PROGRAM OFFX
OFFX USER GUIDE

OFF-DESIGN CYCLE ANALYSIS PROGRAM

The off-design cycle analysis program OFFX is based on the equations developed in *Aircraft Engine Design* and can analyze the following seven different engine cycles (relevant section of textbook is shown within parentheses following cycle):
1. Turbojet without afterburner (Chapter 5 and Appendix E)
2. Turbojet with afterburner (Chapter 5 and Appendix E)
3. Turbofan with separate exhausts (convergent only exhaust nozzles) (Appendix G)
4. Turbofan with mixed exhaust and no afterburning (Chapter 5 and Appendix E)
5. Turbofan with mixed exhaust and afterburning (Chapter 5 and Appendix E)
6. Turboprop (convergent only exhaust nozzle) (Appendix H)
7. Ramjet (Appendix J)

This program is designed to be user friendly and uses multiple menus for program control and data input. When an error occurs in a menu selection or in the format of input data, the user is asked to enter the selection or value again. Multiple calculations for different values of one off-design variable are possible by selecting the iteration variable from a menu and then specifying its minimum, maximum, and incremental values. An off-design input data files can only be obtained by performing a single design point calculation using the on-design cycle analysis program (ONX) and then saving the required output data to a user-named reference data file. This reference data file is the input off-design data file. Program output may be directed to the screen only, the printer only, or both the screen and the printer.

A. MAIN MENU

When OFFX is run, the first thing to appear on the screen is

```
*************************************************************************
*   OFFX - OFF-DESIGN AIRCRAFT ENGINE CYCLE ANALYSIS PROGRAM - VERSION 2.2  *
*                  Copyright (C) by Dr. Jack D. Mattingly                 *
*                      May 1996.  All rights reserved.                    *
*                                                                         *
*  AIAA has exclusive license to promote and sell this copyrighted soft-    *
*  ware.  This program is provided "AS IS" without warranty of any kind.    *
*  Jack D. Mattingly and AIAA do not warrant or guarantee the use, or the   *
*  results of the use, of this software or accompanying user guide in       *
*  terms of correctness, accuracy, reliability, currentness, or otherwise.  *
*  The entire risk and performance of the software is assumed by the user.  *
*                                                                         *
*  OFFX was written for use with the AIAA Education Series textbook AIRCRAFT*
*  ENGINE DESIGN and is based on the engine models contained therein.  It   *
*  is intended for educational use only and not as a replacement for the    *
*  more complex and highly accurate aircraft engine cycle decks used in the *
*  industry.  This program gives accurate performance trends within the     *
*  limitations of the models and user input data.                           *
*                                                                         *
*  The purchaser is granted the right to use one copy of this software      *
*  program on a single terminal connected to a single computer (i.e., with  *
*  a single CPU).  You may NOT network this software program or otherwise   *
*  use it on more than one computer or computer terminal at the same time.  *
*************************************************************************
             Press "Return" (Enter) key to continue
```

This logo identifies the name of the program and its version number. After the user inputs a carriage return (**<CR>**, also called a **RETURN** key and an **ENTER** key), the program displays the following screen for redirecting printed output to a disk file rather than the default printer **PRN**. If the user answers the question **WANT TO CHANGE THE DEFAULT (Y=1)?** with anything other than

1, the program uses the default name for the printer name. The example below shows responses for an output file named **OUTPUT1.PRN** on **Drive A:**. Note that responses are shown in bold letters.

```
*********************************************************
*    The default printer name is "PRN", the standard for   *
*    MS-DOS.  At this point in the program, this can be    *
*    changed to a disk file, e.g. "A:OUTNAME.PRN".         *
*********************************************************
     WANT TO CHANGE THE DEFAULT (Y=1)?   1

ENTER NAME OF PRINTER FILE (MAX OF 14 CHAR)   A:OUTPUT1.PRN
PRINTER FILE IS "A:OUTPUT1.PRN ", CORRECT (Y=1/N=0)?    1
```

The **MAIN MENU** screen is displayed after the printer redirection screen as follows:

```
    *********************************************************
    *                                                       *
    *            OFF-DESIGN ENGINE ANALYSIS PROGRAM         *
    *                                                       *
    *                        MAIN MENU                      *
    *                                                       *
    *********************************************************

         1 - READ/SAVE REFERENCE DATA   (CYCLE 5)
         2 - INPUT OFF-DESIGN CONDITION
         3 - ITERATION VARIABLE              (1)
         4 - OUTPUT DEVICE                   (2)
         5 - PERFORM CALCULATIONS
         6 - EXIT PROGRAM

    ENTER YOUR SELECTION
```

