



Welcome!

Webinar #18: Steam Turbine Tuning

13 December 2017

Agenda:

- * Introduction
- Steam Turbine Characterization
- Goals
- Initial Design
- Tuning tools in GT MASTER
- Tuning tools in THERMOFLEX
- Reminders ----
- * Q & A Session

Presenter: Norm Decker (U.S. HQ)

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



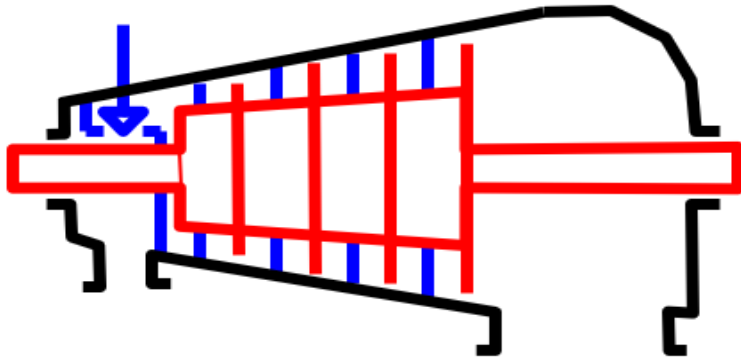
- 1- Assemblies in TFX
- 2- Scripts in Thermodflow programs, GTP-GTM-TFX
- 3- Multi Point Design in GTP-GTM
- 4- Reciprocating Engines in TFX
- 5- TIME in GTM
- 6- Matching ST Performance in STP
- 7- Modeling Solar Systems in TFX
- 8- Combining THERMOFLEX & Application-Specific Programs
- 9- Methods & Methodology in GT PRO & STEAM PRO
- 10- Supplementary Firing & Control Loops in GT PRO & GT MASTER
- 11- The Wind Turbine Feature in Thermoflex
- 12- Modelling GT's in Thermodflow program-as-1
- 13- Thermoflex for on line and off line performance monitoring
- 14- Tflow 27, what's new
- 15- Modelling GT's in Thermodflow program-as-2
- 16- Multi Point Design in GTP-GTM
- 17- Total Plant Cost in THERMOFLEX



18- Steam Turbine Tuning

Steam Turbine Performance Characterization

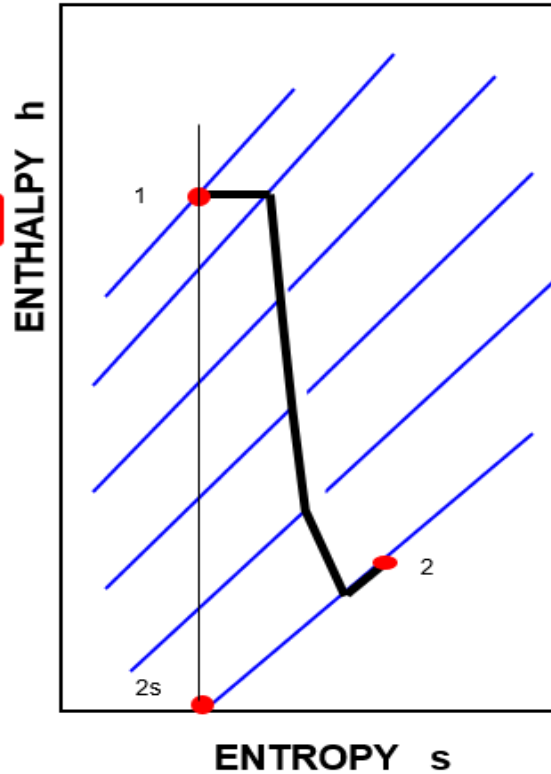
Power = $m (h_1 - h_2)$



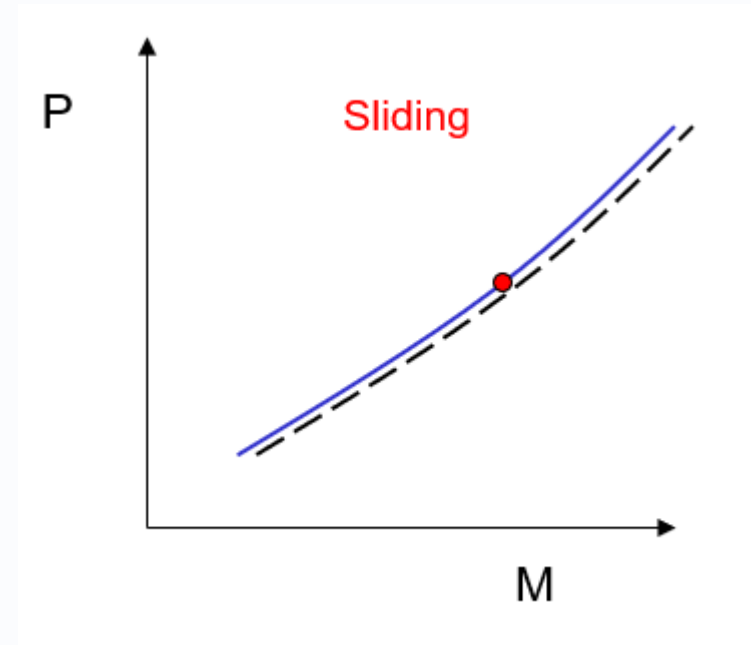
Group overall efficiency

$= (h_1 - h_2) / (h_1 - h_{2s})$

Spans all blading in group, plus exhaust loss and control valve inefficiencies



$(h_1 - h_2) = \text{function of } \{P_1, h_1, P_2, \eta\}$



$P_1 = \text{function of } \{h_1, m, A, P_2\}$

Steam Turbine Performance Characterization

$$\text{Power} = m (h_1 - h_2)$$

$$(h_1 - h_2) = \text{function of } \{P_1, h_1, P_2, \eta\}$$

$$P_1 = \text{function of } \{h_1, m, A, P_2\}$$

To tune a given model to match measured or proposed performance, you need to control these key values:

Flow (m)

Efficiency (η)

Nozzle area (A)

And... some other details...

Steam Turbine Performance Characterization

The Devil, they say, is in the details, but there really are only a few...

Flow isn't the same through all sections, must sum individual groups:

$$\text{Power} = \sum m_i (h_{1i} - h_{2i})$$

There may be leakage streams and sealing steam streams

Exhaust loss varies in a separate way with exhaust volume flow rate

Some power is lost

$$\text{Power} = \sum m_i (h_{1i} - h_{2i}) - \text{Bearing loss} - \text{Gearbox loss} - \text{Generator loss}$$

Tuning Goals

Making just one model operating condition match specified performance

>>> **Single-point Tuning**

Making a simulation (Off-design) model fit performance specs at several operating conditions

>>> **Multi-point Tuning**

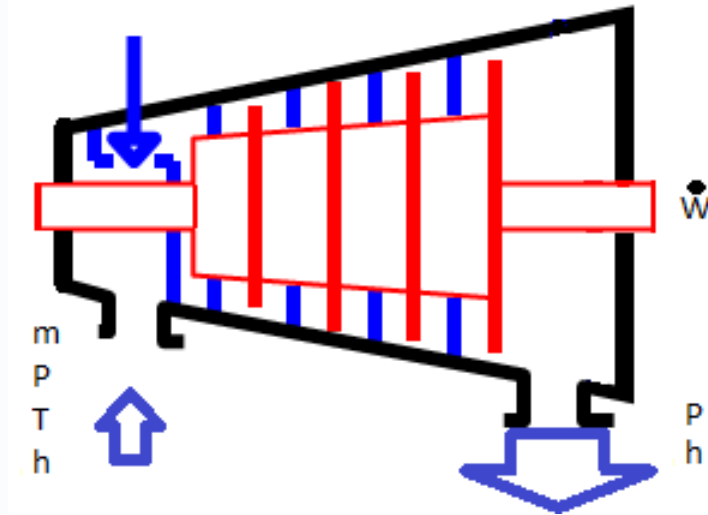
In many cases, a carefully tuned Single-point tuning will also well simulate performance at other operating conditions.

