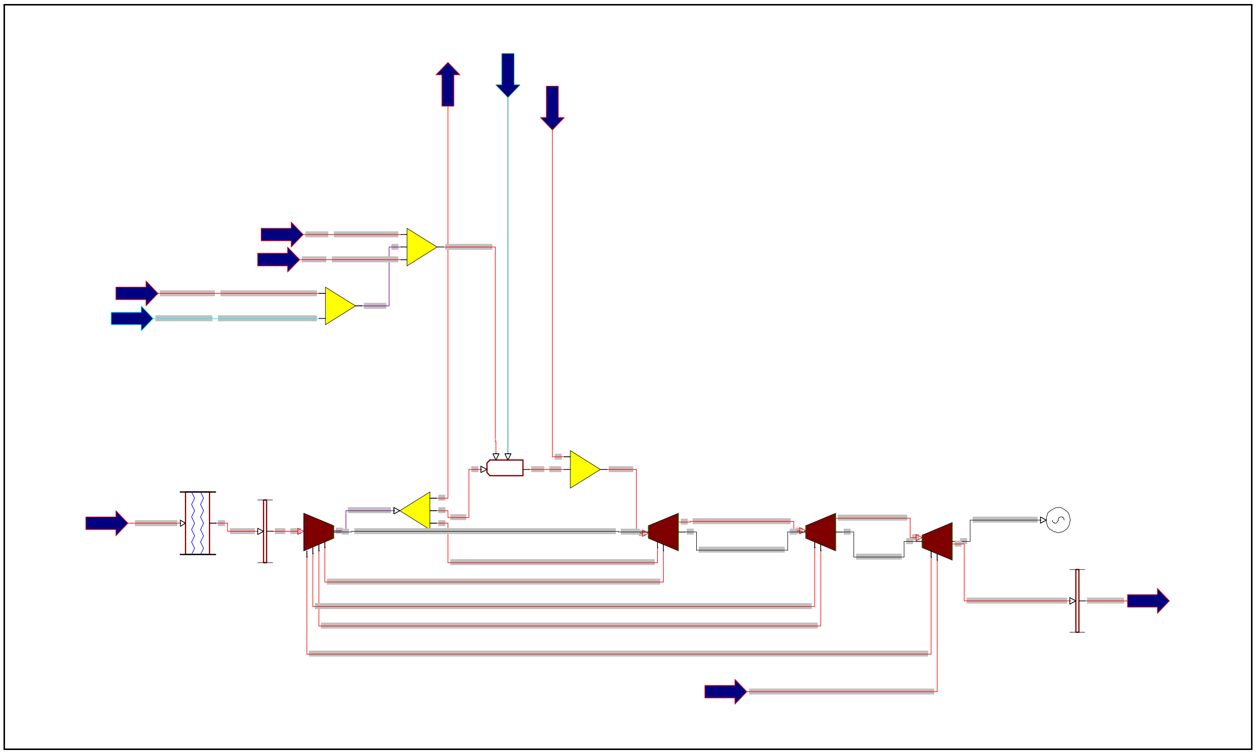
A GateCycle model of the GE 7FB on Synthesis Gas

Introduction

This document describes a GateCycle (GC) version 5.52 model of the General Electric 7FB Gas Turbine (GT) constructed by Marco Dieleman and Milton Venetos for the Department of Energy's National Energy Technology Laboratory (NETL). The model is based on data from a variety of publicly available sources as well as the experience of Mr. Dieleman and Mr. Venetos. Like any model, this model has limitations and it can only provide an estimate of the 7FB's performance on synthesis gas. The 7FB's actual performance may be different from that of the model for a variety of reasons.

The Model

GateCycle version 5.52 was used to construct a model named 7FBNG using GateCycle's separate GT equipment icons (compressor, combustor, and expander). The model's flow sheet diagram is shown below:



The model above represents the 7FB's 18 stage compressor with rotor and nozzle cooling flows for its 3 stage turbine (expander) bled from the compressor's discharge, 7th, 13th, and 17th stages This model contains the following cases:

- Case 7FBNG – A natural gas reference case used to match the model against the GF06MG PG7251FB MNQC data GT library curve set included with GateCycle version 5.52.

- Case 7FBSYN – A synthesis gas case using a blend of natural gas and synthesis gas. The synthesis gas used for this case has the following composition:

Fuel Constituent	Mole Fraction (by volume)
Carbon Monoxide	0.3025
Carbon Dioxide	0.3025
Hydrogen	0.3025
Water	0.0925

The above fuel has a lower heating value (LHV) of 2838.3 BTU/lb.

