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(R) Gas Turbine Engine Performance Presentation for Computer Programs

RATIONALE

Due to the trend towards program implementation in object-oriented languages, this document has been revised to become language independent. Also, the specifics of the traditional FORTRAN implementation have been transferred to ARP4191. Several other updates were made: additions of new engine ratings, ram pressure recovery equations, introduction of ARP5571, rewrite of sections and revision of the units. Also the power definition hierarchy is not specified anymore. It is now left for coordination between the supplier and the user.

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1. SCOPE

This SAE Aerospace Standard (AS) provides the method for presentation of gas turbine engine steady-state and transient performance calculated using computer programs. It also provides for the presentation of parametric gas turbine data including performance, weight and dimensions computed by computer programs.

This standard is intended to facilitate calculations by the program user without unduly restricting the method of calculation used by the program supplier. This standard is applicable to, but not limited to the following program types: data reduction, steady-state, transient, preliminary design, study, specification, status & parametric programs.

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 724-776-4970 (outside USA), www.sae.org.

AS755 Aircraft Propulsion System Performance Station Designation and Nomenclature

2.2 Applicable References

The following references contain material relevant to the subject area of this document, but do not form a part of this document.

2.2.1 SAE Publications

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

ARP210 Definition of Commonly Used Day Types (Atmospheric Ambient Temperature Characteristics Versus Pressure Altitude)

ARP1210 Gas Turbine Engine Interface Test Data Reduction Computer Programs

ARP1420 Gas Turbine Engine Inlet Flow Distortion Guidelines

ARP4191 Gas Turbine Engine Performance Presentation for Digital Computer Programs Using FORTRAN 77

ARP4868 Application Programming Interface Requirements for the Presentation of Gas Turbine Engine Performance on Digital Computers

ARP5571 Gas Turbine Engine Performance Presentation and Nomenclature for Digital Computers Using Object-Oriented Programming

TSB 003 Rules for SAE Use of SI (Metric) Units

2.2.2 ISO Publications

Available from International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland, Tel: +41-22-749-01-11, www.iso.org.

ISO 1000 SI units and recommendations for the use of their multiples and of certain other units

ISO 2533 ISO Standard Atmosphere

2.2.3 Other Documents

NIST-JANAF Thermochemical Tables, Fourth Edition, Parts I and II, Malcolm W. Chase, Jr. Editor, August 1998, ISBN: 1-56396-831-2

NAVY MIL-E-5007D, "ENGINE, AIRCRAFT, TURBOJET AND TURBOFAN, GENERAL SPECIFICATION FOR", 15 Oct 1973 (inactive)

2.3 Program Categorizations

Computer programs which calculate engine performance may be categorized according to their time dependency, method of calculation, and their life cycle phase (concept design, development, production, field use, and overhaul). The program types defined below are not mutually exclusive; in fact it is quite common for two or more of the functions listed to be combined in a single program.

2.3.1 Program Time Dependency

Engine programs can be defined based on their time dependency:

- Steady-State Program
- Transient Program (Real-time or non-real-time)

2.3.2 Engine Program Life Cycle Phase

Engine programs can be defined based on their life cycle phase:

- Preliminary Design Program (Study Program)
- Specification program
- Status Program
- Parametric Program

2.4 Definitions

2.4.1 Program Type Definitions

DATA REDUCTION PROGRAM: Program used to interpret results from performance testing. A data reduction program may directly compute component performance characteristics (e.g., efficiency) from measured data using standard engineering equations. Alternatively, a data reduction program may employ a steady-state or transient engine program as its core, and extend its iteration scheme to match predicted component parameters to engine test data. In the latter case, the predictive capability of the engine model can be used to extrapolate the test results to the desired test condition (which may be unattainable with the given hardware or test facility). The engine model used as the core of this type of data reduction program will nearly always be a status model as defined below. Applications of data reduction programs include:

1. interpretation of test data to facilitate the generation of status models,

2. analysis of performance verification tests,

3. interpretation of engine/airframe performance issues based on aircraft flight tests.

ARP1210 provides additional information on data reduction programs.

