NASA TECHNICAL
MEMORANDUM

NASA TM X-1928

NASA TM X-1928

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF PULSE PRESSURE DISTORTIONS IMPOSED ON THE INLET OF A TURBOFAN ENGINE

by Leon M. Wenzel

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1969

1. Report No. NASA TM X-1928	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF PULSE PRESSURE DISTORTIONS IMPOSED ON THE INLET OF A TURBOFAN ENGINE	5. Report Date November 1969 6. Performing Organization Code
7. Author(s) Leon M. Wenzel	8. Performing Organization Report No. E-5247
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	10. Work Unit No. 720-03 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A YTF-30-P-1 turbofan was operated in an altitude chamber. A distortion device capable of effecting pulse depressions in inlet pressure was installed ahead of the engine. The pulses could be varied in duration and amplitude. The portion of the inlet duct subjected to distortion could be varied circumferentially from 60° to 360° in 60° sectors. The engine stall sensitivity as a function of pulse duration and distortion sector angle was mapped. The amplitude of pulse necessary to stall the engine was found to be an inverse function of pulse duration. The engine was most sensitive to distorted sectors of 180° and 240°. Transient recordings of engine pressures and pressure ratios during stall are presented. Also, data are presented which indicate the circumferential propagation rate of a pressure pulse traveling through the engine to be 20° per stage.

17. Key Words *(Suggested by Author(s))* Turbofan Pulse pressure distortion Compressor stall Inlet	18. Distribution Statement Unclassified - unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 17	22. Price* $3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF PULSE PRESSURE DISTORTIONS IMPOSED ON THE INLET OF A TURBOFAN ENGINE

by Leon M. Wenzel

Lewis Research Center

SUMMARY

A YTF-30-P-1 turbofan was operated in an altitude chamber. A distortion device capable of effecting pulse depressions in inlet pressure was installed ahead of the engine. The pulses could be varied in duration and amplitude. The portion of the inlet duct subjected to distortion could be varied circumferentially from 60° to 360° in 60° sectors.

Engine stall sensitivity as a function of pulse duration and distortion sector angle was mapped. The amplitude of pulse necessary to stall the engine was found to be an inverse function of pulse duration. The engine was most sensitive to distorted sectors of 180° and 240°.

Transient recordings of engine pressures and pressure ratios during stall are presented. Also, data are presented which indicate the circumferential propagation rate of a pressure pulse traveling through the engine to be 20° per stage.

INTRODUCTION

The tolerance of turbojet engines to dynamic distortions in inlet pressure is currently of great interest (e.g., ref. 1). This report presents the results of an investigation in which portions of the inlet of a YTF-30-P-1 turbofan engine were subjected to single pulse depressions in pressure. Distortion sector angle, pulse duration, and pulse amplitude were varied; the engine stall limits were defined with respect to these parameters.

Transient recordings of engine pressures and compressor stage group pressure ratios during stall are presented for several inlet conditions. Also, data are presented which give the rate of circumferential propagation of an inlet pressure pulse as it progresses through the compressor.

SYMBOLS

P	pressure, psi (N/cm^2)
Subscripts:	
f	fan duct
t	total
2	inlet duct
2.1	after first fan stage
2.3	fan discharge
2.6	mid low compressor
3	low-compressor discharge
3.12	mid high compressor
4	high-compressor discharge

APPARATUS

Tests were conducted on a YTF-30-P-1 turbofan engine installed in an altitude chamber. The axial locations of the pressure instrumentation stations of interest in this report are shown in figure 1. At each of the stations indicated, two pressure transducers are provided; one each on the right and left sides of the engine. Miniature pressure transducers are used, mounted so as to have essentially flat frequency response to 400 hertz.

A secondary jet system is located in the engine inlet duct. The system consists of 54 jet nozzles evenly spaced over the inlet annulus. The 54 nozzles are composed of six groups of nine nozzles each. The individual groups each cover a sextant of the inlet. The jet system operates by flowing counter to the primary inlet airflow. The resulting momentum exchange causes a total-pressure loss across the jet system.

Airflow to each of the six nozzle groups is controlled by a servodriven valve having high response (about 150 Hz). The valves can be operated independently to give distortion patterns covering 60° multiples of the inlet.

The inlet and jet system are also shown schematically in figure 1. The jets are 36 inches (91 cm) upstream of the engine face, and the open end of the bellmouth is 129 inches (328 cm) upstream of the jets. This installation is described more fully in reference 2.

The electrical signals supplied to the servovalves were formed on a desk-top analog computer. A gating circuit was provided to set pulse duration. Pulse amplitude was independently controlled. The pulses generated could be switched to drive any desired combination of the six valves.

TEST PROCEDURE

The engine and test chamber were set up to 8600-rpm low rotor speed, rated exhaust nozzle area, and 7.5-psia (5.17-N/cm^2) inlet pressure. All valves were set to near closed and secondary flow rates equalized. The valves to be driven and the pulse duration were chosen and appropriate computer settings made. The initial pulse amplitude was set. The recording system was started and the pulse initiated, opening the prescribed number of valves. If engine stall did not occur, an increment was added to the pulse amplitude, the computer reset, and a larger pulse initiated. This process was repeated until engine stall was encountered. The time required to adjust the pulse amplitude and reset the computer was ample for transients induced by the previous pulse to die out. Stall points were obtained in this manner for distortion sector angles from 60^o to 360^o, and for pulse durations from 6 to 100 milliseconds.

RESULTS AND DISCUSSION

Figure 2 presents the conditions of pulse amplitude and duration which induced engine stall for distortion sector angles of 60^o to 360^o. The ordinate of this plot is the voltage level supplied to the servodriven distortion valve (or valves) from the computer. It is proportional to the amount which the servovalve (or valves) opened.

The shape of the curves indicates that the amplitude of pulse which the engine can tolerate varied inversely with duration. Also, the engine is most sensitive to distortion angles around 180^o and 240^o.

Figure 3 is similar to figure 2; the ordinate in this figure is the magnitude of the pressure pulse in the secondary air supply just upstream of the jet nozzles. More scatter is noted in this figure, but the similarity in the shape of the curves indicates that the servovalves did follow their input signal.

