AEROSPACE INFORMATION REPORT

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Assessment of the Inlet/Engine Total Temperature Distortion Problem

RATIONALE

The document in the current state is still relevant and does not contain any known errors or issues. The committee has agreed that future efforts could improve the document, but currently there is no immediate need to begin this work. The decision was made to submit this document for stabilization.

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1. SCOPE

This report revises ARD50015 document to the AIR format. This report, as was the original, is intended to complement ARP1420C and AIR1419C documents issued by the SAE S-16 Committee on spatial total-pressure distortion. These previous documents addressed only total-pressure distortion and excluded total temperature distortion.

The subject of inlet total temperature distortion is addressed in this report with some background and identification of the problem area. The status of past efforts is reviewed, and an attempt is made to define where we are today. Deficiencies, voids, and limitations in knowledge and test techniques for total temperature distortion are identified.

1.1 Purpose

Suggested approaches to fill these voids and a proposed total temperature distortion methodology are presented. Successful techniques, employed to date, are reviewed and recommendations for future research work are indicated.

1.2 Field of Application

Intake/engine aerodynamic compatibility continues to be a major interface operability consideration affecting the design and development of aircraft propulsion systems. Engine performance degradation, including power loss due to engine blowout and/or compressor instability, has been attributed to engine inlet total temperature distortion (time-variant spatial total temperature distortion and/or total temperature ramp at the Aerodynamic Interface Plane (AIP)). Reported inlet distortion sources include ingestion of gases from armament firings, ingestion of steam from catapult launch systems, ingestion of engine exhaust gases from thrust reverser systems, and ingestion of engine exhaust gases during helicopter and V/STOL aircraft operations.

System operability problems generally have been solved by avoiding or minimizing AIP total temperature variations by system configuration changes and/or operating procedure changes (reduced system operability) to remove the source of high-temperature gases from the capture region of the aircraft inlet system, or by engine accommodations to withstand the distortion. Total temperature distortion avoidance techniques are not practical for all systems. In order to properly account for and accommodate total temperature distortion, guidelines for understanding turbine engine response to and accounting for total temperature distortion are required.

A significant database that can be used as a start for the future formulation of recommended industry guidelines is reported. An inlet total temperature distortion problem assessment and status review, based on available data, are summarized in this report with suggestions for the development of practical guidelines.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

2.1.1.1 ARP1420 Gas Turbine Engine Inlet Flow Distortion Guidelines

2.1.1.2 AIR1419 Inlet Total-Pressure-Distortion Considerations for Gas-Turbine Engines

2.1.1.3 ARP246 Orientation of Engine Axis, Coordinate and Numbering Systems for Aircraft Gas Turbine Engines

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2.1.2 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

2.1.2.1 ASME (81-WA/FE-18) - Baghdadi, S. and Lueke, J. E., Compressor Stability Analysis, Detroit Diesel Allison/USAF APL, 1982.

2.1.2.2 ASME Paper No. 79-GT-10 - Lewis, W. J. and Hurd, R., Augmented Vectored Thrust Engines and the Problem of Avoiding Hot Gas Recirculation, March 1979.

2.1.2.3 ASME 82-GT-189 - Davis, M. W., Jr., A Stage-By-Stage Dual-Spool Compression System Modeling Technique, 1982.

2.1.3 AIAA Publications

Available from American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, Tel: 703-264-7500, www.aiaa.org.

2.1.3.1 AIAA-80-1246 - Walter, W. and Delany, J., Stability Analysis of YF401 Engine in a XFV-12 Aircraft, Pratt and Whitney/Rockwell International, July 1980.

2.1.3.2 AIAA 73-1316 - Braithwaite, W. M., Graber, E. J., and Mehalic, C. M., The Effects of Inlet Temperature and Pressure Distortion on Turbojet Performance, NASA., November 1973 (NASA TMX 71431).

2.1.3.3 AIAA 74-236 - Graber, E. J. and Braithwaite, W. M., Summary of Recent Investigations of Inlet Flow Distortion Effects on Engine Stability, NASA, February 1974.

2.1.3.4 AIAA 70-625 - Rudey, R. A. and Antl, R. J., The Effects of Inlet Temperature Distortion on the Performance of a Turbofan Engine Compressor System, NASA, June 1970.

2.1.3.5 AIAA 79-1310 - Walter, W. A. and Shaw, M., Predicted F100 Engine Response to Circumferential Pressure and Temperature Distortion, Pratt and Whitney, June 1979.

2.1.3.6 AIAA 82-1266 - Das, D. K., Trippi, A., and Peacock, R. E., Unsteady Response of an Axial Flow Compressor to Planar Temperature Transients, Cranfield Institute of Technology/U.S. Naval Post Graduate School, June 1982.

2.1.3.7 AIAA Journal of Aircraft - Amin, N. F. and Richards, C. J., Thrust Reverser Exhaust Plume Reingestion Model Tests, Vol. 21, No. 6, June 1984.

2.1.3.8 AIAA 79-1309 - Braithwaite, W. M. and Soeder, R. H., Combined Pressure and Temperature Distortion Effects on Internal Flow of a Turbofan Engine, June 1979.

2.1.4 U.S. Government Publications

Copies of these documents are available online at http://quicksearch.dla.mil.

2.1.4.1 AEDC-TR-79-39 - Chamblee, C. E., Application of the Multistage Axial Flow Compressor Time-Dependent Mathematical Modeling Technique to the TF41-A-1 Modified (Block 76) Compressor, September 1979.

2.1.4.2 AFAPL-TR-77-58 - Ludwig, G. R., Wind Tunnel Model Study of the Hot Exhaust Plume from the Compressor Research Facility at Wright Patterson Air Force Base, Ohio, October 1977 (also presented as ASME Paper No. 79-GT-186).

2.1.4.3 NACA RM E55E25 - Childs, H. J., Kichendorfer, F. D., Lubick, R. J., Friedman, R., Stall arid Flameout Resulting from Firing of Armament, NACA, August 1955.

2.1.4.4 NACA RM E57C22 - Wallner, L. E., Useller, J. W., and Saari, M. J., A Study of Temperature Transients at the Inlet of a Turbojet Engine, NACA, June 1957.

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Full document details: SAE AIR5867A

2.1.4.5 NACA TN 3766 - Glawe, G. E., Simmons, F. S., and Stickney, T. M., Radiation and Recovery Corrections and Time Constants of Several Chromel-Alumel Thermocouple Probes in High-Temperature, High-Velocity Gas Streams, NACA, October 1956.

2.1.4.6 MIL-E-5007D, Military Specification, Engines, Aircraft, Turbojet and Turbofan, General Specification for, Revised October 1973 (Paragraph 3.1.2.10.5, 3.1.2.10.6, 4.6.4.9).