PARAMETRIC PROGRAM: A special type of preliminary design program. Program which estimates the performance and possibly other figures of merit (e.g., weight and dimensions) of a class of engines of similar configuration over a range of design parameters (e.g., compressor pressure ratio, turbine inlet temperature, airflow). The performance, weight, and dimensions generally result from a less detailed analysis than a conventional preliminary design, specification, or status program. A typical application of a parametric engine program is to provide data to narrow the range of system design parameters for more detailed studies.

PRELIMINARY DESIGN PROGRAM: Program which estimates the engine performance prior to the point in the development of the engine when its performance is defined by a specification. A typical application of a preliminary design program is to provide data to support preliminary aircraft design.

REAL-TIME PROGRAM: Transient performance program whose outputs are generated at a rate at least as fast as the physical system represented.

SPECIFICATION PROGRAM: Program which establishes the guaranteed performance for a specific engine model. A typical use of specification programs is to generate performance data for engine and aircraft guarantees.

STATUS PROGRAM: Program which reflects the current performance status of a specific engine or group of engines. They are normally based on greater test experience than specification programs. Status programs do not alter the commitments established by specification programs. Applications of status programs include:

1. pre-test performance prediction for a specific engine,

2. modeling an engine to investigate test operating procedures for ground test and/or flight test

3. extrapolation and/or interpolation of limited test data.

4. generation of data or simulation of engine for use in simulators

5. prediction of the average performance of a group of engines, e.g., the average of all production engines shipped

6. generation of data for aircraft flight manuals

STEADY-STATE PROGRAM: Program which predicts engine performance for steady-state conditions (i.e., when time derivatives are zero).

STUDY PROGRAM: A program that reflects perturbations or updates to a previously defined engine configuration for investigative purposes, e.g., an impact assessment of a proposed change. Such a program may or may not become a new definition of the engine configuration.

TRANSIENT PROGRAM: Program which predicts engine performance under time-varying conditions. Transient programs may simulate the engine with a simplified control algorithm, or with a detailed simulation of the actual engine control system. Applications of transient programs include:

1. prediction of engine acceleration and deceleration performance

2. support of airframe/engine integration studies, including flight control development

3. generation of data or simulation of engine for use in simulators

4. simulation of the engine for control bench testing.

2.4.2 Other Definitions

MODEL: (1) A computer program together with the appropriate input which simulates the performance (and possibly other characteristics) of a particular gas turbine engine design. (2) A specific member of a gas turbine product line, e.g., PW120 or CFM56-7.

REFERRED ENGINE AIRFLOW (W*R): airflow (W) at a given engine station, indicated by the asterisk, adjusted for the conditions (pressure & temperature) of that reference station. Example: W1R, W1AR, W2R

3. GENERAL REQUIREMENTS

This aerospace standard describes a class of software whose audience is one or a few specific users. It offers standards or recommended practices for the delivery of that software. However, there is every opportunity for the developer and the user to meet to establish the specific needs for that software. This standard provides a basis for identifying the issues of that discussion. Elements of this standard may only be waived by mutual consent of the supplier and the user. Failing agreement to a waiver by both parties, this standard establishes the requirements for the delivered program.

3.1 Program Implementation

3.1.1 The program shall be supplied in a form adaptable to the user's computer. Provision to operate the program on more than one computer type or operating system shall be coordinated between user and supplier.

3.1.2 The program shall be able to function as a subprogram (herein called the engine subprogram) and as an independent program consisting of a main program which calls the engine subprogram.

3.2 Program Operation

3.2.1 Limits

Limits observed by the computer program shall be specified in the user documentation.

The engine program will allow inputs set beyond their specified limit, upon request, provided the supplier believes the results to be credible. If not, the input will be limited. Regardless of the situation, an appropriate numerical status indicator will be provided in the output. The numerical status indicator shall clearly define output validity, limiting parameters and/or the applicable limiting engine controlling parameter.

3.2.2 Program Consistency

Consistency is used here to mean the agreement between model outputs and reference data. Reference data may be a more rigorous model or test data. Consistency criteria vary significantly and depend upon the specific application. The coordination of model consistency is a key element of model delivery.