Menu items **1** through **4** each have a corresponding sub-menu. Menu item **5** has no sub-menu and menu item **6** allows for an orderly exit from this program. The normal procedure is for a user to select menu items **1** through **4** before selecting item **5 - PERFORM CALCULATIONS**, unless the user wants to use the default values or data of sub-menus **1** through **4**. After a user has changed the selection of a sub-menu, this change is stored internally within the program and remains until changed or the program is ended. The current selection for main menu items **1**, **2**, and **4** is displayed within parentheses to the right of that menu item and initially will contain the default value set by the program. As indicated by this main menu, the default selections for main menu items **1**, **2**, and **4** are sub-menu selections **5**, **4**, and **2**, respectively.

B. REFERENCE DATA ENTRY MENU

The **REFERENCE DATA ENTRY MENU** is obtained when the user selects item **1-READ/SAVE REFERENCE DATA** from the **MAIN MENU**. The following menu is displayed on the screen:

```
    *********************************************************
    *            OFF-DESIGN ENGINE ANALYSIS PROGRAM         *
    *                                                       *
    *               REFERENCE DATA ENTRY MENU               *
    *********************************************************

        1 - READ OFF-DESIGN REFERENCE DATA FILE FROM DISK
        2 - WRITE OFF-DESIGN REFERENCE DATA FILE TO DISK
        3 - CHANGE/VIEW OFF-DESIGN REFERENCE DATA FILE
        4 - PAUSE PROGRAM and USE DOS
        0 - RETURN TO MAIN ON-DESIGN MENU

    ENTER YOUR SELECTION
```

A default input data file is loaded into temporary memory when this program is run and can be viewed by initially selecting item **3 - VIEW CURRENT OFF-DESIGN REFERENCE DATA FILE**. This selection is used to view the reference data of the current reference data file. This menu is

used to input the reference data file created by the on-design cycle analysis program (**ONX**). Each reference data file has an associated engine cycle and, as indicated on the **MAIN MENU**, the engine cycle of the default data set is item number 5, which corresponds to that cycle (**5 - TURBOFAN WITH MIXED EXHAUST AND AFTERBURNER**) as listed on the **CYCLE SELECTION MENU** of the on-design cycle analysis program (**ONX**). The user must create a reference data file with the desired engine cycle and values of the design variables before the off-design cycle analysis can be performed. Select another item number to change the current cycle selection from this default value.

A reference data file that was saved to disk by the **ONX** program can be loaded from disk to the program temporary memory by selecting item **1 - READ OFF DESIGN REFERENCE DATA FILE FROM DISK** as shown below. You can use menu item **4 - PAUSE PROGRAM and USE DOS** to enter DOS and check on file names that are already used. After selecting item **4**, enter the word **COMMAND**; enter the word **EXIT** to leave DOS and return to the program.

```
************************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM            *
*                                                          *
*                REFERENCE DATA ENTRY MENU                 *
************************************************************

     1 - READ OFF-DESIGN REFERENCE DATA FILE FROM DISK
     2 - WRITE OFF-DESIGN REFERENCE DATA FILE TO DISK
     3 - CHANGE/VIEW OFF-DESIGN REFERENCE DATA FILE
     4 - PAUSE PROGRAM and USE DOS
     0 - RETURN TO MAIN ON-DESIGN MENU

ENTER YOUR SELECTION   1

ENTER NAME OF DATA FILE + ".DAT" (MAX OF 14 CHARACTERS)    AAFAB.DAT
YOUR INPUT IS "AAFAB.DAT     "     IS THIS CORRECT  (Y=l/N=0)?    1
```

A reference data file includes values of the on-design variables and performance, the off-design conditions, the iteration variable and its values, and selected output device(s). The current reference data file can be saved to disk by selecting item **2 - WRITE OFF-DESIGN REFERENCE DATA FILE TO DISK** as shown below.

```
************************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM            *
*                                                          *
*                REFERENCE DATA ENTRY MENU                 *
************************************************************

     1 - READ OFF-DESIGN REFERENCE DATA FILE FROM DISK
     2 - WRITE OFF-DESIGN REFERENCE DATA FILE TO DISK
     3 - CHANGE/VIEW OFF-DESIGN REFERENCE DATA FILE
     4 - PAUSE PROGRAM and USE DOS
     0 - RETURN TO MAIN ON-DESIGN MENU

ENTER YOUR SELECTION   2

ENTER NAME OF DATA FILE + ".DAT" (MAX OF 14 CHARACTERS)    AAFAB1.DAT
YOUR INPUT IS "AAFAB1.DAT    "     IS THIS CORRECT  (Y=l/N=0)?    1
```

