Welcome!

Webinar #12: Different ways of modelling GT’s in the TF Program Suite
27 September 2017

**Agenda:**
* Introduction
* Modelling Different GTs’ in GT PRO/GT MASTER
* Modelling Different GTs’ in THERMOFLEX
* Examples
* Q & A Session

(pls. send Q’s anytime during the presentation to both the presenter & host)

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Support: Meritt Elmasri (U.S. HQ)
Thermoflow Training and Support

- Standard Training
- On-site Training course
- Advanced Workshop
- Webinars when new version is released
- Help, Tutorials, PPT, Videos
- Technical Support

→ Feature Awareness Webinars
Feature Awareness Webinars

1- Assemblies in THERMOFLEX
2- Scripts in Thermoflow programs
3- Multi Point Design
4- Reciprocating Engines
5- Simplified Annual & TIME
6- Matching ST Performance
7- Modelling Solar Systems
8- Combining Thermoflex & Application Specific
9- Methods and Methodology explained
10- Supplementary Firing & Control Loops in GT PRO/GT MASTER
11- The Wind Turbine Feature in Thermoflex
12 -Different ways of modelling GT’s in the TF Program Suite
The Gas Turbine- An Example

Note the number of compressor bleeds, either for HPT stator cooling or for turbine blade clearance control.
Different GT Models in – GT PRO

- 2 tabs are available to the user in GT PRO ie.

GT Selection: the GT is selected at this point

GT Inputs: 8 input tabs for details of fuel, pressure drops, performance tuning, fuel heating, inlet cooling/chilling etc.
### GT Selection Tab

#### Engine Selection Filter
- Show engines rated from 1 MW to 300 MW
- Sort by:
  - Manufacturer
  - Smallest to largest power
  - Largest to smallest power

#### Other GT Model Options
1. GE engine computed using GE APPS
2. GT Template Defined Gas Turbine Model
3. User-defined Gas Turbine Performance

#### No Gas Turbine
- GE 537/1A
- GE 654/6
- GE LM5000
- GE LM6000
- GE LM16000
- Solar 2.5
- Solar 4.5
- Solar Max 90
- Siemens Industrial 50/60-K85
- Siemens Industrial 50/60-K86
- Siemens Industrial 50/60-K87
- Siemens Industrial 50/60-K88

#### Other Engines
- Various models and specifications listed, including RPM, MWe, etc.

### Reference
**Reference price for basic gas turbine with excluded appearance, excluding stack. It is not a cost estimate for a simple cycle plant.**
No of gas turbines – select as required
Single shaft- tick if appropriate
Display entire/partial GT library – 50/60 Hz GT’s etc – order as required
ID No. – note this column. ID numbers range from minus 3 to 645 and this is an indication of how many unique GT models are resident in GTPro ie.

ID No. -3 : GE Engine Computed Using GE APPS
This is an option for GE internal use & is not available to non GE employees. The APPS program provides performance data for the GE aeroderivative engines (LM2500, LM6000 etc)

ID No. -2: GE Template Defined Gas turbine model
Ref the GT Template xx tool from within the TF program suite. GT Template models are stored in c:\TFlow xx\GTDU

ID No. -1: User Defined Gas Turbine Performance
Enables the user to characterise the GT at one unique operating point in terms of generator power, heat rate, exhaust mass flow and exhaust temperature. This data needs to be provided by a program such as the GE APPS or Siemens SIEPEP in house programs.

ID No. 0: No gas turbine. Self evident & a useful option when just need to focus on the bottoming cycle
No Asterisk Type Engines – Physical Model
ie. ID no. 378

<table>
<thead>
<tr>
<th>ID</th>
<th>Manufacturer &amp; Model</th>
<th>Shafts</th>
<th>RPM</th>
<th>PR</th>
<th>TIT °C</th>
<th>TET °C</th>
<th>Air Flow t/h</th>
<th>Gen Power kW</th>
<th>LHV HR kJ/kWh</th>
<th>LHV Eff %</th>
<th>Price*** MMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>378</td>
<td>Ansaldo AE64.3A</td>
<td>1</td>
<td>5413</td>
<td>17.6</td>
<td>1421</td>
<td>563</td>
<td>763</td>
<td>74550</td>
<td>16065</td>
<td>35.8</td>
<td>22.6</td>
</tr>
</tbody>
</table>

Ref the guidance box for important information regarding limitations on use of the GT model and basic configuration data (ie. combustor type). None Asterisk type engines typically have the least limitations imposed on their operation. The model is a reverse-engineered, detailed, physical engine model to calculate gas turbine performance. Ref GTPro Help Menu ch. 5.2.