3.3 User Documentation

The program supplier shall deliver user documentation with the program. User documentation may be in the form of paper manuals, electronic media, on-line help or remotely accessible instructions (e.g., via the Internet). User documentation shall normally be completely independent of documentation for earlier releases of the program. With the explicit approval of the program user, it is permitted to provide an update to prior documentation.

The program supplier is urged to provide separate documentation that describes installation and checkout of the program from the documentation that describes program operation and interpretation of program output.

3.3.1 The Installation and Program Checkout Documentation

This documentation shall include the following minimum information.

Program Description: The program description section shall designate a unique program identification. This program description section shall also describe the required computer hardware (computer type/model, minimum memory, disk space, etc.), software environment (operating system, compiler including version and options, etc.), programming practices, and software quality assurance standards upon which the program relies. The program supplier and the engine identification shall also be provided.

Program Setup: This section shall include instructions and information to enable the program users or the users' computer staff to set up the program. It shall include sufficient information to set up and execute the program in independent mode or as a subprogram. Any other information necessary to retrieve the program from the delivery media shall be provided. This information shall be provided in paper documentation, electronic media or may also be included in an on-line help system.

Source code for the calling program as well as the input and output statements used directly by the calling program shall be supplied with the computer program documentation. File types shall be defined, e.g., source, or object. Data shall also be defined as internal (binary) or external (readable) form. The supplier is urged to include descriptive comments in the source code to facilitate understanding.

Test Cases: This section shall describe the test cases that the supplier provides for program checkout by the user. All test case inputs and associated results including reasonable bounds for variance of key parameters shall be supplied.

3.3.2 The Program Operating Instructions Documentation

This documentation shall include the following minimum information. Additional requirements for specific model types are given elsewhere in this standard.

Introduction: This section shall provide an overview of the engine model, and of the gas turbine engine being modeled. It shall describe the intended uses for the model. It shall document the nature of, and reason for, revisions to engine computer programs from earlier versions.

Table of Contents: This section should list all documents delivered with the engine program and list the contents of each document. The on-line equivalent should list all major topics included in the on-line help system.

Engine Description: A description of the engine, as represented by this engine program, shall be provided along with any other information to understand the performance and operation of the engine. This must include specification of the "performance level" of the engine model (e.g., minimum new engine, average engine).

Nomenclature: This section describes the rules of nomenclature used in the model and provides an engine cross-section to illustrate station identification.

Input/Output: This section shall include information required to understand the user documentation and program input and output. All program inputs and outputs shall be described in sufficient detail to avoid ambiguity, including their units of measure.

Engine Program Description: This section shall describe the interfaces, options, limitations, and other features of the program, to enable the user to fully understand the capability of the program.

Program Messages: This section shall explain the error, warning and status codes produced by the program.

Identification and Revision Procedure: This section shall provide the unique identification of the program, an associated date, and other information needed to understand the relationship of this engine program to earlier releases.

References: Include details of any citations called out in the document.

Index: Although not mandatory, an index is highly desirable (or a search engine for on-line help systems).

3.3.3 Range of Validity

The boundaries within which the engine program is valid shall be described in the user documentation.

3.3.3.1 When test data is limited, the valid range of an engine program may only be a part of the complete flight envelope. Any such limits of program validity shall be identified in the user documentation.

3.3.3.2 When test and design data are limited, the range of a parametric engine program shall generally be a subset of the full flight envelope and power level range. Also, capabilities such as anti-ice bleed, distortion effects, and windmilling, are often omitted in these programs. Such limitations shall be described in the user documentation. Life and duty cycle assumptions shall also be clearly described in the engine description section of the user documentation to aid interpretation of the predicted performance, weight, and dimensions.

3.3.4 Data Packs

Engine programs can include a mechanism to allow modification of the performance representation (or other program features) using so-called data packs. This often eliminates the need to deliver a completely new engine program. Whenever an engine program provides such a capability, its use is to be described in the user documentation. Further, whenever a new data pack is issued, associated documentation shall be provided to assist users in installation, checkout and interpretation of program results with the data pack. All applicable items listed in 3.3.1 and 3.3.2 shall be addressed.