It is recognized that figures 2 and 3 are plotted in terms of artificial variables. The primary variable, engine inlet pressure, could not be measured precisely because of low signal level and poor wave shape. However, as an indication of the inlet pressure perturbations involved, for pulses in the 3- to 5-volt range in figure 2, inlet pressure reductions of about 0.4 psi (0.276 N/cm^2) were imposed on the steady-state pressure level of 7.5 psia (5.17 N/cm^2). These numbers are not intended as calibrations, but only to give an indication of the pressure perturbation amplitudes experienced.

Figures 4 to 6 are transient recordings of engine stall for distortion angles of 60°, 180°, and 360°, respectively. These transients are typical of the stall boundary points in figure 2. The right (90°)- and left (270°)-side engine pressures and the right- and left-side pressure ratios are shown for each distortion angle. Total pressure at a particular engine station and circumferential location is indicated on each trace (e.g., $P_{t2.3-273^{\circ}}$ signifies total pressure at engine station 2.3 (see fig. 1) and a circumferential location of 273°). For this entire investigation, the distorted area was centered as nearly as possible about the right side.

The test procedure for this investigation was to initiate increasingly larger pulses in inlet pressure until stall occurred. The pulses which did not induce stall can be used to measure the rate at which an inlet pressure pulse propagates circumferentially as it travels back through the engine.

The measurement of this circumferential propagation necessitates an understanding of the response of the inlet duct. The configuration of the duct is shown in figure 7, with transport times upstream and downstream indicated. Figure 8 shows an analytical response of engine inlet pressure to jet flow. The one-dimensional model used to generate these responses is based on the method of Willoh (ref. 3).

The trapezoidal waveform in jet flow is typical of those achieved in the testing. The complex waveform of engine inlet pressure is made up of a primary pulse traveling downstream from the jet nozzles, plus a secondary pulse which travels upstream, reflects off the open inlet, and then travels back downstream to the pressure station. The time required for the reflected pulse to reach the pressure station is approximately 22 milliseconds.

If only a portion of the inlet is perturbed, the inlet duct pressure transducer circumferentially located directly behind the distortion ($P_{t2-90^{\circ}}$) will measure both the primary and reflected pulses. However, the transducer located on the opposite side of the inlet duct ($P_{t2-270^{\circ}}$) will measure only the reflected pulse. This behavior is illustrated in figure 9. Transient recordings of inlet and compressor pressures during a nonstalling (i.e., below the stall boundary of fig. 2) 120° pulse are shown in this figure. A long-duration depression is noted in $P_{t2-90^{\circ}}$, indicating that both primary and reflected pulses passed by. In $P_{t2-270^{\circ}}$, only the reflected pulse is seen.

Similar differences can be noted in the traces for stations 2.3 and 2.6. However, at station 3, the primary pulse can be seen. Thus, the axial distance required for circumferential propagation can be determined.

Figure 10 summarizes this distance required for circumferential propagation for the various distortion angles tested. Indicated on this figure are the distorted angle, the distortion pattern, and the minimum angle through which the primary pulse must propagate. The results show that the axial distance required for the pulse to propagate circumferentially varies directly with the propagation angle. Propagation rate is seen to be 20° per stage.

SUMMARY OF RESULTS

A YTF-30-P-1 turbofan engine was operated in an altitude chamber. Air jets, driven by high-response servovalves, were installed in the engine inlet duct. The jets were operated to effect single pulse depressions in engine inlet pressure. The distorted portion of the inlet was varied circumferentially by sextants from 60° to 360°. Pulse duration was varied from 6 to 100 milliseconds.

The engine stall sensitivity as a function of pulse duration and distortion sector angle was mapped. The pulse amplitude required to stall the engine was found to be an inverse function of pulse duration. The engine was most sensitive to distortion sectors of 180° and 240°.

Transient recordings of engine pressures and pressure ratios during stall are presented. Data are also presented which indicate the circumferential propagation of an inlet pressure pulse as it travels axially through the engine. The propagation rate was measured to be 20° per stage.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 27, 1969,
720-03.

REFERENCES

1. Reid, C.: The Response of Axial Flow Compressors to Intake Flow Distortion. Paper 69-GT-29, ASME, Mar. 1969.
2. Povolny, John H.: Stall and Distortion Investigation of a YTF30-P-1 Turbofan Engine. Paper presented at the AFAPL Airframe - Propulsion Compatibility Symposium, Miami Beach, Fla., June 24-26, 1969.
3. Willoh, Ross G.: A Mathematical Analysis of Supersonic Inlet Dynamics. NASA TN D-4969, 1968.