2.1.4.7 NASA CR-134709 - Hambly, D., Wind Tunnel Test of Model Target Thrust Reversers for the Pratt and Whitney Aircraft JT8D-100 Series Engine Installed in a 727-200 Airplane, NASA/Boeing, September 1974.

2.1.4.8 NASA TM X-2990 - Mehalic, C. M. and Lottig, R. A., Steady-State Inlet Temperature Distortion Effects on the Stall Limits of a J85-GE-13 Turbojet Engine, NASA, February 1974.

2.1.4.9 NASA TM 79136 - Braithwaite, W. M. and Soeder, R. H., Combined Pressure and Temperature Distortion Effects on Internal Flow of a Turbofan Engine, NASA, June 1979 (AIAA 79-1306).

2.1.4.10 NASA TM 82699 - Abdelwahab, M., Effects of Fan Inlet Temperature Disturbances on the Stability of a Turbofan Engine, NASA, December 1981.

2.1.4.11 NASA TP 1031 - Abdelwahab, M., Effects of Temperature Transients at Fan Inlet of a Turbofan Engine, NASA, September 1977.

2.1.4.12 NASA TM X-2921 - Braithwaite, W. M., Experimental Evaluation of a TF30-P-3 Turbofan Engine in an Altitude Facility: Effect of Steady-State Temperature Distortion, NASA, 1974.

2.1.4.13 NASA TMX 52788 - Rudey, R. A. and Antl, R. J., The Effect of Inlet Temperature Distortion on the Performance of a Turbofan Engine Compressor System, June 1970.

2.1.4.14 NASA TM 79237 - Soeder, R. H. and Bobula, G. A., Effect of Steady-State Temperature Distortion and Combined Distortion on Inlet Flow to a Turbofan Engine, August 1979.

2.1.4.15 NASA CR-159754 - Walter, W. A. and Shaw, M., Distortion Analysis for F100(3) Engine, January 1980.

2.1.4.16 NASA CR-135124 - Mazzawy, R. S. and Banks, G. A., Circumferential Distortion Modeling of the TF30-P-3 Compression System (PWA-5448), January 1977.

2.1.4.17 NASA TP 1099 - Glawe, G. E. Holanda, R., and Krause, L. N., Recovery and Radiation Corrections and Time Constants of Several Sizes of Shielded and Unshielded Thermocouple Probes for Measuring Gas Temperature, NASA, 1978.

2.1.4.18 NASA TM 83748 - Klann, G. A., Barth, R. L., and Biesiadny, T. J., A Temperature Distortion Generator for Turboshaft Engine Testing, December 1984.

2.1.4.19 NASA TM 83765 - Biesiadny, T. J., Klann, G. A., and Little, J. K., Response of a Small Turboshaft Engine Compression System, September 1984.

2.1.4.20 NASA CR - 134978 - Tesch, W. A. and Steenken, W. G., Blade and Dynamic Digital Compressor Program - Volume 1 - J85 Clean Inlet Flow and Parallel Compressor Models, NASA, March 1976.

2.1.4.21 NASA CR - 135162 - Tesch, W. A., Moszee, R. H., and Steenken, W. G., Linearized Blade Row Compression Component Model - Stability and Frequency Response Analyses of a J85-13 Compressor, NASA, September 1976.

2.1.4.22 NASA TM 87317 - Biesiadny, T. J., Braithwaite, W. M., Soeder, R. H., and Abdelwahab, M., Summary of Investigations of Engine Response to Distorted Inlet Conditions, September 1986.

2.1.4.23 NASA TM 83771 - Soeder, R. H. and Mehalic, C. M., Effect of Combined Pressure and Temperature Distortion on High-Bypass-Ratio Turbofan Engine Stability, October 1984.

Documents
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Full document details: SAE AIR5867A

2.2 Applicable References

2.2.1 AGARD-LS-72 - Distortion Induced Engine Instability - Mokelke, H., Prediction Techniques, Motoren-und Turbinen-Union Munchen GmbH, Munich, Germany, November 1974.

2.2.2 AGARD-LS-72 - Distortion Induced Engine Instability - Hercock, R. G. and Williams, D. D., Aerodynamic Response (Paper 3), November 1974.

2.2.3 AGARD CP234 - Hercock, R. G., Effects of Intake Flow Distortion on Engine Stability (Paper 20).

2.2.4 AGARD CP-400 - Williams, D. D., Review of Current Knowledge on Engine Response to Distorted Inflow Conditions, presented at the 68th Propulsion and Energy Panel Specialist Meeting, September 1986.

2.2.5 NAPTC-PE-36 - Rich, W. A., TF34-GE-2 Rocket Gas Ingestion Test, NAPTC, May 1974.

2.2.6 NAPTC National Conference on Environmental Effects on Aircraft and Propulsion Systems - Mallett, W. E. and Parcells, R. F., Catapult Steam Ingestion Test of Three Turbofan Engines in the A-7 Aircraft, Vought Aeronautics Company, 1970.

2.2.7 NAPTC National Conference on Environmental Effects on Aircraft and Propulsion Systems - Tomassetti, N. R., Steam Ingestion by Aircraft Gas Turbine Engines, September 1967.

2.2.8 NAPTC National Conference on Environmental Effect on Aircraft and Propulsion Systems - Tomassetti, N. R. and Mink, G. R., Steam Ingestion by Aircraft Gas Turbine Engines II, October 1968.

2.2.9 AHS HPS-23 - Turezeniuk, B., Exhaust Gas Re-ingestion Measurements, November 1979.

2.2.10 Sikorsky - Jackson, M. E. and House, R. L., Exhaust Gas Re-ingestion During Hover In-Ground-Effect. Presented at the 37th Annual Forum of the American Helicopter Society, May 1981.

2.2.11 Temperature Measurement Handbook, Omega Engineering Inc., 1982.

2.2.12 PU-R1-78 - Brimelow, B. and Steenken, W. G., Compatibility Technology Requirements, presented at a Project Squid Workshop on Engine-Airframe Integration for Short-Haul Aircraft, Ed. S.N.B. Murthy, May 1977.

2.2.13 ISA Transactions, Vol. 24, No. 2, page 73 - Elmore, D. L. and Watkins, W. B. - Dynamic Gas Temperature Measurement System, 1985.

2.2.14 Soviet Aeronautics, Vol. 23, No. 1 - Khabibullin, M. G., Nesterov, E. D., and Akhtyamov, Z. V., Some Characteristics of Operation of TJE With Reverser During Airplane Landing, 1980.