4. PROGRAMMING PRACTICES

4.1 Computer Capabilities

As engine performance programs increase in size or complexity, they place greater demands upon their computer hosts. The program execution time will depend on the inherent capability of the host computer, the complexity and level of detail embedded in the model, and the extent of the studies being accomplished using the engine program. These issues need to be understood by both the program supplier and the user so that the program delivers acceptable computing performance on the user’s computer system.

4.2 Program Interface Language

Any ANSI standard computer language (for instance, C, Ada, FORTRAN, C++) may be used for engine computer program interfaces provided the language has been agreed to by the user and the supplier. Languages for which an ANSI standard is not available may also be used, but careful coordination between the supplier and the user regarding language issues (such as compiler choice and specific features to be used) is strongly recommended. The underlying program language is driven by the supplier while the interface language is primarily driven by the user.

4.3 Program Interface Specification

ARP4191 describes the use of FORTRAN and FORTRAN COMMON blocks to manage data communication between user and supplier.

ARP4868 describes the use of a "function-call application program interface" (API) as an alternative to the position-dependent program interface method of ARP4191. The ARP4868 API approach may be implemented using FORTRAN, or languages, such as Ada, C or C++.

ARP5571 provides recommendations for several aspects of gas turbine engine performance modeling using object-oriented (OO) programming systems: nomenclature, application program interface, and user interface.

Interfaces for which a recommended practice or standard is not available may also be used, but careful coordination between the supplier and the user regarding interface issues is strongly recommended.

Engine computer program developers who elect to use a language not described in these practices are expected to comply with the requirements of AS681.

4.4 Platform Dependent Precision

Platform differences (e.g., word length, compiler, operating system) between computers can result in differences in performance output from otherwise identical programs. Differences in output of steady-state programs from the supplied test cases greater than 0.25% should be reviewed with the program supplier. For transient programs, differences smaller than ±1% at a given output time are considered normal for engine transients of 10 seconds or less. Larger differences should be reviewed with the program supplier.

4.5 Station Identification

The numbering system described in AS755 shall be used in program input and output to identify points in the gas flow path significant to engine performance definition. Supplements to AS755, deemed necessary by the program supplier, shall be detailed in the user documentation.

4.6 Parameter Nomenclature

4.6.1 Internal Parameter

This document does not require use of specific names within the engine subprogram.

4.6.2 Interface Parameter

Some compilers limit the number of characters per parameter label. When such a limitation exists, each parameter label shall be determined by the program supplier and defined in the appropriate section of the user documentation. Included as part of the definition, the program supplier shall indicate the corresponding standard parameter name prescribed by AS755 or ARP4191.

Modern programming languages and operating systems permit use of fully descriptive labels for program parameters. However, there will continue to be situations where abbreviated parameter names will be desirable (either for economy or because the computer environment precludes use of long strings). In cases where abbreviated names are to be substituted for fully descriptive names, the list contained in AS755 shall be used to identify input and output parameters of the engine program.

ARP5571 offers recommendations for Object-oriented program parameter nomenclature.

4.7 Standard Thermodynamics

The following shall be used for engine performance determination:

4.7.1 Standard Atmosphere

Ambient temperature and pressure in engine performance programs shall be consistent with ISO 2533 or alternatively ARP210.

4.7.2 Dry Air

Upon request by the program user, the assumed composition of dry air shall be included in the user documentation.

4.7.3 Fuel

Fuel Heating Value assumed by the computer program shall be specified in the user documentation. Fuel Specific Gravity shall also be specified if it is used in the performance calculation or in an associated control model. Other fuel characteristics used in the program shall be provided in the user documentation, if specifically requested by the program user.

4.7.4 Thermochemical Data

Thermochemical data used in the computer program shall be provided in the user documentation, if requested by the program user. Thermochemical data, for the purpose of gas turbine engine performance calculations shall be consistent with data presented in the NIST-JANAF Thermochemical Tables, Fourth Edition, Parts I and II, within the limits of physical representation (e.g., reaction and heat transfer rates), engineering accuracy, and computational efficiency requirements. Upon request by the user, the supplier shall provide a comparison of the thermodynamic process calculations based on his thermochemical data and that given by the NIST-JANAF Thermochemical Tables, within the range of applicable engine operating conditions.

