortex valves to increase stability margin was reported by Moorehead.[2] Several systems using either self-acting mechanical valves, vortex valves, or variable choked exits to control bleed plenum pressure were investigated in a wind tunnel and briefly summarized.[3] More detailed reports[4,5] were published later. Those systems were used to demonstrate the throat-bypass concept in a wind tunnel model. The mechanical valves were not designed to fit within the cowling of a flight weight inlet or to withstand the temperatures encountered in high Mach number flight. Also the valves required an externally supplied and manually regulated reference pressure which would not be practical in a flight application. Wind tunnel tests were restricted to the inlet design Mach number and were mainly concerned with internal airflow disturbances.

In a continuing effort to evaluate throat-bypass systems it was decided to design one that could be flown on a NASA YF-12 aircraft. A feasibility study[6] was conducted by the Lockheed Aircraft Corporation. Candidate valves for bleed plenum exit area control were vortex valves, slide valves, and poppet valves. It was estimated that the mechanical valves would provide greater bleed flow capability. The relief-type poppet valve was selected for the final design because of its faster response characteristics. Two important conclusions of the Lockheed study were that the valves would not adversely effect the operation of the present inlet control system and that aircraft response to a sustained opening of all the bleed valves in one nacelle would be controllable and less violent than an unstart.

An analytical study[7] was conducted to investigate the effects of varying the valve physical configuration (spring rate, damping, etc.) and flight conditions. Finally an experimental investigation[8] of prototype valves was conducted to determine the best size for a damping orifice and to verify the analog simulation of Ref. 7.

A recent wind tunnel program was conducted in the Lewis 10- by 10-Foot Supersonic Wind Tunnel to select a suitable porous cowl-bleed pattern through which the throat bypass airflow is removed and to evaluate the installed performance of the valves. The system was installed in a YF-12 aircraft inlet. It was desired to develop a system which would provide increased tolerance to both internal and external airflow transients. Since present supersonic cruise aircraft research studies point to a Mach 2.2 to 2.7 advanced supersonic transport, testing in the Mach 2.5 to 2.8 range was emphasized. And at these Mach numbers the YF-12 aircraft can fly at lower altitudes where more numer-

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*Aerospace Engineer, member AIAA.

ous atmospheric disturbances are encountered.

This report details the final stability system hardware and test procedure. Some wind tunnel test results are presented which indicate the stability limits that were achieved.

U.S. customary units were used in the design of the valves and for recording experimental data. The units were converted to the International System of Units for presentation in this paper.

Apparatus

Inlet

The inlet used in the wind tunnel tests was a modified YF-12 aircraft inlet. It is an axisymmetric mixed-compression type designed for cruise above Mach 3.0. This inlet was tested at Lewis[9] prior to being modified for the stability system.

Fig. 1 illustrated the basic inlet features. A translating spike provides capability for inlet restart and off design Mach number operation. Spike boundary layer control is accomplished by a porous bleed region. The bleed airflow passes overboard through louvered exits at the ends of the spike support struts. Cowl bleed is taken off through the shock trap. The shock trap helps stabilize the terminal shock and provides cooling air for the engine nozzle. The forward bypass is controlled by the inlet control system to match inlet-engine airflow requirements. Excess airflow is discharged overboard through louvered exits. The aft bypass is manually operated by the pilot to aid the forward bypass in matching inlet-engine airflow. Unless noted otherwise, the aft bypass was closed during these tests. The inlet, attached to a boilerplate nacelle containing a long cold-pipe, was strut mounted in the wind tunnel. Additional details concerning the inlet systems, instrumentation and wind tunnel installation are given in Ref. 9. Campbell's paper[10] also gives additional information regarding the F-12 series aircraft propulsion system.

Throat-Bypass Stability System

Considerable modification of the standard inlet was required for installation of the throat-bypass stability system. The location of the system is shown in Fig. 1 with a more detailed schematic of the final system given in Fig. 2. A band of cowl skin just upstream of the shock trap was replaced with porous skins to allow removal of stability bleed airflow. The entire band had a 40 percent porosity consisting of distributed normal holes. However, the final bleed pattern had a portion of the bleed surface sealed as shown in Fig. 2. The cowling in the bleed region was modified further to provide two circumferential rows of 25 compartments. The compartments housed the self-acting relief-type mechanical valves which control bleed plenum exit area and hence stability bleed airflow. The aft valve compartments had a small amount of continuous bleed flow, shown in Fig. 2, to improve inlet angle of attack capability and peak recovery characteristics.

Unlike the valves of Ref. 3, the ones used in this system do not require a regulated external reference pressure. This is accomplished by the orifice in the piston face which allows air to bleed through into the spring plenum and reference plenum. Therefore, almost equal pressures are maintained on both sides of the piston. The spring preload also acts to keep the valves closed. Because of this self-biasing feature, the valves remain closed for slowly varying disturbances. And as will be shown by test results, the inlet control system is able to handle the slowly varying disturbances. If a fast disturbance occurs, a differential pressure builds up across the piston, since the orifice flow is small. When the force on the piston due to the differential pressure (about 0.34 N/cm^2) exceeds the initial spring force plus the friction force, the valve will open allowing bleed airflow through the valve and overboard through louvered exits.

Another feature of these valves is a removable shield and sensing duct (Fig. 2). It isolates the bottom of the piston from the drop in bleed plenum pressure, P_{ba}, that occurs when the valve opens. This drop in pressure would tend to close the unshielded valve. The benefit of the shield in this application, particularly for the downstream set of valves, is demonstrated in the Results and Discussion section.