A well-tuned model should predict pressures and enthalpies well in addition to predicting power.

Initializing the Steam Turbine

In GT PRO, STEAM PRO, and THERMOFLEX at design:

Inlet P, T, h, and m are known
Exit P is known



Efficiency is estimated (or imposed)

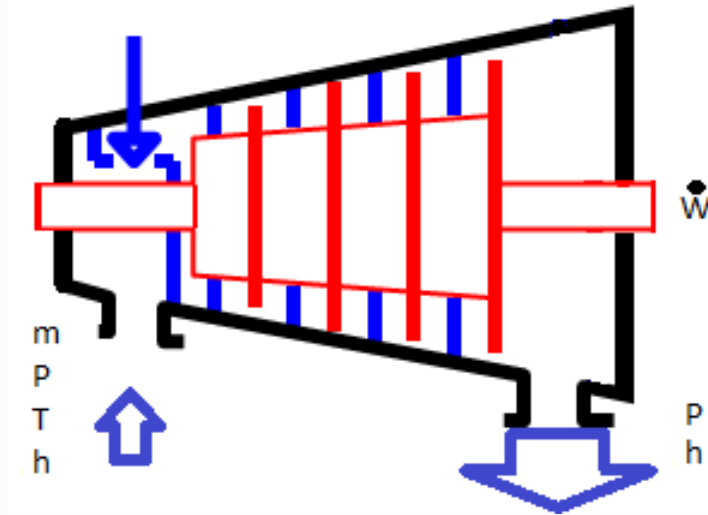
Power, Nozzle Area, and Exit h are computed

The needed elements here were described with details in Webinar #6: Matching ST Performance in STP

Simulating the Steam Turbine

In GT MASTER, STEAM MASTER, and THERMOFLEX at Off-design:

Inlet m and h , are known from upstream, Exit P is known from downstream



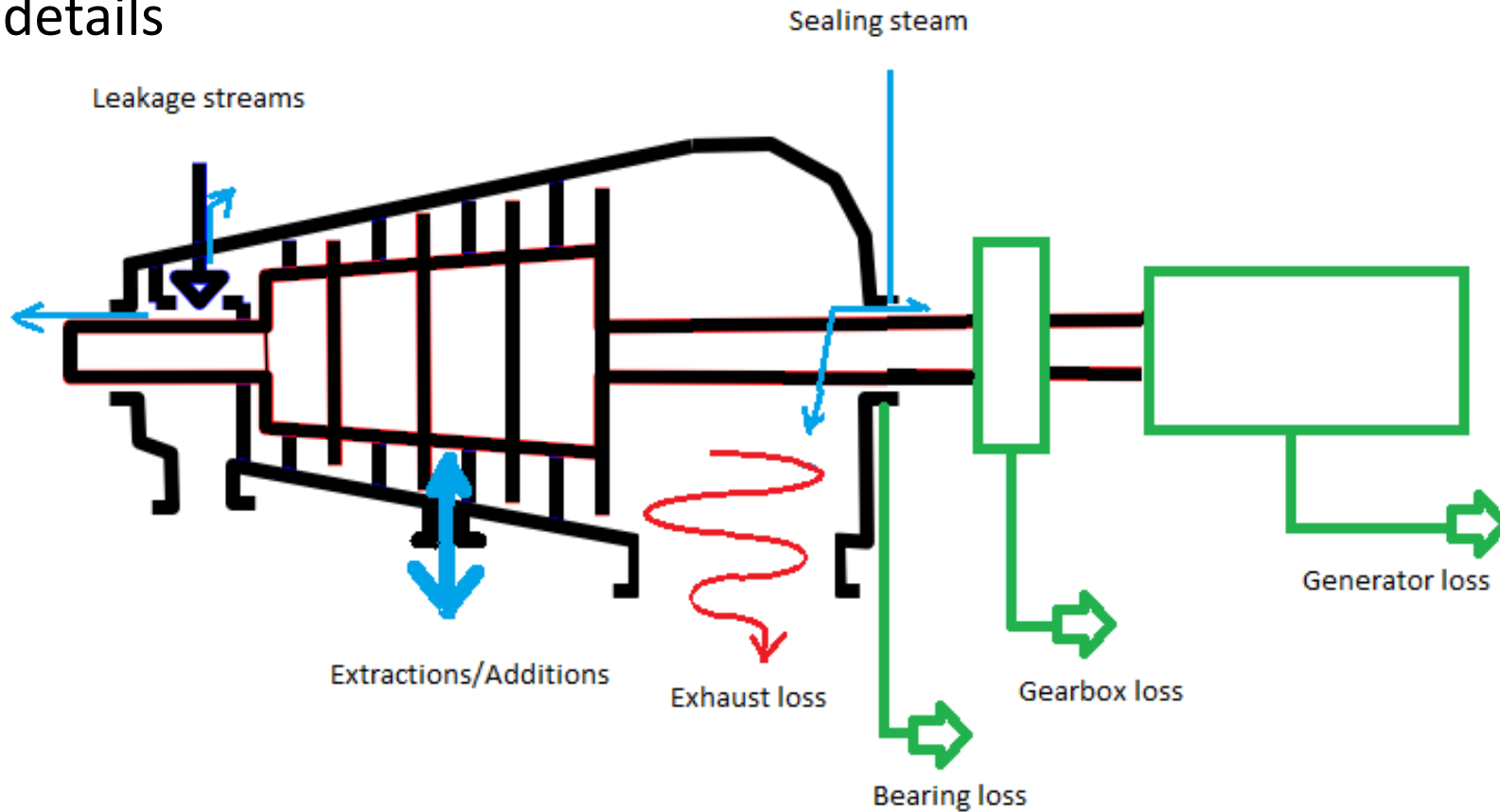
Nozzle area is known from design

Efficiency is determined, based on design point efficiency

Power and Exit h are computed

Simulating the Steam Turbine

... and the details



Tuning Methods

Manually...

With careful examination, the simulation programs have long allowed you to iteratively manipulate the entering and exiting flows, adjust nozzle areas to match upstream pressures, and adjust group efficiencies.

With the Automatic Tuning feature...

Much of the performance matching exercise is made easier - specify for each group the upstream and downstream pressure, upstream and downstream enthalpy, and the group flow – the Tuning feature adjusts Areas and Efficiencies.