- Case 7FBSG2 – A pure synthesis gas case. The synthesis gas used for this case has the following composition:

Fuel Constituent	Mole Fraction (by volume)
Carbon Monoxide	0.4025
Carbon Dioxide	0.1025
Hydrogen	0.4025
Water	0.0925

The above fuel has a lower heating value (LHV) of 4976.1 BTU/lb.

All cases of the model refer to and use tables in the 7FNOX table file. This table file contains the following tables:

Table Name	Description
WAIRMX	maximum air flow vs. ambient temperature
CMPEFF	compressor efficiency vs. ambient temperature & inlet air flow
EXPEFF	expander efficiency vs. ambient temperature & expander inlet flow
TEXMAX	maximum exhaust. temperature vs. ambient temperature & exhaust flow
7FNOX	LHV vs. Nox & H2 content

The model makes extensive use of GateCycle's macro capability. The model's macros and the equations used in these macros are listed in the Appendix. These macros are used for a variety of supplemental calculations (like metal temperatures) and to set the compressor and turbine efficiencies and enforce limits (e.g. maximum exhaust temperature, maximum and minimum air flow, maximum pressure ratio). By enforcing these limits, the macros model the engine's control system. The overall control scheme is as follows:

The POWCNT macro tries to find the "most-limiting" limit between:
Maximum air flow, power, minimum air flow (60% of max. air flow), and pressure ratio.
Based upon this, the inlet air flow rate is set.

The TCOMB combustor control macro also takes some limits into account (maximum first rotor temperature and maximum exhaust temperature) along with the result of the POWCNT macro to set the combustor exit temperature.

The POWCNT macro controls the power by setting the inlet air flow rate provided it is not limited by the maximum pressure ratio (assumed to be when the compressor discharge pressure reaches 275 psia), or the maximum inlet air flow rate. If either of these limits is reached, the POWCNT macro sets the inlet air flow rate to stay within those limits and the power is at the maximum.

If the POWCNT macro calculates the inlet air flow to be less than the minimum (60% of maximum air flow) inlet air flow, it puts the flow at the minimum and then over-estimates power. In this case, where POWCNT overpredicts power, TCOMB takes over the power control. Under normal circumstances the TCOMB macro does not control power, and it sets the firing temperature to the maximum possible (either limited by first rotor temperature, or exhaust temperature). When the POWCNT macro reaches minimum air flow the TCOMB macro will set the combustor exit temperature to a value that allows the calculated power to match the user input target power instead of setting the combustor exit temperature to its maximum possible value.

Key Model Assumptions

Our 7FB model incorporates the following assumptions:

1. The 7FB has a compressor pressure ratio of 18.5:1 at ISO conditions
2. The nozzle and rotor cooling flow extraction locations are the same as those for the 7FA.
3. The 7FB's roughly 100F increase in firing temperature relative to that of the 7FA is achieved largely through the use of better Thermal Barrier Coatings (TBCs).
4. Firing temperature (first rotor temperature) is assumed to be constant for loads of 60% or higher of base load. (Provided it is not limited by exhaust temperature constraints which is actually just about all the time)
5. Off design cooling effectiveness is assumed to be constant in off design cases.

Using the Model

The model is primarily intended for running the 7FB in a simple cycle mode on synthesis gases of different compositions. The 7FBSG2 case is recommended for this use. To perform such a study follow these steps:

1. Open the 7FBSG2 case
2. Go to Inputs… System… System Gas and input the desired synthesis gas composition by specifying the mole fractions of its constituents.
3. Go to Inputs… User Variables… and enter a desired target power value in megawatts into user variable 18.
4. Enter any diluent gases, diluent steam injection, steam for power augmentation, N2 for power augmentation, bleed air etc. in the appropriate streams.
5. Turn the Evaporative Cooler on/off as desired.
6. Enter the desired ambient conditions.
7. Run a GateCycle analysis.

The model will calculate the synthesis fuel gas flow, output power, metal temperatures, cooling flows, etc. The calculated metal temperatures are stored in User Variables 7 to 12. If the model fails to converge, this is most likely a result of inputting a synthesis gas with too low a heating value. The fuel's composition should be altered to up its heating value or it should be blended with natural gas to get the model to converge. Alternatively, you may turn the NOX macro off, if you wish to ignore the fact that the LHV is out of range.

References

The following documents were referenced in the creation of this model. These documents may be freely downloaded from the gepower.com website by searching for the GER- number.

Brooks, Frank J., *GE Gas Turbine Performance Characteristics,* GER-3567H, GE Power Systems October 2000.

