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A STUDY OF THE OPTIMIZATION METHOD USED IN THE NAVY/NASA GAS TURBINE ENGINE COMPUTER CODE

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prepared by

Jerry L. Horsewood

COMPUTER SYSTEMS INTERNATIONAL, INC.

and

Samuel Pines

ANALYTICAL MECHANICS ASSOCIATES, INC.

for

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Project Manager, Laurence H. Fishbach, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

Sources of numerical noise affecting the convergence properties of the Powell's Principal Axis Method of Optimization in the NAVY/NASA Gas Turbine Engine Computer Code were investigated. The principal noise source discovered resulted from loose input tolerances used in terminating iterations performed in subroutine CALCFX to satisfy specified control functions. A minor source of noise was found to be introduced by an insufficient number of digits in stored coefficients used by subroutine THERM in polynomial expressions of thermodynamic properties. Tabular results of several computer runs are presented to show the effects on program performance of selective corrective actions taken to reduce noise.

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FORWARD

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SUMMARY

This report describes the results of a study to investigate the optimization method used in the Navy/NASA Gas Turbine Engine Computer Code (NNEP, formerly designated NEPCOMP). The objective of the study effort was to identify and, where possible, eliminate sources of computational noise in the NNEP code. The scope of the study was limited to the following three tasks:

1. Generate subroutine, labelled common, and common variable cross reference tables from the program source code using utility programs that have been developed by Analytical Mechanics Associates, Inc.

2. Analyze the source code for the purpose of identifying corners and/or singularities in the modelling of various functions. Also, isolate inner loop iterations and assess the adequacy of the criteria used to terminate the iterations.

3. Prepare a final report of the results of the study.

The cross reference tables required for Task 1 were prepared immediately upon receipt of the source code and were used extensively in the performance of Task 2. The generated tables are included as an appendix to this report.

The performance of Task 2 consisted of: (1) analyzing the NNEP source code to identify all internal iterations performed and instances where discontinuities and/or corners occur in system and subsystem models, and (2) executing the program with a variety of test cases to determine the amount of noise being introduced and the resultant effect on iteration behavior.

The only modelling discontinuities/corners identified in the code occurred in subroutine THERM where tabular values of coefficients yielded discontinuities in function values and first derivatives in the sixth or seventh significant digit at tabular points. These small errors may be eliminated without increasing execution time by increasing the number of significant digits of the stored coefficients, and it is recommended that this be done.

The principal sources of noise affecting the outer loop iteration (optimization) sequence were found to be in subroutine CALFX. The tightening of tolerances used to terminate iterations in this routine does result in one or more additional passes through the corresponding inner loops to achieve the more stringent convergence criteria; however, it does not necessarily follow that this always leads to additional CPU time since the reduced noise directly affects the outer loop iteration sequence sufficiently to permit convergence in the outer loop more quickly. It is not axiomatic that the elimination of noise reduces the number of iterations to convergence in the outer loop. Due to the nature of the outer loop iterator, subroutine BOTM, the existence of noise in the function evaluation may tend to hasten or retard convergence. But, when earlier convergence is achieved with noise in the solution, it is due to circumstantial satisfaction of the convergence criterion in BOTM by slightly erroneous results, and the converged value of the performance index may be greater or less than that of converged solution with noise absent.

During the course of the study, a revised outer loop iterator, designated BOTMX, was provided which was designed to operate in the presence of noise. The application of this iterator to several test cases failed to yield favorable results. Although the revised iterator "converged" in a fraction of the iterations required by BOTM, the final value of the performance index was always less, by as much as 8 percent, than the solution achieved by BOTM. After the same number of iterations and function evaluations required for convergence with BOTMX, the value of the performance index achieved with BOTM was, in each case investigated, better than the value obtained with BOTMX.

The conclusions reached in the study are as follows:

1. The principal sources of noise in the NNEP code arise from loose inner loop tolerances employed in subroutine CALCFX. In CALCFX the tolerances are input as part of the SPCNTL or SPEC arrays with default values of 1×10^{-3}. It is recommended that the tolerances be input for each control variable with a value no larger than 1×10^{-6}.

2. The number of significant digits retained in the tabular coefficients in the 16 DATA arrays AHAIR, BHAIR, CHAIR, DHAIR, APAIR, BPAIR, CPAIR, DPAIR, AHSTØC, BHSTØC, CHSTØC, DHSTØC, APSTØC, BPSTØC, CPSTØC and DPSTØC in subroutine THERM should be increased to the limits of the machine to eliminate discontinuities in the function values and first derivatives at tabular points.

3. Additional research of the algorithm employed by subroutine BOTM is warranted. It was observed that the converged value of the performance index was actually achieved in most cases in less than half of the iterations and function evaluations employed to recognize convergence. Thus, improved methods of terminating the iteration seems advisable.

4. The performance of the revised iterator BOTMX was inferior to BOTM on all the test cases investigated. Although additional testing and tuning of BOTMX is encouraged, it is recommended that, until more favorable results with BOTMX are realized, the subroutine BOTM be retained as the production iterator in NNEP.

NOTE: In response to the above conclusions, numbers 1 and 2 have been incorporated into NNEP and the Naval Air Development Center has been working on and has apparently solved the problems pointed out in 3 and 4. The scope of this contract does not permit a reevaluation of the revised code. Preliminary findings of NADC however indicate both faster and better or equal optimum values are now consistently being achieved by the new iterator.

INTRODUCTION

The Navy/NASA Gas Turbine Engine Computer Code (NNEP)(reference 1) is the product of a joint effort by the NASA Lewis Research Center and the Naval Air Development Center. The program is used as a tool for the optimal design of a gas turbine engine, given a prescribed engine configuration with specified engine components which are subject to a set of equality constraints that assure satisfaction of known laws of conservation. The program provides for the imposition of upper and/or lower limits on key engine parameters and permits the specification of up to ten independent variables which may be chosen to maximize or minimize a designated performance index. The method of optimization is a direct search technique know as Powells' Principal Axis Method (reference 2). This technique is represented by subroutine BOTM in the NNEP code.

The implementation of the Principal Axis Method entails the evaluation of a controlled sequence of complete engine designs to define the principal axes for the specific problem posed, followed by another controlled sequence of steps in a direction defined by the principal axes. This procedure is repeated until no further improvement in the performance index can be achieved. This procedure is termed an outer loop iteration. The application of the Principal Axis Method requires that on each function evaluation (complete engine design) all conservation laws and other control equations, in the form of equality constraints, be satisfied. This implies that several internal iterations, known as inner loop iterations, must be performed and convergence achieved on each function evaluation. Such iterations are required in the specification of several individual engine components as well as the engine configuration as a whole. The satisfaction of the limited variables (inequality constraints) need not be satisfied on a given function evaluation. Any violations contribute to a penalty function which is eliminated as part of the outer loop iteration.

Direct optimization techniques are notorious for their slow convergence properties in the vicinity of the solution, and the Principal Axis Method is no exception. In an attempt to improve convergence characteristics, a variety of other optimization techniques in NNEP (actually an earlier version known as NEPCOMP) were tried.* Candidate techniques investigated included both indirect techniques and other direct techniques. None of the alternate techniques investigated yielded any improvement over the Principal Axis Method. Indeed, several of the techniques failed to converge to any solution. It was subsequently determined that the most probable causes for failure of the several techniques to perform as anticipated were noise introduced in the function evaluation computations and/or corners or discontinuities in the modelling of the several engine components.

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* The results of this investigation are described in a Naval Air Development Center memo to the NASA Lewis Research Center. The memo constitutes the final progress report for NASA Defense Purchase Request PR 585286.

The net result of the investigation of alternative optimization techniques was to retain the Principal Axis Method in the production version of NNEP and to continue research with the technique to enhance its convergence characteristics. One aspect of this research was to identify the sources of noise in the code and any discontinuities or corners in the modelling of the engine components that may have contributed to the failure of the other techniques. The idea is that the elimination of causal factors that may have contributed to the poor performance of the other techniques may lead to improved performance of the Principal Axis Method. It is this aspect of the research to which the study effort described herein is directed.

DISCUSSION OF STUDY ACTIVITIES AND RESULTS

Source Code Acquisition and Checkout

Immediately upon award of the contract, a trip was made to the NASA Lewis Research Center to obtain on magnetic tape a copy of the NNEP source code with tabular and input data for a typical test case. The program was installed and compiled on the IBM 360, Model 91 under the OS operating system at the NASA Goddard Space Flight Center in Greenbelt, Maryland. The program listings were reviewed in detail to identify all input/output logical unit assignments and the expected record formats and lengths as required for the proper definition of the job control cards. The compilations indicated several warning level diagnostics which were of three types: (1) array items appearing in equivalence statements were non-subscripted; (2) Fortran mathematical library functions were called with arguments of the wrong type; and (3) real constants with eight or more digits were not specifically declared double precision through the use of a D exponent. In addition the Technical Officer advised of a dimension error in one subroutine, and a review of the I/O units employed by the program pointed out an incorrect logical output unit assignment. These errors were corrected and a complete load module of the revised program was generated.

Initial attempts to execute the test case provided were unsuccessful. Tracing through core dumps that were generated at the time of program abend led to the determination that certain input variables and arrays were not explicitly initialized by the program. Unlike the computers in use at the NASA Lewis Research Center, the OS/360 operating system does not set core to zeroes prior to loading the program. This task must be performed by the applications program. Upon accomplishing this task, the program executed successfully and yielded results that were close to those obtained on the Univac 1110 computer at Lewis. With this accomplished, it was possible to address the primary objectives of the study.

Source Code Cross Reference Analysis

The NNEP source code was passed through a set of utility programs which generate a set of five reports giving extensive cross reference information of subprogram calls, labelled common references and individual common variable references throughout the program. The five reports are as follows:

1. A listing by subprogram of the calling arguments passed to the routine, the subprograms referenced or called by the routine, the labelled commons used by the routine, and the secondary entry points contained in the routine.

2. A list of all secondary entry points in the program with the name of the subprogram in which the entry point appears.

3. A list by subprogram name of all other subprograms which call or reference the subprogram.

4. A list by labelled common name of all subprograms that contain the labelled common.

5. A list by common variable or array name within each labelled common of all subprograms which reference the common variable. The variable or array type and its position relative to the start of the common, in decimal bytes, are also given. For this report, the utility programs use both the labelled common name and total length, printed in decimal bytes, to identify the common. Therefore, if a common is of different lengths in different routines, a separate report is prepared for each length.

The cross reference reports for NNEP are reproduced in Appendix A. These reports indicated two problems with respect to operation on the GSFC computer. One problem was a call to a subroutine SYSOBF, the source code for which was not included with the program. This subroutine is included in the system library on the NASA Lewis computer, but is not required for operation on the GSFC computer. Therefore, the calls to the subroutine were removed. The second problem identified was that labelled common EMØDID was of a different length in one subroutine than in all other subroutines in which it appeared. The discrepancy was due to the failure to properly type the common variables as double precision in the one subroutine. This error was corrected prior to commencing Task 2 of the study.

Analysis of Convergence Problems

The analysis of convergence problems required the repeated execution of test cases under a variety of conditions. The test cases employed for this purpose were provided by the Technical Officer and consisted of two separate data sets. One set, which will be referred to as Data Set A, consisted of a design point case (function evaluation using input values of all independent variables with no iterations), an off-design case requiring satisfaction of all control equations but no optimization, and a case to optimize the engine design to yield maximum thrust. The relatively simple engine configuration consisted of six components - an inlet, a compressor, a duct, a turbine, a nozzle and a shaft connecting the compressor and turbine. Four control variables and associated end conditions were specified. For the optimization case, two independent variables were activated and one inequality constraint was imposed. All cases in Data Set A involved a single mode. To supplement these inputs, the data set also included five tables of gas property data required to be available for reading on logical unit 12. The second input data set, designated Data Set B, included a design point evaluation and five separate optimization cases. Distinct mode numbers were assigned to each of the six cases. Although each of the six cases represented different engine concepts, reflected by different engine parameter values, the configuration for each case consisted of the same 15 components, as follows: an inlet, 2 compressors, 2 turbines, 3 ducts, a splitter, 2 nozzles, 2 shafts, a water injector and a load. A total of eight control variables and associated end conditions were specified along with two inequality constraints. Three optimization variables were activated to yield maximum thrust for the five optimization cases. The data set also included ten tables of gas property data. The two data sets are printed in their entirety in Appendix B.

The analysis was begun with a review of the source code to identify questionable procedures or algorithms in the code that could lead to discontinuities or corners in modelling calculations. In earlier versions of the program, the algorithm used for interpolation and extrapolation in the gas property tables was suspect. However, the routines employed to perform the interpolations and extrapolations had been modified to eliminate the known deficiencies prior to receipt of the source code. Consequently, this portion of the program was not investigated in this study. The review of the source code led to the identification of only one subroutine where discontinuities or corners in the model may occur. This subroutine was THERM which solves thermodynamic equations for specified parameters given a set of input conditions. The solution of these equations involves the evaluation of cubic polynomial expressions of the form

$$y = a_i + b_i x + c_i x^2 + d_i x^3$$

for a given value of the independent variable x. The coefficients a_i, b_i, c_i and d_i are selected from arrays A, B, C and D, respectively, with the value of the index i being dependent on the magnitude of x. The subroutine contains an associated array X with elements x_i representing tabular values of the independent variable at which a change in the coefficients used takes place. The index is chosen such that x is contained in the interval

$$x_i \leq x < x_{i+1} .$$

If $x < x_1$, then $i = 1$ is used. To assure continuity and smoothness in the function, it is necessary that the stored coefficients contain a sufficient number of significant digits such that

$$\lim_{\varepsilon \to 0} \left[y(x_i) - y(x_i - \varepsilon) \right] = 0$$

$$\lim_{\varepsilon \to 0} \left[y'(x_i) - y'(x_i - \varepsilon) \right] = 0$$

where

$$y'(x) = b_i + 2c_i x + 3d_i x^2$$

Due to the finite number of digits maintained by the computer, it is not possible that the indicated differences can be driven to exactly zero; however, the smaller the residuals are the greater will be the continuity and smoothness of the function. A fortran program was written to evaluate the residuals in y and y' at the tabular points $(i \geq 2)$, and it was found that a minimum of six significant figures was maintained in both functions. This level of error was expected since the coefficients are entered with only seven or eight significant digits. This is probably not significant when using a direct optimization technique such as the Principal Axis Method, but could lead to problems with an indirect optimization technique. Since there is no effect on computational speed due to increasing the number of significant digits in the coefficients, however, it is recommended that this be done even if the direct optimization technique is retained.