File View Options Tools Window New Session Control Loops Excel Link Compare Files Scripts Custom Variable List Help

Main Inputs Plant Criteria GT Inputs **ST Inputs** ST Process HRSG Inputs HRSG Process Water Circuits Cooling System Environment Gasification Desalination Site Major Equipment Pipes, Pumps, Re-design in GT PRO COMPUTE

Steam Turbine Main Inputs Stage Groups & Controls Pressure Set Points Exhaust End Hardware ST Leaks Steam Seal System Generator Auxiliaries & Miscellaneous

LPTL Inlet Pressure Control

LPTL Parameters

Specify efficiency degradation Specify enthalpy

Number of stages: 8

Dry stage eff. at design point flow function: 86.3 %

Design point total inlet nozzle adjusted area: 0.1575 ft²

Efficiency degradation: 0 %

Enthalpy at group exit: 949 BTU/lb

Adjust dry stage efficiency to alter group efficiency

Adjust Nozzle Area to alter Pressure/Flow characteristics

Group pressure ratio = 214.3

IP induction

HPTL
11 stages
81.1% Des. Eff.
0% Eff. Degr.
Sliding

LPTL
8 stages
86.3% Des. Eff.
0% Eff. Degr.
Sliding

Manual adjustments in GTM

File View Options Tools Window New Session Control Loops Excel Link Compare Files Scripts Custom Variable List Help

Main Inputs Plant Criteria GT Inputs **ST Inputs** ST Process HRSG Inputs HRSG Process Water Circuits Cooling System Environment Gasification Desalination Site Major Equipment Pipes, Pumps, Re-design in GT PF

Steam Turbine Adjustment Factors

ST Model Adjustments
 Enabled Disabled

HPTL Group Adjustment Factors
 ST Group: **HPTL**

Nozzle Area Adjustment Factors

	Point 1	Point 2	Point 3	Point 4	Point 5
Group inlet volume flow / Design value	40 %	60 %	80 %	100 %	120 %
Group inlet nozzle area adjustment factor	1	1	1	1	1
Design point group inlet volume flow =	25.36 ft ³ /s				

Dry Stage Efficiency Adjustment Factors

	Point 1	Point 2	Point 3	Point 4	Point 5
Group exit volume flow / Design value	40 %	60 %	80 %	100 %	120 %
Group design dry stage efficiency adjustment factor	1	1	1	1	1
Design point group exit volume flow =	127.4 ft ³ /s				

ST Exhaust Loss Adjustment Factors

	Point 1	Point 2	Point 3	Point 4	Point 5
Exhaust volume flow / Design value	40 %	60 %	80 %	100 %	120 %
Exhaust loss adjustment factor	1	1	1	1	1
Design point exhaust volume flow =	18844 ft ³ /s				

Generator Loss Adjustment Factors

	Point 1	Point 2	Point 3	Point 4	Point 5
ST/Generator output	8465 kW	12697 kW	16930 kW	21162 kW	25394 kW
Generator loss adjustment factor	1	1	1	1	1

OK

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ST Model Adjustments: Disabled

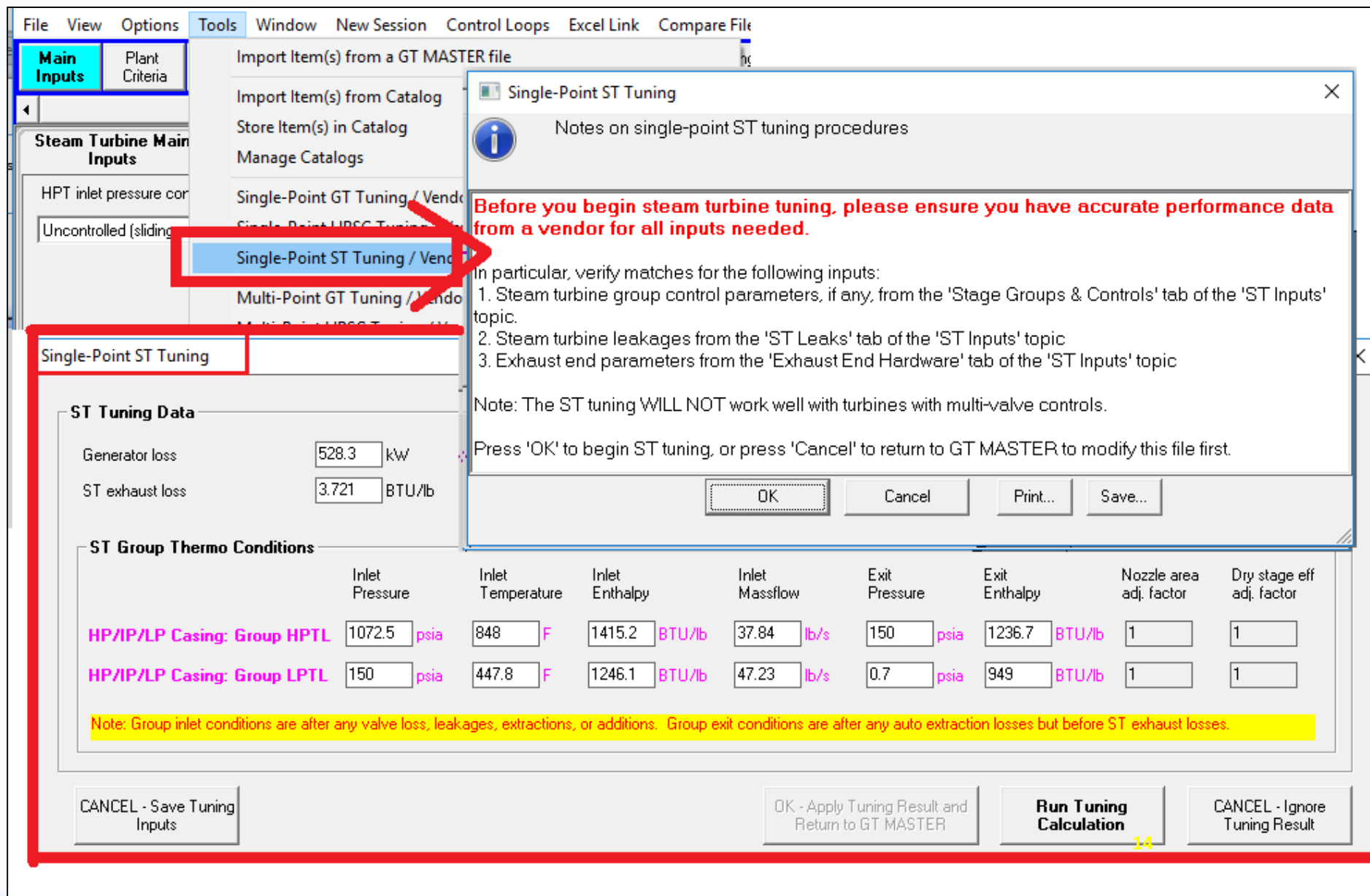
Multi-case adjustments in GTM

ST Model Adjustments

For as many as five distinct operating conditions, you can manually enter Adjustment Factors for Group Nozzle Areas and Efficiencies as well as Exhaust Loss and Generator Loss (if you know what they need to be)

Producing the Adjustment Factors automatically with the Tuning feature, selected from the [Tools] menu of GT MASTER.

Enter the desired conditions, then click [Run Tuning Calculation]



The screenshot shows the Thermoflow software interface with the 'Tools' menu open and 'Single-Point ST Tuning / Vendor' selected. A dialog box titled 'Single-Point ST Tuning' is displayed, containing the following text:

Before you begin steam turbine tuning, please ensure you have accurate performance data from a vendor for all inputs needed.

In particular, verify matches for the following inputs:

1. Steam turbine group control parameters, if any, from the 'Stage Groups & Controls' tab of the 'ST Inputs' topic.
2. Steam turbine leakages from the 'ST Leaks' tab of the 'ST Inputs' topic
3. Exhaust end parameters from the 'Exhaust End Hardware' tab of the 'ST Inputs' topic

Note: The ST tuning WILL NOT work well with turbines with multi-valve controls.