Physical model type engines reside in c:\TFlow xx\GTD as a MACHnnn.GTD file where the nnn equates to the GT id number in the GT Library ie. MACH378.GTD is the physical model for the id. No. 378 GT noted above – these files are not available for manipulation.

AE64.3A - Revised 11-18-2009, estimated price updated September 2016. This machine specification is no longer available new (superseded by engine ID #457).

Source: Ansaldo Energia data recd 11/09

Dry Low NOx Combustor

No change to nominal data

Max model errors in test range: Mex<0.5% kW<0.5% HR<0.5% Tex<5F (2.8C)

Test range: 0 to 120 F (-18 to 49 C) full load dry

Part load model with variable IGV control included
GT Pro - GT Library Selected Engines – Points to Watch (continued)

Engines Having 1 Asterisk – Data Defined
ie. ID no. 192

<table>
<thead>
<tr>
<th>ID</th>
<th>Manufacturer &amp; Model</th>
<th>Shafts</th>
<th>RPM</th>
<th>PR</th>
<th>TIT C</th>
<th>TET C</th>
<th>Air Flow t/h</th>
<th>Gen Power kWc</th>
<th>LHV HR kJ/kWh</th>
<th>LHV Eff %</th>
<th>Price*** MM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>192</td>
<td>GE LM6000 FC SPRINT (*)</td>
<td>2</td>
<td>3000</td>
<td>23.4</td>
<td>-</td>
<td>439</td>
<td>455</td>
<td>42497</td>
<td>9058</td>
<td>39.8</td>
<td>10.1</td>
</tr>
</tbody>
</table>

Guidance

GE LM6000SPT - Revised 06-08-2000, estimated price updated September 2016. This machine specification is no longer available new (superseded by engine ID #236).

(*) -> 'Data-defined' engine model; performance results come from a database of vendor data at selected conditions and interpolation in between.

(*) -> Review following comments for any restrictions on scope of validity of this model. Press F1 for more information.

- Geared version of 60Hz engine
- Standard Combustor
- Source: GE data rcvd 5/00. Standard Combustor
- Model limited to compressor inlet temperature above 40F (4C)
- Model capable of full load only
- Max model errors in test range: Mex<0.5% kWe<0.5% HR<0.5% Tex<5F (2.8C)

The (*) adjacent to the GT name identifies the GT as being a Data Defined Model for which operational limitations will apply. Ref the guidance box for important information regarding limitations on use of the GT model and basic configuration data (ie. combustor type). Ref GTPro Help Menu ch. 5.3. The model data is resident in GTPro as a .GTD file, in this case MACH192.GTD. These files are not available for manipulation.
Engines Having 2 Asterisks – Curve Fit OEM
ie. ID no. 388

<table>
<thead>
<tr>
<th>ID</th>
<th>Manufacturer &amp; Model</th>
<th>Shafts</th>
<th>RPM</th>
<th>PR</th>
<th>TIT C</th>
<th>TET C</th>
<th>Air Flow t/h</th>
<th>Gen Power kWe</th>
<th>LHV HR kJ/kWh</th>
<th>LHV Eff %</th>
<th>Price*** WM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>388</td>
<td>GE 6F 3-econs (**)</td>
<td>1</td>
<td>5100</td>
<td>15.5</td>
<td>596</td>
<td>750</td>
<td>70250</td>
<td>10030</td>
<td>35.9</td>
<td>25.4</td>
<td></td>
</tr>
</tbody>
</table>

**Guidance**

GE 6F 3-ser - Revised 06-29-2010, estimated price updated September 2016. This machine specification is no longer available new.

(**) -> 'Curve fit OEM' model; performance results come from a GT Template model which uses vendor data at selected conditions and interpolation in between.

(**) -> Review following comments for any restrictions on scope of validity of this model. Press F1 for more information.