Eldrid, Roberta, et. al., *The 7FB: The Next Evolution of the F Gas Turbine,* GER-4194, GE Power Systems, April 2001.

Gebhardt, Eric, *The F Technology Experience Story,* GER-3950C, GE Power Systems, October 2000.

Appendix Model Macros

GateCycle Report - Macro Report: MODEL(7FBNG) CASE(7FBSG2)
Prepared using GateCycle Version 5.52.0.r

```
Macro ID : BTUSCF
Macro Description : Calculate LHV of Synthesis gas in Btu/scf
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    CMB1    Lower Heating Value             4746.8994140  BTU/lb
B    CMB1    Fuel Inlet Molecular Weight     18.251291275
C    SYSTEM  User Variable Values -13        228.30364990
D    SYSTEM  User Variable Values -15        60.000000000
E    SYSTEM  User Variable Values -16        14.696000099

X: a*b
Y: 22.414*((d+459.69)/(32+459.69))*453.59237/28.317
Z: x/y

SET  C  TO  Z  AFTER  SYSTEM
```

```
Macro ID : CMPEFF
Macro Description : Compressor Efficiency Lookup
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
B    C1      Inlet Flow                      945.43383789  lb/sec
C    C1      Desired Polytropic Efficiency   .9079352021
D    C1      Inlet Pressure                  14.586945533  psia
E    C1      Inlet Temperature               58.999988555  F


LBL  TBFILE  TABLE   OUTPUT                          COMMENT
F    7FNOX   CMPEFF                                  Compressor Eff

X: (14.5869/d)*b
Y: f(e, x)

SET  C  TO  Y  AFTER  C1
```

```
Macro ID : EX1EFF
Macro Description : Set Expander 1 Eff
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    EX1     Desired Step (polytropic) Effi  .8326854706
B    SYSTEM  User Variable Values - 0        .8326854706

SET  A  TO  B  BEFORE  EX1
```

```
Macro ID : EX2EFF
Macro Description : Set Expander 2 Efficiency
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    EX2     Desired Step (polytropic) Effi  .8326854706
B    SYSTEM  User Variable Values - 0        .8326854706

SET  A  TO  B  BEFORE  EX2
```

```
Macro ID : EX3EFF
Macro Description : Set Expander 3 Efficiency
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    EX3     Desired Step (polytropic) Effi  .8326854706
B    SYSTEM  User Variable Values - 0        .8326854706

SET  A  TO  B  BEFORE  EX3
```

```
Macro ID : EXPEFF
Macro Description : Lookup Expander Efficiency
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
B    C1      Inlet Temperature               58.999988555  F
C    SYSTEM  User Variable Values - 0        .8326854706
E    EX1     Inlet Flow                      867.27459716  lb/sec


LBL  TBFILE  TABLE   OUTPUT                          COMMENT
A    7FNOX   EXPEFF                                  Expander Eff

X: a(b,e)

SET  C  TO  X  AFTER  C1
```

```
Macro ID : NOX
Macro Description : 7F Nox vs H2
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    SYSTEM  User Variable Values -13        228.30364990
B    SYSTEM  User Variable Values -14        15.429205894
C    CMB1    Fuel Inlet Hydrogen             .3837171793

LBL  TBFILE  TABLE   OUTPUT                          COMMENT
D    7FNOX   7FNOX                                   Nox vs. H2 and Bt

X: d(c,b)

CONTROL  A  TO  X
VARY  B  FROM  .0000000000  TO  200.00000000  LOOPAROUND  CMB1
```

```
Macro ID : NOZM1
Macro Description : Nozzle 1 Metal T
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
C    EX1     Nozzle Cooling Temperature      840.99755859  F
D    EX1     Inlet Temperature               2693.8132324  F
E    SYSTEM  User Variable Values - 2        .6735000014
F    SYSTEM  User Variable Values - 8        1445.9417724

X: d- e* (d-c)

SET  F  TO  X  AFTER  EX1
```

```
Macro ID : NOZM2
Macro Description : Nozzle 2 Metal T
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
C    EX2     Nozzle Cooling Temperature      555.80584716  F
D    EX2     Inlet Temperature               2016.0393066  F
E    SYSTEM  User Variable Values - 4        .3887999952
F    SYSTEM  User Variable Values -10        1448.3002929

X: d- e* (d-c)

SET  F  TO  X  AFTER  EX2
```

```
Macro ID : NOZM3
Macro Description : Nozzle 3 Metal T
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
C    EX3     Nozzle Cooling Temperature      287.50204467  F
D    EX3     Inlet Temperature               1566.7877197  F