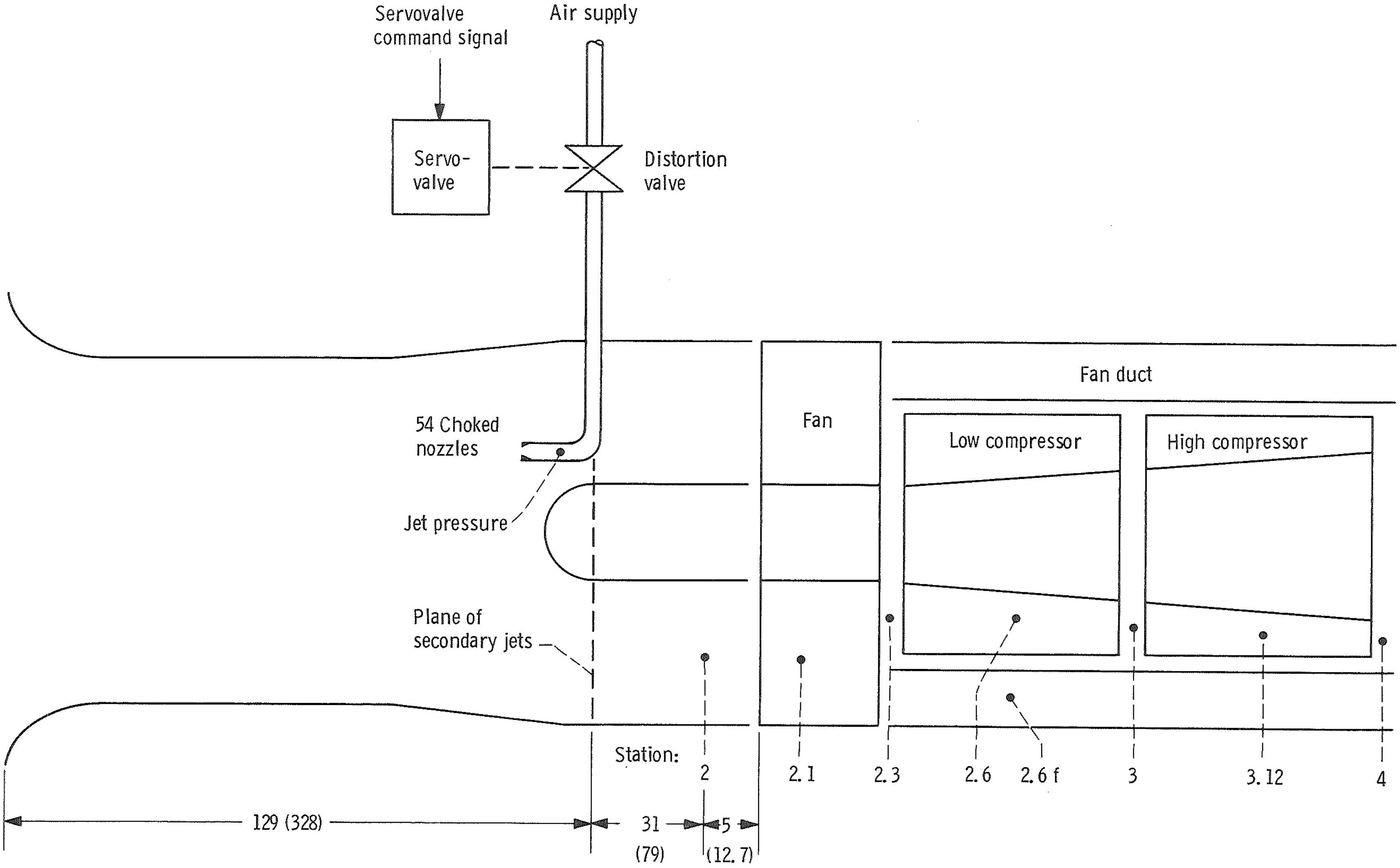


Figure 1. - Schematic diagram of compressors and inlet duct showing instrumentation stations. (Dimensions are in inches (cm).)

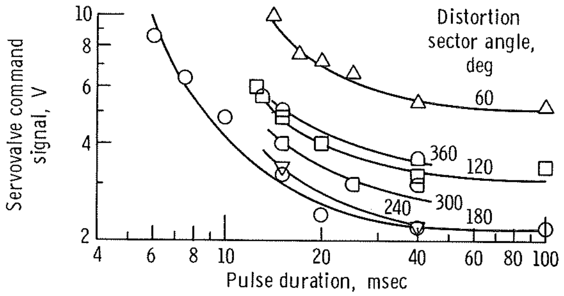


Figure 2. - Stall boundary as function of pulse amplitude, pulse duration, and distortion angle.