Source: GE GTP 3.9.0 06/2010
No change to nominal data
Dry Low NOx Combustor (15/42)

The (**) adjacent to the GT name identifies the GT as being a Curve-Fit OEM Data Model for which operational limitations may apply. Ref the guidance box for important information regarding limitations on use of the GT model and basic configuration data (ie. combustor type). The model uses the same structure as the GT Template model, hence the file for the machine has a .GTT extension ie. in this case MACH388.GTT. These files are not available for manipulation.
In some cases the User may wish to generate their own GT model which can be used at various operating points repeatedly. In this case the user may generate a GT performance file by means of the GT Template program resident in the TF Program suite. Ref Help Volume 4, GT Template and the example files for the GE 6541B and the Solar Mercury 50 GT’s resident in c:\TF26\GTDU\
Have eight input screens as follows:
- Gas Turbine Main Inputs: main inputs entered on this screen include water and steam injection and also the GT fuel definition. If the GT is a User Defined type, then the key performance parameters are also entered on this screen.

- Inlet heating & cooling: inputs available on six sub-tabs include compressor recirculation.

- Model Adjustments: allows the GT to be tuned to specific performance parameters. A useful feature when tuning a library GT to OEM supplied performance data. Feature may be limited in application if GT chosen likewise has performance limitations applied (i.e., full load operation only).

- Controls, margins and genset losses: allows further manipulation of how the GT behaves, particularly how the exhaust temperature trends during part load operation. Care is required in manipulating these variables. Ref the Help menu, Ch. 6.4

- Fuel Heating and GT Cooling: in most part self explanatory, some options such as GT Heat Rejection will be available depending on the GT selected (ref next slide)

- Bleeds & Injections: whether these inputs are available depends at the New Session screen, specifically whether or not the plant includes IGCC.

- Auxiliaries & Miscellaneous: enables fine tuning of these parameters influencing the plant aux loads

- Equipment Options PEACE tab: inputs made here will influence the final plant cost.
Assume that receive the following OEM data:

GT: 6fa, DLN combustor, air cooled generator with 0.8 pf, GT operates at base load, 5231 rpm

Site Conditions: 323 m asl, 10.1 degC, 67.2% RH

GT Performance:
HR 10060 kJ/kW-hr, generator output 76410 kW, 747.9 x10^3 kg/hr, exhaust temp 593.2 degC,

Fuel: Natural Gas @ 20degC

Fuel Composition by volume (%): C1@ 91.34, C2 @3.5, C3 @0.86, C4 @0.37, C5 @0.01, N2 @0.49, CO2 @3.41, H2S @0.02

Losses:
inlet loss = 7.47 mBar, exhaust loss = 24.28 mBar, generator losses = 1173.3kW, fixed aux load = 400.37kW, gear losses = 1079.6kW

How best to model this?

Choose based on given task ie. if an accurate cycle design is required which will dictate major item selection for the bottoming cycle, the User Defined GT may be the best way to go.

On the other hand, if it is required to do a quick economic analysis of two similar CCGT’s, then a tuned library selected GT may be best...
Using the OEM data provided, build the User Defined GT in GTPro. The result is shown below.

GT generator power = 76410 kW
GT Heat Rate @ gen term = 10060 kJ/kWh
GT efficiency @ gen term = 32.31% HHV = 35.79% LHV

Fuel = Balkans NG
28 p
20 T
17.01 m
45177 LHV

Ambient air in
0.9752 p
10.1 T
730.9 m
67.2 %RH
323 m elev.

Steam Properties: IAPWS-IF97
0.9677 p
10.1 T
730.9 m
66.69 RH

GT PRO 26.1 skavale@email.cz
2436 09-27-2017 14:56:40 file=C:\TFLOW26\MYFILES\Webinar_GTmodelling\Balkans_6fa.gtp

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Using the OEM data provided to tune the ID no. 258 Library GT. The result is shown below.

GT generator power = 76407 kW
GT Heat Rate @ gen term = 10063 kJ/kWh
GT efficiency @ gen term = 32.3% HHV = 35.77% LHV
GT @ 100% rating, inferred TIT control model, CC limit

Ambient air in
0.9752 p
10.1 T
730.9 m
67.2% RH
323 m elev.