NOTE: *When saving a data file to disk, the user will need to write down the name given to this data file (filename) and some notes about the data file's content for later use when reading this data file back into this program. However, menu item* **4 - PAUSE PROGRAM and USE DOS** *can be used to temporarily use DOS.*

The reference data file currently in temporary memory will be displayed on the screen by selecting item **3 - VIEW CURRENT OFF-DESIGN REFERENCE DATA FILE.** The following pages show the three pages of the reference data file **AAFAB.DAT** as they would appear on the screen for this engine cycle (turbofan with mixed exhaust and afterburning). Page one lists the values of those

variables considered constant in the off-design analysis. Note that the efficiency of the propeller for this mixed afterburning turbofan engine is zero (**28 - ETA PROP = .0000**).

```
************************************************************
*       OFF-DESIGN REFERENCE DATA  SET   1 , PAGE 1        *
************************************************************
 1 - PI D MAX =  .9700          2 - PI B     =  .9700
 3 - PI A/B   =  .9600          4 - PI N     =  .9800
 5 - PI N     =  .9800          6 - PI TH    =  .3900
 7 - TAU TH   =  .8242          8 - ETA B    =  .9800
 9 - ETA A/B  =  .9700         10 - ETA MECH =  .9800
11 - ETA MECL =  .9900         12 - ETA MECP =  .9800
13 - ETA C`   =  .8684         14 - ETA CH   =  .8742
15 - ETA TL   =  .9173         16 - A5 /A5C  =  .2631
17 - H        = 18000.         18 - CP C     =  .2380
19 - CP T     =  .2950         20 - CP A/B   =  .2950
21 - GAMMA C  = 1.4000         22 - GAMMA T  = 1.3000
23 - GAMMA A/B= 1.3000         24 - PIM MAX  = .9700
25 - BETA     =  .0100         26 - EPS1     = .0500
27 - EPS2     =  .0500         28 - ETA PROP = .0000
29 - ETA GEAR =  .9900

ENTER ANY CHARACTER TO CONTINUE
```

The second and third pages of the reference data file show the selected values of the design variables and the on-design performance.

```
************************************************************
*       OFF-DESIGN REFERENCE DATA  SET   1 , PAGE 2        *
************************************************************
          PARAMETER         REFERENCE
       1 - M0                  1.600
       2 - T0 (R)            394.100
       3 - P0 (PSIA)           3.468
       4 - ALT (FT)        35000.0
       5 - TT4 MAX (R)     3200.00
       6 - TT7 MAX (R)     3600.00
       7 - M5                  .4000
       8 - PI D                .510
      13 - PI C`              3.700
      14 - TAU C`             1.522
      15 - PI CH              5.405
      16 - TAU CH             1.709
      19 - ALPHA               .550

ENTER ANY CHARACTER TO CONTINUE

************************************************************
*       OFF-DESIGN REFERENCE DATA  SET   1 , PAGE 3        *
************************************************************
          PARAMETER        REFERENCE
      20 - F                   .0345
      21 - F AB                .0362
      22 - FO                  .0557
      23 - S (1/H)            1.8181
      24 - SPECIFIC THRUST
           (LBF/LBM/SEC)    110.3810
      25 - AIRFLOW
           (LBM/SEC)         94.5000
      26 - FUEL FLOW
           (LBM/H)          18964.7
      27 - THRUST (LBF)     10431.1

ENTER ANY CHARACTER TO CONTINUE
```

After a read, a save, or viewing of the reference data file, the program automatically returns to the **MAIN MENU** and the number of the current cycle is displayed within parentheses to the right of item **1 - READ/SAVE REFERENCE DATA**. To return to the **MAIN MENU**, enter the number zero.

C. OFF-DESIGN CONDITION MENU

The **OFF-DESIGN CONDITION MENU** is obtained when the user selects item **2 - INPUT OFF-DESIGN CONDITIONS** from the **MAIN MENU**. Five operational limits have been added to OFFX to simulate the physical limits of a specific engine design. These limits are

a. Maximum compressor pressure ratio (PIC) - Item #11 below
b. Maximum pressure at engine station 3 (Pt3) - Item #12 below
c. Maximum temperature at engine station 3 (Tt3) - Item #13 below
d. Maximum % rpm of the low pressure spool with respect to the engine reference rpm - Item #14 below
e. Maximum % rpm of the high pressure spool with respect to the engine reference rpm - Item #15 below

The variation of engine rpm at off-design is estimated by the following assumptions:

a. The rpm of the fan is proportional to the square root of the temperature rise across the fan.
b. The rpm of the high pressure compressor is proportional to the square root of the temperature rise across the high pressure compressor.
c. For turboshaft engines, the rpm of the core is proportional to the square root of the temperature rise across the compressor.