The search for possible sources of noise in the computations was limited to investigating the effects of inner loop tolerances on the iteration characteristics.

A possible source not investigated because the level of effort available was not consistent with the magnitude of the task is the differencing of numbers of the same order of magnitude. Since double precision computations are used throughout the program, this is not expected to be a major source of noise. Also, machine roundoff and truncation and accuracy of library mathematical routines were not considered important because of the use of double precision.

Inner loop iterations are performed in several of the engine component routines, including COOLIT, DBURNR, INLET, MIXER, NOZZLE, TURBIN and WINJEK. In each of these routines, the iteration is on a single variable, and convergence to the specified tolerance is required on each call. The appropriate subroutine is called only once for a given component each time a complete engine performance evaluation is required. Subroutine THERM also performs an inner loop iteration on a single variable under certain conditions; however, it is called many times on each engine performance evaluation. Therefore, the possibility for accumulation of noise effects due to THERM is substantially greater than for the engine component routines. A multiple variable inner loop iteration is performed in subroutine CALCFX to satisfy all the control conditions specified on input. This subroutine provides the interface between the outer loop iterator BOTM and the engine performance calculations. CALCFX returns to BOTM the value of the performance index which is used in controlling the outer loop iterations. The relative tolerances specified for convergence in the engine component subroutines vary between 1×10^{-5} and 5×10^{-4}. There are two flow paths in subroutine THERM that result in inner loop iterations. The tolerances for the two paths are 2×10^{-5} and 2×10^{-6}. The tolerances used in subroutine CALCFX are defined by input through the SPCNTL or the SPEC arrays. The data sets provided for test purposes invoked default values of 1×10^{-3} for these tolerances.

The investigation of noise effects in the various routines was approached by tightening the tolerances used in the several inner loop iterations in selected combinations. For this purpose, all of the engine component routines were tested as a single unit, subroutine THERM was tested as a second unit and CALCFX was treated as a third unit. Within a unit, the tolerances for all inner loop iterations were varied holding the tolerances in the other two units fixed. The behavior of the convergence process was monitored in terms of the number of iterations and function evaluations required for convergence and the final value of the performance index, thrust. Additionally, the convergence progress was monitored in several cases where the behavior failed to conform to an expected pattern.

In the engine component routines, a tolerance level of 1×10^{-10} for all iterations was selected for comparison with the nominal tolerances stated previously. Several cases were executed with both tolerance levels and various combinations of tolerances in subroutines THERM and CALCFX. The results indicated that the tolerance level in the engine component routines had virtually no impact on the solution. In each case, when comparing with equal tolerances in the other routines, the number of iterations and function evaluations were identical for the two tolerance levels. Furthermore, the differences in the final value of thrust were insignificant, varying at most in the sixth significant digit. It was therefore concluded that, at least for the test cases investigated, the engine component routines are not contributing to the noise in the calculations. It was noted with interest that the more stringent convergence criteria did not appear to adversely affect the CPU time for the runs. This is most probably due to strong convergence properties of the inner loop iterations resulting in the achievement of convergence with only minimal additional iterations.

In subroutines THERM and CALCFX, selected combinations of three tolerance levels in each routine were investigated. In THERM, the nominal values were studied in addition to values of 10^{-10} and 10^{-14} while in CALCFX the values included were 10^{-3}, 10^{-6} and 10^{-8}. Initially, a tolerance level of 10^{-10} was tried in CALCFX, but difficulties in achieving convergence at that level led to the selection of 10^{-8} as the most stringent convergence criterion. Due to computer time limitations, not all combinations of tolerances were investigated for all cases. Nevertheless, a sufficiently broad spectrum of combinations were included to adequately assess the noise effects in the cases investigated.

The results of this portion of the study are presented in Tables 1 through 4, inclusive. The tabular entries include the data set designation and mode number to identify the inputs for the case (see Appendix B), the tolerances employed in the two subroutines, the number of iterations and function evaluations required to achieve convergence in the outer loop, the converged value of thrust and, for selected cases, a comment giving noteworthy information concerning the iteration sequence. Table 1 displays results for varying tolerance levels in THERM while holding the tolerance levels in CALCFX to their default values of 10^{-3}. Table 2 gives corresponding results for tighter CALCFX tolerances of 10^{-6}. Tables 3 and 4 reverse the order of presentation of data by varying the tolerances in CALCFX while holding the tolerances fixed in THERM at the nominal and 10^{-10} values, respectively. A review of the tabular data leads to the following observations:

1. The tightening of tolerances in THERM while maintaining default tolerances in CALCFX provides no evidence that major reductions in noise are achieved with the tighter tolerances. Substantial (third significant digit) improvement in thrust is achieved with tighter tolerances for the Data Set A and Data Set B, MODE = 4 input cases; for all other cases the differences in thrust were one or more orders of magnitude smaller.

2. The tightening of tolerances in subroutine THERM while maintaining tolerances of 10^{-6} in CALCFX also provide no evidence that the tolerances in THERM substantially affect the noise. The only case for which the number of iterations was affected by the tolerance level in THERM was the Data Set B, MODE = 4 input case. The number of function evaluations for the MODE = 4 and 5 cases of Data Set B appeared very sensitive to the tolerance level, but this is due to the nature of the outer loop iteration algorithm where slight changes in the performance index can substantially change the iteration sequence. The maximum changes in the performance index occur in the fourth significant digit.

TABLE 1

EFFECT OF TOLERANCE LEVELS IN THERM

Default Tolerances in CALCFX (10^{-3})

Data Set	Mode	THERM tolerance	No. of iterations	No. of function evaluations	Thrust (lbs)	Comments
A	1	Nominal	4	53	4194.84	
A	1	10^{-10}	4	64	4238.93	
A	1	10^{-14}	4	64	4238.93	
B	2	Nominal	6	129	14901.51	
B	3	Nominal	3	74	17556.64	17668 lbs thrust achieved during iteration
B	4	Nominal	4	92	21984.59	22040 lbs thrust achieved during iteration
B	5	Nominal	5	86	25481.00	
B	6	Nominal	4	80	27754.32	
B	2	10^{-10}	6	132	14905.35	
B	3	10^{-10}	3	74	17557.05	17669 lbs thrust achieved during iteration
B	4	10^{-10}	3	70	22641.04	22672 lbs thrust achieved during iteration
B	5	10^{-10}	5	86	25480.97	
B	6	10^{-10}	6	133	27731.79	

TABLE 2

EFFECT OF TOLERANCE LEVELS IN THERM

Tight Tolerances in CALCFX (10^{-6})

Data Set	Mode	THERM Tolerance	No. of Iterations	No. of Function Evaluations	Thrust (lbs)	Comments
A	1	Nominal	3	44	4235.92	
A	1	10^{-10}	3	43	4236.04	
A	1	10^{-14}	3	43	4236.04	
B	2	Nominal	3	63	14895.25	Final thrust achieved at iteration (2,33)
B	3	Nominal	3	79	17574.32	Final thrust achieved at iteration (1,20)
B	4	Nominal	8	160	22729.63	Final thrust achieved at iteration (6,135)
B	5	Nominal	9	175	25595.21	Final thrust achieved at iteration (6,117)
B	6	Nominal	2	68	27913.85	Final thrust achieved at iteration (1,43)
B	2	10^{-10}	3	65	14896.00	Final thrust achieved at iteration (2,34)
B	3	10^{-10}	3	76	17574.77	Final thrust achieved at iteration (1,21)
B	4	10^{-10}	8	215	22745.71	Final thrust achieved at iteration (7,181)
B	5	10^{-10}	14	298	25595.05	Final thrust achieved at iteration (9,180)
B	6	10^{-10}	2	68	27913.53	Final thrust achieved at iteration (1,43)
B	2	10^{-14}	3	65	14896.00	Final thrust achieved at iteration (2,34)
B	3	10^{-14}	3	76	17574.77	Final thrust achieved at iteration (1,21)
B	4	10^{-14}	8	217	22745.69	Final thrust achieved at iteration (7,183)
B	5	10^{-14}	14	313	25595.07	Final thrust achieved at iteration (9,180)
B	6	10^{-14}	2	68	27913.53	Final thrust achieved at iteration (1,43)

TABLE 3

EFFECT OF TOLERANCE LEVELS IN CALCFX

Nominal Tolerances in THERM

Data Set	Mode	CALCFX Tolerance	No. of Iterations	No. of Function Evaluations	Thrust (lbs)	Comments
A	1	10^{-3}	4	53	4194.84	
A	1	10^{-6}	3	44	4235.92	
A	1	10^{-8}	3	45	4235.94	
B	2	10^{-3}	6	129	14901.51	
B	3	10^{-3}	3	74	17556.64	17668 lbs thrust achieved during iteration
B	4	10^{-3}	4	92	21984.59	22040 lbs thrust achieved during iteration
B	5	10^{-3}	5	86	25481.00	
B	6	10^{-3}	4	80	27754.32	
B	2	10^{-6}	3	63	14895.25	Final thrust achieved at iteration (2,33)
B	3	10^{-6}	3	79	17574.32	Final thrust achieved at iteration (1,20)
B	4	10^{-6}	8	160	22729.63	Final thrust achieved at iteration (6,135)
B	5	10^{-6}	9	175	25595.21	Final thrust achieved at iteration (6,117)
B	6	10^{-6}	2	68	27913.85	Final thrust achieved at iteration (1,43)
B	2	10^{-8}	3	63	14895.24	Final thrust achieved at iteration (2,33)
B	3	10^{-8}	5	108	17574.31	Final thrust achieved at iteration (1,20)
B	4	10^{-8}	8	160	22729.57	Final thrust achieved at iteration (6,135)
B	5	10^{-8}	4	75	25586.43	Final thrust achieved at iteration (1,36)
B	6	10^{-8}	2	68	27913.84	Final thrust achieved at iteration (1,43)

TABLE 4

EFFECT OF TOLERANCE LEVELS IN CALCFX

Tight Tolerances in THERM (10^{-6})

Data Set	Mode	CALCFX Tolerances	No. of Iterations	No. of Function Evaluations	Thrust (lbs)	Comments
A	1	10^{-3}	4	64	4238.93	
A	1	10^{-6}	3	43	4236.04	
A	1	10^{-8}	3	44	4236.04	
B	2	10^{-3}	6	132	14905.35	
B	3	10^{-3}	3	74	17557.05	17669 lbs thrust achieved during iteration
B	4	10^{-3}	3	70	22641.04	22672 lbs thrust achieved during iteration
B	5	10^{-3}	5	86	25480.97	
B	6	10^{-3}	6	133	27731.79	
B	2	10^{-6}	3	65	14896.00	Final thrust achieved at iteration (2,34)
B	3	10^{-6}	3	76	17574.77	Final thrust achieved at iteration (1,21)
B	4	10^{-6}	8	2[illegible]5	22745.71	Final thrust achieved at iteration (7,181)
B	5	10^{-6}	14	298	25595.05	Final thrust achieved at iteration (9,180)
B	6	10^{-6}	2	68	27913.53	Final thrust achieved at iteration (1,43)
B	2	10^{-8}	3	65	14896.01	Final thrust achieved at iteration (2,34)
B	3	10^{-8}	5	108	17574.76	Final thrust achieved at iteration (1,21)
B	4	10^{-8}	9	241	22744.93	Final thrust achieved at iteration (8,210)
B	5	10^{-8}	4	75	25586.29	Final thrust achieved at iteration (1,36)
B	6	10^{-8}	2	68	27913.53	Final thrust achieved at iteration (1,43)

3. The tightening of tolerances used by CALCFX from 10^{-3} to 10^{-6} has a noticeable effect on performance index.* The largest change occurs in the second significant digit of the MODE = 4 input case of Data Set B.

   The further tightening of the tolerances to 10^{-8} had virtually no impact on the solution except for the MODE = 5 input case in which the iteration simply terminated earlier at a slightly smaller value of thrust. After the same number of iterations and function evaluations with a tolerance level of 10^{-6}, the iterator had achieved the same thrust as that of the converged value for a tolerance level of 10^{-8}. Again, this is a case in which slight differences in the value of the performance index can significantly alter the outer loop iteration sequence.

4. The effect of tolerance levels used by CALCFX on the number of iterations and function evaluations required for convergence is unpredictable. A review of the iteration histories indicated that the first occurrence of the final thrust (to five significant digits) is achieved in most cases several iterations and function evaluations prior to the determination of convergence. The point in the iteration sequence where this occurs is given under the "Comments" heading for several of the cases. The two numbers enclosed in parentheses and separated by a comma denote the number of iterations and number of function evaluations, in that order, where the final thrust is achieved. Note that, for a given mode, these numbers are identical for CALCFX tolerances of 10^{-6} and 10^{-8} except for the MODE = 5 case discussed above. Similar numbers are not shown for the tolerance level of 10^{-3} because noise in the calculations rendered any such analysis meaningless. As noted in the Comments, some intermediate iterations for a tolerance level of 10^{-3} yielded values of thrust that substantially exceeded the final converged value. This is almost certainly due to noise in the calculations.

It is concluded from the preceding observations that tightening tolerances used by subroutine CALCFX from the default values of 10^{-3} to a level of 10^{-6} will substantially reduce noise in the computations. However, doing this will not necessarily reduce the number of iterations and function evaluations required for convergence. It is recommended that attention be given to the convergence criteria of the outer loop iteration for the purpose of more rapidly determining that convergence has been achieved. The tolerance levels in subroutine THERM appear to have little impact on convergence using the Principal Axis Method. However, if this direct iteration technique were to be replaced with an indirect method, it is believed that the samll noise introduced by the loose tolerances in THERM may then impede convergence.

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* This effect was noted previously in the Final Progress Report of a Naval Air Development Center study for NASA Lewis Research Center on Optimization Methods for the Navy/NASA Gas Turbine Engine Code, NASA Defense Procurement Request PR 782875.