E    SYSTEM  User Variable Values - 6        0.0817999989
F    SYSTEM  User Variable Values -12        1462.1420898

X: d- e* (d-c)

SET  F  TO  X  AFTER  EX3
```

```
Macro ID : PWRCNT
Macro Description : Power Control
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    C1      Desired Input Air Flow Rate     945.44561767  lb/sec
B    SYSTEM  Net Cycle Power                 209.81134033  MW
C    SYSTEM  User Variable Values -18        210.00000000
D    SYSTEM  User Variable Values -19        953.26287841
E    C1      Inlet Flow                      945.43383789  lb/sec
F    EX1     Inlet Pressure                  274.96591186  psia

X: max(max(max((b/c), (e/d)), (0.6*d)/e), (f/275))
Y: 1
```

```
Z: max((0.6*d),(1/max(max((b/c), (e/d)), (f/275))*a))*0.1+0.9*a

SET  A  TO  Z  AFTER
```

```
Macro ID : RTRM1
Macro Description : Rotor 1 Metal T
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    EX1     Main Outlet Temperature         2016.0393066  F
B    EX1     Cooling Cp                      .2597183883   BTU/lb-F
C    EX1     Rotor Cooling Temperature       779.05572509  F
D    EX1     Rotor Inlet Temp.               2549.1464843  F
E    SYSTEM  User Variable Values - 1        .6238999963
F    SYSTEM  User Variable Values - 7        1444.7867431

X: d- e* (d-c)

SET  F  TO  X  AFTER  EX1
```

```
Macro ID : RTRM2
Macro Description : Rotor 2 Metal T
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    EX2     Main Outlet Temperature         1566.7877197  F
B    EX2     Cooling Cp                      .2507489026   BTU/lb-F
C    EX2     Rotor Cooling Temperature       779.05572509  F
D    EX2     Rotor Inlet Temp.               1974.1451416  F
E    SYSTEM  User Variable Values - 3        .4359999895
F    SYSTEM  User Variable Values - 9        1453.0860595

X: d- e* (d-c)

SET  F  TO  X  AFTER  EX2
```

```
Macro ID : RTRM3
Macro Description : Rotor 3 Metal T
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    EX3     Main Outlet Temperature         1176.3248291  F
B    EX3     Cooling Cp                      .2439080626   BTU/lb-F
C    EX3     Rotor Cooling Temperature       58.999988555  F
D    EX3     Rotor Inlet Temp.               1564.1557617  F
E    SYSTEM  User Variable Values - 5        0.0678000003
F    SYSTEM  User Variable Values -11        1462.1062011

X: d- e* (d-c)

SET  F  TO  X  AFTER  EX3
```

```
Macro ID : TCOMB
Macro Description : Combustor Control
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    S1      Inlet Temperature               1176.2595214  F
B    SYSTEM  User Variable Values -17        1200.0000000
C    EX1     Rotor Inlet Temp.               2549.1464843  F
D    EX1     Inlet Pressure                  274.96591186  psia
E    CMB1    Desired Combustor Exit Tempera  2693.8088378  F
F    SYSTEM  Net Cycle Power                 209.81134033  MW
G    SYSTEM  User Variable Values -18        210.00000000
H    SYSTEM  User Variable Values -19        953.26287841
I    C1      Inlet Flow                      945.43383789  lb/sec

X: max(max((c/2550), (a/b)), (0.6*h)/i*(f/g))
Y: 1

CONTROL  X  TO  Y
VARY  E  FROM  1600.0000000  TO  2750.0000000  LOOPAROUND
```

```
Macro ID : TEXMAX
Macro Description : Texh. Max
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
B    EX1     Inlet Flow                      867.27459716  lb/sec
C    C1      Inlet Temperature               58.999988555  F
D    SYSTEM  User Variable Values -17        1200.0000000


LBL  TBFILE  TABLE   OUTPUT                          COMMENT
A    7FNOX   TEXMAX                                  Texh Max vs. Tamb

X: a(c,b)

SET D  TO  X  AFTER  EX1
```

```
Macro ID : WAIRMX
Macro Description : Max Air Flow
Macro Enabled : Yes

LBL  COMP    VARIABLE                        VALUE         UOM
A    C1      Inlet Flow                      945.43383789  lb/sec
B    C1      Inlet Pressure                  14.586945533  psia
D    C1      Inlet Temperature               58.999988555  F
E    SYSTEM  User Variable Values -19        953.26287841

LBL  TBFILE  TABLE   OUTPUT                          COMMENT
C    7FNOX   WAIRMX                                  Maximum Air Flow

X: b/14.5869
Y: c(d)*x

SET  E  TO  Y  AFTER  C1
```