4.8 Programming Standards

4.8.1 The choice of platform, compiler and compiler settings should be coordinated between user and supplier.

4.8.2 The program supplier shall provide automatic preventative action for the following illegal arithmetic operations or processes:

a. The square root of a negative number

b. Illegal arguments to exponential functions

c. Illegal arguments to logarithmic and inverse trigonometric routines

d. Division by zero

This preventative action shall preclude these illegal arguments from being transferred to the user's system supplied routines. When any of these conditions renders the case invalid, an appropriate numerical status indicator shall indicate the specific problem(s) encountered. The program shall be capable of continuing with the next case provided the user's program does not override this capability.

4.8.3 The program supplier shall assume that the computer memory is not cleared when the program is loaded.

4.8.4 The engine program, while operating in subprogram mode, shall be available as one call, rather than separate calls to a collection of routines which, when taken in combination, represent the engine.

5. PROGRAM CAPABILITIES

When a feature described in this section is present, it shall follow the practices herein.

5.1 Power Definition

Specification of the engine power setting for which program output is desired shall be available via simple input. For example, the user must be able to request take-off power at an operating condition of choice without knowledge of the intricacies of power management or control schedule.

The engine power setting desired shall be set by input of rating code, power code, power lever angle or some combination of these. Alternative methods of specifying power level, e.g. via input of a net thrust demand or a shaft output torque demand, may be provided. The program's method of dealing with conflicting demands, i.e. input of both power lever angle and thrust demand, shall be clearly explained in the program documentation.

Recommendations for Object-Oriented programs are in ARP5571. New programming practices allow character strings for rating code values.

5.1.1 Power Lever Angle (PLA)

Power Lever Angle is the preferred option for engine programs which include a simulation of the engine control and its schedule.

5.1.2 Power Code (PC)

Power Code may be substituted for power lever angle in situations where the actual power lever angle is not known. Table 1 provides recommended power code assignments.

TABLE 1 - POWER CODE ASSIGNMENTS

	Power Code	Definition
Augmented	100.0 to 60.0	Maximum to Minimum
Nonaugmented	50.0 to 20.0	Maximum to Idle
Reverse	15.0 to 5.0	Idle to Maximum

5.1.3 Rating Code (RC)

Examples of Rating Code definitions are given in Table 2. Rating Code allows specification via a single input of ratings which might require different power lever angles as flight or atmospheric conditions vary. The allowable input values of rating code may be mnemonic character strings, but are more typically numerical codes, e.g., "50" for commercial engine take-off rating. Table 2 provides the rating code assignments based on common industry usage. Rating code values that are not shown in the table are available for uses mutually agreeable to the user and supplier.

TABLE 2 - RATING CODE ASSIGNMENTS

	Rating Code	Definition Military	Definition Commercial
	100.0	Maximum	Emergency
Augmented	90.0	Maximum Continuous	Maximum
	60.0	Minimum	Minimum
	55.0	---	Wet Takeoff
	51 to 59	Emergency or Contingency	---
		---	30-second OEI
		---	2-minute OEI
		---	2 1/2-minute OEI
		---	30-minute OEI
		---	Continuous OEI
	55.0	Maximum	
	50.0	Intermediate	(Dry) Takeoff
	45.0	Maximum Continuous	Maximum Continuous
Nonaugmented	40.0	---	Maximum Climb
	35.0	---	Maximum Cruise
	21.0	Flight Idle	Flight Idle
	20.0	Ground Idle	Ground Idle
Reverse	15.0	Idle	Idle
	5.0	Maximum	Maximum

OEI: One Engine Inoperative

5.2 Inlet Representation

5.2.1 Inlet Mode

The engine program shall calculate performance when provided with any of the following combinations:

1. Altitude, free stream Mach number, deviation of ambient temperature from standard, inlet ram pressure recovery (one of the options of 5.2.2), and a temperature increment for inlet heating DT1(A) to be added to the free stream total temperature T0: T1(A) = T0 + DT1(A).