During the course of the study, a revised version of the Principal Axis Method iterator was supplied by the Technical Officer with instructions to investigate its apparent improved convergence characteristics. The primary difference in the new algorithm is the use of a least squares quadratic curve fit of four points to locate the performance index minimum along the line search of the outer loop iteration. The objective of this modification is to minimize the effects of noise in the outer loop iteration. The revised iterator was installed on the IBM 360, Model 91 computer at NASA GSFC and, after eliminating problems arising from the failure to explicitly initialize certain arrays, successful execution of the program was achieved. Testing of the revised iterator was performed using the Data Set B input cases.

The five optimization cases of Data Set B were executed with various combinations of tolerance levels in subroutines THERM and CALCFX and the results are tabulated in Table 5. As predicted, convergence with the revised iterator was repeatedly achieved in substantially fewer iterations and function evaluations than required by the original iterator. It was noted, however, that the final value of thrust achieved with the revised iterator was routinely less than that obtained with the original iterator. In one case (MODE = 4), the difference was eight percent. This suggests that the reduced computational requirements may simply be a result of an early termination of the iteration process. A direct comparison of the performance of the two iterators was made by tabulating the maximum thrust achieved with the original iterator within the number of function evaluations required for convergence with the revised iterator. These values of thrust are presented in the last column of Table 5. It is seen that these values are consistently higher than the final values achieved with the revised iterator. The values shown in the last column of Table 5 are within 0.8 percent of the converged values obtained with the original iterator. The conclusion to be drawn from these results is that the performance of the original iterator is better than that of the revised iterator. Therefore, it is recommended that the original iterator be retained and that the number of iterations and function evaluations be reduced by relaxing the convergence criteria or through improved convergence detection techniques that may be identified through additional research with the algorithm.

TABEL 5

PERFORMANCE OF MODIFIED ITERATOR WITH LEAST SQUARES FIT

Data Set B

Mode	THERM Tolerance	CALCFX Tolerance	No. of Iterations	No. of Function Evaluations	Thrust (lbs)	Thrust Acheived by Original Iterator *
2	Nominal	10^{-3}	1	35	14309.96	14878
3	Nominal	10^{-3}	1	33	17574.77	17626
4	Nominal	10^{-3}	3	71	21061.60	22039
5	Nominal	10^{-3}	3	92	25275.46	25481
6	Nominal	10^{-3}	1	37	27445.12	27654
2	Nominal	10^{-6}	1	33	14314.65	14895
3	Nominal	10^{-6}	1	34	17574.14	17574
4	Nominal	10^{-6}	3	71	21060.93	22679
5	Nominal	10^{-6}	1	54	25275.18	25586
2	10^{-10}	10^{-3}	1	35	14310.10	14889
3	10^{-10}	10^{-3}	1	33	17575.44	17627
4	10^{-10}	10^{-3}	3	71	21062.32	22672
5	10^{-10}	10^{-3}	3	92	25275.31	25481
6	10^{-10}	10^{-3}	1	37	27438.64	27657
2	10^{-10}	10^{-6}	1	33	14315.00	14896
3	10^{-10}	10^{-6}	1	34	17574.59	17575
4	10^{-10}	10^{-6}	3	72	21061.15	22700
5	10^{-10}	10^{-6}	1	54	25275.03	25586
6	10^{-10}	10^{-6}	1	36	27432.57	27700

* Maximum value achieved within the number of iterations and function evaluations required for convergence with modified iterator.

CONCLUSIONS

As a result of the analyses performed and supporting data generated in the study, the following conclusions are drawn:

1. The only modelling discontinuities and corners identified in the code were minor and are located in subroutine THERM. Tables of coefficients used in cubic polynomials are stored to seven or eight significant digits in internal DATA arrays. At tabular points in the independent variable, the use of successive entries in the coefficient tables can lead to discontinuities in the evaluated function and first derivative in the seventh or higher significant digit. The retention of more significant digits in the coefficient tables can virtually eliminate the discontinuities at no additional cost in computer time.

2. The principal source of computational noise, as it affects the performance of the Principal Axis Method iterator, is the tolerances to which the control equations are satisfied on each funtion evaluation. The default values of the tolerances, which are 1×10^{-3}, lead to inaccuracies in the performance index in the third or higher significant digit. In a sequence of function evaluations, these inaccuracies appear to act more as a bias than as pure noise. Consequently, the convergence characteristics are, on the average, not substantially different from those achieved with tighter tolerances. Rather, the effect is to converge on different values of the independent variables which yield a slightly different value of the performance index. The error in performance index due to loose tolerances in satisfying the control equations can be positive or negative and the magnitude can exceed the differences in performance index evaluated at the different values of independent variables. Therefore, it is possible that the solution with loose tolerances can appear better than that achieved with tight tolerances, but this more favorable result is erroneous and can not be achieved in fact. It is recommended that the default tolerances be overridden for each control variable through program input in either the SPCNTL or SPEC arrays contained in the namelist D input data set. It is recommended that the tolerances be input no greater than 1×10^{-6}.

3. The tolerances used in the inner loop iterations in the engine component subroutines and in subroutine THERM appear adequate for use with the Principal Axis Method iterator. No computational noise was observed in varying the tolerances of the engine component subroutines; slight noise was observed in varying the tolerances in THERM. Tightening the tolerances in THERM is recommended in any implementations of an indirect optimization technique.

APPENDIX A

Source Code Cross Reference Reports

TABLE A-1

PROGRAM SUBROUTINE INFORMATION

```
        MAIN
REFERENCED SUB-PROGRAMS
 NEPCAL   GONEP    BOTM     BOTM2    FINPRT   NEPINP
REFERENCED COMMONS
 DBL      SNGL     NEPOPT   CANTRL

        SUBROUTINE   NEPCAL
REFERENCED SUB-PROGRAMS
 SYSOBF   INPUT    FLOCAL   FINPRT   DMINV
REFERENCED COMMONS
 DBL      SNGL     NEPOPT   CANTRL   INSTAL
 ENTRY POINTS
 NEPINP   GONEP

        SUBROUTINE   BOTM
CALLING ARGUMENT
 X,E,N,EF,ESCALE,IPRINT,ICON,MAXIT,W
REFERENCED SUB-PROGRAMS
 CALCFX   LSTCPT
REFERENCED COMMONS
 NEPOPT

        SUBROUTINE   BOTM2
CALLING ARGUMENT
 X,E,N,EF,ESCALE,IPRINT,ICON,MAXIT,W
REFERENCED SUB-PROGRAMS
 CALCFX   ZTOPZ
REFERENCED COMMONS
 NEPOPT

        SUBROUTINE   CALCFX
CALLING ARGUMENT
 NOPT,X,DEP
REFERENCED SUB-PROGRAMS
 GONEP    LSTCPT   EXIT
REFERENCED COMMONS
 DBL      SNGL     NEPOPT

        SUBROUTINE   COMPRS
REFERENCED SUB-PROGRAMS
 TLCOK    THERM
REFERENCED COMMONS
 DBL      SNGL

        SUBROUTINE   CONFIG
REFERENCED SUB-PROGRAMS
 INPRT
REFERENCED COMMONS
```

```
DBL        SNGL


       SUBROUTINE    COOLIT
CALLING ARGUMENT
 NSTAGE,FACTOR,TIN,TOUT,TCOOL,PCBLED
REFERENCED COMMONS
 JBLEED


       SUBROUTINE    DBURNR
REFERENCED SUB-PROGRAMS
 TLOOK    THERM
REFERENCED COMMONS
 DBL       SNGL


       SUBROUTINE    FIGURE
CALLING ARGUMENT
 JTYPE,JFLOW,JCONF


       SUBROUTINE    FLOCAL
CALLING ARGUMENT
 IGET,SS,EROR
REFERENCED SUB-PROGRAMS
 TLOOK    INLET    DBURNR   WINJEK   COMPRS   TURBIN   HEATXC   SPLITR
 MIXER    NOZZLE
REFERENCED COMMONS
 DBL       SNGL      JBLEED   INSTAL


       SUBROUTINE    HEATXC
CALLING ARGUMENT
 I
REFERENCED SUB-PROGRAMS
 TLOOK    THERM
REFERENCED COMMONS
 DBL       SNGL


       SUBROUTINE    INLET
REFERENCED SUB-PROGRAMS
 THERM    TLOOK
REFERENCED COMMONS
 DBL       SNGL


       SUBROUTINE    INPRT
REFERENCED SUB-PROGRAMS
 SYSUBF   SUMERY
REFERENCED COMMONS
 DBL       SNGL      CANTRL   JBLEED
 ENTRY POINTS
 FINPRT


       SUBROUTINE    INPUT
CALLING ARGUMENT
 MADE
```

```
REFERENCED SUB-PROGRAMS
 NAMEPR  TREAD   CONFIG  FIGURE  INPRT
REFERENCED COMMONS
 DBL      SNGL     NEPOPT  INSTAL  EMODID  CANTRL  JBLEED


      SUBROUTINE   LSTOPT
REFERENCED COMMONS
 DBL      SNGL


      SUBROUTINE   DMINV
CALLING ARGUMENT
 A,N,D,L,M


      SUBROUTINE   MIXER
REFERENCED SUB-PROGRAMS
 THERM
REFERENCED COMMONS
 DBL      SNGL


      SUBROUTINE   NAMEPR
CALLING ARGUMENT
 IN,NOUT,NREAD,PINPUT
REFERENCED SUB-PROGRAMS
 CONVRT


      SUBROUTINE   NOZZLE
REFERENCED SUB-PROGRAMS
 THERM    TLOOK
REFERENCED COMMONS
 DBL      SNGL     INSTAL


      SUBROUTINE   SPLITR
REFERENCED COMMONS
 DBL      SNGL


      FUNCTION     SPLN01
CALLING ARGUMENT
 NLOC,X,XINDEP


      FUNCTION     THERM
CALLING ARGUMENT
 IC,ARG,FACLD


      SUBROUTINE   TREAD
CALLING ARGUMENT
 II,X,Y,Z,FXYZ
REFERENCED SUB-PROGRAMS
 SPLN01
REFERENCED COMMONS
 DBL      SNGL
 ENTRY POINTS
```

```
TLOOK


      SUBROUTINE   TURBIN
REFERENCED SUB-PROGRAMS
 THERM   TLOCK    COOLIT
REFERENCED COMMONS
 DBL      SNGL      JBLEED


      SUBROUTINE   WINJEK
REFERENCED SUB-PROGRAMS
 THERM
REFERENCED COMMONS
 DBL      SNGL


      SUBROUTINE   ZTOPZ
CALLING ARGUMENT
 NRUN,X,XE,NX,EP,TOL,VALID,NGRD,KTOP,MAXPRT
REFERENCED SUB-PROGRAMS
 LSTOPT


      SUBROUTINE   CONVRT
REFERENCED SUB-PROGRAMS
 EXIT
REFERENCED COMMONS
 EMODID   CANTRL


      SUBROUTINE   SUMERY
REFERENCED COMMONS
 EMODID   DBL      SNGL      INSTAL
```

TABLE A-2

PROGRAM ENTRY POINTS

ENTRY POINT SUMMARY

ENTRY	SUB-PROGRAM
NEPINP	NEPCAL
GCNEP	NEPCAL
FINPRT	INPRT
TLOOK	TREAD

TABLE A-3

SUBROUTINE CROSS REFERENCE TABLE

NAME	SUBROUTINES REFERENCING MEMBER						
BOTM	MAIN						
BOTM2	MAIN						
CALCFX	BOTM	BOTM2					
COMPRS	FLOCAL						
CONFIG	INPUT						
CONVRT	NAMEPR						
COOLIT	TURBIN						
DBURNR	FLOCAL						
DMINV	NEPCAL						
EXIT	CALCFX	CONVRT					
FIGURE	INPUT						
FINPRT	MAIN	NEPCAL					
FLOCAL	NEPCAL						
GONEP	CALCFX	MAIN					
HEATXC	FLOCAL						
INLET	FLOCAL						
INPRT	CONFIG	INPUT					
INPUT	NEPCAL						
LSTOPT	BOTM	CALCFX	ZTOPZ				
MIXER	FLOCAL						
NAMEPR	INPUT						
NEPCAL	MAIN						
NEPINP	MAIN						
NOZZLE	FLOCAL						
SPLITR	FLOCAL						
SPLNQ1	TREAD						
SUMERY	INPRT						
SYSOBF	INPRT	NEPCAL					
THERM	COMPRS	DBURNR	HEATXC	INLET	MIXER	NOZZLE	TURBIN
	WINJEK						
TLCCK	COMPRS	DBURNR	FLOCAL	HEATXC	INLET	NOZZLE	TURBIN
TREAD	INPUT						
TURBIN	FLOCAL						
WINJEK	FLOCAL						
ZTOPZ	BOTM2						

TABLE A-4

COMMON CROSS REFERENCE TABLE

NAME	SUBROUTINES REFERENCING MEMBER					
CANTRL	CONVRT	INPRT	INPUT	MAIN	NEPCAL		
CBL	CALCFX	COMPRS	CONFIG	DBURNR	FLOCAL	HEATXC	INLET
	INPRT	INPUT	LSTOPT	MAIN	MIXER	NEFCAL	NOZZLE
	SPLITR	SUMERY	TREAD	TURBIN	WINJEK		
EMODID	CONVRT	INPUT	SUMERY				
INSTAL	FLOCAL	INPUT	NEPCAL	NOZZLE	SUMERY		
JBLEED	COOLIT	FLOCAL	INPRT	INPUT	TURBIN		
NEPOPT	BOTM	BOTM2	CALCFX	INPUT	MAIN	NEFCAL	
SNGL	CALCFX	COMPRS	CONFIG	DBURNR	FLOCAL	HEATXC	INLET
	INPRT	INPUT	LSTOPT	MAIN	MIXER	NEFCAL	NOZZLE
	SPLITR	SUMERY	TREAD	TURBIN	WINJEK		

TABLE A-5

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON DBL LENGTH 14584

VARIABLE	TYPE	ADDR	SUBROUTINE
DATINP	R*8	0	MAIN
			INLET
			INPRT
			INPUT
			MIXER
			CALCFX
			COMPRS
			CBURNR
			FLOCAL
			HEATXC
			LSTOPT
			NEFCAL
			NOZZLE
			SPLITR
			SUMERY
			TURBIN
			WINJEK
DATOUT	R*8	7200	INLET
			INPRT
			INPUT
			MIXER
			CALCFX
			COMPRS
			CBURNR
			FLOCAL
			HEATXC
			LSTOPT
			NOZZLE
			SPLITR
			SUMERY
			TURBIN
			WINJEK
WTF	R*8	11520	INLET
			INPRT
			INPUT
			MIXER
			CALCFX
			COMPRS
			CBURNR
			FLOCAL
			HEATXC
			LSTOPT
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
TOPRES	R*8	11840	INLET
			INPRT