Figs. 3 and 4 are photographs of the inlet showing the installation of the throat bypass stability system. Fig. 3 is an interior view of the inlet with the spike removed. Some of the porous cowl skin was removed to expose the bleed plenum and valves. Two of the valve pistons were held open to show the stability bleed airflow passage out of the inlet. One valve was removed and replaced by an orifice plate. Sets of different sized orifices were used instead of the valves during the steady-state tests to determine a good bleed hole pattern. Also shown is one of four symmetrically spaced pipes that supply high pressure air for a valve lockup system. The lockup system allows the pilot to keep the valves locked in the closed position. The four supply pipes are manifolded and valved so that all stability valves in either row can be locked simultaneously. Fig. 4 is an external view of the same region as that shown in Fig. 3. Some of the louvered exits, through which the stability bleed airflow passes overboard, were removed to expose the mounted valves.

The aft set of valves were used primarily to provide shock stability for airflow transients (usually internal) which unstart the inlet by moving the terminal shock forward ahead of the throat. The shield sensing duct was attached to the cowl surface just ahead of the shock trap to provide fast response to forward shock motion. Valves in the forward plenums were intended to relieve pressure rises in that region due to things like angle of attack changes and reduction in inlet Mach number (upstream or external disturbances). Such pressure rises can cause local choking which will unstart the inlet.

Self-Acting Mechanical Valves

A valve is shown schematically in greater detail in Fig. 5. It is constructed primarily of titanium and weighs about 1 kg. The piston is guided on the housing center post with greater clearance between the housing and piston outside diameter to prevent interference and binding. Leakage is controlled by two graphite piston rings. The valve seat was bellmouth shaped to give the valve a good flow coefficient. A strain gage arrangement was used to indicate valve piston position. Only eight valves in each row, about 45° apart, were instrumented. The orifice between the spring and reference plenums provides damping of piston motion. This orifice was sized during the prototype valve tests.[8]

Fig. 6 is a photograph of a disassembled valve that shows most of the features discussed above. Additional valve details are given in Ref. 8.

Some mechanical difficulties were encountered with the valves during the test program. When exercising the valve piston it was found that sometimes the piston would not exceed about 80 percent of its stroke without rotating the piston. Other times it was found that the piston would not close fully, but would remain open about 20 percent. This is believed to be due to distortion of the valve housing when the valves are bolted to their mounting. Reasons for the malfunctions have not been completely determined at the writing of this paper. The problems appear to be minor and are under further investigation.

Procedure

The initial wind tunnel testing was devoted to selecting a bleed pattern compatible with the shielded valve. Various bleed patterns were obtained by sealing different regions of the stability bleed surface. Steady-state inlet and stability bleed performance data were obtained for each pattern for various bleed plenum exit areas. Valves were replaced by a fixed orifice on the plenum exit as shown in Figs. 3 and 4. To obtain these data, inlet diffuser exit airflow was varied by a remotely actuated plug assembly mounted at the downstream end of the cold pipe contained in the nacelle. The plug choked the pipe exit airflow. Stability limits were obtained for reductions in diffuser exit corrected airflow and changes in angle of attack.

The ability of the system to absorb transients was then determined. To simulate engine airflow transients the plug assembly was removed and the airflow disturbance generator, shown in Fig. 1, was installed. It was mounted at the upstream end of the cold pipe near the compressor face station. Airflow across the assembly was choked. The assembly consisted of five sliding plate valves which were hinged so that they could expand like an umbrella. The amount of assembly expansion and each sliding valve was remotely controlled by electrohydraulic servomechanisms. Diffuser exit airflow transients were obtained by pulsing the airflow disturbance generator valves from an open to a closed position. A single triangular-wave pulse, which can be transformed by Fourier analysis to obtain frequency information, was used. Ramp rates varying from slower than that required to actuate the valves to the maximum rate of the sliding valves were selected. 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 airflow change was converted to a Stability Index (SI) or percent change in airflow that the inlet would withstand (see Symbol List). These data were obtained for the modified inlet with and without the valves locked. Tests were also conducted with a forward bypass control system which handled transients that were too slow to actuate the valves. These tests demonstrate how the two systems complement each other. The forward bypass control shown in Fig. 1 operates in principle like the actual inlet control.[9,10] This control infers shock position from a single static pressure. The error in shock position is fed to a proportional plus integral controller which commands the forward doors to open or close, depending on whether the shock is upstream or downstream of its desired position.

Inlet tolerance to an upstream disturbance consisting of a transient in tunnel flow-field Mach number and flow angularity was also tested. The transient was introduced by rotation of a hinged plate mounted on the tunnel floor at the tunnel geometric throat station. A schematic and photograph of the gust generator device are shown in Fig. 7. The device is similar to one used previously,[11] but has provisions to permit remote operation. The plate was initially held in a 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° arc, changing the reflected shock position and strength.

Results and Discussion

Steady-State Diffuser Exit Airflow Disturbances

The stability bleed airflow characteristics and inlet performance for the final bleed pattern are shown in Fig. 8 for a free-stream Mach number of 2.47. The bleed pattern was not optimized to give the best possible performance for internal disturbances as in Ref. 3. Rather, it was selected because it gave adequate results to allow demonstration of both upstream and downstream valve operation under simulated flight conditions. In addition, the inlet with the valves locked closed gave performance about the same as, or better than, the standard inlet (no stability bleed) at Mach 2.1 and above.

Data for the stability bleed characteristics are shown in Fig. 8(a). The plot with bleed plenum pressure recovery P_{ba}/P_0 shows the maximum potential that can be obtained without the shield on the valve. Maximum potential of the shielded valve is illustrated by the plot with sensing duct pressure recovery P_{sd}/P_0. The valve characteristics cannot be included on these plots because they do not operate for slowly changing disturbances.

Data for each solid curve represents a fixed bleed plenum exit area and were obtained by varying diffuser exit airflow. The bleed plenum exit areas ranged from 0 to 107 percent of the full open valve geometric area of 53.4 square centimeters. The minimum bleed operation lines correspond to supercritical operation (terminal shock downstream). Maximum bleed airflows were obtained at minimum stable or peak recovery conditions. A maximum stability bleed mass-flow ratio or about 0.05 was obtained. The supercritical bleed mass-flow ratio with the valves closed was only 0.005.