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2.3 Definitions

AIP	Aerodynamic Interface Plane
AIR	SAE Aerospace Information Report
ARP	SAE Aerospace Recommended Practice
HGR	Hot Gas Re-ingestion
MPR	Circumferential Distortion Multiple-Per-Revolution Element
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
PCB	Plenum Chamber Burning
PR	Pressure Ratio
PR1	Pressure Ratio on Undistorted Stability Limit Line
PRDS	Pressure Ratio on Distorted Stability Limit Line
PRO	Operating Pressure Ratio
ΔPRS	Loss in Stability Pressure Ratio with Total Temperature Distortion
REGI	Rocket Exhaust Gas Ingestion
SMavailable	Stability Margin Available (PR1 - PRO)/PRO
ΔSM	Loss in Stability Margin
Ti	Indicated (measured) Temperature
Tt	Corrected Thermocouple Temperature
ΔT/T	(Tmax - Tmin)/Tave
ΔTC/T	Circumferential Distortion Intensity Element
ΔTR/T	Radial Distortion Intensity Element
ΔTRISE	The Total Temperature Rise at the AIP Over the Time of Interest
$\dot{\bar{T}}1$	Rate of Change of Average Total Temperature at AIP
$\dot{T}1$	Maximum Local Total Temperature Rise Rate
MAX$\Delta\bar{T}1$	Maximum Face-Average Total Temperature Rise
MAXΔTlocal	Maximum Local Total Temperature Rise
TC(θ)crit	The Minimum Circumferential Total Temperature Distortion Extent which, when Combined with a Given Total Temperature Ramp Rate, Will Cause Stall
V/STOL	Vertical/Short Takeoff and Landing
$Wa\sqrt{\theta_2}/\delta_2$	Corrected Airflow
δ_2	Pressure Ratio
θ_2	Temperature Ratio
θ+	Circumferential Distortion Extent Element

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3. CONCLUSIONS

Engine inlet total temperature distortion has required significant attention during the development of system operability for some aircraft systems.

System operability problems of past and current systems generally have been solved by total temperature distortion avoidance techniques. Where avoidance techniques are not practical, accommodation techniques at the expense of performance and/or operability are adopted.

Future aircraft-engine systems may require transient or sustained high engine power with inlet total temperature distortion; practices based on avoidance may not be adequate. Trade-off values for engine performance versus total temperature distortion tolerance are needed to maximize overall system performance.

An industry practice for the development of a total temperature distortion methodology and test assessment/verification guidelines is needed. SAE Committee S-16 can provide an effective forum for this development via the analysis and evaluation of state-of-the-art procedures and the coordination and integration of inlet total temperature distortion technology.

Combined spatial total temperature distortions and a total temperature ramp can be analyzed by assuming that spatial total temperature distortions degrade the stability limit line and a total temperature ramp raises the operating line. These effects are additive.

The effect of a total temperature ramp on the operating line can be estimated by a dynamic simulation with either stage-by-stage or lumped volumes. A stage-by-stage simulation is typically not required for the total temperature ramp rates associated with hot gas re-ingestion from exhaust systems.

The combined effects of total temperature and total pressure distortions depend on the relative orientation and intensity of the distortion patterns. Where significant total pressure and total temperature distortions occur together in a specific situation, a methodology for accounting for their combined effect on stability needs to be developed.

Spatial total temperature distortion indices analogous to the spatial total pressure distortion indices contained in ARP1420C have correlated engine data within the accepted ±2 units ΔPRS accuracy band. Additional data and analysis are needed before an SAE Aerospace Recommended Practice can be established.

During scale model testing for exhaust gas re-ingestion, not all scaling laws can be satisfied simultaneously. When far-field effects predominate, geometric and buoyancy scaling must be satisfied. When near-field effects predominate, as for V/STOL re-ingestion near the ground, geometric scaling and full-scale exhaust gas Mach number are required. There is an undetermined middle ground between the near-field and far-field modeling situations where neither scaling approach has been justified. Further experimental studies are required to resolve this area.

There are insufficient test data in the available literature to entirely substantiate the guideline procedures given in this report; additional effort is needed.

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4. INLET TOTAL TEMPERATURE DISTORTION PROBLEM ASSESSMENT

Conventional aircraft engine systems are based on configurations and/or operational procedures which are usually designed to avoid inlet total temperature distortion. Where avoidance is not possible, engine performance requirements are degraded as required to maintain control authority (avoid uncontrolled engine power loss).

a. Methods to Avoid/Minimize Engine Inlet Total Temperature Distortion

1. Design of armament system locations to avoid capture of armament gases by the engine inlet
2. Design of armament and armament launch methods to minimize the capture of armament gases
3. Design of steam catapult system to minimize leakage
4. Design of V/STOL aircraft and engines and engine thrust reversers to avoid/minimize exhaust gas re-ingestion
5. Establishment of mission/maneuver limitations to avoid/minimize armament gas/exhaust gas ingestion
6. Engine power management to limit reverser thrust at low aircraft Mach number to avoid/minimize engine exhaust gas ingestion

b. Methods Used to Accommodate Inlet Total Temperature Distortion

1. Engine power lever management during armament firing maneuvers to increase stability margin
2. Engine control schedule modification to reduce fuel flow/engine power during armament firing to increase stability margin
3. Engine control schedule modifications to compressor bleeds or variable stators during armament firings to increase stability margin
4. Engine control schedule modification to provide continuous ignition during armament firings to minimize the occurrence of sustained engine blowout/power loss
5. Engine/aircraft operating procedures during V/STOL operations to maintain inlet total temperature distortion within engine stability margin limits
6. Tradeoffs in engine performance to obtain an increased stability margin

When rotary-wing aircraft operate near the ground (i.e., in ground effect), engine exhaust can be contained by the rotor down wash and recirculated to the engine inlet. With vertical/short takeoff and landing (V/STOL) aircraft, the jet stream impinges on the ground, flows outward from the impingement points, and eventually reaches the engine inlet. This leads to hot gas ingestion. Other potential sources of inlet total temperature distortion are gun or rocket-exhaust gas ingestion, steam ingestion from carrier catapults, wakes from other aircraft, and backflow from the aircraft nacelle. Engine tests and flight tests are usually required to measure the magnitude and the effects of inlet total temperature distortion on an engine in question. Several mechanisms of hot gas recirculation are illustrated in Figure 1.

Some aircraft-engine systems require sustained high engine power with inlet total temperature distortion. Inlet total temperature distortion is assessed to be a potentially serious problem which requires resolution for the development of these propulsion systems. Stability margin allocations for defined inlet total temperature distortion conditions require quantification and test verification in the development of compressor stability assessment audits.