When any limit is exceeded at off-design, the engine throttle (TT4) is reduced until the limit is just met. The default off-design conditions for **OFFX** are shown below. Note that there are no limits imposed.

```
************************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM            *
*                                                          *
*                OFF-DESIGN CONDITION MENU                 *
************************************************************

 1 - MACH NUMBER - - - - - - - - - - - - =     .00
 2 - ALTITUDE  - - - - - - - - - - - - - =      .0 FT
     AMBIENT:
 3 -   TEMPERATURE - - - - - - - - - - - =  518.70 R
 4 -   PRESSURE  - - - - - - - - - - - - = 14.6960 PSIA
 5 - MAX TEMP (TT4) LVG COMBUSTOR  - - - =  3200.0 R
 6 - MAX TEMP (TT7) LVG AB -  (0=AB OFF) =  3600.0 R
 7 - EXHAUST PRESSURE RATIO (P0/P9)  - - =  1.0000
11 - MAX COMPR PRESSURE RATIO   (0=NONE) =     .00
12 - MAX PRESSURE AT STATION 3  (0=NONE) =      .0 PSIA
13 - MAX TEMP AT STATION 3      (0=NONE) =      .0 R
14 - MAX % REF RPM - LP SPOOL   (0=NONE) =      .0 %
15 - MAX % REF RPM - HP SPOOL   (0=NONE) =      .0 %

# OF VARIABLE YOU WISH TO CHANGE (0=NONE)
```

When variable **2 - ALTITUDE** is changed the program automatically changes the ambient temperature and pressure (items 3 and 4).

D. ITERATION VALUE MENU

The **ITERATION VALUE MEN**U is obtained when the user selects item **3 - ITERATION VARIABLE** from the **MAIN MENU**. The following menu is shown on the terminal screen:

```
************************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM            *
*                                                          *
*                    ITERATION VALUE MENU                  *
************************************************************
CURRENT ITERATION VARIABLE IS #1

SINGLE OFF-DESIGN POINT CALCULATION:
     1 - FIXED THROTTLE (TT4)
     2 - ENGINE THROTTLED FOR REQUIRED THRUST
MULTIPLE OFF-DESIGN POINT CALCULATIONS:
     3 - MACH NUMBER
     4 - AMBIENT TEMP (R)
     5 - AMBIENT PRESSURE (PSIA)
     6 - ALTITUDE (FEET)
     7 - TOTAL TEMP (TT4) LVG COMBUSTOR (R)
     8 - TOTAL TEMP (TT7) LVG AFTERBURNER (R)
     9 - EXHAUST PRE SURE RATIO (P0/P9)
     0 - RETURN TO MAIN OFF-DESIGN MENU

ENTER SELECTION
```

The current value for this menu is item **1 - FIXED THROTTLE.** The user must select another item number to change the iteration variable from this current value. If item **2 - ENGINE THROTTLED FOR REQUIRED THRUST** is selected, the user is asked to input the required thrust in lbf. After the selection of an item number corresponding to multiple off-design point calculations, the user will be asked to enter the MINIMUM VALUE, MAXIMUM VALUE, and INCREMENT. If the user wants to change the current minimum value, maximum value, and/or incremental value while either changing or retaining the current iteration variable, the desired iteration variable must be selected and the user will then be asked to input the minimum value, maximum value, and incremental value. For example, if the user elects to change iteration variable **3 - MACH NUMBER** to a minimum value of 0, maximum value of 2, and incremental value of 0.1, then one must enter selection 3 and the following interaction occurs.

```
************************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM            *
*                                                          *
*                    ITERATION VALUE MENU                  *
************************************************************
CURRENT ITERATION VARIABLE IS #1

SINGLE OFF-DESIGN POINT CALCULATION:
     1 - FIXED THROTTLE (TT4)
     2 - ENGINE THROTTLED FOR REQUIRED THRUST
MULTIPLE OFF-DESIGN POINT CALCULATIONS:
     3 - MACH NUMBER
     4 - AMBIENT TEMP (R)
     5 - AMBIENT PRESSURE (PSIA)
     6 - ALTITUDE (FEET)
     7 - TOTAL TEMP (TT4) LVG COMBUSTOR (R)
     8 - TOTAL TEMP (TT7) LVG AFTERBURNER (R)
     9 - EXHAUST PRE SURE RATIO (P0/P9)
     0 - RETURN TO MAIN OFF-DESIGN MENU

ENTER SELECTION  3

MINIMUM VALUE = ?  0
MAXIMUM VALUE = ?  3
ITERATION INCREMENT = ?  0.1

MINIMUM VALUE =       .00
MAXIMUM VALUE =      3.00
INCREMENT     =       .10
IS THIS CORRECT (Y=1/N=0) ?  1
```