The stability bleed performance maps demonstrate the advantage of using the shielded type valve. Consider the unshielded valve first. When the YF-12 is flying at Mach 2.47 at a typical altitude, an increase of 0.03 in bleed plenum recovery P_{ba}/P_0 would be required to start the valve open. Therefore, starting at the operating point indicated by the solid symbol, the valves would not start open until P_{ba}/P_0 reaches a value of about 0.37. Assuming no additional increase in P_{ba}/P_0 is required to open the valve, the maximum stability bleed mass-flow ratio that could be achieved is about 0.04. In actuality, some additional increase in P_{ba}/P_0 is required to open the valve. Therefore, the maximum stability bleed mass-flow ratio would be less than 0.04. Now consider the shielded valve. The same increase in sensing duct pressure recovery is required to open the shielded valve. In this case, however, the maximum value of P_{sd}/P_0 increases with increasing mass-flow ratio instead of decreasing as for P_{ba}/P_0. Thus, the shielded valve will provide the maximum possible stability bleed airflow. Also, the data for valves closed indicate that the available change in pressure recovery to open the valve is more than $1\frac{1}{2}$ times greater for the shielded valve (0.36 to 0.49 for P_{sd}/P_0 versus 0.34 to 0.42 for P_{ba}/P_0). This could be important at higher altitudes where an increase in recovery greater than 0.03 would be required to open the valve. Also, it might be desired to operate the inlet at a higher efficiency (higher pressure recovery) which would decrease the margin in plenum pressure recovery available to open the valve.

The actual stability attained for the Mach 2.47 conditions can be determined from the inlet performance map (Fig. 8(b)). The pressure recovery and mass-flow ratio terms have been normalized by dividing by their values at the operating point for the transient tests. Thus the coordinates of the solid symbols are 1.0, 1.0. If total temperature is assumed to remain constant, an alternate equation for stability index, SI, can be obtained by manipulation of the equation in the Symbol List:

$$SI = \left\{1 - \left[\frac{m_2/m_0}{(m_2/m_0)_{op}}\right]_{mins} \Bigg/ \left[\frac{P_2/P_0}{(P_2/P_0)_{op}}\right]_{mins}\right\} \times 100$$

Therefore, Fig. 8(b) shows that the maximum SI is 14.3 for a valve area of 107 percent. With the valves closed the SI is about 4.5 percent. Thus, the net gain due to the valves opening will be about 10 percent.

A small part of the stability results from the increase in total pressure recovery as the terminal shock moves forward. But most of the stability results from the increase in mass-flow that is bypassed. It should be noted that bleeding ahead of the shock trap resulted in increased shock trap flow, which also contributed to the increase in stability.

Similar steady-state results were obtained at Mach 2.76 as shown by the data in Fig. 9. In that case the maximum SI was 12.6 percent; and with the valves closed, about 5 percent.

Transient Diffuser Exit Airflow Disturbances

Inlet tolerance to diffuser exit corrected airflow transients is shown in Fig. 10 for a Mach number of 2.47. A typical disturbance pulse is illustrated in the figure. The results are plotted as stability index, SI, against a normalized disturbance rate, NDR. The disturbance rate is the absolute ramp rate or time rate of change of the pulse in diffuser exit corrected airflow. The disturbance rate is converted to NDR by multiplying by 100 over the operating point value of the diffuser exit corrected airflow. Thus NDR is the percent change in diffuser exit corrected airflow per second. As NDR increases, the airflow is changing more rapidly and the disturbance has higher frequency content.

Data for Mach 2.47 are shown in Fig. 10 for the inlet with the stability valves locked closed, with the valves operating and with the valves and the forward bypass control operating. As expected the inlet has the least tolerance when neither the valves or the forward bypass is operating (circle symbols). However, inlet stability does increase from about 6.5 to 14 percent at the highest NDR, because the inlet volume is able to absorb a larger disturbance as the disturbance rate increases. When the valves are operating there is no improvement in inlet stability below a NDR of about 4 because the disturbance rate is too slow to open the valves. However, as NDR increases, the valves open, increasing inlet stability by about 7 percent more than with the valves closed. This is slightly less than the increase predicted by the steady-state data of Fig. 8. This discrepancy may be partly due to the larger maximum exit area used during the steady-state tests. The capability of the forward bypass is exceeded at a NDR of about 40 percent/sec. Above 40 only the stability valves provide the increase in inlet stability. Between 4 and 40 the valves enhance the capability of the forward bypass control system. Below a NDR of 4 the forward bypass system provides large amounts of stability where the disturbance rates are too slow to open the valves. If desired the amount of overlap of the two systems could be adjusted by changing the response of the forward bypass control system or the valves. For example, a slower bypass system could be used or the valve response could be changed by varying the reference orifice size.

The stability that would be provided by the forward bypass system is actually less than that shown in Fig. 10. The reason for this is that these tests were conducted with the forward bypass initially closed to make it easier to relate the airflow disturbance generator area change to a corrected airflow change. In flight at Mach 2.47 the forward bypass would be partially open. It would therefore reach its maximum flow area for a smaller disturbance. The corresponding steady-state stability that would be provided by the forward bypass control under these conditions is about 20 percent. Stability data were also obtained for the standard inlet (without porous cowl bleed) but are not shown in Fig. 10. In general, the standard inlet stability was 3 to 4 percent less than the modified inlet with the valves locked closed.

Similar transient results were obtained at Mach 2.76 as shown by the data in Fig. 11. The valves appear to begin working at slightly lower NDR than at Mach 2.47. This could be due to a higher free-stream total pressure at Mach 2.76. The valves again provide an additional stability of 7 percent - about the same as that indicated by the steady-state data of Fig. 9.