2. Ambient pressure and temperature, total pressure and total temperature at the inlet/engine interface T1(A), and a temperature increment for inlet heating DT1(A) to be added to the free stream total temperature: T0 = T1(A) - DT1(A).

3. Other options, as coordinated between user and supplier.

5.2.2 Inlet Ram Pressure Recovery

Several options for inlet ram pressure recovery shall be provided (identified by the inlet ram pressure recovery selection). Two categories of options are provided. The first is used for engine inlet average recovery. The second provides the ability to differentiate primary and secondary stream recoveries. The specific options are defined in Table 3.

TABLE 3 - INLET RAM PRESSURE RECOVERY ASSIGNMENTS

Inlet Ram Pressure Recovery Selection	Definition
Average Recovery Options	
1	A specified inlet ram pressure recovery standard. A typical inlet pressure recovery ratio is defined by the following equations and conditions: Recovery = 1 from zero to 1 Mach number Recovery = $1-0.075(M_0-1)^{1.35}$ from 1.0 to 5.0 Mach Number Recovery = $800/(M_0^4+935)$ above 5.0 Mach number with M_0=flight Mach number (Obtained from: MIL-E-5007D, 15 Oct 1973, p.12, 13)
2	The input value of pressure recovery.
3	The recovery is defined as a function of referred engine airflow and/or free stream Mach number. It usually includes inlet frictional losses as well as shock losses, if any.
Differentiated Primary and Secondary Stream Options	
4	The input value of recovery of primary stream engine; and the input value of recovery of secondary stream.
5	The input value of recovery of primary stream. The recovery of the secondary stream is defined as a function of referred engine airflow and/or free stream Mach number.
6	The recovery of primary stream is defined as a function of referred engine airflow and/or free stream Mach number. The recovery of secondary stream is defined as a function of referred engine airflow and/or free stream Mach number.

Options 4, 5, and 6 are intended for use with bypass engines.

Options 3, 5, and 6 provide for a functional relationship between inlet ram pressure recovery and engine airflow and/or free stream Mach number. They require a user supplied subprogram.

The user supplied subprogram shall interpret the value of the inlet ram pressure recovery based on the Inlet Ram Pressure Recovery Calculation Option, as presented in Table 4. Upon request, the supplier's engine program shall call this user supplied subprogram. Refer to ARP4191 or ARP5571 for more details.

TABLE 4 - INLET RAM PRESSURE RECOVERY CALCULATION OPTIONS

Option	Inlet Ram Pressure Recovery
1.0	Average
2.0	Primary Stream
3.0	Secondary Stream

5.2.3 Distortion

The effects of inlet pressure and temperature distortion (radial, circumferential, and temporal) on the engine may be included in the program when data or estimates are available. ARP1420 shall be consulted for details.

5.3 Customer Services

5.3.1 Bleed Air

The engine program shall calculate performance when air is extracted for customer services, including customer anti-ice. The user shall be able to specify the amount of air extracted from each bleed station as a flow rate and/or, where applicable, as a ratio to a referenced engine station gas flow. If the user specifies non-zero values for both rate and ratio of the bleed air, the resulting total bleed flow is the sum of the two specified values. The corresponding output temperatures and pressures shall include engine induced heat transfer and pressure losses up to the bleed port interface.

5.3.2 Power Extraction

The engine program shall calculate engine performance when power is extracted. The user can specify the amount of power extracted, usually from a gearbox drive pad connected to a given engine shaft.

5.4 Engine Supplied Nozzle Effects

5.4.1 Nozzle parameters used in the calculation of engine performance shall be included in the program output. The nozzle parameters shall include:

a. Nozzle area(s)

b. All gas flows

c. All engine discharge gas temperatures and pressures

d. Ideal gross thrust

e. Required user-supplied nozzle cooling airflow

5.4.2 When a separate subprogram, or supplementary data are needed to define external geometry of an engine supplied nozzle for user performance calculations, the appropriate data shall be included in the program output.

5.5 Parasitic Flows

Parasitic flows include planned flows, other than the customer bleed flow, discharged from the engine at points other than the exhaust nozzle. As these flows may impact installation or nacelle design, the engine program shall calculate the effect on engine performance of such planned flows, and the total pressure, total temperature, and flow for each parasitic flow shall be included in the program output.