NOTE: *The program saves the minimum value of the iteration variable in the computer variable that is displayed when viewing the* **OFF-DESIGN CONDITION MENU**. *For example, the above interaction will set the Mach number listed in the* **OFF-DESIGN CONDITION MENU** *to a value of* **0**. *This minimum value can be changed from the* **OFF-DESIGN CONDITION MENU** *without using the* **ITERATION VALUE MENU**. *Iteration for variables 3 through 6 and variable 9 proceeds from minimum value to maximum value. If iteration variable* **7 - TOTAL TEMP (TT4) LVG COMBUSTOR (R)** *is selected, afterburner operation is turned off before proceeding with iteration from maximum value to minimum value (unless the thrust goes below zero before reaching the minimum value). If iteration variable* **8 - TOTAL TEMP (TT7) LVG AFTERBURNER (R)** *is selected, iteration proceeds from maximum value to minimum value unless* T_{t6} *is reached first).*

As another example, consider that the user wants to determine the engine performance when the engine thrust equals 4000 lbf. The user would select item **2 - ENGINE THROTTLED FOR REQUIRED THRUST** from the **ITERATION VALUE MENU** and enter the value of required thrust when requested. The interaction required would be:

```
*********************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM         *
*                                                       *
*                   ITERATION VALUE MENU                *
*********************************************************
CURRENT ITERATION VARIABLE IS #1

SINGLE OFF-DESIGN POINT CALCULATION:
     1 - FIXED THROTTLE (TT4)
     2 - ENGINE THROTTLED FOR REQUIRED THRUST
MULTIPLE OFF-DESIGN POINT CALCULATIONS:
     3 - MACH NUMBER
     4 - AMBIENT TEMP (R)
     5 - AMBIENT PRESSURE (PSIA)
     6 - ALTITUDE (FEET)
     7 - TOTAL TEMP (TT4) LVG COMBUSTOR (R)
     8 - TOTAL TEMP (TT7) LVG AFTERBURNER (R)
     9 - EXHAUST PRE SURE RATIO (P0/P9)
     0 - RETURN TO MAIN OFF-DESIGN MENU

ENTER SELECTION  2
ENTER THE REQUIRED THRUST (LB) AT PARTIAL THROTTLE    4000
THE REQUIRED THRUST AT PARTIAL THROTTLE IS    4000.0 (Y=1/N=0)?     1
```

NOTE: The program saves the value of required thrust in a computer variable that is displayed when viewing the **OFF-DESIGN CONDITION MENU** as item **10 - REQUIRED THRUST**. The above interaction will set variable **10 - REQUIRED THRUST** in the **OFF DESIGN CONDITION MENU** to a value of 4000 lbf. This value can be changed from the **OFF-DESIGN CONDITION MENU** without using the **ITERATION VALUE MENU**.

E. DATA OUTPUT DEVICE(S)

The menu entitled **DATA OUTPUT DEVICE(S)** is obtained when the user selects item **4 - OUTPUT DEVICE** from the **MAIN MENU**. The following menu is displayed on the screen:

```
************************************************************
*            OFF-DESIGN ENGINE ANALYSIS PROGRAM            *
*                                                          *
*                   DATA OUTPUT DEVICE(S)                  *
************************************************************
CURRENT SELECTION IS ITEM #2

     1 - OUTPUT TO PRINTER ONLY
     2 - OUTPUT TO TERMINAL SCREEN ONLY
     3 - OUTPUT TO BOTH PRINTER AND TERMINAL SCREEN
     0 - RETURN TO MAIN MENU

ENTER YOUR SELECTION
```

As indicated on the **MAIN MENU** and this menu, the default output device is item number **2 - OUTPUT TO TERMINAL SCREEN ONLY**. The user must select another item number to change the current cycle selection from this default value. After entry of an output device selection, the program automatically returns to the **MAIN MENU** and the number of the current output device is displayed within parentheses to the right of item **4 - OUTPUT DEVICE**. The user can only change the output device(s) to another selection by use of this menu. To return to the **MAIN MENU**, enter the number zero.