The data with the forward bypass control operational indicate that the control is effective to a higher NDR than at Mach 2.47. This could be due to the higher gain of the pressure feedback signal to diffuser exit airflow which results in a higher control loop gain. The actual inlet control adjusts the controller gain to compensate for this, but the control used in these tests did not. The steady-state stability that would be provided by the forward bypass control under flight conditions is 19 percent. The standard inlet stability was 1 to 2 percent less than the modified inlet with the valves locked.

Angle of Attack and Mach Number Disturbances

Steady-state data showing the inlet tolerance to angle of attack at Mach 2.47 is given in Fig. 12. These data were taken with fixed exits. The data indicate that the inlet would have an angle of attack capability of about 2° with the valves locked closed. When the valves are operational, this is more than enough angle of attack capability to give the necessary increase in bleed plenum pressure recovery (about 0.03) to open the valves. As can be seen from Fig. 12, relatively small valve openings allow quite large angle of attack capabilities. It should be remembered that if a change in angle of attack occurs too slowly, the valves will not open. However, those disturbances should be handled by the inlet spike control.

The inlet tolerance to the disturbance created by the wind tunnel gust generator is shown in Figs. 13 and 14. For the transient of Fig. 13 the initial Mach number and flow angle at the spike tip were 2.55 and 0°, respectively. The gust generator created a change of about 0.15 in Mach number and 2.4° in angle of attack. The change in conditions occurred in about 0.025 second. The valve trace shows the valve opens about 25 percent and then starts to drift closed. This demonstrates the transient operating nature of the valves. Only one other upstream valve and no downstream valves were observed to open during the transient. (Recall that only 8 valves in each row are instrumented.) About 1.25 seconds after the disturbance occurs, the inlet unstarted as shown by the sharp drop in bleed plenum and cowl surface static pressures. (The cowl pressure is at the same axial location as the forward valves.) The noise observed on the valve position trace after unstart, is believed to be due to excitation of a resonance somewhere in the strain gage setup, and not to actual piston motion. The inlet unstarted in 0.3 second for the same disturbance when all the valves were locked closed. A 1-centimeter spike translation was required to prevent the inlet from unstarting. The 1.25 seconds should be adequate time for the inlet spike control system to act to prevent unstart, but the 0.3 second would be marginal.

A second transient is shown in Fig. 14, in which the initial Mach number and flow angle were 2.68 and 0°. All instrumented upstream valves and 2 downstream valves were observed to open for this disturbance. The typical upstream valve trace shows the valve opening about 30 percent and then drifting closed. Just prior to unstart the inlet went into an unexplained unstable oscillation visible in the pressure traces. The inlet unstarted about 1.68 seconds after the disturbance occurred. With all valves locked closed, the inlet unstarted in less than 0.1 second. In this case a spike translation of 4 centimeters was required to prevent inlet unstart. At the maximum spike travel rate, this travel would require more than 0.3 second. Thus, without the valves operating, the inlet spike control system would be incapable of compensating for the disturbance.

Summary of Results

A throat bypass stability system in a YF-12 aircraft inlet was demonstrated by wind tunnel testing. The system concept should be suitable for flight testing on a NASA YF-12 research aircraft. Stability bleed airflow is removed through a porous bleed region just ahead of the inlet shock trap. Two circumferential rows of relief-type mechanical valves control bleed plenum exit area and, hence, bleed airflow. The valves have a shield and duct which sense an actuating pressure rather than being actuated directly by the bleed plenum pressure. Such an arrangement provides better valve response to airflow disturbances in this application. By design, the valves do not open for slowly varying disturbances to eliminate the need for an external, regulated reference pressure. A lockup system allows the pilot to lock all valves closed in either row.

The inlet was subjected to single triangular wave pulses in diffuser exit corrected airflow at Mach numbers of 2.47 and 2.76. The aft valves permitted additional decreases in airflow of up to 7 percent of the operating point airflow, at rates faster than can be handled by the inlet forward bypass control system. Since the forward bypass control system handles disturbances that are too slow to actuate the valves, the two systems were found to complement each other quite well.

The inlet was also subjected to a disturbance consisting of a decrease in Mach number and an increase in angle of attack produced by a tunnel gust generator. For this type of disturbance, the forward valves relieve pressure rises that could result in local choking and inlet unstart. It was found that the valves kept the inlet started long enough for the inlet spike control system to have prevented unstart. With the valves locked closed, the inlet unstarted rapidly and would not have given sufficient time (or at best, would have been marginal) for the inlet control system to act.

Some minor mechanical difficulties were encountered with the valves. These problems do not appear to be serious and are under further investigation.

Symbol List

FBY	forward bypass
M	Mach number
m	mass flow rate, kg/sec
$m\sqrt{\theta}/\delta$	corrected airflow, kg/sec
NDR	normalized disturbance rate, NDR = $SI/(\Delta t/2)$, percent/sec
P	total pressure, N/cm^2
SI	stability index, $SI = \left\{1 - \left[\left(\frac{m\sqrt{\theta}}{\delta}\right)_{mins} \Big/ \left(\frac{m\sqrt{\theta}}{\delta}\right)_{op}\right]_2\right\} \times 100$, percent
Δt	triangular wave pulse width, sec
α	angle of attack, deg
δ	ratio of local total pressure to standard sea level pressure
θ	ratio of local total temperature to standard sea level temperature

Subscripts:

ba	bleed plenum-aft compartment (Fig. 2)
bf	bleed plenum-forward compartment (Fig. 2)
flt	flight condition
mins	minimum stable (just before unstart) operation
op	operating point conditions for transient tests
sd	shielded valve sensing duct (Fig. 2)
0	free-stream conditions
2	diffuser exit (compressor face) station