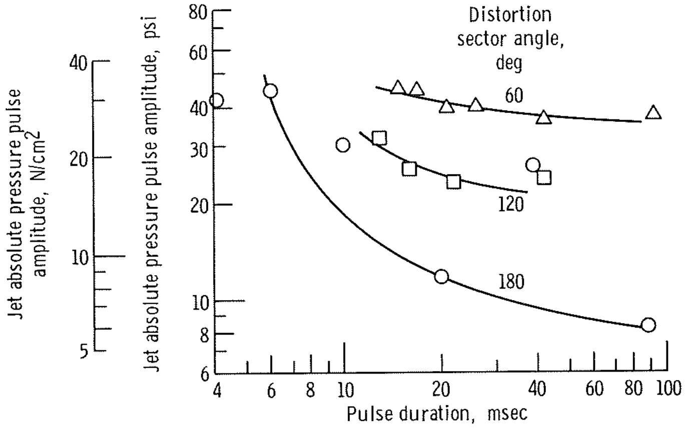
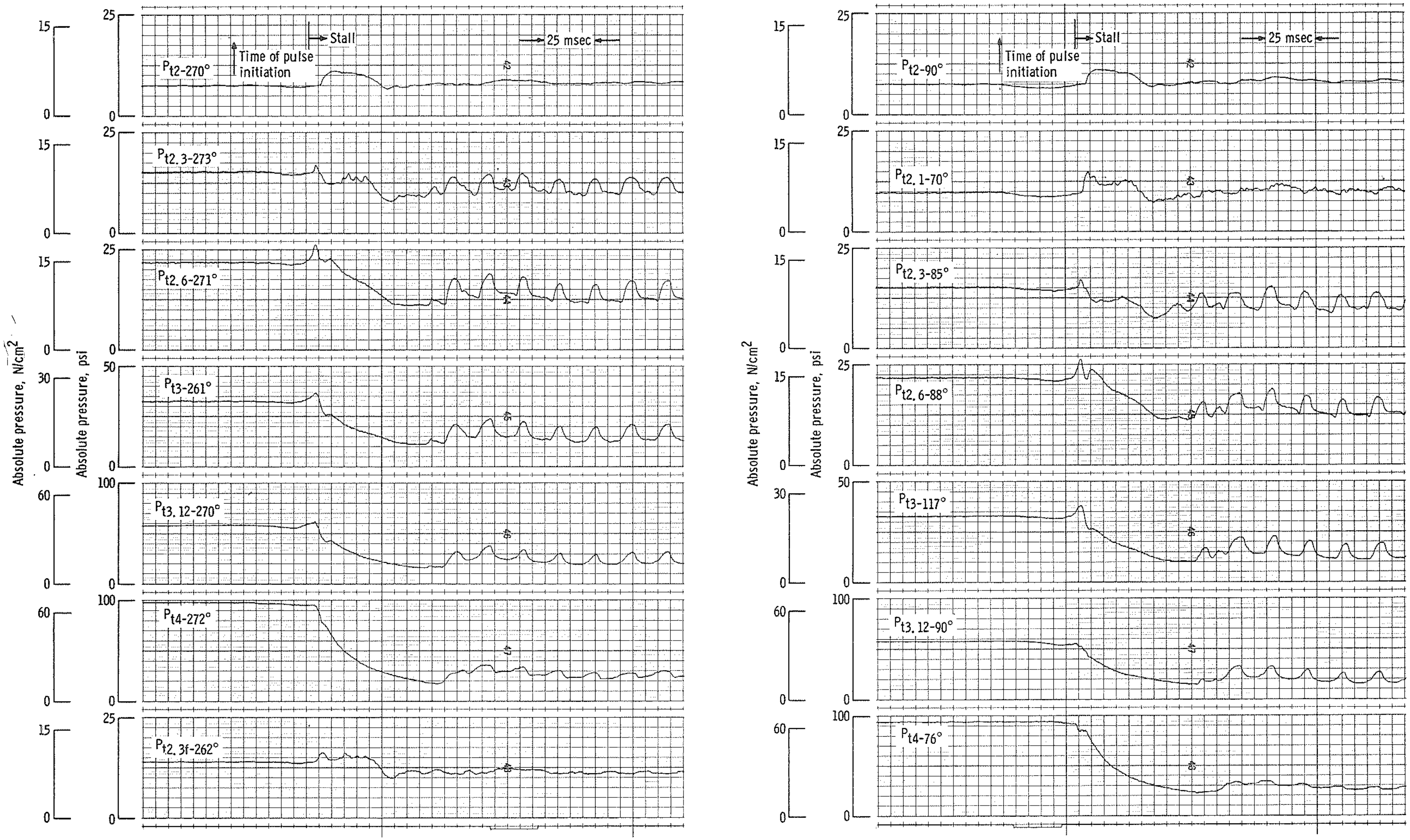
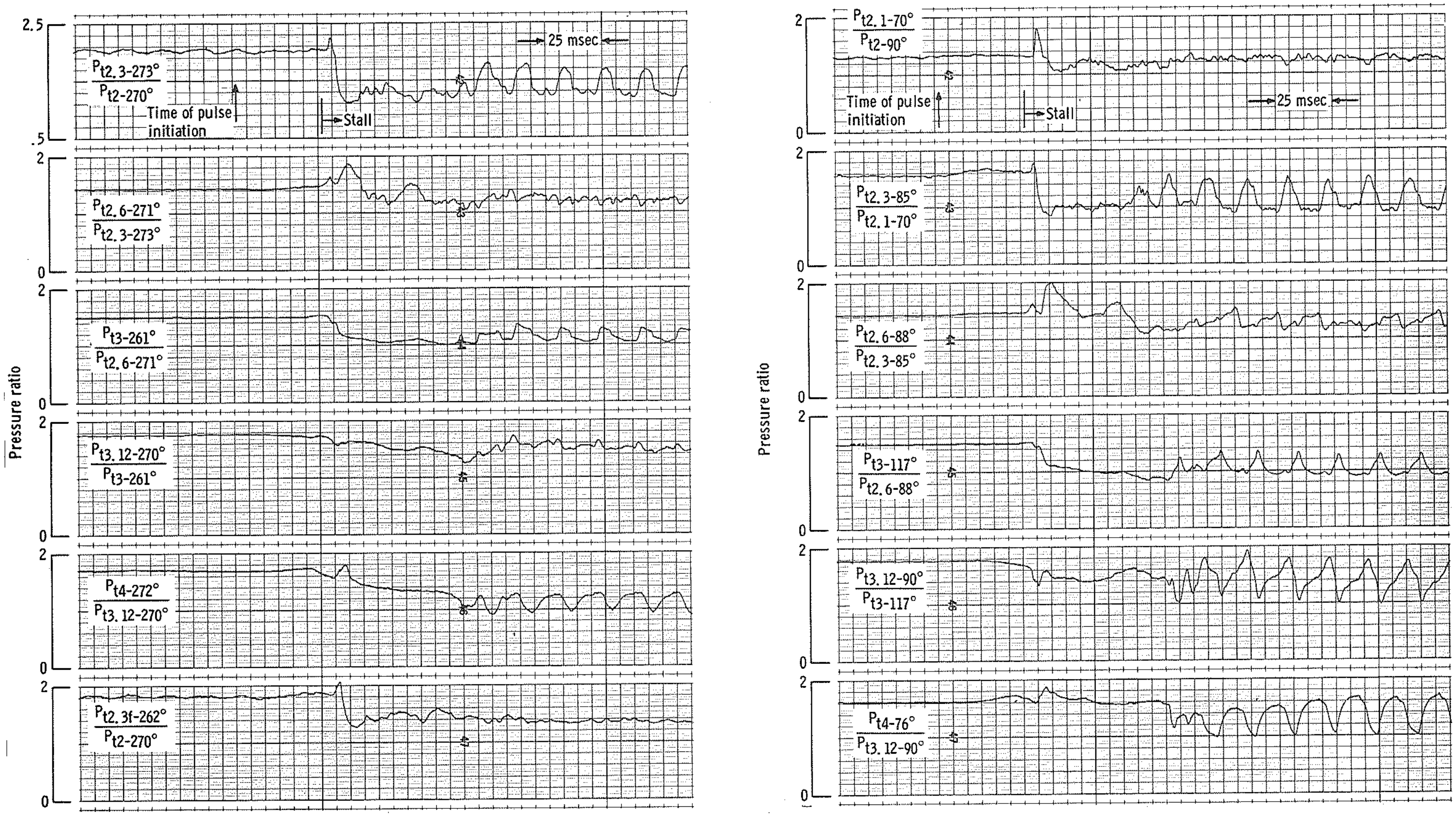


Figure 3. - Stall boundary as function of jet absolute pressure pulse amplitude, pulse duration, and distortion angle.



(a) Left-side pressures.

