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Gas Turbine Engine Real Time Performance Model Presentation for Digital Computers

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) provides guidance for the presentation of gas turbine engine transient performance models with the capacity to be implemented as digital computer programs operating in real time and is intended to complement AS681.

Such models will be used in those applications where a transient program must interface with physical systems. These applications are characterized by the requirement for real time transient response.

These models require attention to unique characteristics that are beyond the scope of AS681. This document is intended to facilitate the development of mathematical models and the coordination of their requirements with the user. It will not unduly restrict the modeling methodology used by the supplier.

The objective of this document is to define a recommended practice for the delivery of mathematical models intended for real time use. Models used in this application may also be contained in deliverable computer programs covered by AS681.

1.1 Mathematical Model Presentation:

The presentation of mathematical models can include, but is not limited to, the following:

a. Executable computer programs
b. Program listings
c. Block diagrams
d. Tabular data
e. Plotted data

A description of the model will be included in the Model Implementation Guide (6.2, Items 4 and 10).

1.2 Applications:

The applications of real time engine models include, but are not limited to, the following:

a. Flight simulators
b. Avionic and control system development
c. Control system embedded software

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Standards (AS) shall apply.

AS681	Gas Turbine Engine Steady State Performance Presentation for Digital Computer Programs
AS755	Gas Turbine Engine Performance Station Identification and Nomenclature

2.2 Definitions:

Terms used in this document are defined below:

REAL TIME PROGRAMS: This phrase describes transient performance computer programs whose outputs are generated at a rate at least as fast as the physical system represented.

ENGINE MODEL: A mathematical representation of a gas turbine engine which accepts as its inputs the controlled variables of the system.

CONTROL SYSTEM MODEL: A mathematical representation of the control system which may include sensors, controllers, and actuators.

ENGINE/CONTROL MODEL: A mathematical representation of the system resulting from the combination of the engine and its control system.

TARGET COMPUTER: A computing system on which the real time program is to execute.

MODEL TIME STEP: A time increment used in the model, for example, in a numerical integration algorithm. Note that for some models different time steps are used in various elements of the model.

PROGRAM EXECUTION TIME: The time required for a real time program to complete all calculations for a given time step for a given computer and operating system. Real time operation requires that the program execution time for a model element be smaller than the time step for that element.

REFERENCE DATA BASE: A collection of empirical and/or analytical data from which the model is derived and to which model output may be compared. If required, data may be a collection of flight/ground test cases.

3. MODEL REQUIREMENTS:

3.1 General Requirement:

The real time model will be representative of the engine or engine/control system described in the Model Implementation Guide (6.2, Item 3).

3.2 Structure:

The model's structure will facilitate its implementation on the target computer system and will be coordinated between the user and supplier. Information regarding implementation should be included in the Model Implementation Guide (6.2, Item 7).

3.3 Dynamic Response:

The model is intended to provide for the prediction of engine transient response to time-varying inputs. A minimum requirement for the model is the ability to simulate, in a numerically stable fashion, the effects of normal throttle, load and mission profile transients (including start and shut down).

3.4 Numerical Stability:

A model can produce divergent or oscillatory response in its outputs if the model time step is increased beyond a certain value. The model supplier will determine this value and should include it in the Model Implementation Guide (6.2, Item 9).

3.5 Numerical Accuracy:

The supplier will determine the effect of the model time step on the accuracy of the model outputs. This information should be included in the Model Implementation Guide (6.2, Item 9).

3.6 Validity:

The boundaries, both functional and parametric, within which the model is valid should be described in the Model Implementation Guide (6.2, Item 9).

3.7 Consistency:

Consistency herein means the agreement between model outputs and the reference data base. Consistency criteria may include transient event times, small signal and large disturbance response, and steady state results. Consistency requirements vary significantly and depend upon the specific application of a real time model. The coordination of model consistency is a key element of real time model delivery (5.4). Data documenting the model's consistency should be included in the Model Implementation Guide (6.2, Item 9).

3.8 Engine Limits:

Design limits on engine performance should not be included as limits in the engine model (e.g., "redline" rotor speeds, maximum burner pressure). Software indicators ("flags") may be included to alert the user to design exceedance conditions. The control system model may include these limits where appropriate.