Results of inlet total temperature distortion investigations have shown that there is a significant effect on engine stability. Inlet spatial distortion is divided into circumferential and radial factors, with circumferential distortion described on a ring-by-ring basis in terms of intensity, extent, and multiple-per-revolution elements. Engines tested were less tolerant of circumferential total temperature distortion at a fixed operating condition as the extent of the distortion increased. Diametrically opposed total temperature distortion sectors had less effect on the compression system than single distorted sectors. The location of the engine-inlet total temperature sensor, used as a control input, can also have a significant effect on the response of the engine to total temperature distortion.

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Engine testing for operation with total temperature distortion, based on industry-accepted or government-specified test techniques, has not always been required. The decision to address total temperature distortion testing is often based on program risk assessments, test cost estimates, and the lack of established inlet total temperature distortion testing techniques which are realistic and meaningful relative to the projected aircraft-engine mission usage. Evaluation of the effects of inlet total temperature distortion on engine performance and stability historically has often been based on analytical (math model) assessments.

The operability demands of some aircraft-engine systems result in the assessment that inlet total temperature distortion is a major factor in stability assessment audits. The need exists to establish recognized industry practices and procedures.

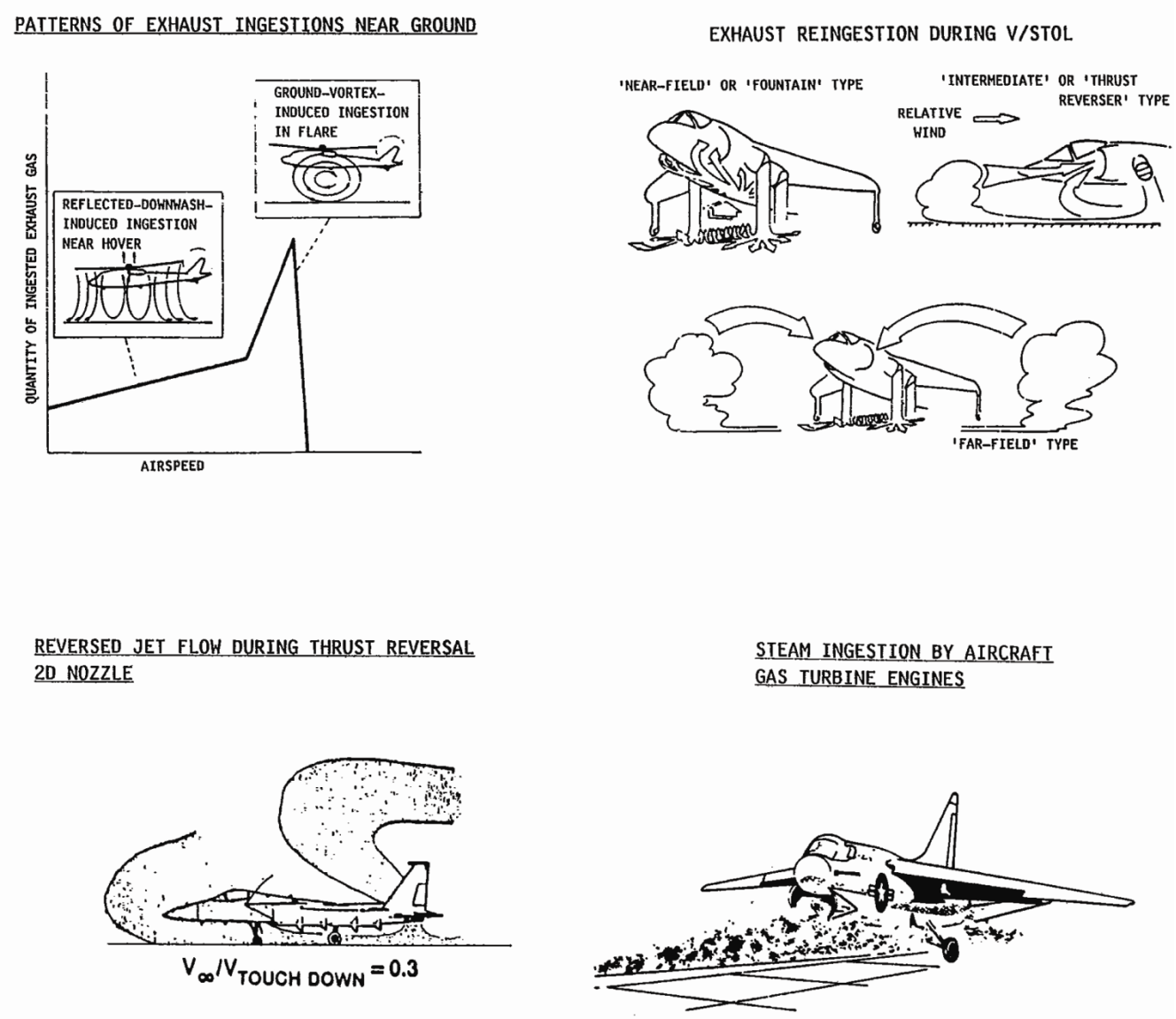

Figure 1 - Hot gas recirculation mechanisms

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5. STATUS OF PAST AND PRESENT EFFORTS

This section summarizes work done to investigate and understand the nature of adverse engine inlet total temperature conditions on gas turbine engines. The adverse condition takes the form of a sudden increase in inlet total temperature as in the case of rocket exhaust gas ingestion or inlet total temperature distortion encountered in V/STOL operation. A combination of the total temperature ramp and total temperature distortion is experienced during a catapult launch in which steam is ingested by the engine, and also during a vertical landing by a V/STOL aircraft. The following paragraphs review the cause and effect of these total temperature disturbances, test techniques used in their evaluation, solutions to some of the problems, and various mathematical models developed in an attempt to understand and predict the behavior of engines subjected to total temperature distortion.

This background information leads to the methodology proposed for analyzing combined total temperature distortion and total temperature ramps in Section 6. If the approach of Section 6 differs from the analysis contained in a reference, then the rationale for the new approach is discussed.

Although total temperature distortion caused several known aircraft incidents, it had not been examined except for a few investigations in the 1950s. In the 1960s, higher speed aircraft encountered stability problems not predicted by the available analytical models. At that time, it was thought desirable to investigate the effect of nonuniform inlet total temperature on engine stability. In the mid-1960s, investigations of engine stability and inlet flow distortion resumed. Prime interest was in time-variant total pressure distortion and both steady-state and time-variant total temperature distortion. Results of these investigations were incorporated into analytical models and thus provided a base for a better understanding of the effects of total temperature distortion.