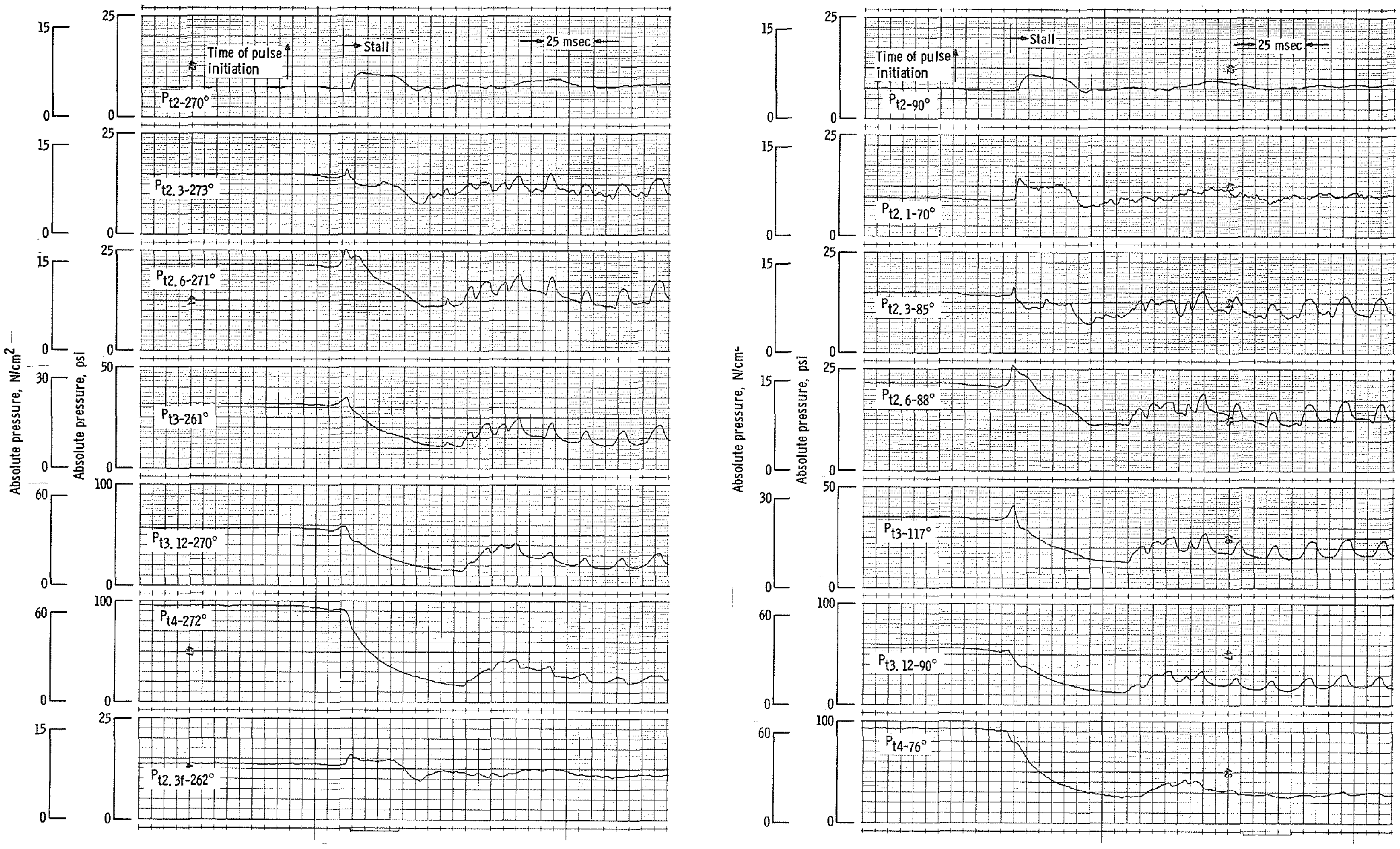
(b) Right-side pressures.



(c) Left-side pressure ratios.

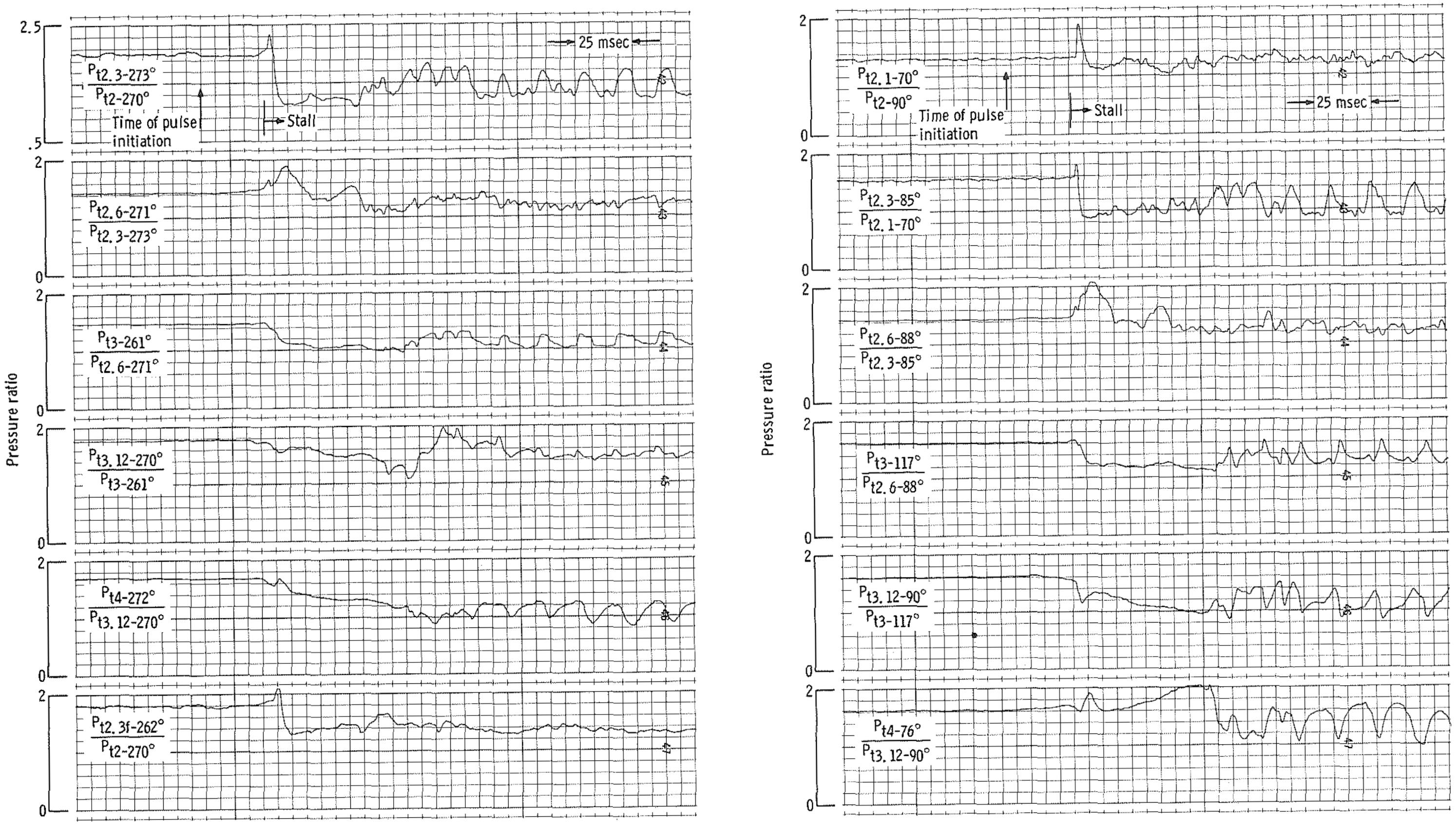
(d) Right-side pressure ratios.