Fuel = Balkans NG
28 p
20 T
17.02 m
45177 LHV

p(bar), T(°C), M[t/h], Q[kW], Steam Properties: IAPWS-IF97

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This menu item allows heat rejection hardware to be incorporated into the GT cooling circuit which normally bleeds compressor air to the turbine stages for cooling purposes. Additional heat rejection can be realised via combustor cooling. Hence two schemes for heat rejection are possible ie.

Care is required when manipulating these parameters with User Defined GT’s. Ref Help > GTPro > ch.6.1.2
For some GT library models, heat rejection is built-in. The user then has the choice of defining the disposition of the rejected heat (either to an external source or to the cycle) i.e., GT ID no. 55 - in either case, the quantity of rejected heat is the same...
Depending on the GT model, a number of heat rejection schemes may be a feature of the machine. By choosing the “Built In” option, all heat rejection schemes are accounted for. By choosing the “User defined” option, all heat rejection schemes are still accounted for but the user has more control over the sources and sinks in the heat rejection scheme. GT ID no. 544
Some Library GT models will also include model streams which the user has no control over. An example is GT ID no. 553 which includes intercooling of the compressor air by means of water injected as a fine mist, this improving cycle efficiency.

Have the given set of conditions:

GT: LM6000PC SPRINT, std combustor, air cooled generator with 0.9 pf, GT operates at base load, LPT rpm 3627

Site Conditions: 474 m asl, 8.7 degC, 75.4% RH

GT Performance:
- HR 9134 kJ/kW-hr, generator output 48682 kW, 469.139 x10^3 kg/hr, exhaust temp 446 degC,
- Fuel: Natural Gas @ 20degC
- Fuel Composition by volume (%): C1@ 91.34, C2 @3.5, C3 @0.86, C4 @0.37, C5 @0.01, N2 @0.49, CO2 @3.41, H2S @0.02
- Losses: inlet loss =9.967 mBar, exhaust loss = 14.95 mBar, generator losses = 662kW, gear losses = 460kW

Mass Balance:
- Fuel in @ 8.899 t/hr, NOx water spray @ 9.136 t/hr, SPRINT spray @ 3.677 t/hr, exhaust (as above), air inlet flow @ 450.72 t/hr.

Ref next slide for GTPro simulation result.
GT PRO - GT Inputs Tab – Features Included By Default

Ambient air in
0.9577 p
8.7 T
451.8 m
75.4 %RH
474 m elev.

Fuel = Russian_NG
43 p
15 T
8.881 m
49162 LHV

p[bar], T[°C], M[ℓ/h], Q[kW], Steam Properties: IAPWS-IF97

Included by default

GE LM6000 SPT (ID # 553)
(Data-defined Model)

GT efficiency @ gen term = 35.95% HHV = 39.87% LHV
GT Heat Rate @ gen term = 9029 kJ/kWh
GT generator power = 48381 kW

Includes

GT @ 100 % rating
41.37 p
15 T
9.136 m
1.029 WTR/FUEL

NOx = 28 ppmv d @ 15% O2

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Performing a simple mass balance around the engine:
Have 472.432 T/hr flowing into the machine
Have 469.139 T/hr flowing out of the machine

This leaves a difference of + 3.293 T/hr ie. more is flowing into the machine than is flowing out. This difference is assigned to the compressor bleed air (unloading the compressor at this condition).

The GT Pro Inputs are shown on the following slides
GT PRO Inputs – Main GT Inputs Tab

Ambient air in
0.9577 p
8.7 T
450.7 m
75.4 %RH
474 m elev.

4.3% Δ

Fuel = Russian NG
40 p
15 T
9.041 m
49162 LHV

0.9478 p
8.7 T
450.7 m
74.62 RH

3.435 m
3.677 m

45 p
38 T
9.136 m
1.011 WTR/FUEL

GT generator power = 48682 kW
GT Heat Rate @ gen term = 9134 kJ/kWh
GT efficiency @ gen term = 39.53% HHV = 39.41% LHV

As required

User Def GT

GT efficiency @ gen term = 35.53% HHV
GT Heat Rate @ gen term = 9134 kJ/kWh
GT generator power = 48682 kW

As required

48682 kW
9134 kJ/kWh LHV
39.41 % LHV eff.
100 % load

98.66 % eff.