Devices to create steady-state and time-variant inlet total temperature and total pressure distortions and combined total temperature and total pressure distortions were required to simulate the inlet flow distortion that occurs in the operational environment. Total temperature distortions were created by using hydrogen-fueled total temperature distortion generators or hot-air injection systems.

5.1 Spatial Total Temperature Distortion

The sources of total temperature distortion that are of concern include weapons wake ingestion, V/STOL hot gas re-ingestion, thrust reverser exhaust ingestion, and steam ingestion. Although different in detail than total pressure distortion, the average effect on the compressor map is basically the same. The overall result is a reduction in stability margin.

Helicopter flight tests were conducted with a CH-47 and YUH-61A (Reference 2.2.9) to determine the effect of re-ingesting hot exhaust gases. Inlet total temperatures of 610 °R were reached along with a total temperature distortion of $\Delta TC/T$ = 0.11. Hot gas ingestion resulted in a decrease in horsepower; severe total temperature distortion resulted in a recoverable stall (surge). Understanding of re-ingestion during hover was gained by testing a 1/15th scale model (Reference 2.2.10). Primary design variables were nozzle area, inboard blade geometry, and engine location. Based on these tests, an optimum design was chosen for full-scale production aircraft. Another helicopter engine subjected to total temperature distortion was the T700 (Reference 2.1.4.19). Part of the test consisted of placing the engine inlet total temperature sensor at various locations. When the inlet total temperature sensor detects either the cold or hot part of the distorted flow, the control will adjust fuel flow and variable geometry accordingly and change the compressor stability margin differently than if the sensor detects the average inlet total temperature. Therefore, the location of the sensor(s) is important to engine stability and to the analysis of total temperature distortion.

Hot gas re-ingestion in the Harrier (AV-8B) V/STOL aircraft is within the tolerance of the compression system, consequently this aircraft does not have a flow stability problem during operations in ground effect. The proposed use of plenum chamber burning in the engine front nozzles will increase the total temperature of any ingested gas. The airframe and engine manufacturers have conducted rig and full-scale tests of various nozzle, inlet, and mechanical deflector designs in an attempt to reduce the levels of gas re-ingestion (Reference 2.1.2.2).

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Test data on a J85 turbojet (Reference 2.1.4.8) includes both circumferential and radial total temperature distortions. Sufficient information is available to define the loss in stability pressure ratio (ΔPRS) and total temperature distortion descriptors (12 total temperature rakes with five probes per rake). This information is useful for checking out a proposed distortion descriptor. Other test data are available for an Allison compressor (Reference 2.1.2.1), the TF30 turbofan engine (References 2.1.3.3, 2.1.4.11, 2.1.4.12, 2.1.3.8, and 2.1.4.14), another turbofan engine (Reference 2.1.4.13), and the T700 turboshaft engine (Reference 2.1.4.18). Results of the TF30 engine tests, where square-wave distortion patterns of 90, 180, and 270° were impressed on the engine, showed stall occurred with 14 to 20% ΔT/T total temperature distortions. Total temperature distortion patterns are angularly displaced in the direction of rotor rotation as they move through the engine; they tend to follow the particle path. Rotation of the distortion pattern was also observed during J85 engine testing with a 180° pattern.

5.2 Total Temperature Ramps

Significant total temperature ramps at the engine inlet can be induced by rocket exhaust-gas ingestion (REGI), by gun gas ingestion, by exhaust gas re-ingestion in helicopters and V/STOL aircraft, and by steam ingestion during catapult launch in naval aircraft.

Total temperature ramps are always accompanied by some amount of spatial total temperature distortion. The question then becomes: Are there occasions when total temperature ramps are the predominant cause of engine stall? The literature indicates the following condition in Table 1 when it is the primary cause:

Table 1 – Importance of temperature ramps

Condition	Importance of Total Temperature Ramps
Rocket Gas Ingestion Gun Gas Ingestion	Predominant Effect
Engine Exhaust Gas Re-ingestion Steam Ingestion	Secondary Effect

5.3 Laboratory Test Data

Total temperature distortion patterns and total temperature ramps have usually been produced by hydrogen-fueled total temperature distortion generators, schematically shown in Figure 2.

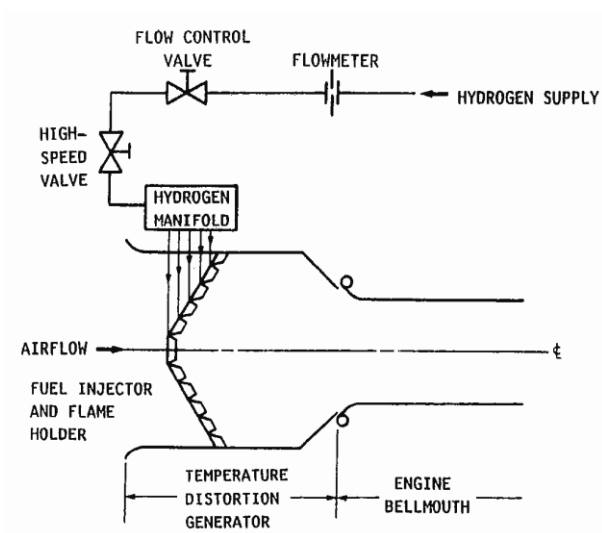

Figure 2 - Hydrogen-fueled total temperature distortion generator

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The gaseous hydrogen burner is installed upstream of the inlet bellmouth. The burner can be remotely rotated 30° in either direction from center position to map the distortion by rotating the distortion pattern past engine instrumentation. Each of the four individually controlled burner quadrants used to set the distortion pattern circumferential extent has five swirl-can pilot burners, an ignition source for the hydrogen, five annular flameholder gutters (individually controlled to set the distortion pattern radial extent), one radial gutter, and tubes to supply hydrogen to the proper location for ignition. For steady-state distortions, the valves for the quadrants of interest are opened slowly until the desired total temperature level is reached at the engine inlet. For time-variant total temperature distortions, a trapped volume of high-pressure hydrogen is released through the high-speed valve to the desired quadrants and flameholder gutters. Rise rate and magnitude of the total temperature transient are functions of the pressure and volume of the trapped hydrogen.

A large amount of published engine test data exists, which demonstrates that pure total temperature ramps with rates on the order of 2000 to 10000 °R/s can induce engine stall or combustor blow-out (References 2.1.4.4, 2.1.4.11, and 2.1.4.13). References 2.1.2.3 and 2.1.4.22 are comprehensive distortion-effects survey papers, which include summaries of available total temperature ramp data.