Figure 4. - Engine parameters during stall. Pulse duration, 15 milliseconds; distortion angle, 60°.



(a) Left-side pressures.

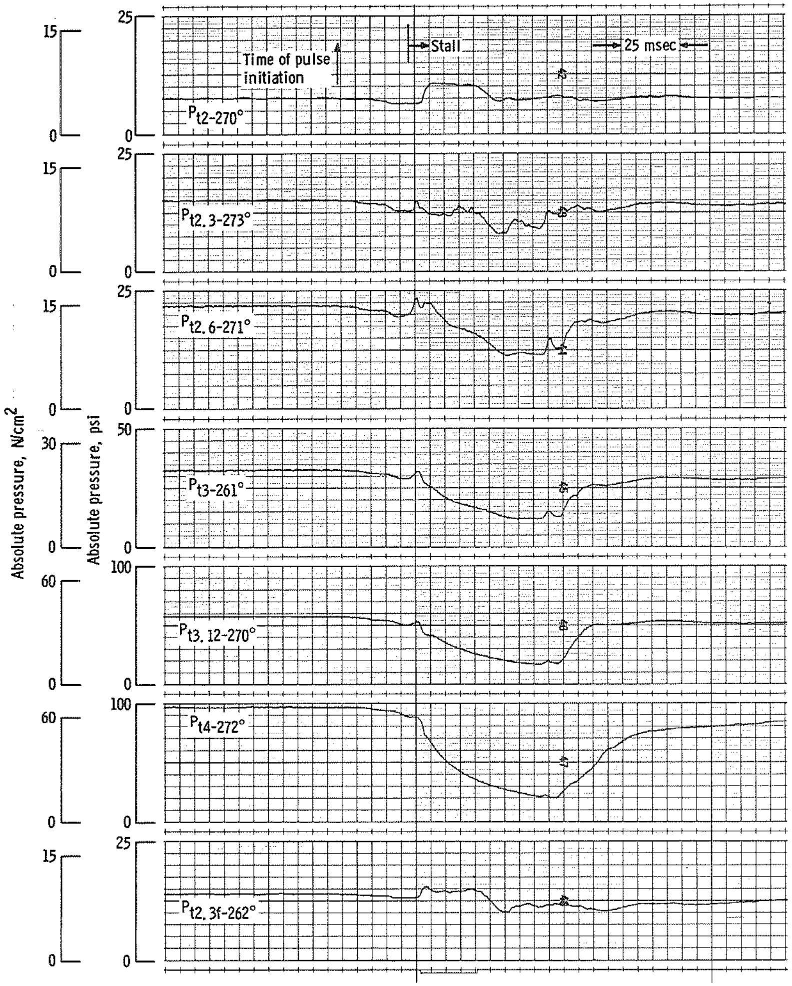
(b) Right-side pressures.



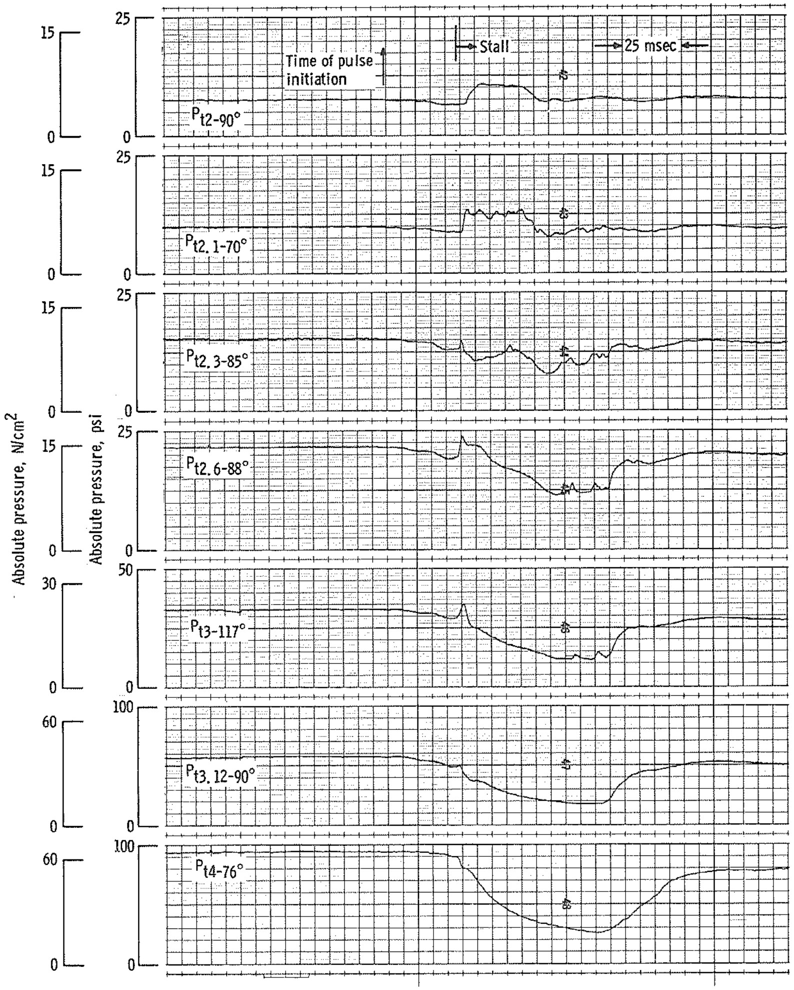
(c) Left-side pressure ratios.