COMMON DSL (CONTINUED)

VARIABLE	TYPE	ADDR	SUBROUTINE
			MIXER
			COMPRS
			CBURNR
			FLECAL
			HEATXC
			LSTOPT
			NOZZLE
			SPLITR
			SUMERY
			TURBIN
			WINJEK
TOTEMP	R*8	12160	INLET
			INPRT
			MIXER
			COMPRS
			CBURNR
			HEATXC
			LSTOPT
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
FAR	R*8	12480	INLET
			INPRT
			MIXER
			COMPRS
			CBURNR
			HEATXC
			LSTOPT
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
CORFLO	R*8	12800	INLET
			INPRT
			MIXER
			COMPRS
			CBURNR
			FLECAL
			HEATXC
			LSTOPT
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
VMACH	R*8	13120	INLET
			INPRT
			MIXER
			LSTOPT
			NOZZLE
			WINJEK

COMMON DBL (CONTINUED)

VARIABLE	TYPE	ADDR	SUBROUTINE
STATP	R*8	13448	INPRT
			MIXER
			LSTOPT
			NOZZLE
ERROR	R*8	13768	INPRT
			FLCCAL
			LSTOPT
TOL	R*8	14088	NEFCAL
TOLTT	R*8	14096	NEFCAL
DERV	R*8	14104	INPUT
			FLCCAL
			NEFCAL
DTOL	R*8	14264	FLCCAL
			NEFCAL
PERRF	R*8	14424	INPRT
			INPUT
			CALCFX
			FLCCAL
			LSTOPT
			NEFCAL
			SUMERY

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON SNGL LENGTH 5360

VARIABLE	TYPE	ADDR	SUBROUTINE
JM1	I*4	0	INLET
			MIXER
			COMPRS
			CBURNR
			FLOCAL
			HEATXC
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
JM2	I*4	4	MIXER
			CBURNR
			FLOCAL
			HEATXC
			TURBIN
JP1	I*4	8	INLET
			MIXER
			COMPRS
			CONFIG
			CBURNR
			FLOCAL
			HEATXC
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
JP2	I*4	12	COMPRS
			CBURNR
			FLOCAL
			HEATXC
			SPLITR
JCX	I*4	16	MAIN
			INLET
			INPRT
			MIXER
			CALCFX
			COMPRS
			CONFIG
			CBURNR
			FLOCAL
			HEATXC
			NEFCAL
			NOZZLE
			SPLITR
			TURBIN
			WINJEK
LOCTBL	I*4	20	INLET
			COMPRS

COMMON SNGL (CONTINUED)

VARIABLE	TYPE	ADDR	SUBROUTINE
			CBURNR
			FLCCAL
			HEATXC
			NEFCAL
			NOZZLE
			TURBIN
JCCMP	I*4	2180	INPUT
			CONFIG
			FLCCAL
IWAY	I*4	2460	MAIN
			INPRT
			INPUT
			CBURNR
			FLCCAL
			NEFCAL
			NOZZLE
			TURBIN
NIT	I*4	2464	INPRT
			INPUT
			CALCFX
			LSTOPT
			NEFCAL
			TURBIN
ITAB	I*4	2468	TREAD
			NEFCAL
JCCNF	I*4	2748	INPRT
			INPUT
			CALCFX
			CCNFIG
			FLCCAL
			HEATXC
			NEFCAL
JTYPE	I*4	3708	INPRT
			INPUT
			CCNFIG
			FLCCAL
			LSTOPT
			TURBIN
JFLOW	I*4	3948	MAIN
			INPUT
			CCNFIG
			FLCCAL
			HEATXC
IDEDAP	I*4	4228	INPRT
			INPUT
			NEFCAL
KKINDS	I*4	4288	MAIN
			INPRT
			INPUT
			CALCFX
			CONFIG

COMMON SNGL (CONTINUED)

VARIABLE	TYPE	ADDR	SUBROUTINE
			FLCCAL
			NEPCAL
			SUPERY
NCCMP	I*4	5688	INPRT
			INPUT
			CONFIG
			FLCCAL
			LSTOPT
			NEPCAL
NOSTAT	I*4	5692	INPRT
			INPUT
			CONFIG
			LSTOPT
NITER	I*4	5696	NEPCAL
NFINIS	I*4	5700	INPRT
			CALCFX
			FLCCAL
			LSTOPT
			NEPCAL
NPASS	I*4	5704	INPRT
			FLCCAL
			LSTOPT
			NEPCAL
JCC	I*4	5708	MAIN
			INPUT
			CONFIG
			FLCCAL
NTBL	I*4	5712	TREAD
			NEPCAL
NCTS	I*4	5716	INPRT
			CONFIG
			FLCCAL
			NEPCAL
JCIND	I*4	5720	NEPCAL
JCDEP	I*4	5800	FLCCAL
			NEPCAL
JCVIND	I*4	5880	NEPCAL
JCVDEP	I*4	5960	FLCCAL
			NEPCAL
KDTYP	I*4	6040	FLCCAL
			NEPCAL
IDONE	I*4	6120	MAIN
			INPUT
			MIXER
			COMPRS
			DBURNR
			FLCCAL
			NOZZLE
			TURBIN

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON CANTRL LENGTH 20

VARIABLE	TYPE	ADDR	SUBROUTINE
LONG	L*4	0	MAIN
			INPRT
			INPUT
			CONVRT
			NEFCAL
PUNT	L*4	4	MAIN
			INPRT
			INPUT
			CONVRT
			NEFCAL
NCASE	I*4	8	INPRT
			INPUT
			NEFCAL
NCODE	I*4	12	MAIN
			INPRT
			INPUT
			NEFCAL
AMAC	L*4	16	MAIN
			INPRT
			INPUT
			CONVRT
			NEFCAL

```
COMMON VARIABLE CROSS REFERENCE TABLE

COMMON  SMODID          LENGTH        8

VARIABLE    TYPE       ADDR   SUBROUTINE
 SEPDAT     R*4          4      CONVRT
```

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON SMODIL LENGTH 16

VARIABLE	TYPE	ADDR	SUBROUTINE
SERDAT	R*8	0	INPUT
			SUMERY
GPMCDE	R*8	8	INPUT
			SUMERY

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON INSTAL LENGTH 260

VARIABLE	TYPE	ADDR	SUBROUTINE
AEXN	R*8	0	FLCCAL
			NOZZLE
AMINDS	R*8	8	INPUT
			FLCCAL
BLMAX	R*8	16	INPUT
			FLCCAL
BRMAX	R*8	24	INPUT
			FLCCAL
SPLDES	R*8	32	INPUT
			FLCCAL
DBCAT	R*8	40	FLCCAL
DLIP	R*8	48	FLCCAL
DSPIL	R*8	56	FLCCAL
AFACTR	R*8	64	FLCCAL
DEN	R*8	72	FLCCAL
AZER	R*8	80	FLCCAL
FBL	R*8	88	FLCCAL
AZACAP	R*8	104	FLCCAL
FSPIL	R*8	112	FLCCAL
AMAXEN	R*8	120	FLCCAL
ACAPT	R*8	128	FLCCAL
AENT	R*8	136	FLCCAL
AMAXFT	R*8	144	FLCCAL
AEXIT	R*8	152	FLCCAL
			SUMERY
CMF	R*8	160	FLCCAL
AMPK	R*8	168	FLCCAL
CMPK	R*8	176	FLCCAL
CMS	R*8	184	FLCCAL
CDSPL	R*8	192	FLCCAL
CDBL	R*8	200	FLCCAL
QQ	R*8	216	FLCCAL
CDLP	R*8	224	FLCCAL
AR	R*8	232	FLCCAL
CDBT	R*8	240	FLCCAL
SPILL	L*4	248	INPUT
			FLCCAL
			NEFCAL
			NOZZLE
			SUMERY
BDAT	L*4	252	INPUT
			FLCCAL
			NEFCAL
			NOZZLE
			SUMERY
INLTDS	L*4	256	INPUT
			FLCCAL
			NEFCAL

```
COMMON  INSTAL (CONTINUED)

VARIABLE    TYPE       ADDR    SUBROUTINE
                                NOZZLE
                                SUMERY
```

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON [illegible] LENGTH 28

VARIABLE	TYPE	ADDR	SUBROUTINE
SUMBLD	R*8	0	FLCCAL
			TURBIN
YEAR	R*8	8	INPUT
			COCLIT
ELIFE	R*8	16	INPUT
			COCLIT
CALBLD	L*4	24	INPRT
			INPUT
			COCLIT
			FLCCAL
			TURBIN

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON NEPORT LENGTH 68

VARIABLE	TYPE	ADDR	SUBROUTINE
DEBUG	R*8	0	MAIN
			INPUT
			CALCFX
DEPO	R*8	8	CALCFX
			NEPCAL
SELAST	R*8	16	CALCFX
			NEPCAL
DD	R*8	24	BCTM
			CALCFX
NDSET	I*4	32	BCTM
			CALCFX
NPARTS	I*4	36	CALCFX
			NEPCAL
ESCALE	R*8	40	MAIN
			INPUT
NPASSO	I*4	48	MAIN
			BCTM2
			CALCFX
NVOPT	I*4	52	MAIN
			INPUT
			CALCFX
			NEPCAL
NJOPT	I*4	56	INPUT
			CALCFX
BOTM	L*4	60	INPUT
			CALCFX
			NEPCAL
BCTMM	L*4	60	BCTM
			MAIN
			BCTM2
TOPZ	L*4	64	BOTM
			MAIN
			BCTM2
			INPUT
			CALCFX
			NEPCAL

APPENDIX B

Input Data Sets

TABLE B-1

DATA SET A

NAMELIST INPUTS

```
TEST ENGINE FOR CSI
&D NMODES=1,DRAW=T &END
&D MODE=1,DEBUG=1,
KONFIG(1,1)='INLT',1.0,2.0,SPEC(1,1)=100,4*0,1.0,
KONFIG(1,2)='COMP',2.0,3.0,SPEC(1,2)=1.2.0,1,3707,1,3708,
1,3709,3*0.,.90,8,1,
KONFIG(1,3)='DUCT',3.0,4.0,SPEC(1,3)=.05,0,0.2800,1.0,18300,
KONFIG(1,4)='TURB',4.0,5.0,SPEC(1,4)=3.5,1,1,3801,1,3802,1,
1,0,1,.9,5600,1,
KONFIG(1,5)='NOZZ',5.0,6.0,SPEC(1,5)=0,1,0,0,.985,1,0,0,1,
KONFIG(1,6)='CNTL',SPCNTL(1,6)=1,4,'STAP',8,5,0,1,0.,0.,
KONFIG(1,7)='CNTL',SPCNTL(1,7)=1,2,'STAP',8,4,0,1,1.1,2.0,
KONFIG(1,8)='CNTL',SPCNTL(1,8)=1,1,'STAP',8,2,0,1,0.,0.,
KONFIG(1,9)='CNTL',SPCNTL(1,9)=1,10,'DCUT',8,10,0,1,0.,0.,
KONFIG(1,10)='SHFT',2,4,0,0,SPEC(1,10)=5600.,8*1.,
KONFIG(1,11)='OPTV',0,0,5,0,SPEC(1,11)=3*0,1,4*0,1,
KONFIG(1,12)='OPTV',0,0,3,0,SPEC(1,12)=0,0,3000,4,4*0,1,
KONFIG(1,13)='LIMV',SPLIMV(1,13)=0,.7,1.1,'DCUT',6,2,0,0,1,
&END
&D ALTF=30000,MACH=0.6,LABEL=T,
&END
MACH 0.6 AT 30000 FEET - NO OPTIMIZATION
&D NVOPT=-4 &END
OPTIMIZE THE PREVIOUS CASE
&D ENDIT=1 &END
```

TABLE B-2

DATA SET A

GAS PROPERTY TABLES

3707		HPC FLOW WITH VARIABLE STATORS						0
ANGL	3	-5.00	0.00	10.00				
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
FLOW	7	0.1520	0.1580	0.1640	0.1730	0.1820	0.1840	0.1840
FLOW	7	0.1910	0.1960	0.2060	0.2140	0.2210	0.2250	0.2260
FLOW	7	0.2330	0.2440	0.2500	0.2550	0.2580	0.2600	0.2610
FLOW	7	0.2690	0.2840	0.2930	0.3000	0.3040	0.3050	0.3060
FLOW	7	0.3080	0.3230	0.3350	0.3480	0.3530	0.3550	0.3560
FLOW	7	0.3490	0.3820	0.3930	0.4080	0.4170	0.4210	0.4240
FLOW	7	0.4240	0.4380	0.4540	0.4700	0.4770	0.4800	0.4810
FLOW	7	0.4580	0.4720	0.4860	0.5020	0.5100	0.5140	0.5160
FLOW	7	0.4880	0.5030	0.5160	0.5300	0.5370	0.5410	0.5440
FLOW	7	0.5240	0.5350	0.5510	0.5660	0.5750	0.5780	0.5800
FLOW	7	0.5580	0.5710	0.5850	0.6020	0.6090	0.6110	0.6150
FLOW	7	0.6430	0.6550	0.6680	0.6800	0.6850	0.6890	0.6910
FLOW	7	0.7120	0.7250	0.7350	0.7480	0.7510	0.7530	0.7540
FLOW	7	0.7860	0.7950	0.8040	0.8090	0.8100	0.8100	0.8100
FLOW	7	0.8600	0.8600	0.8600	0.8600	0.8600	0.8600	0.8600
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
FLOW	7	0.3520	0.3580	0.3640	0.3730	0.3820	0.3840	0.3840
FLOW	7	0.3910	0.3960	0.4060	0.4140	0.4210	0.4250	0.4260
FLOW	7	0.4330	0.4440	0.4500	0.4550	0.4580	0.4600	0.4610
FLOW	7	0.4690	0.4840	0.4930	0.5000	0.5040	0.5050	0.5060
FLOW	7	0.5080	0.5230	0.5350	0.5480	0.5530	0.5550	0.5560
FLOW	7	0.5690	0.5820	0.5930	0.6080	0.6170	0.6210	0.6240
FLOW	7	0.6240	0.6380	0.6540	0.6700	0.6770	0.6800	0.6810
FLOW	7	0.6580	0.6720	0.6860	0.7020	0.7100	0.7140	0.7160
FLOW	7	0.6880	0.7030	0.7160	0.7300	0.7370	0.7410	0.7440
FLOW	7	0.7240	0.7350	0.7510	0.7660	0.7750	0.7780	0.7800
FLOW	7	0.7580	0.7710	0.7850	0.8020	0.8090	0.8110	0.8150
FLOW	7	0.8430	0.8550	0.8680	0.8800	0.8850	0.8890	0.8910
FLOW	7	0.9120	0.9250	0.9350	0.9480	0.9510	0.9530	0.9540
FLOW	7	0.9860	0.9950	1.0040	1.0090	1.0100	1.0100	1.0100
FLOW	7	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
FLOW	7	0.7520	0.7580	0.7640	0.7730	0.7820	0.7840	0.7840
FLOW	7	0.7910	0.7960	0.8060	0.8140	0.8210	0.8250	0.8260
FLOW	7	0.8330	0.8440	0.8500	0.8550	0.8580	0.8600	0.8610
FLOW	7	0.8690	0.8840	0.8930	0.9000	0.9040	0.9050	0.9060

TABLE B-2 (CONT.)