Press 'OK' to begin ST tuning, or press 'Cancel' to return to GT MASTER to modify this file first.

Buttons: OK, Cancel, Print..., Save...

The 'ST Tuning Data' section includes the following input fields:

ST Tuning Data	
Generator loss	528.3 kW
ST exhaust loss	3.721 BTU/lb

The 'ST Group Thermo Conditions' section includes the following table:

	Inlet Pressure	Inlet Temperature	Inlet Enthalpy	Inlet Massflow	Exit Pressure	Exit Enthalpy	Nozzle area adj. factor	Dry stage eff adj. factor
HP/IP/LP Casing: Group HPTL	1072.5 psia	848 F	1415.2 BTU/lb	37.84 lb/s	150 psia	1236.7 BTU/lb	1	1
HP/IP/LP Casing: Group LPTL	150 psia	447.8 F	1246.1 BTU/lb	47.23 lb/s	0.7 psia	949 BTU/lb	1	1

Note: Group inlet conditions are after any valve loss, leakages, extractions, or additions. Group exit conditions are after any auto extraction losses but before ST exhaust losses.

Buttons: CANCEL - Save Tuning Inputs, OK - Apply Tuning Result and Return to GT MASTER, Run Tuning Calculation, CANCEL - Ignore Tuning Result

[OK-Apply Result & Return],
 results will be written to
 the [Model Adjustments]
 feature of the [ST Inputs]
 topic, ready to be
 employed.

Single-Point ST Tuning

ST Tuning Data

Generator loss kW Generator loss correction factor Estimated ST/Generator output kW

ST exhaust loss BTU/lb Exhaust loss correction factor

ST Group Thermo Conditions

	Inlet Pressure	Inlet Temperature	Inlet Enthalpy	Inlet Massflow	Exit Pressure	Exit Enthalpy	Nozzle area adj. factor	Dry stage eff. adj. factor
HP/IP/LP Casing: Group HPTL	<input type="text" value="1072.5"/> psia	<input type="text" value="848"/> F	<input type="text" value="1415.2"/> BTU/lb	<input type="text" value="40"/> lb/s	<input type="text" value="150"/> psia	<input type="text" value="1239"/> BTU/lb	<input type="text" value="1.057"/>	<input type="text" value="0.9867"/>
HP/IP/LP Casing: Group LPTL	<input type="text" value="150"/> psia	<input type="text" value="440.3"/> F	<input type="text" value="1242"/> BTU/lb	<input type="text" value="50"/> lb/s	<input type="text" value="0.7"/> psia	<input type="text" value="951"/> BTU/lb	<input type="text" value="1.053"/>	<input type="text" value="0.9821"/>

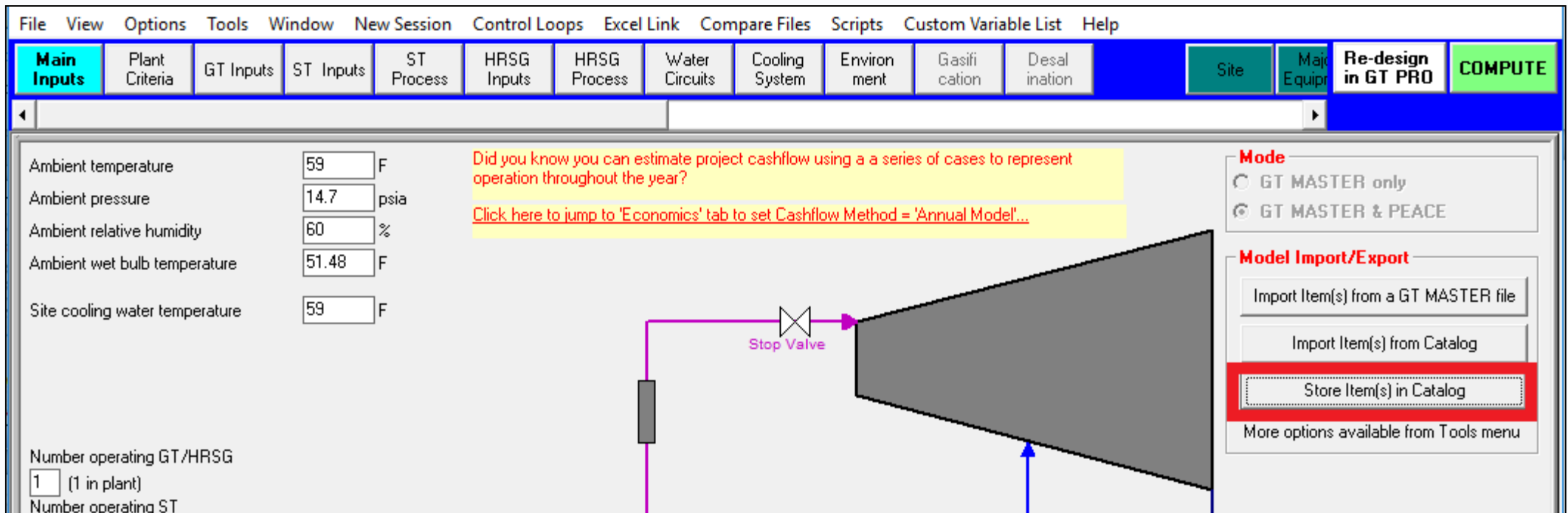
Steam Turbine Tuning Successful

Steam turbine tuning calculation successful.

To apply computed results to your steam turbine model, click on <OK -Apply Tuning Result and Return to GT MASTER> button.

Note: Group inlet conditions are after any valve loss, leakages, extractions, or additions. Group exit conditions are after any auto extraction losses but before ST exhaust losses.

The Tuned Steam Turbine
can be stored in the 'Catalog' to be
available for being directly loaded
into a different GT MASTER file