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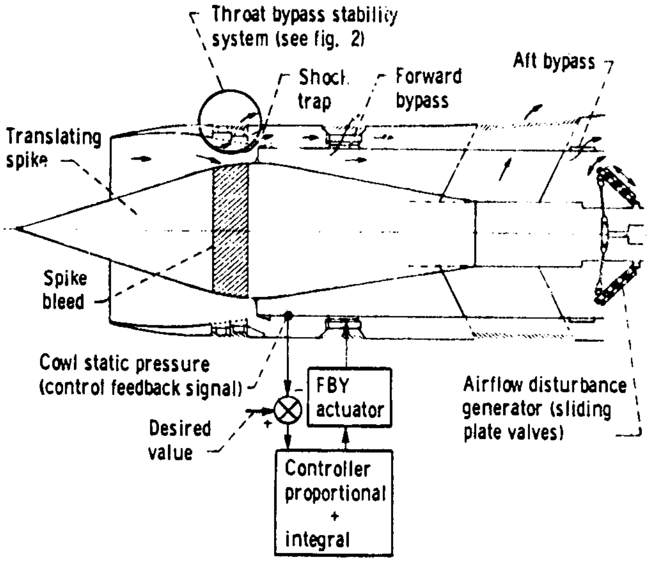


Figure 1. - Schematic of YF-12 inlet showing bleeds and bypasses and installation of throat-bypass stability system.

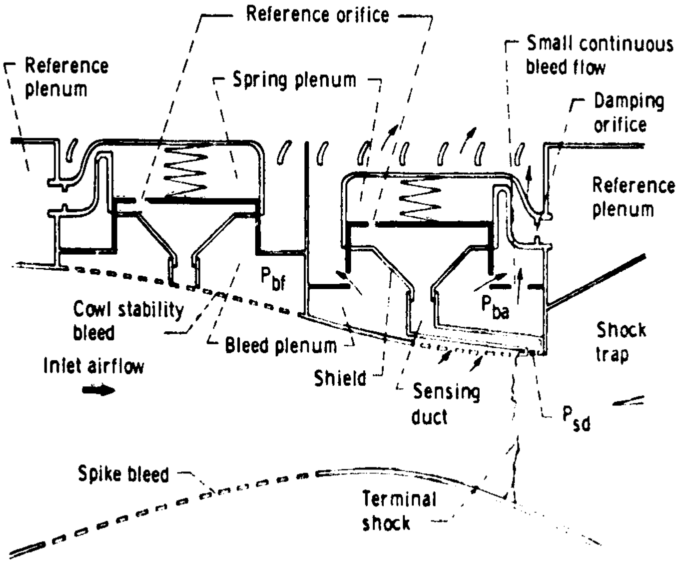


Figure 2. - Final throat-bypass stability system installed in YF-12 inlet.

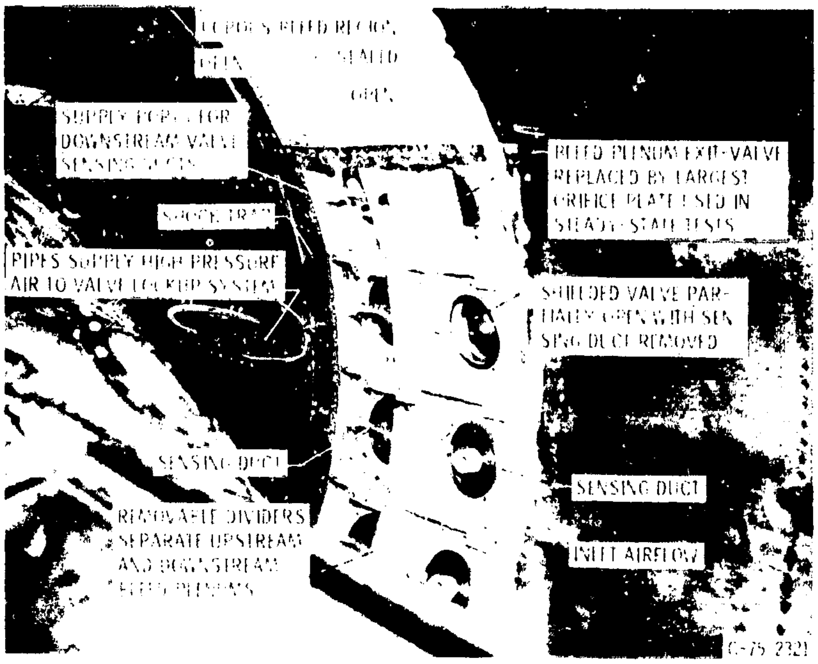


Figure 3. - Internal view of inlet showing porous cowl bleed region and throat bypass stability system installation with spike removed.

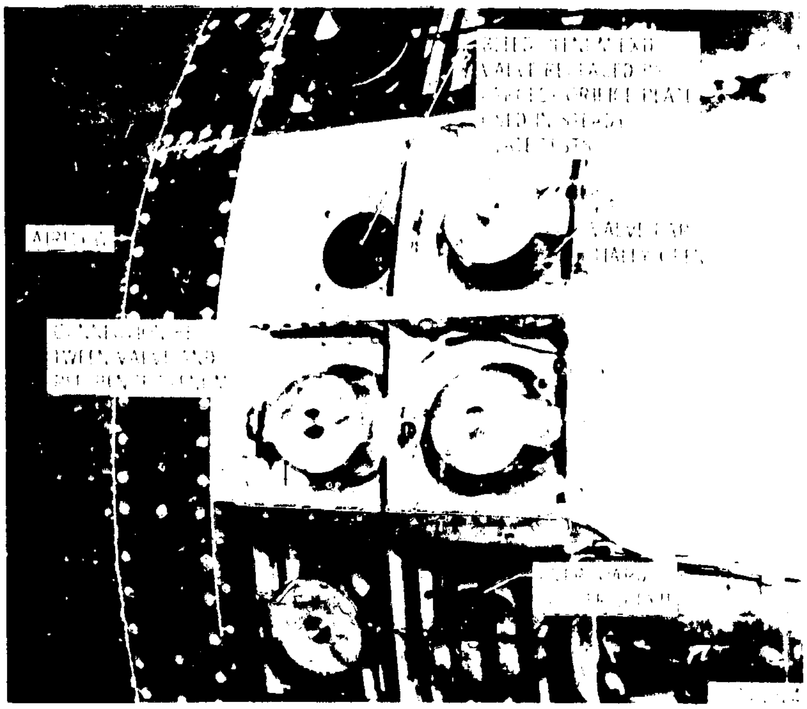


Figure 4. - External view of inlet showing installation of throat bypass stability system.