Total temperature ramp data have generally been correlated in the format of total temperature rise versus total temperature ramp rate. The data in Figure 3 (taken from Reference 2.1.4.10) imply that the engine will be stable for total temperature ramp rates below the threshold rate. However, the characteristics of the total temperature distortion generator are such that low ramp rates also produce low total temperature rise, so there is really no quantitative stability information below the threshold ramp rate. The ramp rate of interest for V/STOL operation ranges from 7 to 15% of the threshold rate so this form of data analysis may not be suitable for V/STOL applications.

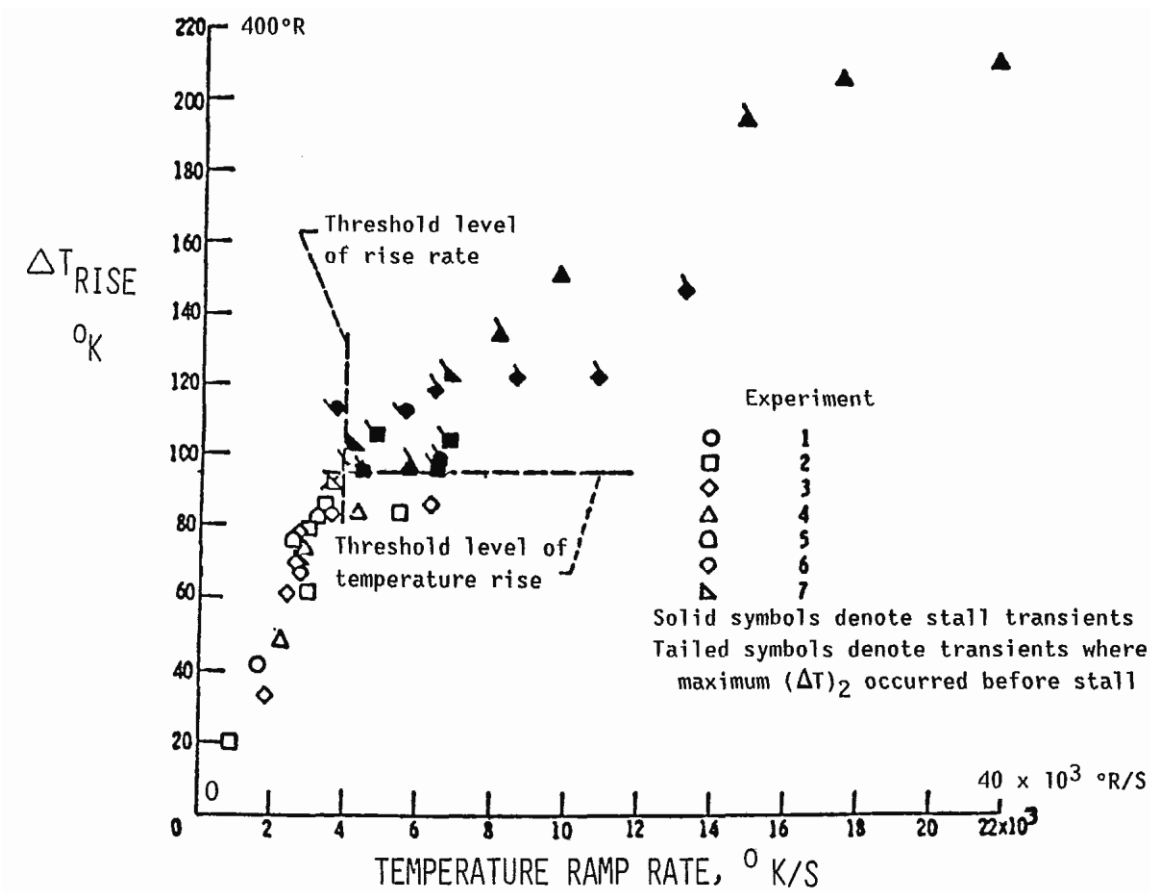

Figure 3 – Total temperature ramp data expressed as total temperature rise versus total temperature ramp rate

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Data above the threshold level of rise rate imply that higher ramp rates have less effect on flow stability because an engine can tolerate a higher level of total temperature rise as ramp rate increases. References 2.1.4.10 and 2.1.4.11 conclude that this is a false trend due to the total temperature at the AIP increasing during the time for the total temperature rise to reach the stalling stage and for the stall to propagate to the detection location. These references conclude that the total temperature rise at the stage that initiates stall is independent of ramp rate.

Data from all existing total temperature ramp generators show an appreciable spatial distortion during the ramp. The destabilizing effect of this spatial distortion is not included in the analysis of References 2.1.4.10 and 2.1.4.11.

In an effort to overcome the inadequacies of the method of References 2.1.4.10 and 2.1.4.11, the procedure proposed in Section 3 and Appendix B defines the engine sensitivity to steady-state spatial total temperature distortion, evaluates the loss in stability pressure ratio due to the transient spatial total temperature distortion measured during a ramp using this same sensitivity, and estimates the increase in operating line due to a total temperature ramp. The loss in stability margin due to spatial distortion and a total temperature ramp are added linearly. Data analyzed by this procedure show increasing loss in stability margin as ramp rate increases.

5.4 Flight Test Data

Rocket-gas and gun-gas ingestion have induced engine stall or combustor blow-out on some combat aircraft. Weapons gas ingestion is always a concern when establishing rocket launcher and gun locations during the initial design phase of a new aircraft. Avoidance has historically proved the most cost effective and practical means of solving this problem.

For example, one of the earliest cases where weapons gas ingestion caused significant engine stall problems occurred during the 1950s on the F-86 and F-94C aircraft, as reported by NACA in Reference 2.1.4.3. It was concluded that the total temperature ramp rate alone was enough to stall the engine. The paper recommended moving the cannon source away from the inlet.

The effects of exhaust-gas re-ingestion on the CH-47 helicopter engine (T55) are reported in Reference 2.2.9. No engine stalls were encountered during these tests, but significant exhaust gas re-ingestion did occur. The fastest observed instantaneous total temperature rise rate was 360 °R/s, which is significantly below the typical threshold rates required for engine stall, as determined on other engines. Although engine stall did not occur, significant spatial total temperature distortion was recorded. For the case of exhaust gas re-ingestion, it was concluded that the total temperature ramp is a secondary effect.

During the late 1960s, A-7A aircraft equipped with TF30-P-6 engines encountered steam-ingestion-induced engine stalls during catapult launch, as reported in Reference 2.2.7. This paper concluded that spatial inlet total temperature distortion was the major contributor; the problem was not a total temperature ramp as in the case of rocket-gas ingestion. An avoidance technique (the catapult system was sealed) helped solve this problem.