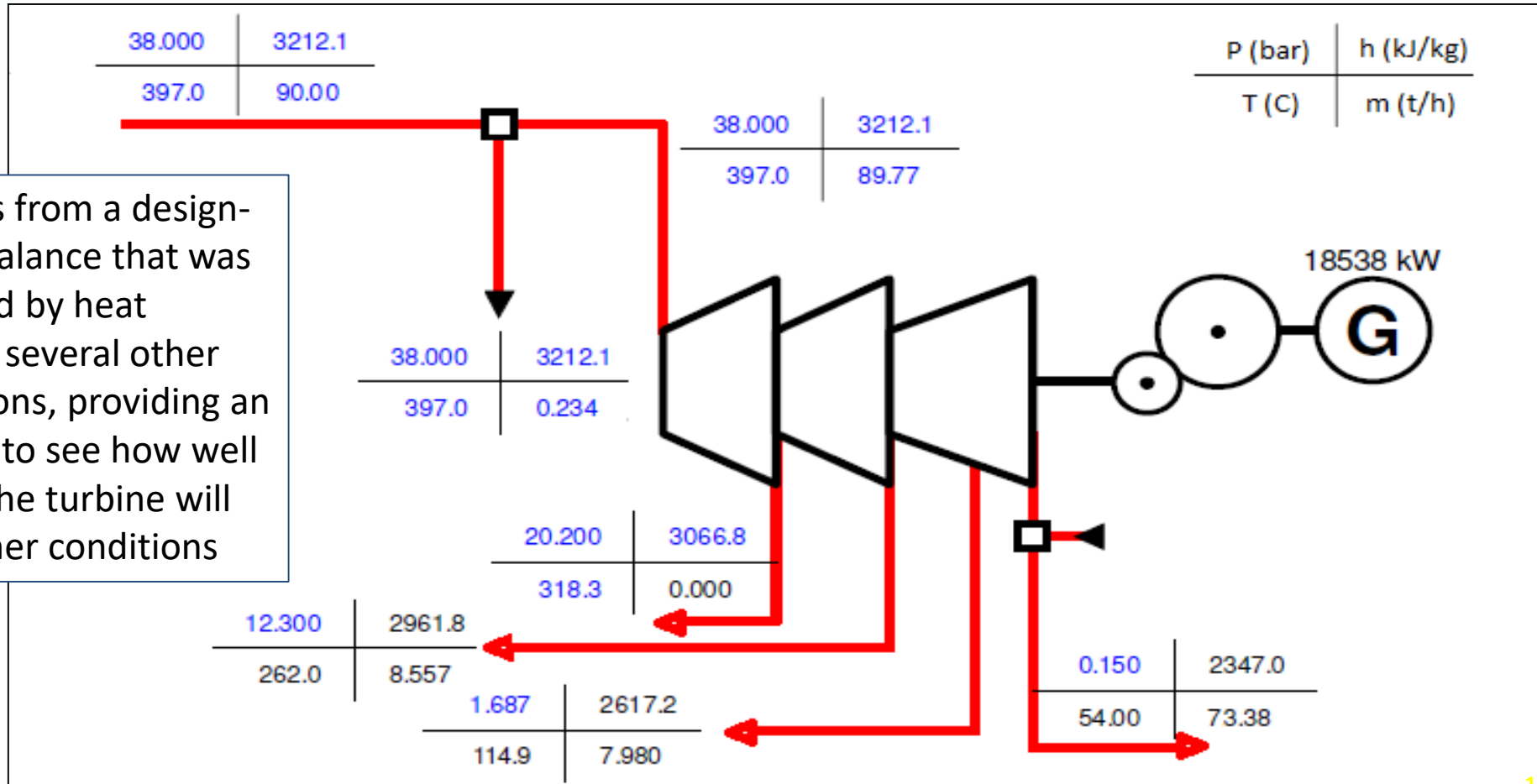


The screenshot shows the Thermoflow software interface with the following elements:

- Menu Bar:** File, View, Options, Tools, Window, New Session, Control Loops, Excel Link, Compare Files, Scripts, Custom Variable List, Help.
- Navigation Tabs:** Main Inputs (selected), Plant Criteria, GT Inputs, ST Inputs, ST Process, HRSG Inputs, HRSG Process, Water Circuits, Cooling System, Environment, Gasification, Desalination, Site, Major Equipment, Re-design in GT PRO, COMPUTE.
- Main Inputs Panel:**
 - Ambient temperature: 59 F
 - Ambient pressure: 14.7 psia
 - Ambient relative humidity: 60 %
 - Ambient wet bulb temperature: 51.48 F
 - Site cooling water temperature: 59 F
 - Number operating GT/HRSG: 1 (1 in plant)
 - Number operating ST: (empty)
- Diagram:** A schematic showing a purple line representing a steam flow path. It starts from the left, passes through a grey rectangular component, then through a valve labeled "Stop Valve", and finally enters a large grey trapezoidal component representing a steam turbine. A blue arrow points upwards towards the bottom of the turbine.
- Text Box:** A yellow box with red text: "Did you know you can estimate project cashflow using a series of cases to represent operation throughout the year? Click here to jump to 'Economics' tab to set Cashflow Method = 'Annual Model'..."
- Mode Selection:**
 - Mode:
 - GT MASTER only
 - GT MASTER & PEACE
- Model Import/Export:**
 - Import Item(s) from a GT MASTER file
 - Import Item(s) from Catalog
 - Store Item(s) in Catalog** (highlighted with a red border)
 - More options available from Tools menu

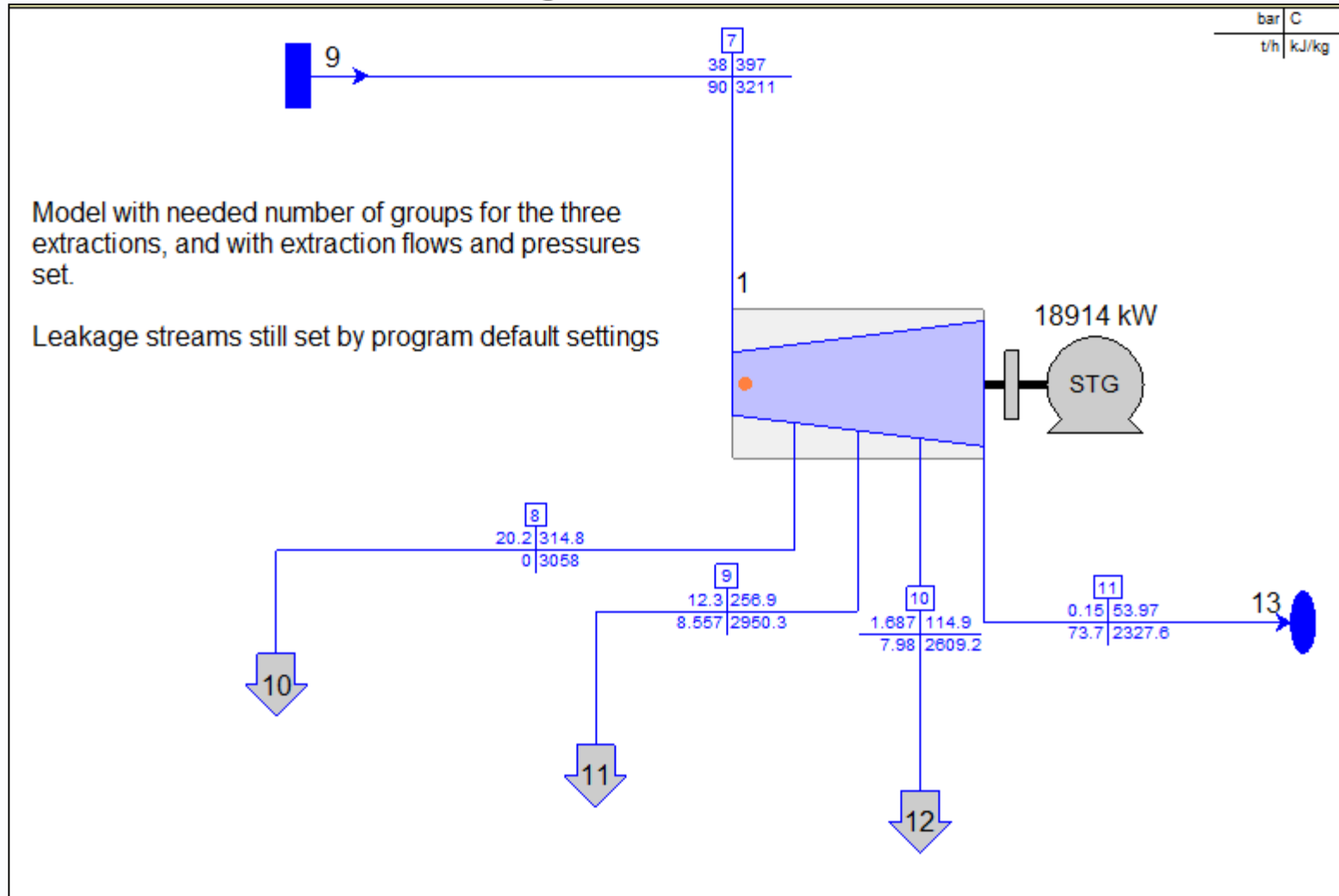
ST Tuning in THERMOFLEX

This image is from a design-point heat balance that was accompanied by heat balances for several other load conditions, providing an opportunity to see how well a model of the turbine will 'track' at other conditions