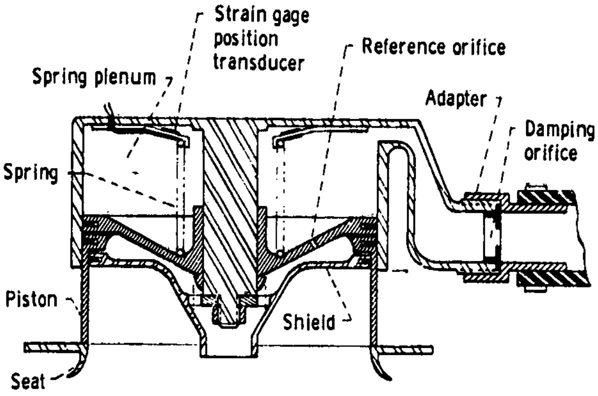


Figure 5. - Details of stability system relief valve.

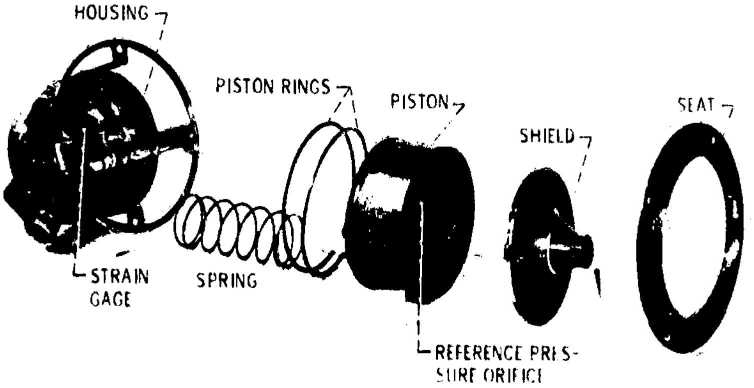
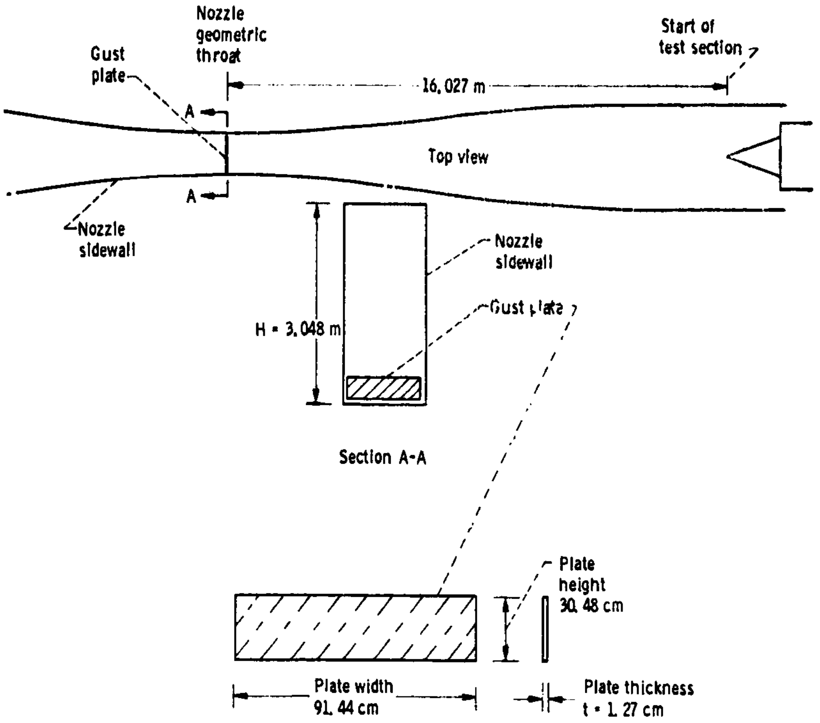
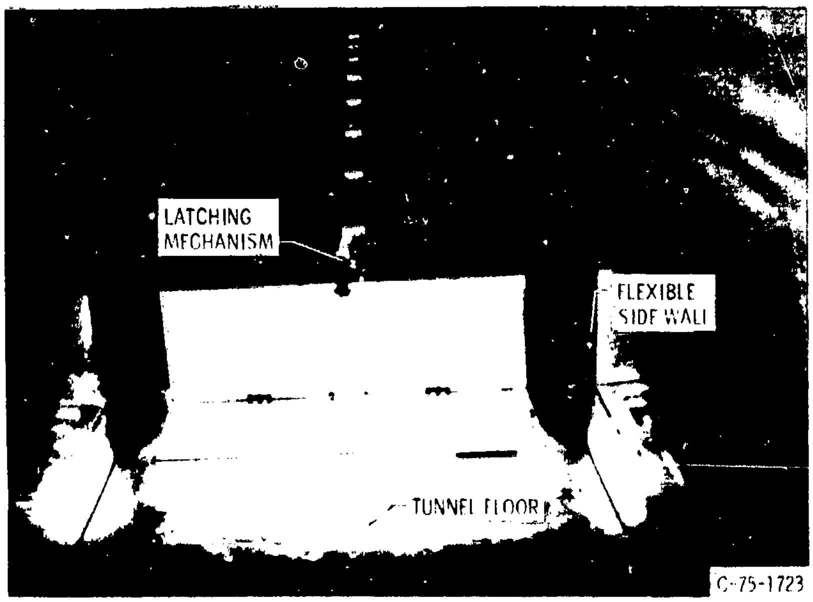