Full-scale tests in the UK focused on hot-gas re-ingestion (HGR) aspects of STOVL aircraft (Reference 2.2.4), where avoidance techniques were investigated. HGR characteristics are defined in terms of AIP mean total temperature rise and time-variant spatial distortion during dynamic landing maneuvers, using a tethered Harrier aircraft. Maximum total temperature measurements with hot-gas re-ingestion are shown in Figure 4. Mean total temperature rise rates lie in the range of 300 to 600 K/s (540 to 1080 °R/s) with maximum local rates being in the range of 1000 to 1500 K/s (1800 to 2700 °R/s). Engine entry total temperature increases up to 150 K (270 °R) can occur transiently with maximum local total temperature rises being about 200 K (360 °R).

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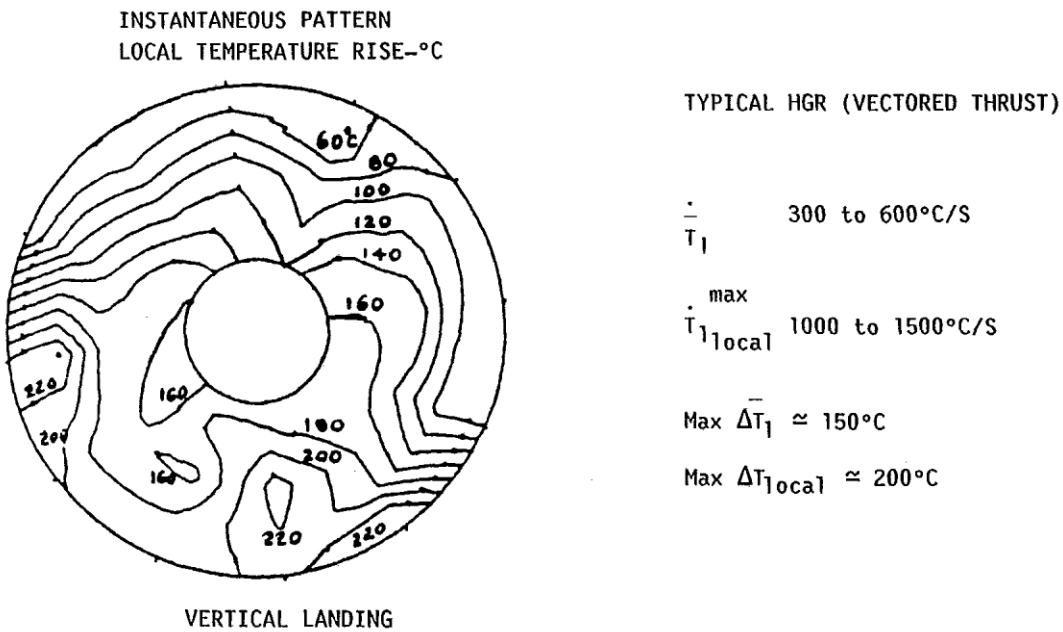

Figure 4 - Typical total temperature measurements with hot gas re-ingestion

Configurations designed to minimize HGR were investigated and engine tolerance to total temperature distortion was evaluated. Results indicated that engine distortion response depends both on the time-rate-of-change of intake mean total temperature as well as spatial distortion. The reduction in tolerance to spatial total temperature distortion as total temperature ramp rate increases can be seen in Figure 5. Data from both the Pegasus plenum chamber burning (PCB) engine and the TF30-P-3 engine (References 2.1.4.11 and 2.1.4.12) show that there is very little loss in spatial total temperature distortion tolerance due to the 300 to 600 K/s (540 to 1080 °R/s) ramp rates experienced with V/STOL applications.

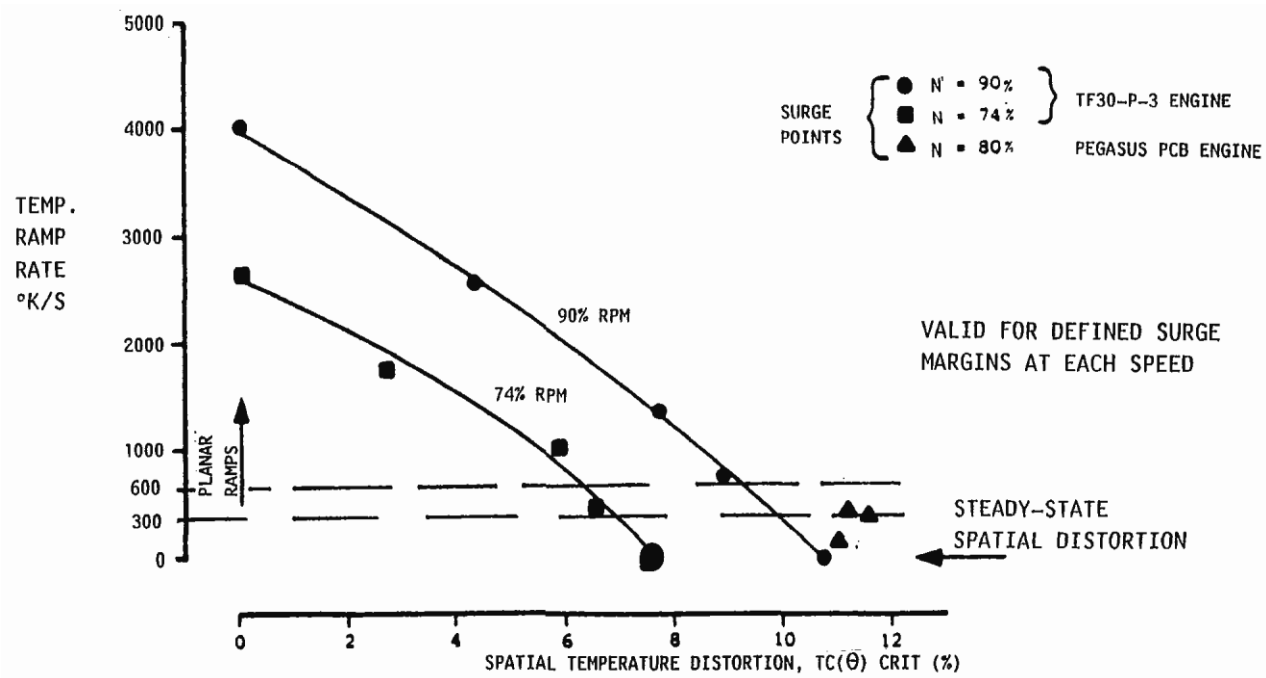

Figure 5 - Reduction in spatial total temperature distortion tolerance due to a total temperature ramp

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5.5 Combined Total Pressure and Total Temperature Distortion

Total temperature distortion encountered during aircraft operations may be accompanied by total pressure distortion. While little experimental work has been done on combined time-variant total pressure and total temperature distortions, investigations have been carried out to examine the effects of combined steady-state total pressure and total temperature distortion on engine stability. Devices to generate combined inlet total temperature and total pressure distortion patterns have been developed and used successfully in conjunction with turbojet, turbofan, and turboshaft engines. Tests using these devices have verified that inlet total temperature distortion does not create inlet total pressure distortion and, conversely, inlet total pressure distortion does not produce inlet total temperature distortion.