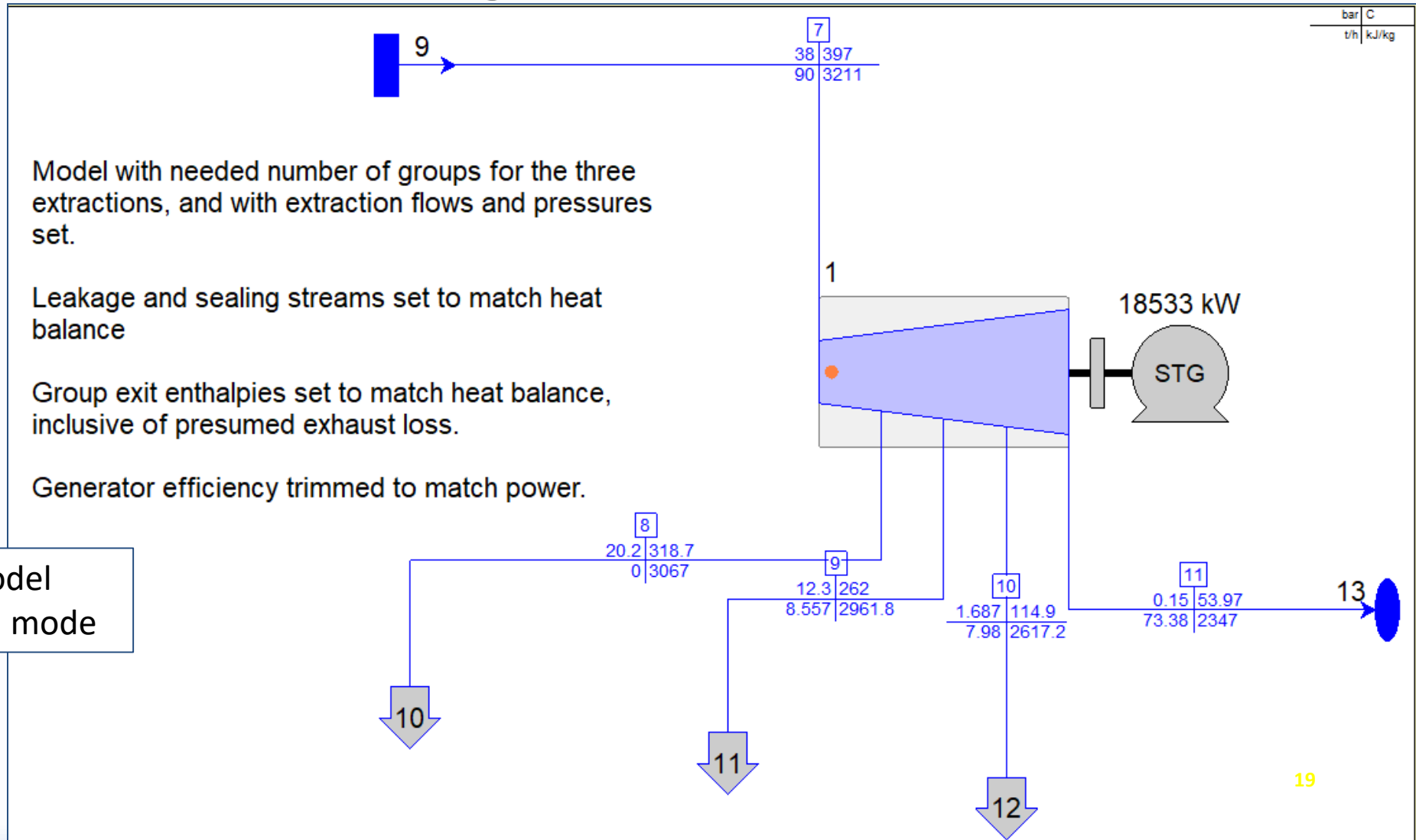
ST Tuning in THERMOFLEX

Initial TFX model



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ST Tuning in THERMOFLEX



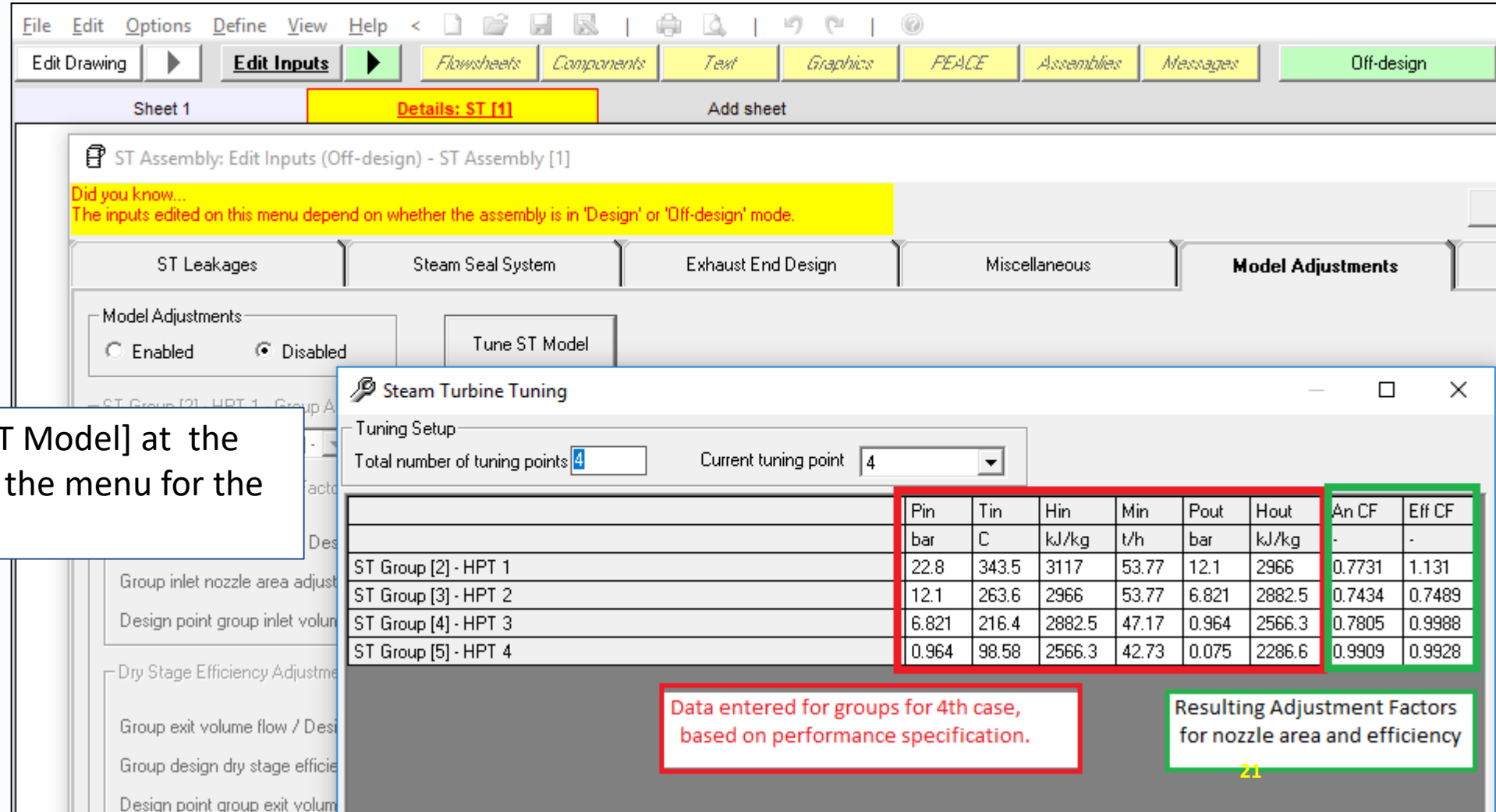
Trimmed TFX model
adjusted in Design mode