3.9 Power Definition:

One of the inputs to the control system model will be power setting demand. When possible, the inputs to the control system model for the particular application, such as power lever angle (PLA) or collective pitch, should be used in place of an arbitrary numerical description, such as power code (PC) or rating code (RC).

3.10 Station Identification:

The numbering system described in AS755 should be used in the real time model to identify the stations in the gas flow path that are significant to the model. The station numbering system used should be documented in the Model Implementation Guide (6.2, Item 5).

3.11 Nomenclature:

The list of symbols contained in AS755 should be used for identification of appropriate parameters in the model. In defining the labels used for interfaces with external systems, the supplier should attempt to meet the commonality standards established by AS755. Nomenclature documentation should be included in the Model Implementation Guide (6.2, Items 5 and 6).

3.12 Initialization:

The requirements for initialization of a model should be carefully coordinated between supplier and user. The supplier will define all parameters for which initial values are required. These are values that must be present prior to the initial execution of the model.

4. MODEL OPTIONS:

4.1 Coordination:

Provisions for the effects described in this section may be negotiated where appropriate. Coordination of these capabilities between user and supplier is particularly important in real time models since memory requirements and execution time can be limiting factors in the use of the program.

4.2 Environmental and Flight Conditions:

The model should accept environmental and flight condition inputs (e.g, engine face total pressure and temperature, ambient pressure and temperature, angle of attack, side slip angle).

4.3 Customer Services:

The model should accurately represent performance when air bleed and power are extracted for customer services.

4.4 Engine Anti-Icing System:

The model should have the capability of representing engine performance with anti-icing systems both on and off.

4.5 Subidle Operation:

The model should produce representative outputs for starting, windmilling, relight, and shutdown transients.

4.6 Thrust Generation:

If the supplier provides or has the primary responsibility for the performance of an engine thrust producing system (e.g., vectoring nozzles, reversers, propellors), then the model should represent this system.

4.7 Variable Geometry:

If the engine represented by the model incorporates variable geometry features, then the model should reflect the effects on engine performance attributed to the variable geometry setting(s).

4.8 External Loads:

If the engine represented by the model is connected to an external load mechanism (e.g., generator, propellor, rotor), then the model should allow for the effects of the load on the engine's operation.

4.9 Engine Instability:

The model should produce responses that result from engine instabilities (e.g., compressor surge, rotating stall, burner blowout).

4.10 Alternate Control Modes:

Engine/control system models should be capable of representing operation in all selectable control modes (e.g., primary and reversionary thrust control).

4.11 Malfunctions:

The model should represent engine responses to malfunctions and operations beyond normal envelopes. This can include:

a. Control system failures (e.g., sensors, power sources, actuators, computing elements)

b. Engine mechanisms (e.g., fuel valves, variable stator vanes, surge bleeds, clearance bleeds, turbomachinery blading, thrust-reverser, starter)

c. Accessories (e.g., customer bleeds, oil systems, accessory gearbox)

d. Abnormal operating conditions (e.g., foreign object ingestion, icing, extreme aircraft angles of attack, excessive tailwinds or crosswinds during ground operation, volcanic ash, engine separation, inlet ramp failure).

e. Contingencies rating (e.g., one engine inoperative, reversionary mode).

5. COORDINATION REQUIREMENTS:

5.1 Computer Capabilities:

In order to ensure that the model is capable of meeting the user's requirements, estimates of target computer performance and program storage capacity should be provided by the user. An estimate of the computer resources required by a real time program should be included in the Model Implementation Guide (6.2, Item 8).

5.2 Precision:

Hardware and software differences (e.g., word length, compiler and operating systems, utility routines) among computers may cause discrepancies in performance output from otherwise identical programs. These should be coordinated between user and supplier.

5.3 Interface With Other Models:

The model, when implemented on the user's target computer, should be capable of interfacing with other real time models (e.g., vehicle, external load and inlet models). The interaction between the engine/control model and any other model should be closely coordinated. The user should provide documentation describing the intended usage of the required interface items to the model supplier. If third party software is used, additional requirements may be needed.

5.4 Consistency:

The requirements for the demonstration of consistency should be based on the specific application. Negotiations between user and supplier should be aimed at the specification of comparison cases that are sufficient to demonstrate consistency.