Figure 6. - Disassembled stability system relief valve. C-75-2482



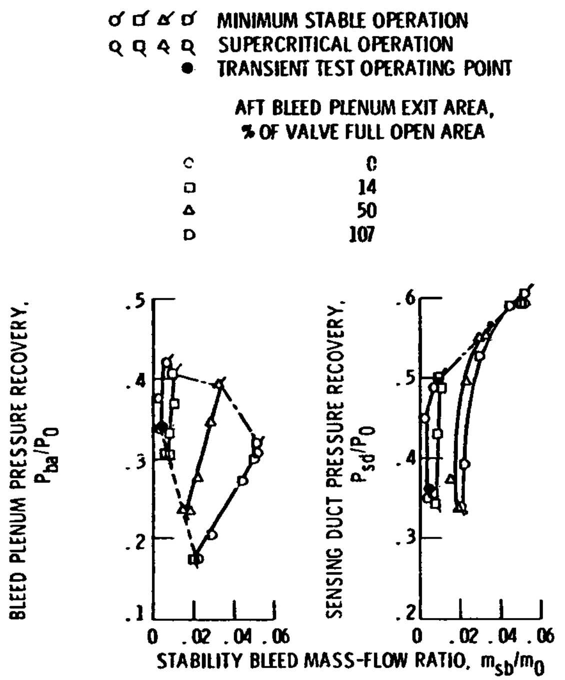
(a) Schematic showing location and size of gust generator.

Figure 7. - Details of gust generator in 10' x 10' Supersonic Wind Tunnel.

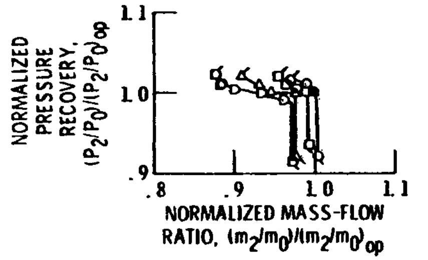


(b) PHOTOGRAPH OF GUST GENERATOR LOOKING UPSTREAM.

Figure 7. - Concluded.

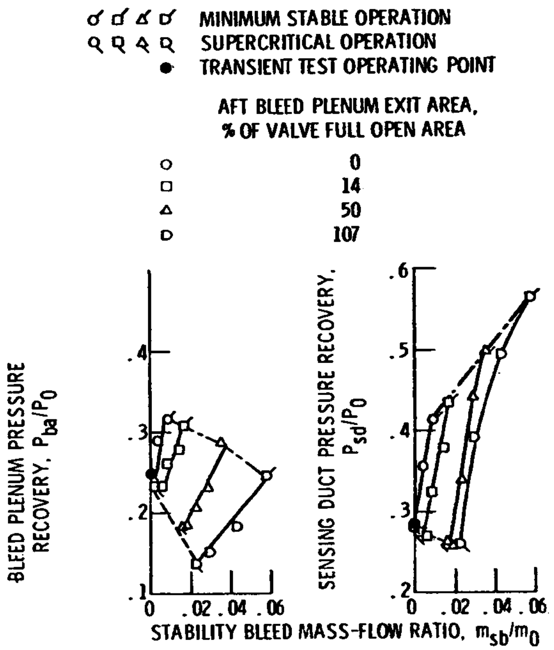


(a) COWL STABILITY-BLEED PERFORMANCE.

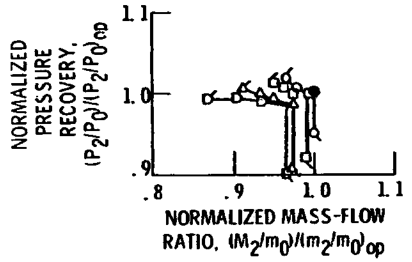


(b) INLET PERFORMANCE.

Figure 8. - Performance of final stability bleed configuration. Upstream valves closed. Inlet operating at Mach 2.47 and approximate flight angle conditions. Reynolds number 7.19 x 10^6 based on cowl-lip diameter.



(a) COWL STABILITY-BLEED PERFORMANCE.



(b) INLET PERFORMANCE.

Figure 9. - Performance of final stability bleed configuration. Upstream valves closed. Inlet operating at Mach 2.76 and approximate flight angle of attack conditions. Reynolds number 6.63 x 10^6 based on cowl-lip diameter.

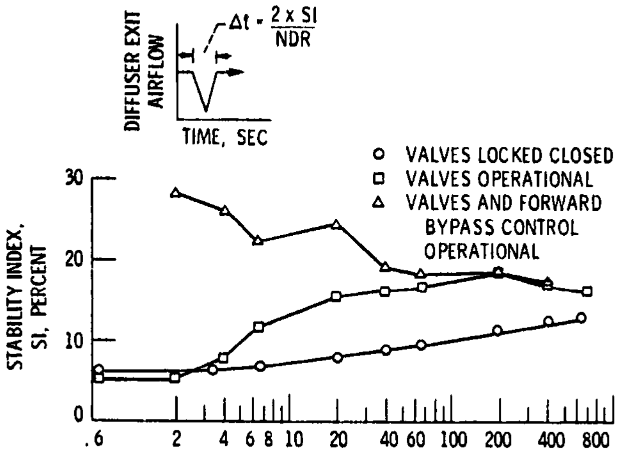


Figure 10. - Inlet transient stability when subjected to a single triangular pulse in diffuser exit corrected airflow. Inlet at Mach 2.47 and approximate flight angle of attack conditions. (Corresponding steady-state performance shown in fig. 8.)