F. CALCULATIONS

The user-specified off-design cycle calculations are performed after the user selects item **5 - PERFORM CALCULATIONS** from the **MAIN MENU**. The off-design results for the DEFAULT data are shown on the following page when no operational limits are imposed.

Note that the INPUT CONSTANTS list includes values for the power takeoff from both the low and high pressure spools and their corresponding takeoff shaft efficiency. In addition, values of off-design limits are included at the bottom of the INPUT CONSTANTS list.

To conserve vertical space in the output, corresponding pressure (PI) and temperature (TAU) ratio are output together separated only by "/". This allowed output of the % rpm for both the low and high pressure spools and listing the off-design limit that is just met.

```
FILE: DEFAULT            OFF-DESIGN CALCULATIONS             PAGE  1

         ***** FIXED AREA TURBINE - TURBOFAN ENGINE *****
INPUT CONSTANTS
PID MAX = .9700   CP C    = .2380   CP T    = .2950   CP AB   = .2950
ETA B   = .9800   GAM C   =1.4000   GAM T   =1.3000   GAM AB  =1.3000
ETA  AB = .9700   PI B    = .9700   PI AB   = .9600   PI N    = .9800
ETA C`  = .8693   ETA CH  = .8769   ETA MH  = .9800   ETA ML  = .9900
PI TH   = .4329   TAU TH  = .8420   ETA TL  = .9160   ETA MPL = .9800
BLEED   =  1.00%  COOL #1 =  5.00%  COOL #2 =  5.00%  PTOL(KW)= 206.9
PIM MAX = .9700   TAU M1  = .9681   TAU M2  = .9739   ETA MPH = .9800
PIC MAX =   .00   PT3 MAX =    .0   TT3 MAX =    0.R  PTOH(KW)=    .0
RPML MAX=    .0%  RPMH MAX=    .0%

PARAMETER                    REFERENCE           OFF-DESIGN
M0                                1.60                  .01
T0 (R)                           411.9                518.7
P0 (PSIA)                          4.373               14.696
ALT (FT)                       30000.0                    .0
TT4 (R)                         3200.0               3200.0
TT7 (R)                         3600.0               3600.0
PI R  / TAU R             4.250/ 1.512         1.000/ 1.000
PI D                               .933                 .970
PI C  / TAU C            16.000/ 2.422        24.892/ 2.781
PI C` / TAU C`            3.500/ 1.495         4.971/ 1.669
PI CH / TAU CH            4.571/ 1.620         5.007/ 1.667
PI TL / TAU TL            .5219/ .8724         .5004/ .8647
LP SPOOL - % REF RPM           100.00               106.06
HP SPOOL - % REF RPM           100.00                99.96
M5 / M5P                  .4000/ .3823         .4190/ .2983
M6                                .4113                .4114
GAMMA M                          1.318                1.314
CP M                              .282                 .285
P0/P9                            1.000                1.000
PT9/P9                          12.627                4.576
Limit                                                  None
PT5`/PT5                          .998                 .950
PT6/PT5                           .965                 .959
TT6/TT5                           .889                 .907
ALPHA                             .300                 .229
MDOT (LBM/S)                    200.00               241.73
MDOT CORR (LBM/S)               173.27               241.71
AREA0 (SQFT)                      4.38               283.15
AREA0*(SQFT)                      3.51                 4.89
F                                .0350                .0360
F AB                             .0316                .0309
FO (OVERALL)                     .0554                .0567
T9/T0                           4.8681               4.8853
V9/V0                           3.0616              356.5556
M9/M0                           1.4392              167.4145
A9/A0                           1.6678                 .0144
A9/A8                           2.4440               1.3694
S (1/H)                         1.8252               1.5787
F/M (LBF/LBM/S)                 109.21               129.38
FUEL FLOW (LB/H)                39867.               49372.
THRUST (LBF)                    21842.               31275.
PROP EFF (%)                     50.06                  .56
THERM EFF (%)                    44.87                32.49
```

NOTE: Without limits, the compressor pressure ratio raises to nearly 25, the fan pressure and high pressure ratios raise to about 5, and the low pressure spool % rpm raises to about 106% of the rpm at reference flight condition.