662 Qrej
582.6 (elec. & windage loss)
79.44 (mech. loss)

40 p
15 T
9.041 m
49162 LHV

4.3% Δ

Fuel = Russian NG
40 p
15 T
9.041 m
49162 LHV

9.967 millibar

0.9478 p
8.7 T
450.7 m
74.62 RH

3.435 m
3.677 m

45 p
38 T
9.136 m
1.011 WTR/FUEL

As required

14.95 DP millibar

0.9727 p
446 T
469.1 m

N2= 71.56 %
O2= 12.59 %
CO2= 3.344 %
H2O= 11.64 %
AR= 0.8615 %

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GT MAST... - Different GT Models

In transitioning the GTPro model to GTMaster, the user has the following features available:

- for a GT from the GT Library: Manipulation of the GT load (assuming that the model is the physical model type or has no part load restrictions if it is a either a Data Defined type or Curve Fit OEM type model

- Reselect GT: the user can select to power the cycle already defined with another (similar performance) GT. A useful feature in the case of a repowering type study. If the No GT option is selected then the GT Inputs screen becomes the same as the HRSG Inlet screen from GTPro

GT Master - GT Inputs tab: same as in GTPro with the same sub tabs except for the Equipment Options PEACE tab which is omitted. Note that significant hardware items that were not defined in GTPro can not now be defined in GTMaster. Hence if inlet air chilling was not defined in GTPro, it cannot be subsequently defined in GTMaster. Compressor air recirculation is however still able to be defined in GTMaster even though in GTPro it may have been ignored.
Visual Cues from Heat Balances

Red GT always denotes a GT selected from the GT library resident in GT PRO- the ID No.

A white GT denotes the user defined type GT No.

Note: In GT PRO v.26 all inputs defining the gas turbine heat balance are preserved when changing from a built-in model to the User Defined Gas Turbine model. Previously (GT PRO v.25) only the heat rate, power, exhaust flow, and exhaust temperature were preserved.
A couple of methods are available to the THERMOFLEX user in which to model the GT.

Method 1- By selecting the GT PRO Gas Turbine option from the gas/air group & connecting the appropriate sources & sinks (air, fuel, steam injection etc). The completed component appears as:

Clicking into the GT icon opens up it’s input screen – note the similarity to the normal GT PRO GT Input screen. The GT can be reselected from ID No. -3 to XX (with the exception of ID . 0 )
Introduction – GT’s & GT Modelling – THERMOFLEX (continued)

Method 2- By building up the gas turbine from discrete components. The completed GT appears as:

Example of aeroderivative multi-shaft GT, ref sample file S2-24

Note: care is required when taking this type of model into off design mode since this type of GT model does not incorporate the required performance correction curves

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GT’s & GT Modelling – THERMOFLEX (continued)

Additional factors to bear in mind when modelling GT’s by the 2nd method
- Neither the compressor icon, turbine icon and combustor icon are a flow dictating device, hence the correct flow for the model needs to be defined, usually by fix a flow at the air source.

- Even the simplest GT uses compressor bleed air for turbine cooling (typically the 1st stage NGV’s), hence a cooled turbine stage icon will need to be included. Partially this IS a flow dictating device since the cooling flow stream is a function of the design metal temperature.

- The Turn Rubber On, Control Loop and Shaft Balancing features in TFX all make the GT modelling exercise fairly straight forward.
GT’s & GT Modelling – THERMOFLEX (continued)

GT Modelling exercise to illustrate some of the points from the previous page: the ID 378 engine GT PRO results provide the THERMOFLEX model input data.

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GT Modelling exercise to illustrate some of the points from the previous page: the ID 378 engine THERMOFLEX equivalent model
Main points to note are that:
- if the GT model is from the GT library, then the normal GT MASTER type off design inputs are available to the user when in TFX OD mode

-if the GT model has been built up from discrete icons, then off design operation will likely require reference to OEM performance data. Part load runs can be achieved either by manipulating the compressor inlet airflow or by applying control loops to manage various parameters at once (caution required)
Q & A Time....