ST Tuning in THERMOFLEX

Data from related heat balance cases

	Case 1	Case 2	Case 3	Case 4
Pin	38	38	38	38
Tin	397	397	374	357
Hin	3212.1	3212.1	3157.9	3116.9
min	89.77	80.77	62.77	53.77
Group flow	89.77	80.77	62.77	53.77
Pe1	20.2	19.02	14.4	12.098
hex1	3066.8	3073.3	3023.5	2966
mex1	0	0	0	0
Group flow	89.77	80.77	62.77	53.77
Pe2	12.3	10.88	8.158	6.821
hex2	2961.8	2964.8	2917.4	2882.5
mex2	8.557	8.1	7.181	6.598
Group flow	81.213	72.67	55.589	47.172
Pe3	1.687	1.509	1.142	0.964
hex3	2617.2	2621.4	2589.4	2566.3
mex3	7.98	7.053	5.335	4.439
Group flow	73.233	65.617	50.254	42.733
Pexh	0.15	0.13	0.09	0.075
hexh after seal addition	2347	2349.7	2322.3	2303.6
mexh	73.38	65.76	50.4	42.88
Mseal	0.234	0.234	0.234	0.234
Mmu	0.087	0.087	0.087	0.087
diff	0.147	0.147	0.147	0.147
Generator Power	18,538	16,520	12,194	10,025
h before seal addition	2345.263492	2347.625	2319.81	2300.802

ST Tuning in THERMOFLEX



Did you know...
The inputs edited on this menu depend on whether the assembly is in 'Design' or 'Off-design' mode.

ST Leakages | Steam Seal System | Exhaust End Design | Miscellaneous | **Model Adjustments**

Model Adjustments
 Enabled
 Disabled
 Tune ST Model

Steam Turbine Tuning

Tuning Setup
 Total number of tuning points: 4
 Current tuning point: 4

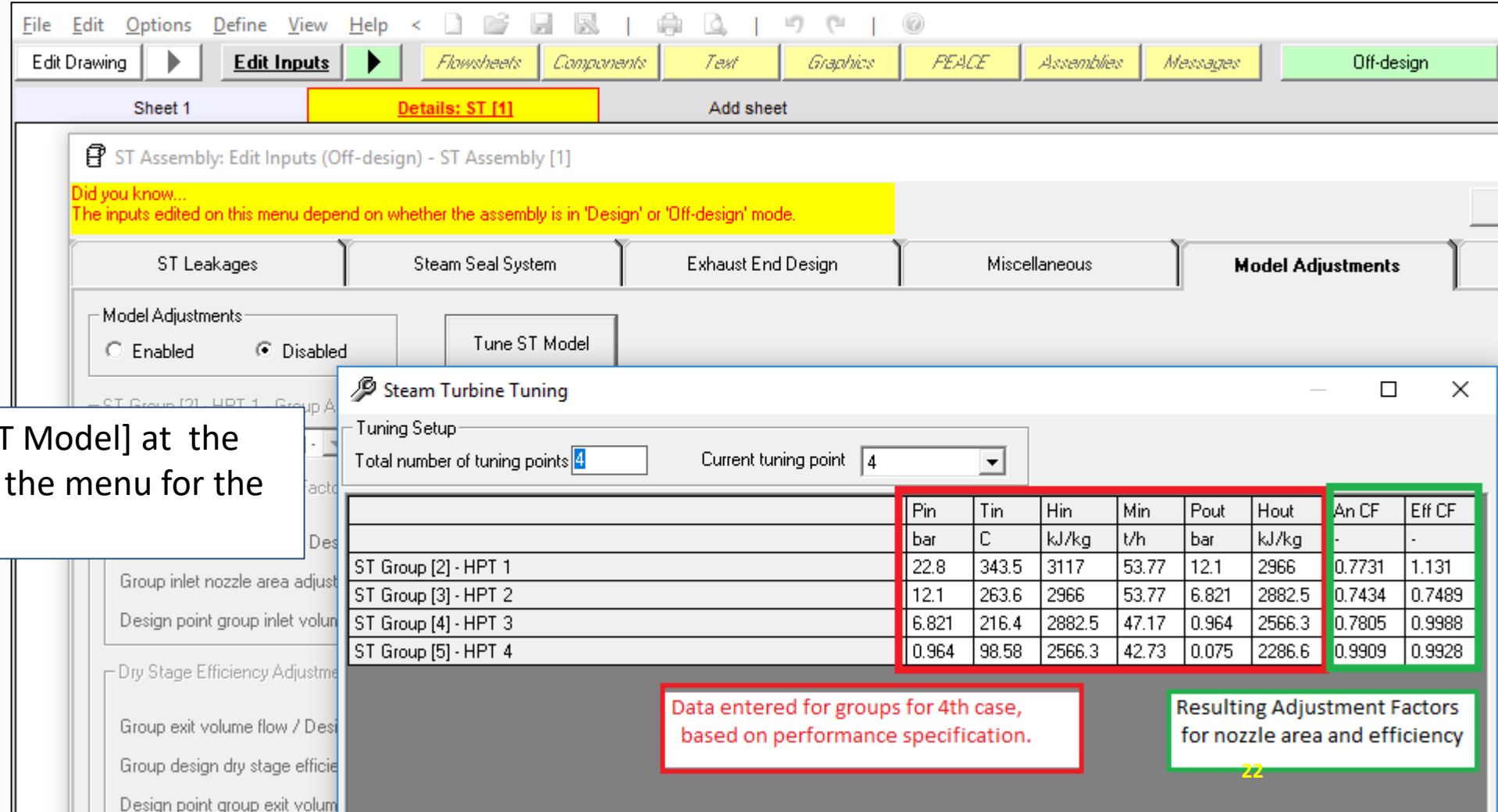
	Pin	Tin	Hin	Min	Pout	Hout	An CF	Eff CF
	bar	C	kJ/kg	t/h	bar	kJ/kg	-	-
ST Group [2] - HPT 1	22.8	343.5	3117	53.77	12.1	2966	0.7731	1.131
ST Group [3] - HPT 2	12.1	263.6	2966	53.77	6.821	2882.5	0.7434	0.7489
ST Group [4] - HPT 3	6.821	216.4	2882.5	47.17	0.964	2566.3	0.7805	0.9988
ST Group [5] - HPT 4	0.964	98.58	2566.3	42.73	0.075	2286.6	0.9909	0.9928

Data entered via [Tune ST Model] at the Model Adjustments tab of the menu for the ST Assembly

Data entered for groups for 4th case, based on performance specification.

Resulting Adjustment Factors for nozzle area and efficiency

ST Tuning in THERMOFLEX



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The inputs edited on this menu depend on whether the assembly is in 'Design' or 'Off-design' mode.