FLOW	7	0.9080	0.9230	0.9350	0.9480	0.9530	0.9550	0.9560
FLOW	7	0.9693	0.9820	0.9930	1.0080	1.0170	1.0210	1.0240
FLOW	7	1.0240	1.0380	1.0540	1.0700	1.0770	1.0800	1.0810
FLOW	7	1.0580	1.0720	1.0860	1.1020	1.1100	1.1140	1.1160
FLOW	7	1.0880	1.1030	1.1160	1.1300	1.1370	1.1410	1.1440
FLOW	7	1.1240	1.1350	1.1510	1.1660	1.1750	1.1780	1.1800
FLOW	7	1.1580	1.1710	1.1850	1.2020	1.2090	1.2110	1.2150
FLOW	7	1.2430	1.2550	1.2680	1.2800	1.2850	1.2890	1.2910
FLOW	7	1.3120	1.3250	1.3350	1.3480	1.3510	1.3530	1.3540
FLOW	7	1.3860	1.3950	1.4040	1.4090	1.4100	1.4100	1.4100
FLOW	7	1.4600	1.4600	1.4600	1.4600	1.4600	1.4600	1.4600
EOT								
3708		HPC EFF WITH VARIABLE STATURS						0
ANGL	3	-5.00	0.00	10.00				
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
EFF	7	0.8775	0.8287	0.6981	0.5314	0.3315	0.1950	0.1950
EFF	7	0.9165	0.8853	0.8141	0.6435	0.4339	0.3071	0.2730
EFF	7	0.9301	0.9165	0.8609	0.7459	0.5216	0.2779	0.1755
EFF	7	0.9399	0.9301	0.8931	0.7917	0.6289	0.3900	0.2340
EFF	7	0.9487	0.9418	0.9194	0.8434	0.7264	0.5479	0.3120
EFF	7	0.9613	0.9545	0.9409	0.8824	0.7975	0.6776	0.5333
EFF	7	0.9711	0.9672	0.9574	0.9145	0.8463	0.7468	0.6191
EFF	7	0.9779	0.9730	0.9652	0.9262	0.8677	0.7693	0.6493
EFF	7	0.9818	0.9789	0.9721	0.9379	0.8804	0.7868	0.6640
EFF	7	0.9857	0.9838	0.9779	0.9467	0.8950	0.8092	0.6864
EFF	7	0.9886	0.9867	0.9828	0.9584	0.9077	0.8151	0.6922
EFF	7	0.9925	0.9896	0.9896	0.9701	0.9184	0.8336	0.7069
EFF	7	0.9896	0.9886	0.9857	0.9574	0.9067	0.8219	0.6825
EFF	7	0.9818	0.9760	0.9682	0.9331	0.8833	0.7956	0.6513
EFF	7	0.8950	0.8950	0.8863	0.8677	0.8317	0.7546	0.5918
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
EFF	7	0.9000	0.8500	0.7160	0.5450	0.3400	0.2000	0.2000
EFF	7	0.9400	0.9080	0.8350	0.6600	0.4450	0.3150	0.2800
EFF	7	0.9540	0.9400	0.8830	0.7650	0.5350	0.2850	0.1800
EFF	7	0.9640	0.9540	0.9160	0.8120	0.6450	0.4000	0.2400
EFF	7	0.9730	0.9660	0.9430	0.8650	0.7450	0.5620	0.3200
EFF	7	0.9860	0.9790	0.9650	0.9050	0.8180	0.6950	0.5470
EFF	7	0.9960	0.9920	0.9820	0.9380	0.8680	0.7660	0.6350
EFF	7	1.0030	0.9980	0.9900	0.9500	0.8900	0.7890	0.6660
EFF	7	1.0070	1.0040	0.9970	0.9620	0.9030	0.8070	0.6810
EFF	7	1.0110	1.0090	1.0030	0.9710	0.9130	0.8300	0.7040
EFF	7	1.0140	1.0120	1.0080	0.9830	0.9310	0.8360	0.7100
EFF	7	1.0180	1.0150	1.0150	0.9950	0.9420	0.8550	0.7250
EFF	7	1.0150	1.0140	1.0110	0.9820	0.9300	0.8430	0.7000
EFF	7	1.0070	1.0010	0.9930	0.9570	0.9060	0.8160	0.6680
EFF	7	0.9180	0.9180	0.9090	0.8930	0.8530	0.7740	0.6070

TABLE B-2 (CONT.)

SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
EFF	7	0.8550	0.8075	0.6802	0.5177	0.3230	0.1900	0.1900
EFF	7	0.8530	0.8626	0.7932	0.6270	0.4227	0.2993	0.2660
EFF	7	0.9063	0.8530	0.8388	0.7268	0.5082	0.2707	0.1710
EFF	7	0.9158	0.9063	0.8702	0.7714	0.6127	0.3800	0.2280
EFF	7	0.9244	0.9177	0.8959	0.8217	0.7077	0.5339	0.3040
EFF	7	0.9367	0.9301	0.9168	0.8597	0.7771	0.6603	0.5196
EFF	7	0.9462	0.9424	0.9329	0.8911	0.8246	0.7277	0.6032
EFF	7	0.9528	0.9481	0.9405	0.9025	0.8455	0.7495	0.6327
EFF	7	0.9567	0.9538	0.9471	0.9139	0.8579	0.7666	0.6470
EFF	7	0.9604	0.9585	0.9528	0.9224	0.8721	0.7885	0.6688
EFF	7	0.9633	0.9614	0.9576	0.9338	0.8845	0.7942	0.6745
EFF	7	0.9671	0.9642	0.9642	0.9452	0.8949	0.8122	0.6887
EFF	7	0.9642	0.9633	0.9604	0.9329	0.8835	0.8009	0.6650
EFF	7	0.9567	0.9509	0.9434	0.9092	0.8607	0.7752	0.6346
EFF	7	0.8721	0.8721	0.8636	0.8455	0.8104	0.7353	0.5766
EOT								
3709		HPC PR WITH VARIABLE STATORS						0
ANGL	3	-5.00	0.00	10.00				
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
PR	7	1.7135	1.6730	1.4894	1.3059	1.1017	1.0000	1.0000
PR	7	2.0600	1.9583	1.7900	1.5506	1.3159	1.1889	1.1529
PR	7	2.4371	2.2948	2.0806	1.8153	1.5300	1.3564	1.2806
PR	7	2.7330	2.5900	2.3759	2.0700	1.7747	1.5606	1.4436
PR	7	3.0489	2.8753	2.6818	2.3759	2.0600	1.7900	1.6271
PR	7	3.4871	3.2989	3.0894	2.7430	2.4018	2.0959	1.8665
PR	7	3.8748	3.7065	3.4871	3.1253	2.7330	2.3759	2.0853
PR	7	4.1089	3.9455	3.7012	3.3189	2.9212	2.5288	2.2130
PR	7	4.3283	4.1701	3.9154	3.4971	3.0642	2.6565	2.3047
PR	7	4.5930	4.4148	4.1494	3.7112	3.2630	2.8347	2.4424
PR	7	4.8583	4.6595	4.3895	3.9307	3.4565	2.9724	2.5701
PR	7	5.5360	5.2713	4.9601	4.4148	3.8794	3.3341	2.8447
PR	7	6.0866	5.7754	5.4289	4.8224	4.2259	3.6400	3.0642
PR	7	6.5654	6.2701	5.8931	5.2201	4.5577	3.8947	3.2836
PR	7	6.8613	6.7542	6.2954	5.5306	4.8377	4.1295	3.4618
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
PR	7	2.0730	2.0120	1.7360	1.4600	1.1530	1.0000	1.0000
PR	7	2.5540	2.4410	2.1860	1.8280	1.4750	1.2840	1.2300
PR	7	3.1610	2.9470	2.6250	2.2260	1.7970	1.5360	1.4220
PR	7	3.6360	3.3510	3.0690	2.6090	2.1350	1.8430	1.6670
PR	7	4.0810	3.8200	3.5290	3.0690	2.5940	2.1880	1.9430
PR	7	4.7400	4.4570	4.1420	3.6210	3.1080	2.6480	2.3030
PR	7	5.3230	5.0700	4.7400	4.1960	3.6060	3.0690	2.6320

TABLE B-2 (CONT.)

PR	7	5.6750	5.4300	5.0620	4.4870	3.8490	3.2990	2.8240
PR	7	6.0050	5.7670	5.3840	4.7550	4.1040	3.4910	2.9620
PR	7	6.4030	6.1350	5.7360	5.0770	4.4030	3.7590	3.1690
PR	7	6.8020	6.5030	6.0970	5.4070	4.6940	3.9660	3.3610
PR	7	7.8210	7.4230	6.9550	6.1350	5.3300	4.5100	3.7740
PR	7	8.6490	8.1810	7.6600	6.7480	5.8510	4.9700	4.1040
PR	7	9.3690	8.9250	8.3580	7.3460	6.3500	5.3530	4.4340
PR	7	9.8140	9.6530	8.9630	7.8130	6.7710	5.7060	4.7020
SPED	15	0.600	0.700	0.750	0.800	0.810	0.820	0.830
		0.840	0.850	0.860	0.870	0.900	0.935	0.985
		1.035						
R	7	1.000	1.050	1.150	1.300	1.450	1.600	1.750
PR	7	2.7919	2.6900	2.2291	1.7682	1.2555	1.0000	1.0000
PR	7	3.6620	3.4065	2.9840	2.3828	1.7932	1.4743	1.3841
PR	7	4.6089	4.2515	3.7137	3.0474	2.3310	1.8951	1.7047
PR	7	5.3520	4.9530	4.4552	3.6870	2.9455	2.4078	2.1139
PR	7	6.1453	5.7094	5.2234	4.4552	3.6620	2.9840	2.5748
PR	7	7.2458	6.7732	6.2471	5.3771	4.5204	3.7522	3.1760
PR	7	8.2194	7.7569	7.2458	6.3373	5.3520	4.4552	3.7254
PR	7	8.8072	8.3581	7.7835	6.8233	5.8246	4.8393	4.0461
PR	7	9.3583	8.9609	8.3213	7.2708	6.1837	5.1600	4.2765
PR	7	10.0230	9.5754	8.9091	7.8086	6.6830	5.6075	4.6222
PR	7	10.6893	10.1500	9.5120	8.3597	7.1690	5.9532	4.9429
PR	7	12.3911	11.7264	10.9448	9.5754	8.2311	6.8617	5.6326
PR	7	13.7738	12.9523	12.1222	10.5992	9.1012	7.6299	6.1837
PR	7	14.9762	14.2247	13.2879	11.5978	9.9345	8.2695	6.7348
PR	7	15.7194	15.4505	14.2982	12.3777	10.6376	8.8590	7.1823
ECT								
3801		HPT FLOW WITH VARIABLE AREA						0
AREA	3	0.50	1.00	1.50				
SPED	3	4523.0	5654.0	6685.0				
PR	14	1.000	1.300	1.500	1.600	1.800	2.000	2.200
		2.500	2.800	3.100	3.300	3.500	3.600	5.000
FLOW	14	0.000	7.650	8.550	8.887	9.313	9.575	9.730
		9.875	9.950	9.990	10.005	10.020	10.020	10.020
FLOW	14	0.000	7.887	8.550	8.787	9.112	9.350	9.520
		9.680	9.770	9.820	9.835	9.850	9.850	9.850
FLOW	14	0.000	8.112	8.563	8.750	9.020	9.225	9.375
		9.525	9.595	9.640	9.655	9.670	9.670	9.670
SPED	3	4523.0	5654.0	6685.0				
PR	14	1.000	1.300	1.500	1.600	1.800	2.000	2.200
		2.500	2.800	3.100	3.300	3.500	3.600	5.000
FLOW	14	0.000	15.300	17.100	17.775	18.625	19.150	19.460
		19.750	19.900	19.980	20.010	20.040	20.040	20.041
FLOW	14	0.000	15.775	17.100	17.575	18.225	18.700	19.040
		19.360	19.540	19.640	19.670	19.700	19.700	19.701
FLOW	14	0.000	16.225	17.125	17.500	18.040	18.450	18.750
		19.050	19.190	19.260	19.310	19.340	19.340	19.341
SPED	3	4523.0	5654.0	6685.0				
PR	14	1.000	1.300	1.500	1.600	1.800	2.000	2.200
		2.500	2.800	3.100	3.300	3.500	3.600	5.000
FLOW	14	0.000	22.550	25.650	26.662	27.338	28.725	29.190

TABLE B-2 (CONT.)