Tests have been conducted on turbojet (J85) and turbofan (TF30, TF34) engines to investigate the effect of combined total temperature and total pressure distortion on engine behavior. The total temperature distortion patterns (180° extent square wave) were generated using a gaseous hydrogen burner upstream of the engine inlet, while 180° extent total pressure distortions were screen generated. The effect of the combined distortions on stability was determined by reducing exhaust nozzle area until stall occurred in the case of the J85, while with the TF30 and TF34, the magnitude of the total temperature distortion was slowly increased until stall was reached. The effects of the relative position of the distortions were also investigated: The heated section was rotated relative to a fixed screen with the J85, whereas with the TF30 and TF34, the screen could be indexed independently of the heated section.

The loss in stability pressure ratio due to the combined distortions is dependent on the orientation of the high total temperature and low total pressure regions. The largest stability pressure ratio loss resulted when high total temperature and low total pressure regions coincided while diametrically opposed distortions had the smallest effect on stability pressure ratio loss (References 2.1.3.2, 2.1.3.8, and 2.1.4.23). The tests also revealed that total temperature distortion, unlike total pressure distortion which creates total temperature distortion as it is attenuated in passing through the compression system, is not greatly attenuated as it moves through the compression system. In the TF30 tests, total pressure distortions of 9% at the compressor inlet were attenuated to 1% at the compressor exit, while total temperature distortions of 9% at the compressor inlet resulted in total temperature distortion levels of 7% at the compressor exit.

It should be noted that the major portion of combined total temperature and total pressure distortion data that have been acquired has been used to develop and validate analytical engine models. Several such models have been developed by engine manufacturers for turbojet and low and high bypass ratio turbofan engines.

5.6 Computer Simulation of Engine Response

The cost of ground testing (rig, wind-tunnel, engine) and flight testing has led to a further need to improve prediction methods to provide reliable assessments of compatibility problems and anticipate solutions earlier in the design phase of a project. Analytical computer simulations or models have been developed to predict the effects of inlet flow distortion on gas turbine engine stability and performance. These computer models are necessary to understand such effects, and to extend and augment data acquired during engine testing under distorted inlet conditions in ground or altitude chamber test facilities to conditions not tested. Analytical engine simulations are used for stability assessments at critical flight conditions, where the inlet conditions are known from model- and/or full-scale inlet testing, and to predict stall recovery characteristics.

The analytical simulations developed employ a wide variety of techniques to satisfy the unique operating requirements for a specific engine; however, there are some characteristics these computer models share. These simulations use parallel compressor theory which assumes a compressor can be separated into a discrete number of parallel flow paths, each operating at the same mechanical speed, but with different inlet total pressure and total temperature. Each segment may operate at a different corrected speed, operating condition, and stability margin while maintaining a given exit static pressure. Other assumptions to aerodynamically link the parallel compressor segments can also be utilized. These are based on the available compression system rig test data or upon prior simulation or test experience. Rig or engine test data are required to ensure correlation between computer model and engine results.

Both steady-state and transient computer models employing this theory have been developed and show excellent agreement with measured data. Simulations have been developed for the J85 (References 2.1.4.20 and 2.1.4.21), TF30 (Reference 2.1.4.16), and F100 engines (Reference 2.1.4.15). Results published in the open literature show good agreement between computer predicted and experimental values for both inlet total pressure and total temperature distortion, and for total temperature ramps.

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Computer programs for simulating the transient engine response to inlet distortions have also been developed to run in a real-time environment. These simulations are extremely useful for variable geometry scheduling and fuel control development work under distorted inlet conditions.

More complicated computer models employ individual blade row simulations for each stage of multistage compressors. These computer models have been largely limited to axial-flow compressors, but attempts at modeling compression systems containing centrifugal compressors have been made. Although work continues with these more complicated computer models, good agreement has been achieved in some cases. For instance, computer predictions indicated that stall would initiate in the first stage of a multistage axial flow compressor subjected to a severe inlet total temperature ramp; this prediction was later validated by test. Another computer model was able to predict the total temperature distortion stability limit for an engine in terms of the typical total-temperature-rise, total-temperature-rate correlation format.

In summary, analytical computer models are an industry accepted method of predicting the effects of inlet flow distortion on engine stability and performance and are widely used by turbine engine manufacturers. These simulations are very useful for evaluating stability margin requirements for new engines and applications, and for defining acceleration fuel flow, bleed, and geometry scheduling to ensure engine responsiveness and stability under both clean and distorted inlet flow conditions. Other uses for these analytical computer models include evaluating the compression system performance characteristics required for distortion-tolerant engine design, i.e., to explore compressor speed line shape and the relative locations of peak efficiency and stall.

6. SUGGESTED APPROACH TO A TOTAL TEMPERATURE DISTORTION METHODOLOGY

Information currently available enables propulsion engineers to develop definitions, construct a sample format, and formulate guidelines for dealing with total temperature distortion. The format chosen for spatial total temperature distortion parallels that of ARP1420C on total pressure distortion as it is a convenient reference system and it correlates the limited data available. The distortion methodology outlined in this report applies to inlet total temperature distortion and total temperature ramps. Guidelines to quantify these effects are developing, and therefore, periodic updates are anticipated. The effects of combined total pressure and total temperature distortions on engine stability and performance were addressed briefly with regard to test techniques, but are not treated by this methodology.

These guidelines can be used to create a method to minimize the risk of engine instability induced by total temperature distortion. The degree to which the guidelines for descriptor use, assessment techniques, and testing are applied to a specific program should be consistent with the expected severity of the compatibility problem.

Guidelines are provided to:

a. Identify the inlet/engine aerodynamic interface plane (AIP)

b. Express spatial inlet total temperature distortion in terms of numerical distortion descriptor elements

c. Provide an empirical correlation technique for translating distortion descriptors into parameters suitable for stability and performance assessments

d. Express total temperature ramps in terms of the time variation of the face-average inlet total temperature

e. Evaluate the effect on flow stability of the combination of spatial total temperature distortion and a total temperature ramp

f. Quantify engine compressor stability margins

g. Conduct assessments to quantify the effects of inlet total temperature distortion on engine stability

h. Provide a total temperature distortion procedure to identify potentially critical stability conditions

i. Define both airframe and engine tests to evaluate propulsion system stability and to develop a database for stability and performance assessments

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