5.6 Fluid Injection

When engine operation allows the use of fluid (e.g., water/alcohol) injection for augmentation, the engine program shall compute engine performance for such operation. The injected flow rate used in the performance calculation shall be included in the program output.

5.7 Fuel Properties

When the engine program allows the user to vary fuel properties (lower heating value, specific gravity), the following restrictions apply:

a. The range of fuel property values is limited to that of the fuels with which the engine can be operated.

b. The allowable variation in fuel properties for a specific fuel shall be based on requirements set forth by appropriate agencies.

5.8 Windmilling

The engine program may offer prediction of performance under windmilling conditions. If so, the user documentation shall specify the conditions (e.g., altitude versus Mach number regime) for which program output is valid.

5.9 Reverse Thrust

The engine program may include prediction of the performance of the engine with an attached thrust reverser or spoiler. If so, the user documentation shall specify the conditions and engine limits (e.g., power setting) for which program output is valid.

5.10 User Defined Control Schedules

If the engine program includes control schedules that can be changed by the user, a description of the control schedule options shall be provided in the user documentation. The engine program output shall define the setting of the control schedule parameter(s) for which the performance is calculated. If the user has the option to change any control schedules without consulting the program supplier, a description of the method of input and the permissible variation shall be included in the user documentation. In these situations, both the program user and the program supplier need to have a thorough understanding of the user's requirements, and agree to the methods used to achieve these requirements.

5.11 Engine Stability

If the engine program indicates component stability problems (e.g., compressor surge, burner blow-out), the appropriate numerical status indicator shall be set.

5.12 User Supplied Programs

The engine program, when used as a subprogram, may be required to interface with user supplied programs representing such features as engine inlet, ejector inlet for an engine supplied nozzle, exhaust nozzle, ports for customer services, or secondary nozzles for boundary layer control. The operation of the user supplied program and the engine subprogram must be closely coordinated to allow for successful interaction between them, and to ensure the necessary input and output is provided. The program user shall provide documentation to the program supplier describing the intended use of all interface items.

5.13 Transient Programs

It is particularly important that there be close coordination between the program supplier and the program user for transient programs. The paragraphs that follow indicate some of the issues requiring discussion, and some of the more common practices for transient models.

5.13.1 Time Interval Control

Transient programs usually have a set time increment which shall be used internally and the user may select how many internal time increments should be run before output is needed. An input value (e.g., TIMEO) shall be used to set the time interval between generated outputs. Alternatively the user can supply an integer value which is defined as a number of time steps between generated outputs. It is suggested that this time interval be an odd multiple of the internal time increment. Another input (e.g., ZTIMET) shall be used to define the termination time of a given transient case.

If the transient engine program is being called as a subprogram, execution control shall return to the calling program after an input value of time (e.g., ZTIME).

5.13.2 When the program user is required to perform studies that vary an input parameter with time, the responsibility to provide this capability belongs to the user.

5.13.3 Provision to schedule an input parameter against internal engine parameters (e.g., distortion parameters versus intake mass flow, power extraction versus shaft speed) shall be the responsibility of the program user. The program user shall obtain the internal engine parameters required for these calculations from the engine subprogram output.

5.13.4 Steady State Initialization

A steady-state solution providing initial conditions for the transient shall be generated whenever the input value of time, (e.g., ZTIME) has a value of zero. However, it should be recognized that a transient simulation usually includes a representation of the engine control system which may not be amenable to a steady-state solution. Some initial unsteady behavior may result. In this case, the steady-state solution may not exactly agree with a quiescent transient solution. The transient solution shall not be used for steady-state performance analysis.

6. INPUT/OUTPUT

6.1 Program Interface Definition

For many years, engine programs were developed using the FORTRAN language. AS681 was developed, in part, to specify the standard for communicating between the calling program and the engine subprogram. Today, many languages are available to develop the engine subprogram and the calling program. Other communication methods may be preferable, even if FORTRAN is the language of choice. This standard no longer insists on the traditional program interface. ARP4191 defines the traditional program interface, for those who choose to use it. ARP4868 describes an alternate program interface that is also compliant to this Aerospace Standard.