	29.625	29.850	29.970	30.015	30.060	30.060	30.061
FLOW 14	0.000	23.662	25.650	26.362	27.337	28.050	28.560
	29.040	29.310	29.460	29.505	29.550	29.550	29.551
FLOW 14	0.000	24.337	25.888	26.250	27.060	27.675	28.125
	28.575	28.785	28.920	28.965	29.010	29.010	29.011
EOT							
3802	HPT EFF WITH VARIABLE AREA						0
AREA 3	0.50	1.00	1.50				
SPED 4	4000.0	5000.0	5680.0	8000.0			
PR 14	1.000	1.250	1.750	2.000	2.150	2.380	2.500
	2.750	3.250	3.500	4.000	4.500	4.750	5.000
EFF 14	0.7533	0.7577	0.7661	0.7702	0.7723	0.7753	0.7771
	0.7805	0.7861	0.7884	0.7907	0.7911	0.7904	0.7893
EFF 14	0.7560	0.7645	0.7791	0.7852	0.7888	0.7925	0.7930
	0.7933	0.7937	0.7938	0.7922	0.7886	0.7860	0.7830
EFF 14	0.7560	0.7643	0.7783	0.7834	0.7861	0.7895	0.7913
	0.7940	0.7981	0.7993	0.8002	0.7989	0.7976	0.7956
EFF 14	0.7560	0.7640	0.7772	0.7819	0.7840	0.7853	0.7859
	0.7862	0.7855	0.7848	0.7834	0.7819	0.7810	0.7801
SPED 4	4000.0	5000.0	5680.0	8000.0			
PR 14	1.000	1.250	1.750	2.000	2.150	2.380	2.500
	2.750	3.250	3.500	4.000	4.500	4.750	5.000
EFF 14	0.8370	0.8419	0.8512	0.8557	0.8581	0.8615	0.8635
	0.8672	0.8734	0.8760	0.8786	0.8790	0.8782	0.8770
EFF 14	0.8400	0.8495	0.8657	0.8725	0.8765	0.8806	0.8811
	0.8815	0.8819	0.8820	0.8802	0.8762	0.8733	0.8700
EFF 14	0.8430	0.8492	0.8648	0.8705	0.8735	0.8772	0.8792
	0.8822	0.8867	0.8881	0.8891	0.8877	0.8862	0.8840
EFF 14	0.8400	0.8485	0.8636	0.8687	0.8711	0.8726	0.8732
	0.8736	0.8727	0.8720	0.8705	0.8688	0.8678	0.8668
SPED 4	4000.0	5000.0	5680.0	8000.0			
PR 14	1.000	1.250	1.750	2.000	2.150	2.380	2.500
	2.750	3.250	3.500	4.000	4.500	4.750	5.000
EFF 14	0.7533	0.7577	0.7661	0.7702	0.7723	0.7753	0.7771
	0.7805	0.7861	0.7884	0.7907	0.7911	0.7904	0.7893
EFF 14	0.7560	0.7645	0.7791	0.7852	0.7888	0.7925	0.7930
	0.7933	0.7937	0.7938	0.7922	0.7886	0.7860	0.7830
EFF 14	0.7560	0.7643	0.7783	0.7834	0.7861	0.7895	0.7913
	0.7940	0.7981	0.7993	0.8002	0.7989	0.7976	0.7956
EFF 14	0.7560	0.7640	0.7772	0.7819	0.7840	0.7853	0.7859
	0.7862	0.7855	0.7848	0.7834	0.7819	0.7810	0.7801
EOT							

TABLE B-3

DATA SET B

NAMELIST INPUTS

```
HAM STC FAN CN ACV T701
&D NMODES=6,SEPDAT=1,LONG=F,MODESN=1,DRAW=F,AMAC=F,ITPRT=0 &END
&D MODE=1,DEBUG=1,
KONFIG(1,1)=4HINLT,1,0,2,0,SPEC(1,1)=665.580,4*0,.992,SPEC(12,1)=31,
KONFIG(1,2)=4HCOMP,2,0,3,0,SPEC(1,2)=1.200,0,1,3951,1,3952,1,3953,0,-0,0,.885,
1.269,1.13,
KONFIG(1,3)=4HSPLT,3,0,12,15,SPEC(1,3)=.08194483,
KONFIG(1,15)=4HWINJ,15,0,4,0,SPEC(1,15)=0,.8,0,1,
KONFIG(1,4)=4HCOMP,4,0,5,6,SPEC(1,4)=1.310,.0876,1,3954,1,3955,1,3956,0,0,0,
.8280,11.88,.9538,
KONFIG(1,5)=4HDUCT,5,0,7,0,SPEC(1,5)=.050,0,0,2880,.9950,18400,0,0,0,.050,
KONFIG(1,6)=4HTURB,7,6,8,0,SPEC(1,6)=3.6306,1,1,9011,1,9012,1,1,.0574,1,.879,
10200,1,
KONFIG(1,7)=4HTURB,8,0,9,0,SPEC(1,7)=2.200,0,1,9013,1,9014,1,1,1,1,.887,13333,
1,
KONFIG(1,8)=4HDUCT,9,0,10,0,SPEC(1,8)=.0080,
KONFIG(1,9)=4HNOZZ,10,0,11,0,SPEC(1,9)=0,.84944,0,0,.98231,0,0,0,1,
KONFIG(1,10)=4HDUCT,12,0,13,0,SPEC(1,10)=.008,
KONFIG(1,11)=4HNOZZ,13,0,14,0,SPEC(1,11)=0,.94302,0,0,.98362,0,0,0,1,
KONFIG(1,12)=4HSHFT,6,4,14,0,SPEC(1,12)=13650,8*1,
KONFIG(1,13)=4HSHFT,2,7,0,0,SPEC(1,13)=13267,.3,3*1,.96,3*1,
KONFIG(1,14)=4HLOAD,SPEC(1,14)=-100,
KONFIG(1,20)=4HCNTL,SPCNTL(1,20)=1,7,4HSTAP,8,10,0,1,
KONFIG(1,21)=4HCNTL,SPCNTL(1,21)=1,6,4HSTAP,8,8,0,1,
KONFIG(1,22)=4HCNTL,SPCNTL(1,22)=1,4,4HSTAP,8,7,0,1,1.05,1.6,
KONFIG(1,23)=4HCNTL,SPCNTL(1,23)=1,3,4HSTAP,8,13,0,1,
KONFIG(1,24)=4HCNTL,SPCNTL(1,24)=1,2,4HSTAP,8,4,0,1,1.05,1.6,
KONFIG(1,25)=4HCNTL,SPCNTL(1,25)=1,1,4HSTAP,8,2,0,1,
KONFIG(1,26)=4HCNTL,SPCNTL(1,26)=1,12,4HDOUT,8,12,0,1,
KONFIG(1,27)=4HCNTL,SPCNTL(1,27)=1,13,4HDOUT,8,13,0,1,
KONFIG(1,28)=4HLINV,SPLINV(1,28)=0,0.7,1,10,4HDOUT,6,2,0,0,1,
KONFIG(1,29)=4HLINV,SPLINV(1,29)=0,0.6,1,1,4HDOUT,6,4,0,0,1,
KONFIG(1,30)=4HOPTV,0,0,2,0,SPEC(1,30)=0,-6,5,10,4*0,.01,
KONFIG(1,31)=4HOPTV,0,0,5,0,SPEC(1,31)=0,0,2880,4,4*0,1,
KONFIG(1,32)=4HOPTV,0,0,11,0,SPEC(1,32)=0,0,0,1,4*0,1,
KONFIG(1,33)=4HCNTL,SPCNTL(1,33)=4,5,4HDOUT,6,2,1,15,0,,
&END
&D MODE=2,
KONFIG(1,1)=4HINLT,1,0,2,0,
KONFIG(1,2)=4HCOMP,2,0,3,0,
KONFIG(1,3)=4HSPLT,3,0,12,15
KONFIG(1,15)=4HWINJ,15,0,4,0,
KONFIG(1,4)=4HCOMP,4,0,5,6,
KONFIG(1,5)=4HDUCT,5,0,7,0,
KONFIG(1,6)=4HTURB,7,6,8,0,
KONFIG(1,7)=4HTURB,8,0,9,0,
KONFIG(1,8)=4HDUCT,9,0,10,0,
KONFIG(1,9)=4HNOZZ,10,0,11,0,
```

```
KCNFIG(1,10)=4HDUCT,12,0,13,0,
KCNFIG(1,11)=4HNOZZ,13,0,14,0,
KONFIG(1,12)=4HSHFT,6,4,14,0,
KONFIG(1,13)=4HSHFT,2,7,0,0,
KONFIG(1,14)=4HLOAD,
KONFIG(1,20)=4HCNTL,SPCNTL(1,20)=1,7,4HSTAP,8,10,0,1,
KONFIG(1,21)=4HCNTL,SPCNTL(1,21)=1,6,4HSTAP,8,8,0,1,
KCNFIG(1,22)=4HCNTL,SPCNTL(1,22)=1,4,4HSTAP,8,7,0,1,1.05,1.6,
KONFIG(1,23)=4HCNTL,SPCNTL(1,23)=1,3,4HSTAP,8,13,0,1,
KONFIG(1,24)=4HCNTL,SPCNTL(1,24)=1,2,4HSTAP,8,4,0,1,1.05,1.6,
KONFIG(1,25)=4HCNTL,SPCNTL(1,25)=1,1,4HSTAP,8,2,0,1,
KONFIG(1,26)=4HCNTL,SPCNTL(1,26)=1,12,4HDOUT,8,12,0,1,
KONFIG(1,27)=4HCNTL,SPCNTL(1,27)=1,13,4HDOUT,8,13,0,1,
KONFIG(1,28)=4HLIMV,SPLIMV(1,28)=0,0,7,1,10,4HDOUT,6,2,0,0,1,
KONFIG(1,29)=4HLIMV,SPLIMV(1,29)=0,0,6,1,1,4HDOUT,6,4,0,0,1,
KONFIG(1,30)=4HOPTV,0,0,2,0,SPEC(1,30)=0,-6,5,10,4*0,.01,
KONFIG(1,31)=4HOPTV,0,0,5,0,SPEC(1,31)=0,0,2880,4,4*0,1,
KCNFIG(1,32)=4HOPTV,0,0,11,0,SPEC(1,32)=0,0,0,1,4*0,1,
KCNFIG(1,33)=4HCNTL,SPCNTL(1,33)=4,5,4HDOUT,6,2,1.15,0.,
&END
&D MODE=3,
KONFIG(1,1)=4HINLT,1,0,2,0,
KONFIG(1,2)=4HCCMP,2,0,3,0,
KCNFIG(1,3)=4HSPLT,3,0,12,15
KONFIG(1,15)=4HWINJ,15,0,4,0,
KCNFIG(1,4)=4HCOMP,4,0,5,6,
KCNFIG(1,5)=4HDUCT,5,0,7,0,
KCNFIG(1,6)=4HTURB,7,6,8,0,
KCNFIG(1,7)=4HTURB,8,0,9,0,
KCNFIG(1,8)=4HDUCT,9,0,10,0,
KCNFIG(1,9)=4HNOZZ,10,0,11,0,
KCNFIG(1,10)=4HDUCT,12,0,13,0,
KONFIG(1,11)=4HNOZZ,13,0,14,0,
KONFIG(1,12)=4HSHFT,6,4,14,0,
KCNFIG(1,13)=4HSHFT,2,7,0,0,
KONFIG(1,14)=4HLOAD,
KCNFIG(1,20)=4HCNTL,SPCNTL(1,20)=1,7,4HSTAP,8,10,0,1,
KCNFIG(1,21)=4HCNTL,SPCNTL(1,21)=1,6,4HSTAP,8,8,0,1,
KCNFIG(1,22)=4HCNTL,SPCNTL(1,22)=1,4,4HSTAP,8,7,0,1,1.05,1.6,
KCNFIG(1,23)=4HCNTL,SPCNTL(1,23)=1,3,4HSTAP,8,13,0,1,
KONFIG(1,24)=4HCNTL,SPCNTL(1,24)=1,2,4HSTAP,8,4,0,1,1.05,1.6,
KCNFIG(1,25)=4HCNTL,SPCNTL(1,25)=1,1,4HSTAP,8,2,0,1,
KCNFIG(1,26)=4HCNTL,SPCNTL(1,26)=1,12,4HDOUT,8,12,0,1,
KONFIG(1,27)=4HCNTL,SPCNTL(1,27)=1,13,4HDOUT,8,13,0,1,
KONFIG(1,28)=4HLIMV,SPLIMV(1,28)=0,0,7,1,10,4HDOUT,6,2,0,0,1,
KCNFIG(1,29)=4HLIMV,SPLIMV(1,29)=0,0,6,1,1,4HDOUT,6,4,0,0,1,
KCNFIG(1,30)=4HOPTV,0,0,2,0,SPEC(1,30)=0,-6,5,10,4*0,.01,
KCNFIG(1,31)=4HOPTV,0,0,5,0,SPEC(1,31)=0,0,2880,4,4*0,1,
KCNFIG(1,32)=4HOPTV,0,0,11,0,SPEC(1,32)=0,0,0,1,4*0,1,
&END
&D MODE=4,
KCNFIG(1,1)=4HINLT,1,0,2,0,
```