Now consider the case when speed limits are placed on both the low pressure spool and high pressure spool of 103% and 100% of REF RPM, respectively. When these limits are applied to the above example, the combustor exit temperature (TT4) is reduced from 3200.0 R to 3086.6 R in order to meet the low pressure spool rpm limit of 103% of REF RPM and the following results are obtained.

```
FILE: DEFAULT            OFF-DESIGN CALCULATIONS              PAGE  2

         ***** FIXED AREA TURBINE - TURBOFAN ENGINE *****
INPUT CONSTANTS
PID MAX = .9700   CP C    = .2380   CP T    = .2950   CP AB   = .2950
ETA B   = .9800   GAM C   =1.4000   GAM T   =1.3000   GAM AB  =1.3000
ETA  AB = .9700   PI B    = .9700   PI AB   = .9600   PI N    = .9800
ETA C`  = .8693   ETA CH  = .8769   ETA MH  = .9800   ETA ML  = .9900
PI TH   = .4329   TAU TH  = .8420   ETA TL  = .9160   ETA MPL = .9800
BLEED   =  1.00%  COOL #1 =  5.00%  COOL #2 =  5.00%  PTOL(KW)= 206.9
PIM MAX = .9700   TAU M1  = .9681   TAU M2  = .9739   ETA MPH = .9800
PIC MAX = 24.00   PT3 MAX = 450.0   TT3 MAX = 1660.R  PTOH(KW)=    .0
RPML MAX= 103.0%  RPMH MAX= 100.0%

PARAMETER                     REFERENCE            OFF-DESIGN
M0                                 1.60                   .01
T0 (R)                            411.9                 518.7
P0 (PSIA)                         4.373                14.696
ALT (FT)                        30000.0                    .0
TT4 (R)                          3200.0                3086.6
TT7 (R)                          3600.0                3600.0
PI R  / TAU R             4.250/ 1.512          1.000/ 1.000
PI D                               .933                  .970
PI C  / TAU C            16.000/ 2.422         22.740/ 2.703
PI C` / TAU C`            3.500/ 1.495          4.617/ 1.631
PI CH / TAU CH            4.571/ 1.620          4.925/ 1.658
PI TL / TAU TL            .5219/ .8724          .5045/ .8662
LP SPOOL - % REF RPM           100.00                103.00
HP SPOOL - % REF RPM           100.00                 98.18
M5 / M5P                  .4000/ .3823          .4153/ .3139
M6                                .4113                 .4114
GAMMA M                           1.318                 1.315
CP M                               .282                  .284
P0/P9                             1.000                 1.000
PT9/P9                           12.627                 4.218
Limit                                          % RPM LP Spool
PT5`/PT5                           .998                  .959
PT6/PT5                            .965                  .959
TT6/TT5                            .889                  .904
ALPHA                              .300                  .242
MDOT (LBM/S)                     200.00                227.18
MDOT CORR (LBM/S)                173.27                227.17
AREA0 (SQFT)                       4.38                266.11
AREA0*(SQFT)                       3.51                  4.60
F                                 .0350                 .0345
F AB                              .0316                 .0324
FO (OVERALL)                      .0554                 .0569
T9/T0                            4.8681                4.9808
V9/V0                            3.0616              348.4641
M9/M0                            1.4392              162.0786
A9/A0                            1.6678                 .0150
A9/A8                            2.4440                1.3166
S (1/H)                          1.8252                1.6185
F/M (LBF/LBM/S)                  109.21                126.46
FUEL FLOW (LB/H)                 39867.                46499.
THRUST (LBF)                     21842.                28730.
PROP EFF (%)                      50.06                   .57
THERM EFF (%)                     44.87                 31.06
```

When off-design calculations are performed for different values of one off-design variable (Iteration Variable greater than 2), a special column is output for the engine limit (L) and a numerical code is output for the limit that restricted the result.