(d) Right-side pressure ratios.

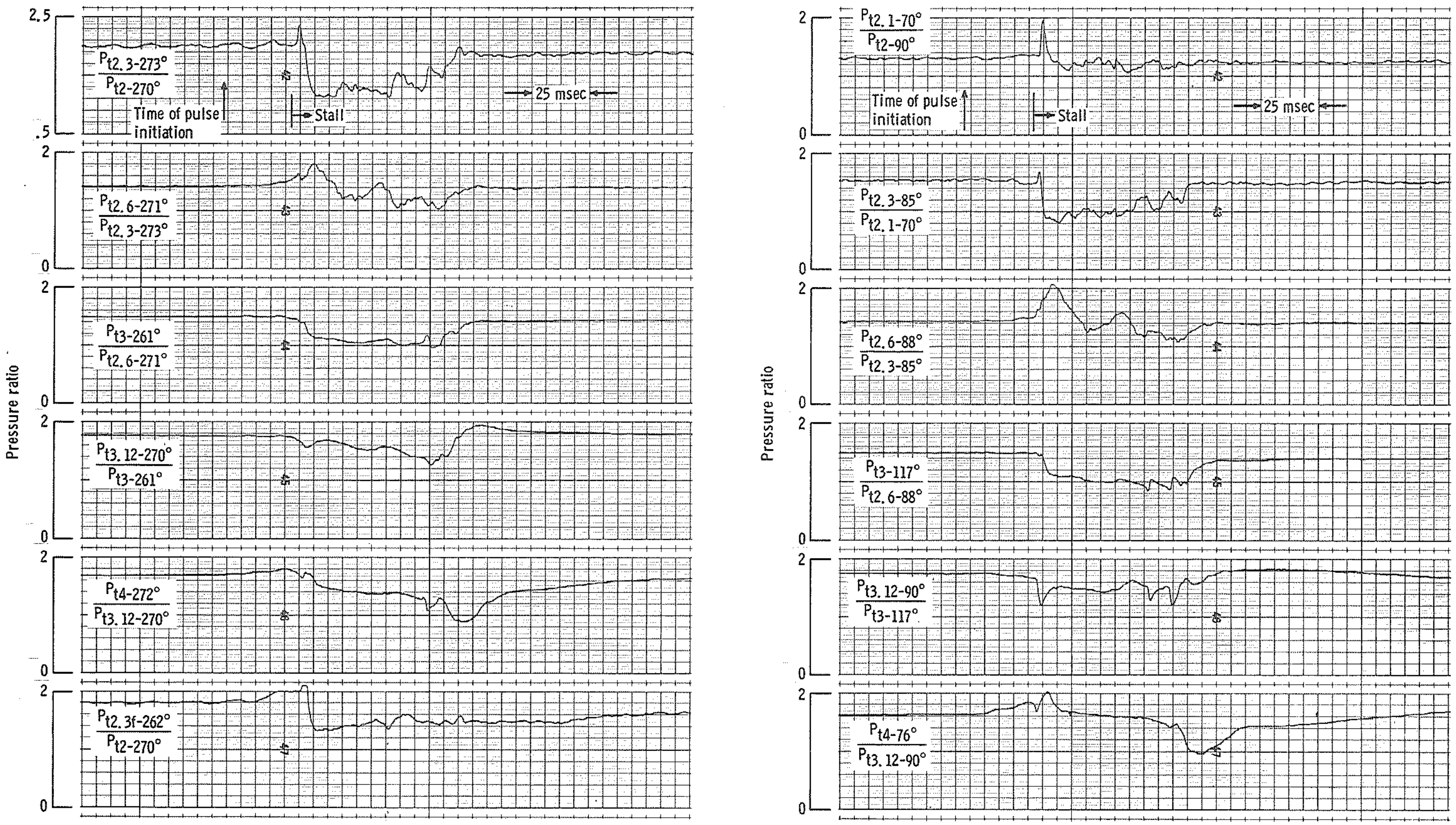
Figure 5. - Engine parameters during stall. Pulse duration, 15 milliseconds; distortion angle, 180°.



(a) Left-side pressures.



(b) Right-side pressures.



(c) Left-side pressure ratios.

(d) Right-side pressure ratios.

Figure 6. - Engine parameters during stall. Pulse duration, 15 milliseconds; distortion angle, 360°.

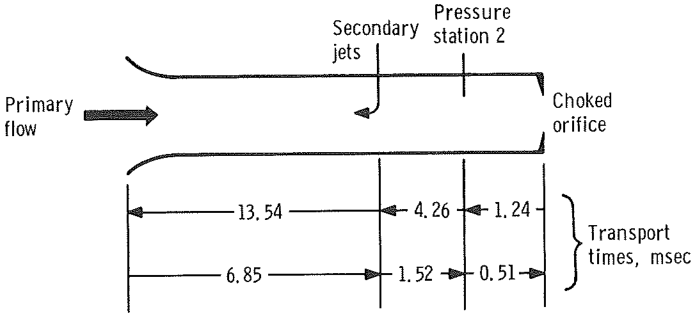


Figure 7. - Inlet duct configuration indicating pressure pulse transport times.