TABLE B-3 (CONT.)

```
KONFIG(1,2)=4HCOMP,2,0,3,0,
KONFIG(1,3)=4HSPLT,3,0,12,15
KONFIG(1,15)=4HWINJ,15,0,4,0,
KONFIG(1,4)=4HCOMP,4,0,5,6,
KONFIG(1,5)=4HDUCT,5,0,7,0,
KONFIG(1,6)=4HTURB,7,6,8,0,
KONFIG(1,7)=4HTURB,8,0,9,0,
KONFIG(1,8)=4HDUCT,9,0,10,0,
KONFIG(1,9)=4HNOZZ,10,0,11,0,
KONFIG(1,10)=4HDUCT,12,0,13,0,
KONFIG(1,11)=4HNOZZ,13,0,14,0,
KONFIG(1,12)=4HSHFT,6,4,14,0,
KONFIG(1,13)=4HSHFT,2,7,0,0,
KONFIG(1,14)=4HLOAD,
KONFIG(1,20)=4HCNTL,SPCNTL(1,20)=1,7,4HSTAP,8,10,0,1,
KONFIG(1,21)=4HCNTL,SPCNTL(1,21)=1,6,4HSTAP,8,8,0,1,
KONFIG(1,22)=4HCNTL,SPCNTL(1,22)=1,4,4HSTAP,8,7,0,1,1.05,1.6,
KONFIG(1,23)=4HCNTL,SPCNTL(1,23)=1,3,4HSTAP,8,13,0,1,
KONFIG(1,24)=4HCNTL,SPCNTL(1,24)=1,2,4HSTAP,8,4,0,1,1.05,1.6,
KONFIG(1,25)=4HCNTL,SPCNTL(1,25)=1,1,4HSTAP,8,2,0,1,
KONFIG(1,26)=4HCNTL,SPCNTL(1,26)=1,12,4HDOUT,8,12,0,1,
KONFIG(1,27)=4HCNTL,SPCNTL(1,27)=1,13,4HDOUT,8,13,0,1,
KONFIG(1,28)=4HLINV,SPLINV(1,28)=0,0.7,1,10,4HDOUT,6,2,0,0,1,
KONFIG(1,29)=4HLINV,SPLINV(1,29)=0,0.6,1,1,4HDOUT,6,4,0,0,1,
KONFIG(1,30)=4HOPTV,0,0,2,0,SPEC(1,30)=0,-6,5,10,4*0,.01,
KONFIG(1,31)=4HOPTV,0,0,5,0,SPEC(1,31)=0,0,2880,4,4*0,1,
KONFIG(1,32)=4HOPTV,0,0,11,0,SPEC(1,32)=0,0,0,1,4*0,1,
&END
&D MODE=5,
KONFIG(1,1)=4HINLT,1,0,2,0,
KONFIG(1,2)=4HCOMP,2,0,3,0,
KONFIG(1,3)=4HSPLT,3,0,12,15
KONFIG(1,15)=4HWINJ,15,0,4,0,
KONFIG(1,4)=4HCOMP,4,0,5,6,
KONFIG(1,5)=4HDUCT,5,0,7,0,
KONFIG(1,6)=4HTURB,7,6,8,0,
KONFIG(1,7)=4HTURB,8,0,9,0,
KONFIG(1,8)=4HDUCT,9,0,10,0,
KONFIG(1,9)=4HNOZZ,10,0,11,0,
KONFIG(1,10)=4HDUCT,12,0,13,0,
KONFIG(1,11)=4HNOZZ,13,0,14,0,
KONFIG(1,12)=4HSHFT,6,4,14,0,
KONFIG(1,13)=4HSHFT,2,7,0,0,
KONFIG(1,14)=4HLOAD,
KONFIG(1,20)=4HCNTL,SPCNTL(1,20)=1,7,4HSTAP,8,10,0,1,
KONFIG(1,21)=4HCNTL,SPCNTL(1,21)=1,6,4HSTAP,8,8,0,1,
KONFIG(1,22)=4HCNTL,SPCNTL(1,22)=1,4,4HSTAP,8,7,0,1,1.05,1.6,
KONFIG(1,23)=4HCNTL,SPCNTL(1,23)=1,3,4HSTAP,8,13,0,1,
KONFIG(1,24)=4HCNTL,SPCNTL(1,24)=1,2,4HSTAP,8,4,0,1,1.05,1.6,
KONFIG(1,25)=4HCNTL,SPCNTL(1,25)=1,1,4HSTAP,8,2,0,1,
KONFIG(1,26)=4HCNTL,SPCNTL(1,26)=1,12,4HDOUT,8,12,0,1,
KONFIG(1,27)=4HCNTL,SPCNTL(1,27)=1,13,4HDOUT,8,13,0,1,
```

TABLE 8-3 (CONT.)

```
KONFIG(1,28)=4HLINV,SPLINV(1,28)=0,0.7,1,10,4HDOUT,6,2,0,0,1,
KONFIG(1,29)=4HLINV,SPLINV(1,29)=0,0.6,1,1,4HDOUT,6,4,0,0,1,
KONFIG(1,30)=4HOPTV,0,0,2,0,SPEC(1,30)=0,-6,5,10,4*0,.01,
KONFIG(1,31)=4HOPTV,0,0,5,0,SPEC(1,31)=0,0,2880,4,4*0,1,
KONFIG(1,32)=4HOPTV,0,0,11,0,SPEC(1,32)=0,0,0,1,4*0,1,
&END
&D MODE=6,
KONFIG(1,1)=4HINLT,1,0,2,0,
KONFIG(1,2)=4HCOMP,2,0,3,0,
KONFIG(1,3)=4HSPLT,3,0,12,15
KONFIG(1,15)=4HWINJ,15,0,4,0,
KONFIG(1,4)=4HCOMP,4,0,5,6,
KONFIG(1,5)=4HDUCT,5,0,7,0,
KONFIG(1,6)=4HTURB,7,6,8,0,
KONFIG(1,7)=4HTURB,8,0,9,0,
KONFIG(1,8)=4HDUCT,9,0,10,0,
KONFIG(1,9)=4HNOZZ,10,0,11,0,
KONFIG(1,10)=4HDUCT,12,0,13,0,
KONFIG(1,11)=4HNOZZ,13,0,14,0,
KONFIG(1,12)=4HSHFT,6,4,14,0,
KONFIG(1,13)=4HSHFT,2,7,0,0,
KONFIG(1,14)=4HLOAD,
KONFIG(1,20)=4HCNTL,SPCNTL(1,20)=1,7,4HSTAP,6,10,0,1,
KONFIG(1,21)=4HCNTL,SPCNTL(1,21)=1,6,4HSTAP,8,8,0,1,
KONFIG(1,22)=4HCNTL,SPCNTL(1,22)=1,4,4HSTAP,6,7,0,1,1.05,1.6,
KONFIG(1,23)=4HCNTL,SPCNTL(1,23)=1,3,4HSTAP,8,13,0,1,
KONFIG(1,24)=4HCNTL,SPCNTL(1,24)=1,2,4HSTAP,8,4,0,1,1.05,1.6,
KONFIG(1,25)=4HCNTL,SPCNTL(1,25)=1,1,4HSTAP,8,2,0,1,
KONFIG(1,26)=4HCNTL,SPCNTL(1,26)=1,12,4HDOUT,8,12,0,1,
KONFIG(1,27)=4HCNTL,SPCNTL(1,27)=1,13,4HDOUT,8,13,0,1,
KONFIG(1,28)=4HLINV,SPLINV(1,28)=0,0.7,1,10,4HDOUT,6,2,0,0,1,
KONFIG(1,29)=4HLINV,SPLINV(1,29)=0,0.6,1,1,4HDOUT,6,4,0,0,1,
KONFIG(1,30)=4HOPTV,0,0,2,0,SPEC(1,30)=0,-6,5,10,4*0,.01,
KONFIG(1,31)=4HOPTV,0,0,5,0,SPEC(1,31)=0,0,2880,4,4*0,1,
KONFIG(1,32)=4HOPTV,0,0,11,0,SPEC(1,32)=0,0,0,1,4*0,1,
&END
&D NVCFT=-4,SPEC(1,1)=684,SPEC(1,2)=1.05,SPEC(10,2)=4.9,SPEC(1,3)=.0937,
SPEC(1,4)=1.32,
SPEC(2,9)=.84832,SPEC(5,9)=.98246,SPEC(2,11)=.94374,SPEC(5,11)=.98371,
SPEC(4,5)=2700,SPEC(1,6)=3.64,SPEC(1,7)=2.39,SPEC(1,11)=1925,SPEC(1,15)=.01,
MODE=2,LABEL=T &END
1 ON 1 --- WET
&D SPEC(1,11)=3462.0,SPEC(1,1)=983.407,SPEC(10,2)=4.97,SPEC(1,7)=4.0,
SPEC(1,6)=3.60,MODE=3,SPEC(1,15)=0,
SPEC(2,9)=.87512,SPEC(5,9)=.98236,SPEC(2,11)=.93944,SPEC(5,11)=.98324,
SPEC(1,12)=14050,SPEC(1,13)=12600,NCODE=1,SPEC(5,2)=25.773,SPEC(1,2)=1.504,
SPEC(1,4)=1.29,
SPEC(4,5)=3000,SPEC(3,31)=3000,LABEL=T,SPEC(1,3)=.05622638 &END
1 AND 1/2 FANS ON 1 ENGINE---- DRY
&D SPEC(1,15)=.01,MODE=4,SPEC(4,5)=2938,SPEC(1,11)=2744,SPEC(10,2)=2.44,
SPEC(2,9)=.86228,SPEC(5,9)=.98287,SPEC(2,11)=.94313,SPEC(5,11)=.98364,
&END
```

TABLE B-3 (CONT.)

```
1 AND 1/2 FANS ON 1 ENGINE ----- WET
 &D SPEC(1,11)=7760,SPEC(1,1)=1742.3,SPEC(10,2)=-5.58,SPEC(1,7)=3.0,
 SPEC(1,6)=3.6,MODE=5,SPEC(1,15)=0,
 SPEC(2,9)=.90815,SPEC(5,9)=.98247,SPEC(2,11)=.93468,SPEC(5,11)=.98260,
 SPEC(1,12)=15100,SPEC(1,13)=11500,NCODE=1,SPEC(5,2)=51.546,SPEC(3,31)=3210,
 SPEC(1,4)=1.271,SPEC(1,2)=1.37,SPEC(4,5)=3190,LABEL=T,SPEC(1,3)=.0331617  &END
 3 FANS ON ONE ENGINE --EMERGENCY VTOL--- DRY
 &D MODE=6,SPEC(1,15)=.01,SPEC(1,1)=1034,SPEC(1,2)=1.3,SPEC(10,2)=-5.98,
 SPEC(1,11)=7200,SPEC(4,5)=2949,
 SPEC(2,9)=.90777,SPEC(5,9)=.98262,SPEC(2,11)=.93505,SPEC(5,11)=.98266,
 SPEC(1,3)=.07168,SPEC(1,4)=1.25,SPEC(1,6)=3.66,SPEC(1,7)=2.4,SPEC(1,11)=7200,
 SPEC(1,12)=14582,SPEC(1,13)=10757 &END
 3 FANS ON ONE ENGINE --EMERGENCY VTOL--- WET
 &D ENDIT=1 &END
```

TABLE 8-4

DATA SET 8

GAS PROPERTY TABLES

3951	HAM STD. VARIABLE PITCH FAN MAP **FLOW** R=1.2,SPED=1,PICH=0							
PICH	3	-6.00	0.0	5.0				
SPED	4	.900	.950	1.00	1.05			
R	6	1.0	1.1	1.2	1.3	1.4	1.6	
FLOW	6	27.35	29.78	31.20	32.60	34.30	35.40	
FLOW	6	29.20	30.73	32.28	33.72	35.30	36.42	
FLOW	6	30.48	31.98	33.45	34.80	36.26	37.37	
FLOW	6	31.50	33.08	34.60	35.81	37.07	37.68	
SPED	5	.800	.900	1.00	1.10	1.13		
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.6
FLOW	7	28.85	30.75	31.90	32.90	33.85	35.18	36.00
FLOW	7	30.70	32.82	34.30	35.25	36.27	37.68	38.70
FLOW	7	33.60	35.90	37.15	38.05	38.80	39.80	40.60
FLOW	7	36.20	38.25	39.31	40.10	40.79	41.39	41.82
FLOW	7	37.20	39.10	40.20	40.80	41.50	42.30	42.80
SPED	4	.900	.950	1.00	1.05			
R	6	1.0	1.1	1.2	1.3	1.4	1.6	
FLOW	6	34.90	36.50	37.52	38.34	39.58	40.60	
FLOW	6	36.30	37.93	38.95	39.70	40.69	41.60	
FLOW	6	37.70	39.22	40.09	40.82	41.69	42.50	
FLOW	6	39.38	40.51	41.28	41.89	42.65	43.30	
EOT								
3952	HAM STD. VARIABLE PITCH FAN MAP **EFF** R=1.2,SPED=1,PICH=0							
PICH	3	-6.00	0.0	5.0				
SPED	4	.900	.950	1.00	1.05			
R	6	1.0	1.1	1.2	1.3	1.4	1.6	
EFF	6	.850	.877	.882	.868	.840	.800	
EFF	6	.850	.878	.886	.877	.847	.800	
EFF	6	.850	.877	.888	.880	.850	.800	
EFF	6	.850	.872	.886	.882	.856	.800	
SPED	5	.800	.900	1.00	1.10	1.13		
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.6
EFF	7	.850	.880	.885	.880	.867	.835	.800
EFF	7	.850	.883	.887	.885	.876	.850	.808
EFF	7	.850	.884	.887	.885	.880	.850	.810
EFF	7	.850	.879	.886	.880	.862	.840	.800
EFF	7	.830	.850	.865	.850	.848	.830	.780
SPED	4	.900	.950	1.00	1.05			
R	6	1.0	1.1	1.2	1.3	1.4	1.6	
EFF	6	.850	.880	.882	.875	.850	.800	
EFF	6	.850	.884	.886	.880	.858	.815	
EFF	6	.850	.880	.865	.880	.850	.800	
EFF	6	.850	.880	.882	.880	.850	.800	
EOT								
3953	HAM STD. VARIABLE PITCH FAN MAP **PR** R=1.2,SPED=1,PICH=0							
PICH	3	-6.00	0.0	5.0				
SPED	4	.900	.950	1.00	1.05			
R	6	1.0	1.1	1.2	1.3	1.4	1.6	

TABLE B-4 (CONT.)