All programs shall provide the following inputs and outputs as appropriate to the engines being modeled. The actual labels are provided in ARP4191, for FORTRAN programs, and in ARP5571, for object-oriented programs.

6.2 Minimum Input List

Note that in the following, engine inlet station 1A applies to turbofan and other engines using average of all streams. In other cases, e.g., turboshafts, the station is 1.

Documentation:

Numerical case identification

Engine program designation/indicator

User title

Environment:

Inlet mode selection

Pressure altitude

Ambient pressure

Ambient temperature

Ambient temperature minus Standard Atmospheric temperature

Free stream Mach number

Installation:

Inlet pressure and temperature distortion selection

Inlet Ram pressure recovery selection

Primary stream inlet ram pressure recovery

Secondary stream inlet ram pressure recovery

Inlet ram pressure recovery at station 1(A)

Engine inlet total pressure at station 1(A)

Engine inlet total temperature at station 1(A)

Temperature to be added to free stream total temperature at station 0

High pressure compressor bleed flow

High pressure compressor bleed flow ratio (bleed flow over reference flow)

Customer high pressure rotor power extraction

Power Level:

Rating code

Power code

Power lever angle

Delivered shaft power

Delivered shaft torque

Delivered shaft rotational speed

Windmilling selection

Transient:

Time from start of transient case at which control is to be returned to calling program

Termination time of transient case

Output time interval

Polar moment of inertia of external load on the power turbine

Program Input/Output:

Input file identification

Output file identification

6.3 Minimum Output List

Note that in the following, engine inlet station 1A applies to turbofan and other engines using average of all streams. In other cases, e.g., turboshafts, the station is 1.

Documentation:

Engine program security classification

Engine program title(s) / program identification

Numerical status indicator

Environment:

Pressure altitude

Ambient pressure

Ambient temperature

Ambient temperature minus Standard Atmospheric temperature

Free stream Mach number

Installation:

Temperature added to T0

Primary stream inlet ram pressure recovery

Secondary stream inlet ram pressure recovery

Inlet ram pressure recovery at station 1(A)

Customer high pressure rotor power extraction

Boat-tail angle

High pressure compressor total bleed flow (combined result of inputs of bleed flow, and bleed flow ratio)

High pressure compressor total bleed flow ratio - (total bleed flow over referenced engine station gas flow)

High pressure compressor bleed flow total pressure

High pressure compressor bleed flow total temperature

Power Level:

Rating code

Power code

Power lever angle

Engine Performance:

Net thrust

Gross thrust (for primary stream or mixed exhaust flow)

Bypass stream gross thrust

Ideal gross thrust (for primary stream or mixed exhaust flow)

Bypass stream ideal gross thrust

Ram drag

Delivered shaft power

Delivered shaft torque

Specific fuel consumption

Fuel flow, main combustor

Fuel flow, total of all combustors

Fuel lower heating value

High pressure rotor rotational speed

Intermediate pressure rotor rotational speed

Low pressure rotor rotational speed

Delivered shaft rotational speed

Engine inlet total pressure at station 1(A)

Bypass exhaust flow total pressure

Primary or mixed exhaust flow total pressure

Engine inlet total temperature at station 1(A)

Bypass exhaust flow total temperature

Primary or mixed exhaust flow total temperature

Control temperature (cockpit display)

Engine inlet flow at station 1(A)

First compressor inlet flow

Bypass exhaust flow

Primary or mixed exhaust flow

High pressure compressor stability margin

Intermediate pressure compressor stability margin

Low pressure compressor stability margin

Bypass exhaust nozzle throat effective area

Primary or mixed exhaust nozzle throat effective area

Output time, from start of transient case

6.4 Program Output

Display of program output shall be under the control of the calling program.

6.5 Units

Input and output parameter values may be based on either the metric International System of Units (SI) or US customary units. The selection of one set or the other should be coordinated between user and supplier. For some parameters, the aircraft industry deviates from the US Customary units and/or the SI units. Appendix B defines the units that should be used for either system.