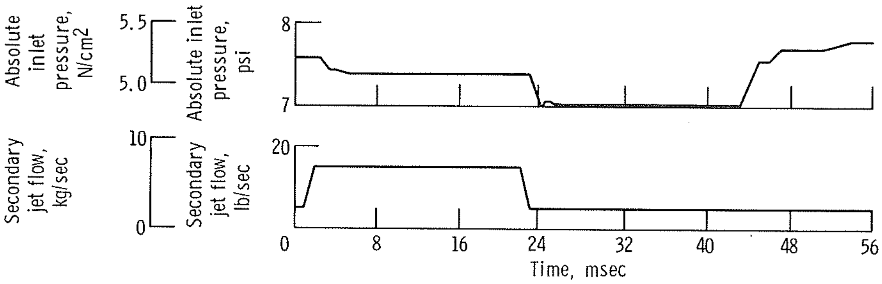
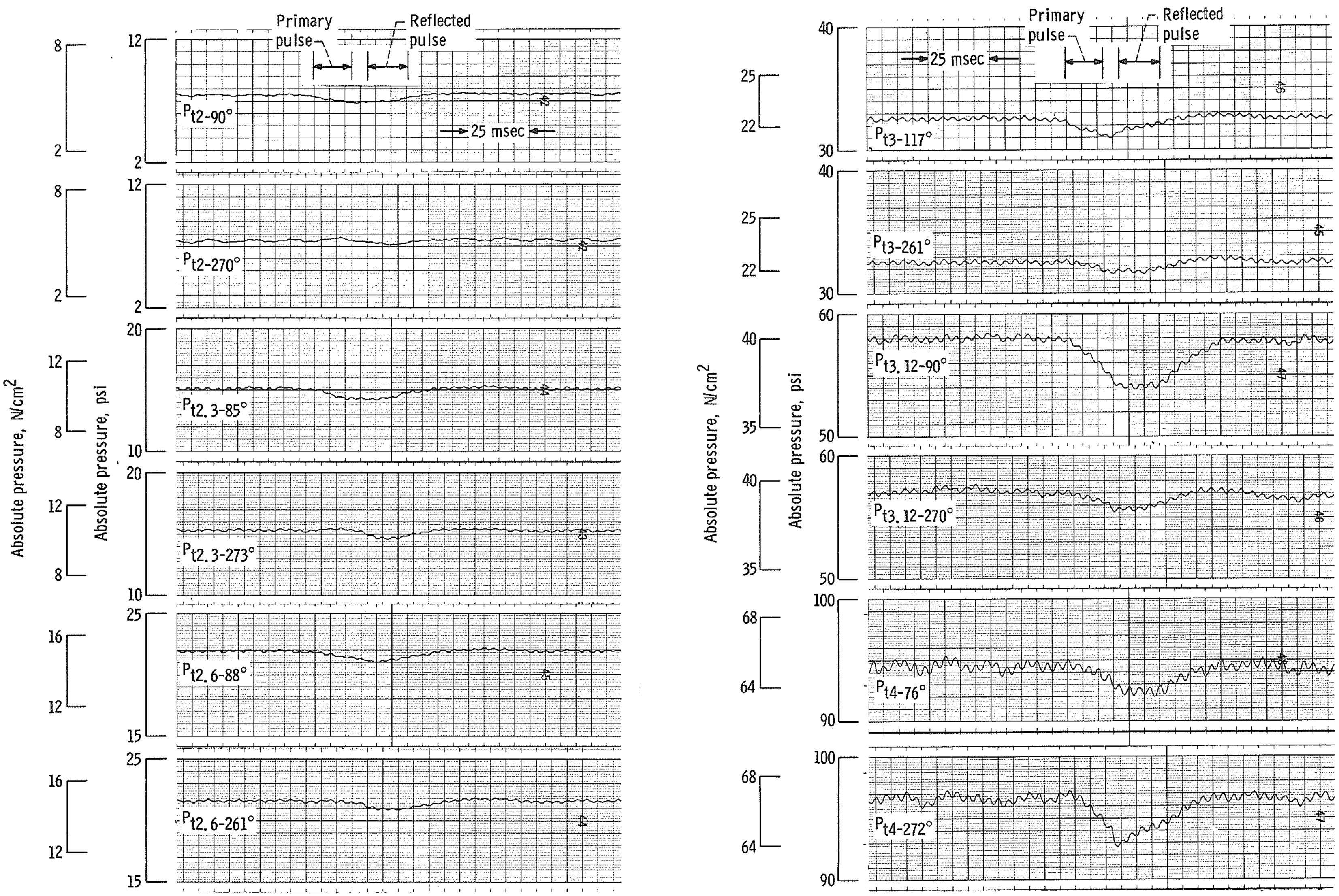


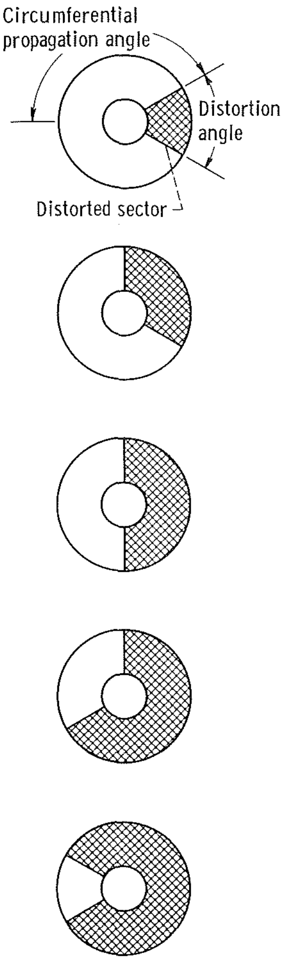
Figure 8. - Analytical inlet duct response calculated for jet flow pulse shown.



(a) Stations 2 to 2.6.

(b) Stations 3 to 4.

Figure 9. - Engine pressures for 15-millisecond, 120° pulse which did not effect stall.



Distortion angle, deg	Circumferential propagation angle, deg	Primary pulse first observed at left-side engine station-
60	150	3.12
120	90	3
180	90	3
240	30	2.6
300	30	2.6

Figure 10. - Summary of axial distance required for circumferential propagation, for various distortion angles.

NASA-Langley, 1969 —— 28

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546
OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AN
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Retur

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*
>
> —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546