PR	6	1.162	1.155	1.144	1.129	1.107	1.078	
PR	6	1.195	1.181	1.165	1.148	1.123	1.085	
PR	6	1.219	1.204	1.187	1.167	1.136	1.093	
PR	6	1.238	1.225	1.208	1.184	1.146	1.096	
SPED	5	.800	.900	1.00	1.10	1.13		
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.6
PR	7	1.166	1.146	1.133	1.122	1.110	1.090	1.071
PR	7	1.198	1.181	1.170	1.161	1.150	1.131	1.103
PR	7	1.247	1.233	1.220	1.208	1.194	1.165	1.127
PR	7	1.294	1.272	1.257	1.243	1.226	1.192	1.142
PR	7	1.310	1.286	1.269	1.255	1.237	1.206	1.152
SPED	4	.900	.950	1.00	1.05			
R	6	1.0	1.1	1.2	1.3	1.4	1.6	
PR	6	1.209	1.198	1.192	1.186	1.174	1.145	
PR	6	1.236	1.228	1.220	1.212	1.194	1.158	
PR	6	1.262	1.252	1.242	1.232	1.213	1.171	
PR	6	1.292	1.277	1.265	1.251	1.229	1.182	
EOT								
3954		ALLISON HP COMPRESSOR **FLOW** R=1.3,SPED=1						
ANGL	1	0.0						
SPED	8	.70	.80	.85	.90	.95	1.00	1.05
		1.10						
R	4	1.0	1.1	1.2	1.3			
FLOW	4	24.50	25.20	26.30	26.90			
R	6	1.0	1.1	1.2	1.3	1.4	1.5	
FLOW	6	38.30	39.70	40.40	41.00	41.20	41.50	
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.6
FLOW	7	47.00	48.30	49.10	49.90	50.30	50.70	50.80
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.7
FLOW	7	59.10	59.90	61.40	62.20	62.60	63.40	63.60
FLOW	7	77.50	79.10	81.10	82.60	83.90	85.00	85.60
FLOW	7	96.80	98.40	99.00	100.0	100.3	100.5	100.5
FLOW	7	105.0	105.9	106.2	106.5	106.8	107.0	107.0
FLOW	7	109.0	110.0	110.0	110.0	110.0	110.0	110.0
EOT								
3955		ALLISON HP COMPRESSOR **EFF** R=1.3,SPED=1						
ANGL	1	0.0						
SPED	8	.70	.80	.85	.90	.95	1.00	1.05
		1.10						
R	4	1.0	1.1	1.2	1.3			
EFF	4	.670	.690	.650	.500			
R	6	1.0	1.1	1.2	1.3	1.4	1.5	
EFF	6	.775	.792	.780	.740	.650	.500	
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.6
EFF	7	.798	.830	.830	.820	.780	.700	.600
R	7	1.0	1.1	1.2	1.3	1.4	1.5	1.7
EFF	7	.820	.830	.834	.833	.830	.800	.650
EFF	7	.825	.830	.836	.837	.830	.800	.650
EFF	7	.820	.830	.843	.845	.830	.800	.650
EFF	7	.790	.821	.827	.829	.824	.790	.650
EFF	7	.780	.800	.810	.820	.810	.780	.650
EOT								

TABLE B-4 (CONT.)

```
 3956         ALLISON HP COMPRESSOR **PR** R=1.3,SPED=1
ANGL   1       0.0
SPED   8        .70        .80        .85        .90        .95       1.00       1.05
               1.10
R      4        1.0        1.1        1.2        1.3
PR     4      3.480      3.260      2.850      2.290
R      6        1.0        1.1        1.2        1.3        1.4        1.5
PR     6      5.790      5.380      4.900      4.300      3.650      3.000
R      7        1.0        1.1        1.2        1.3        1.4        1.5        1.6
PR     7      7.350      6.980      6.650      6.250      5.540      4.630      4.000
R      7        1.0        1.1        1.2        1.3        1.4        1.5        1.7
PR     7      9.550      9.350      8.780      8.300      7.790      7.000      5.250
PR     7     13.000     12.670     12.200     11.650     11.000      9.900      7.820
PR     7     17.000     16.400     16.000     15.000     13.600     12.340     10.300
PR     7     18.790     17.500     17.040     16.180     14.800     13.500     11.600
PR     7     19.500     18.100     17.600     16.750     15.400     13.900     12.100
EOT
 9011         ALLISON HP TURBINE MAP  SPED=10000,PR=4.74 **FLOW**
AREA   1     1.0000
SPED   5     8000.0     9000.0    10000.0    11000.0    12000.0
PR    14     1.3242     1.3732     1.4918     1.6531     1.9137     2.1366     2.6013
             3.5187     3.7205     3.9202     4.1110     4.2784     4.4459     4.6134
FLOW  14     .76554     .79203     .84504     .89804     .95104     .97754     1.0040
             1.0148     1.0148     1.0148     1.0148     1.0148     1.0148     1.0148
PR    14     1.3038     1.4210     1.5778     1.8084     1.9868     2.2696     2.5127
             2.6996     3.0236     3.6188     3.8431     4.0652     4.2777     4.4645
FLOW  14     .76554     .81854     .87154     .92454     .95104     .97754     .99079
             .99741     1.0040     1.0083     1.0083     1.0083     1.0083     1.0083
PR    14     1.2680     1.3567     1.5729     1.8407     2.0540     2.4066     3.6814
             3.9324     4.1849     4.4254     4.6384     4.7804     4.9225     5.0645
FLOW  14     .76554     .81854     .87154     .92454     .95104     .97754     1.0022
             1.0022     1.0022     1.0022     1.0022     1.0022     1.0022     1.0022
PR    14     1.2156     1.3556     1.5492     1.8564     2.1053     2.5587     3.7495
             4.0325     4.3179     4.5902     4.8316     4.9926     5.1535     5.3145
FLOW  14     .76554     .81654     .87154     .92454     .95104     .97754     .99588
             .99588     .99588     .99588     .99588     .99588     .99588     .99588
PR    14     1.2170     1.3506     1.6510     2.1447     2.3701     2.7279     3.8026
             4.1196     4.4414     4.7489     5.0202     5.2011     5.3819     5.5628
FLOW  14     .79203     .84504     .89804     .95104     .96429     .97754     .99020
             .99020     .99020     .99020     .99020     .99020     .99020     .99020
EOT
 9012         ALLISON HP TURBINE MAP  SPED=10000,PR=4.74  **EFF**
AREA   1     1.0000
SPED   5     8000.0     9000.0    10000.0    11000.0    12000.0
PR    14     1.3243     1.4323     1.5515     1.6859     1.8386     2.0127     2.2105
             2.4363     2.6560     2.9956     3.3413     3.7432     3.9853     4.2784
EFF   14     .81557     .83426     .84628     .85243     .85441     .85385     .85223
             .84576     .84645     .84262     .83870     .83448     .83009     .82233
PR    14     1.3038     1.4181     1.5463     1.6869     1.8496     2.0333     2.2429
             2.4641     2.7607     3.0819     3.4528     3.8896     4.1521     4.4645
EFF   14     .78371     .81546     .83389     .84667     .85499     .85939     .86171
             .86214     .86189     .86048     .85851     .85624     .85268     .84629
```

TABLE 8-4 (CONT.)

PR	14	1.2680	1.3870	1.5213	1.6720	1.8413	2.0336	2.2525
		2.5027	2.7919	3.1306	3.5295	4.0072	4.2971	4.6384
EFF	14	.73317	.78479	.81350	.83231	.84585	.85527	.86217
		.86721	.87038	.87152	.87113	.86882	.86522	.85921
PR	14	1.2156	1.3388	1.4776	1.6337	1.8121	2.0126	2.2409
		2.5033	2.8041	3.1587	3.5874	4.1176	4.4426	4.8316
EFF	14	.64933	.73683	.78211	.81057	.82889	.84356	.85493
		.86351	.87065	.87492	.87565	.87264	.86857	.86164
PR	14	1.2170	1.3435	1.4869	1.6483	1.8324	2.0415	2.2770
		2.5474	2.8570	3.2180	3.6628	4.2323	4.5859	5.0202
EFF	14	.60045	.70480	.75764	.79101	.81322	.82981	.84400
		.85510	.86454	.87166	.87348	.86920	.86426	.85562
ECT								
9013		ALLISON LP (POWER) TURBINE MAP SPED=10000,PR=3.69 **FLOW**						
AREA	1	1.0000						
SPED	10	5555.5	6666.6	7777.7	8888.8	10000.0	11111.1	12222.2
		13333.3	14444.4	15555.5				
PR	14	1.1131	1.1450	1.1808	1.2219	1.2699	1.3274	1.3983
		1.4906	1.6214	1.8757	2.6344	2.8159	4.0000	6.0000
FLOW	14	.55849	.60864	.65878	.70892	.75907	.80921	.85935
		.90950	.95964	1.0098	1.0377	1.0377	1.0377	1.0377
PR	14	1.0971	1.1332	1.1737	1.2200	1.2739	1.3383	1.4182
		1.5234	1.6791	2.0161	2.8740	3.1727	4.0000	6.0000
FLOW	14	.55849	.60864	.65878	.70892	.75907	.80921	.85935
		.90950	.95964	1.0098	1.0316	1.0316	1.0316	1.0316
PR	14	1.0699	1.1098	1.1547	1.2060	1.2658	1.3373	1.4254
		1.5439	1.7218	2.1417	2.9961	3.3036	4.0000	6.0000
FLOW	14	.55849	.60864	.65878	.70892	.75907	.80921	.85935
		.90950	.95964	1.0098	1.0265	1.0265	1.0265	1.0265
PR	14	1.1235	1.1791	1.2441	1.3220	1.4186	1.5496	1.7468
		1.9175	2.2503	3.0274	3.3307	3.6740	4.0000	6.0000
FLOW	14	.65878	.70892	.75907	.80921	.85935	.90950	.95964
		.98471	1.0098	1.0228	1.0228	1.0228	1.0228	1.0228
PR	14	1.1394	1.2084	1.2916	1.3950	1.5366	1.7537	1.9435
		2.3426	3.0953	3.4012	3.7460	4.1225	5.0000	6.0000
FLOW	14	.70892	.75907	.80921	.85935	.90950	.95964	.98471
		1.0098	1.0203	1.0203	1.0203	1.0203	1.0203	1.0203
PR	14	1.1593	1.2463	1.3543	1.5031	1.7348	1.9428	2.4000
		3.1552	3.5107	3.8633	4.2450	4.6404	5.0000	6.0000
FLOW	14	.75907	.80921	.85935	.90950	.95964	.98471	1.0098
		1.0187	1.0187	1.0187	1.0187	1.0187	1.0187	1.0187
PR	14	1.1866	1.2977	1.4468	1.6890	1.9077	2.3971	3.1738
		3.4840	3.8319	4.2100	4.6041	4.9906	5.0000	6.0000
FLOW	14	.80921	.85935	.90950	.95964	.98471	1.0098	1.0181
		1.0181	1.0181	1.0181	1.0181	1.0181	1.0181	1.0181
PR	14	1.2263	1.3760	1.6160	1.8346	2.3234	3.2032	3.5168
		3.8874	4.2472	4.6412	5.0248	5.1344	5.5000	6.0000
FLOW	14	.85935	.90950	.95964	.98471	1.0098	1.0188	1.0188
		1.0188	1.0188	1.0188	1.0188	1.0188	1.0188	1.0188
PR	14	1.2893	1.5190	1.7277	2.1811	3.2093	3.5137	3.8640
		4.2432	4.6365	5.0188	5.1144	5.2100	5.5000	6.0000
FLOW	14	.90950	.95964	.98471	1.0098	1.0208	1.0208	1.0208

TABLE B-4 (CONT.)

		1.0208	1.0208	1.0208	1.0208	1.0208	1.0208	1.0208
PR	14	1.4034	1.5963	1.9956	3.1628	3.4721	3.8187	4.1952
		4.5871	4.9706	5.0558	5.1411	5.2263	5.5000	6.0000
FLOW	14	.95964	.98471	1.0098	1.0236	1.0236	1.0236	1.0236
		1.0236	1.0236	1.0236	1.0236	1.0236	1.0236	1.0236
ECT								
9014		ALLISON LP (POWER) TURBINE MAP SPED=10000.PR=3.69 **EFF**						
AREA	1	1.0000						
SPED	10	5555.5	6666.6	7777.7	8888.8	10000.0	11111.1	12222.2
		13333.3	14444.4	15555.5				
PR	14	1.1131	1.1854	1.2699	1.3699	1.4883	1.6304	1.8028
		2.0053	2.2685	2.6475	3.2892	3.7487	4.3128	4.9983
EFF	14	.81330	.87170	.88087	.87065	.85259	.83010	.80524
		.78396	.75609	.71646	.65727	.62599	.59674	.55948
PR	14	1.0571	1.1754	1.2654	1.3700	1.4932	1.6405	1.8243
		2.0380	2.2925	2.6863	3.3326	3.7878	4.3536	5.0543
EFF	14	.67735	.82691	.87451	.88817	.88572	.87400	.85275
		.83597	.82018	.78088	.72316	.69280	.66347	.63533
PR	14	1.0699	1.1531	1.2478	1.3565	1.4828	1.6328	1.8160
		2.0383	2.3009	2.6676	3.2532	3.6662	4.1823	4.8276
EFF	14	.34733	.72380	.83285	.87684	.89434	.89650	.88755
		.87422	.86254	.83589	.78809	.76033	.73230	.70455
PR	14	1.1235	1.2171	1.3234	1.4480	1.5866	1.7531	1.9528
		2.1952	2.4884	2.9038	3.5435	3.9826	4.5251	5.1978
EFF	14	.52600	.74513	.83293	.87603	.89593	.90365	.90243
		.89529	.88580	.86028	.81813	.79406	.76946	.74460
PR	14	1.1394	1.2377	1.3485	1.4748	1.6216	1.7918	1.9927
		2.2349	2.5234	2.9091	3.4795	3.8639	4.3324	4.9082
EFF	14	.45621	.65715	.80181	.85686	.88640	.90300	.91043
		.91043	.90771	.89289	.86178	.84220	.82147	.79975
PR	14	1.1593	1.2642	1.3819	1.5170	1.6730	1.8535	2.0663
		2.3189	2.6202	3.0219	3.6015	3.9869	4.4535	5.0242
EFF	14	.40092	.65483	.77254	.83645	.87411	.89762	.91091
		.91755	.92000	.90985	.88499	.86855	.85070	.83151
PR	14	1.1866	1.2961	1.4189	1.5602	1.7225	1.9099	2.1294
		2.3852	2.6893	3.0900	3.6504	4.0176	4.4572	4.9906
EFF	14	.36935	.61857	.74297	.81356	.85793	.88712	.90593
		.91893	.92668	.92195	.90426	.89128	.87673	.86051
PR	14	1.2263	1.3406	1.4683	1.6169	1.7857	1.9810	2.2064
		2.4840	2.7758	3.1828	3.7355	4.0925	4.5156	5.0248
EFF	14	.37093	.59745	.72072	.79327	.84200	.87506	.89889
		.91791	.92673	.92771	.91575	.90576	.89414	.88069
PR	14	1.2693	1.4121	1.5430	1.6965	1.8731	2.0725	2.2950
		2.5531	2.8716	3.2758	3.8100	4.1491	4.5464	5.0188
EFF	14	.41850	.59697	.70975	.78006	.82773	.86378	.89355
		.91579	.92775	.93035	.92362	.91650	.90777	.89718
PR	14	1.4034	1.5309	1.6695	1.8284	2.0048	2.1984	2.4197
		2.6820	2.9984	3.3839	3.8853	4.1950	4.5531	4.9706
EFF	14	.51617	.83720	.72160	.77999	.82518	.86276	.89173
		.91182	.92421	.93048	.92786	.92350	.91753	.90995
ECT								

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