Code	Limit	Code	Limit
0	None	1	PIC
2	Pt3	3	Tt3
4	% rpm LP spool	5	% rpm HP spool

As an example, consider that the user wants to find the off-design performance of the above engine with the rpm limits at 20,000 ft. altitude over the range of Mach numbers from 0.0 to 2.5. The following output will result:

```
 FILE: DEFAULT            OFF-DESIGN CALCULATIONS              PAGE  2

          ***** FIXED AREA TURBINE - TURBOFAN ENGINE *****
 INPUT CONSTANTS
 PID MAX = .9700   CP C    = .2380   CP T    = .2950   CP AB   = .2950
 ETA B   = .9800   GAM C   =1.4000   GAM T   =1.3000   GAM AB  =1.3000
 ETA  AB = .9700   PI B    = .9700   PI AB   = .9600   PI N    = .9800
 ETA C`  = .8693   ETA CH  = .8769   ETA MH  = .9800   ETA ML  = .9900
 PI TH   = .4329   TAU TH  = .8420   ETA TL  = .9160   ETA MPL = .9800
 BLEED   =  1.00%  COOL #1 =  5.00%  COOL #2 =  5.00%  PTOL(KW)= 206.9
 PIM MAX = .9700   TAU M1  = .9681   TAU M2  = .9739   ETA MPH = .9800
 PIC MAX = 24.00   PT3 MAX = 450.0   TT3 MAX = 1660.R  PTOH(KW)=    .0
 RPML MAX= 103.0%  RPMH MAX= 100.0%

M0  =    .01    ALT =   20000. FT    T0  = 447.40 R
P0  =   6.7590 PSIA  P0/P9 = 1.0000  TT4 = 3200.0 R  TT7   = 3600.0 R

   M0 THRUST   AIR   FUEL   F/MDOT    S    PI C PI C`  ALPHA PT9/P9  V9/V0 L
        (LBF) (LB/S) (LB/H)
  .01 14907. 116.12  24330. 128.37 1.6321 24.00 4.800   .229   4.42 380.33 1
  .10 14697. 116.82  24469. 125.81 1.6649 24.00 4.801   .229   4.45  38.13 1
  .20 14671. 118.95  24893. 123.34 1.6967 24.00 4.801   .229   4.54  19.18 1
  .30 14871. 122.57  25610. 121.33 1.7221 24.00 4.803   .230   4.70  12.91 1
  .40 15300. 127.75  26636. 119.76 1.7409 24.00 4.805   .230   4.93   9.80 1
  .50 15964. 134.63  27993. 118.57 1.7536 24.00 4.808   .231   5.24   7.96 1
  .60 16877. 143.37  29710. 117.71 1.7604 24.00 4.811   .231   5.64   6.75 1
  .70 18052. 154.15  31816. 117.11 1.7625 24.00 4.813   .232   6.13   5.90 1
  .80 19349. 166.15  34144. 116.46 1.7646 23.77 4.778   .234   6.68   5.26 4
  .90 20258. 176.09  36036. 115.05 1.7788 22.70 4.604   .241   7.12   4.74 4
 1.00 21335. 187.65  38224. 113.75 1.7908 21.60 4.427   .249   7.62   4.32 4
 1.10 22525. 200.32  40592. 112.45 1.8021 20.51 4.248   .258   8.18   3.98 4
 1.20 23611. 212.87  42901. 110.91 1.8170 19.21 4.035   .269   8.72   3.69 0
 1.30 24347. 223.55  44812. 108.91 1.8406 17.55 3.761   .284   9.15   3.44 0
 1.40 25197. 235.55  46946. 106.97 1.8631 16.01 3.505   .300   9.62   3.22 5
 1.50 26161. 248.97  49311. 105.08 1.8849 14.59 3.268   .318  10.15   3.03 5
 1.60 27258. 264.04  51947. 103.23 1.9057 13.29 3.050   .336  10.75   2.87 5
 1.70 28501. 280.96  54879. 101.44 1.9255 12.11 2.852   .356  11.42   2.72 5
 1.80 29898. 299.92  58131.  99.68 1.9443 11.05 2.674   .375  12.18   2.60 5
 1.90 31459. 321.14  61731.  97.96 1.9623 10.10 2.513   .396  13.03   2.49 5
 2.00 33195. 344.83  65705.  96.26 1.9794  9.25 2.369   .416  13.97   2.38 5
 2.10 34234. 364.13  68854.  94.02 2.0113  8.21 2.192   .445  14.62   2.29 2
 2.20 34731. 380.07  71409.  91.38 2.0560  7.10 2.005   .482  14.99   2.19 2
 2.30 35324. 397.87  74281.  88.78 2.1028  6.15 1.844   .519  15.41   2.10 2
 2.40 36014. 417.68  77499.  86.22 2.1519  5.32 1.707   .557  15.85   2.02 2
 2.50 36802. 439.73  81097.  83.69 2.2036  4.62 1.590   .594  16.33   1.95 2
```

NOTE: *For the above example, the limit changes from the compressor pressure ratio (L=1) at low Mach, to % rpm for the low pressure spool (L=4) at Mach numbers around 0.8, to no limit (L=0) for Mach of 1.2 and 1.3, to % rpm for the high pressure spool (L=5) at Mach numbers around 1.4, and to the pressure at station 3 (L=2) for Mach greater that 2.0.*