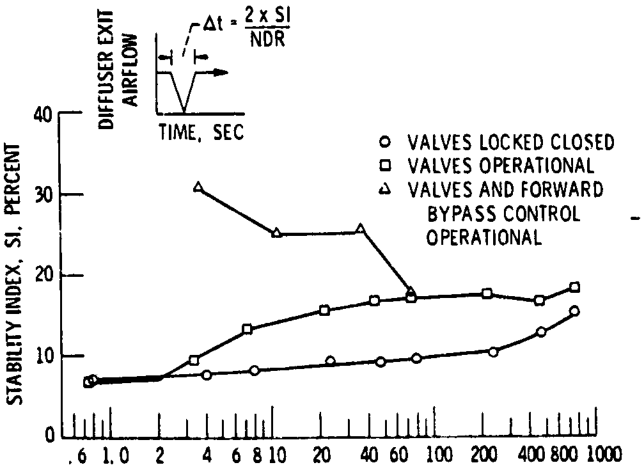


Figure 11. - Inlet transient stability when subjected to a single triangular pulse in diffuser exit corrected airflow. Inlet at Mach 2.76 and approximate flight angle of attack conditions. (Corresponding steady state performance shown in fig. 9.)

E-8437

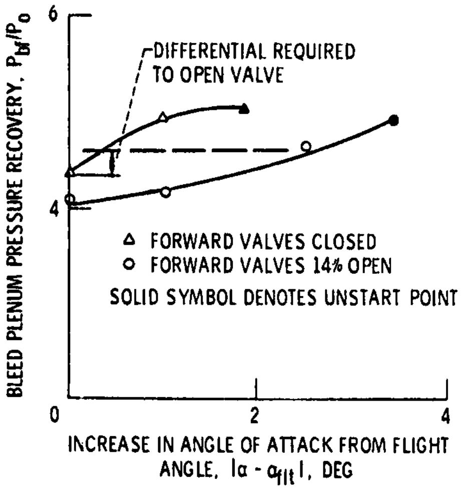


Figure 12. - Typical steady-state data showing bleed system performance for changes in inlet angle of attack. Mach number 2.47, spike retracted 1.27 cm from scheduled position, downstream valves closed.

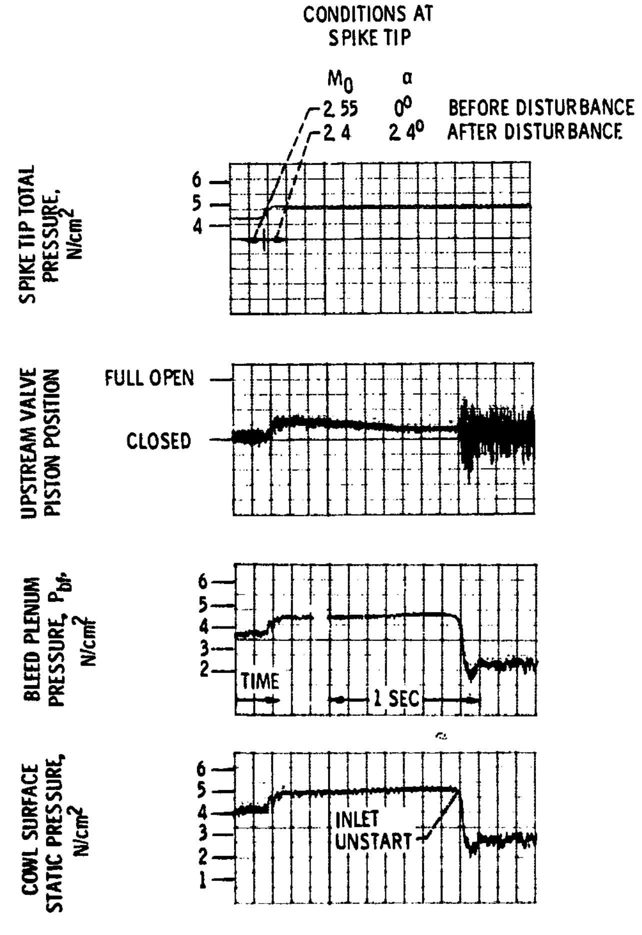


Figure 13. - Inlet response to tunnel gust generator disturbance. (Valve located at top of inlet looking downstream.)

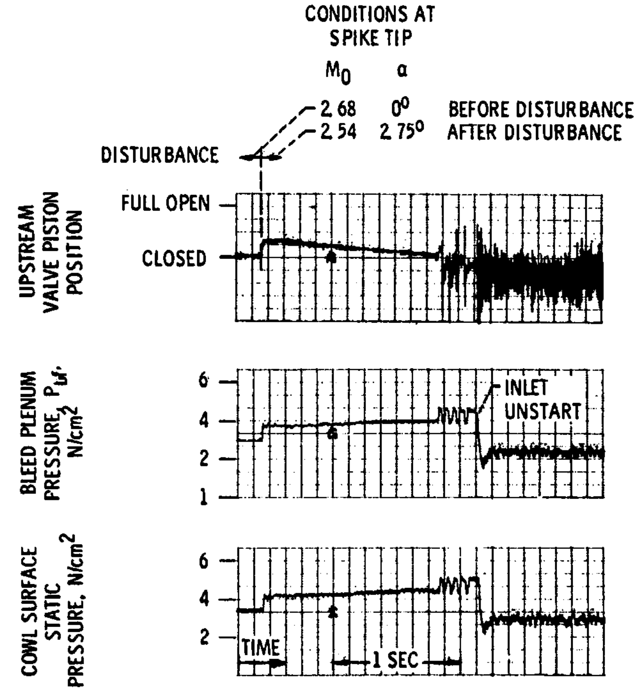


Figure 14. - Inlet response to tunnel gust generator disturbance. (Valve located at top of inlet looking downstream.)