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Steam Turbine Tuning

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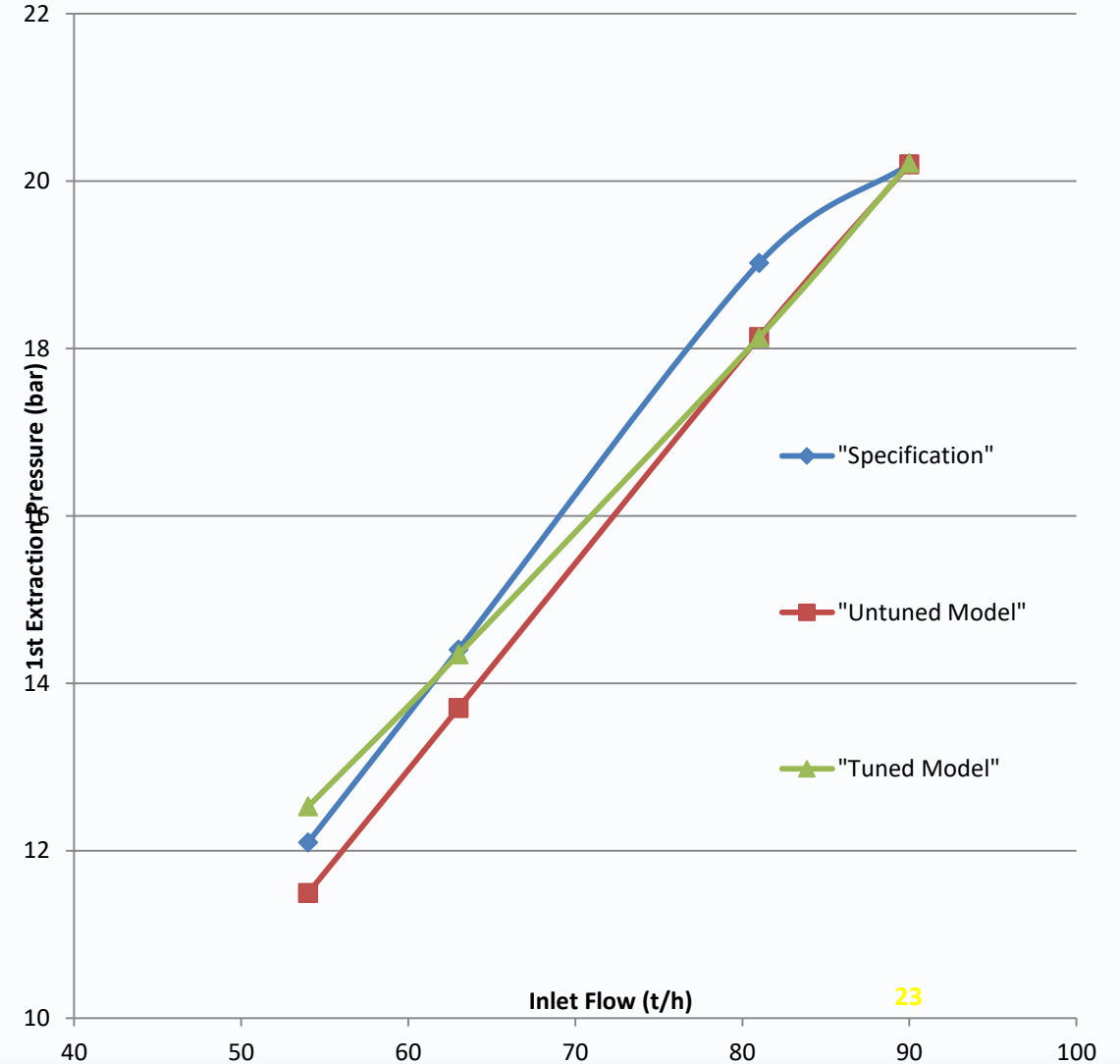
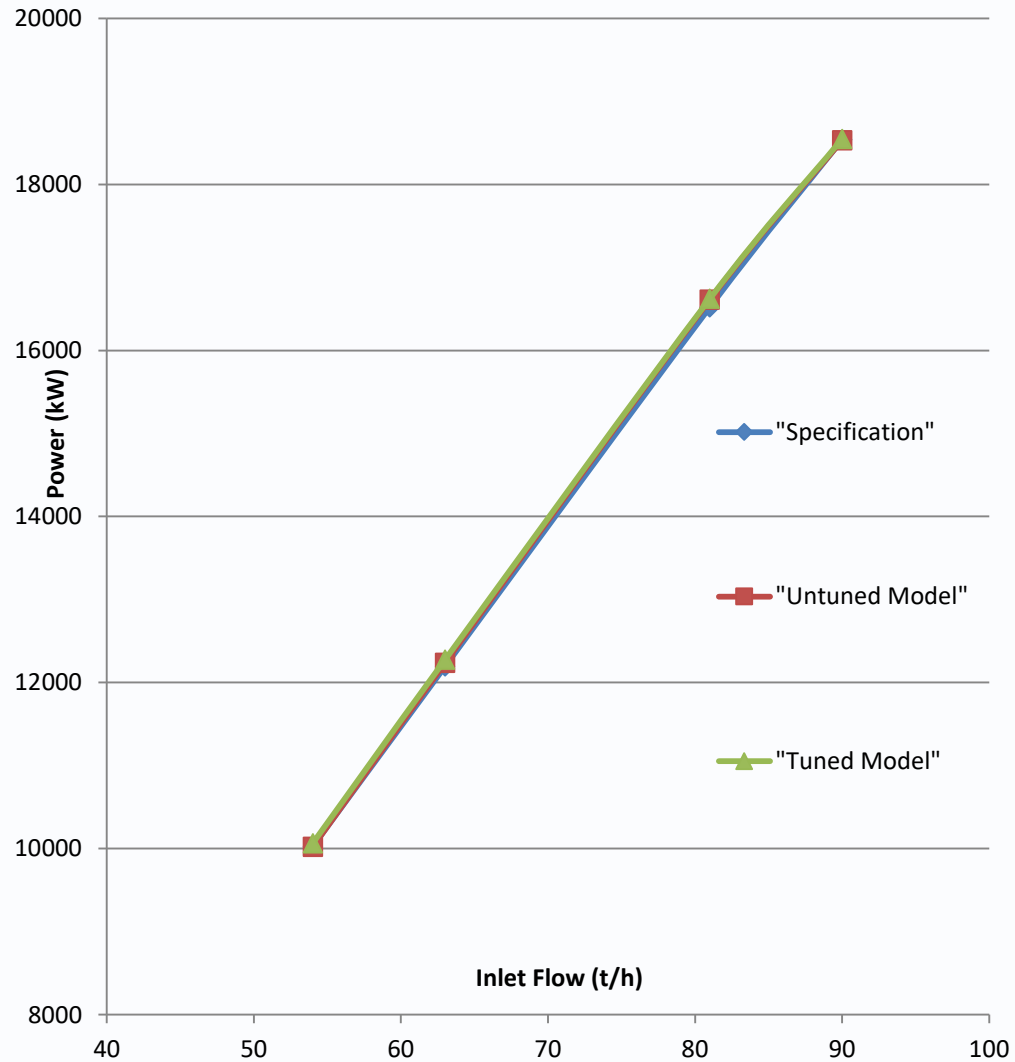
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Data entered for groups for 4th case, based on performance specification.

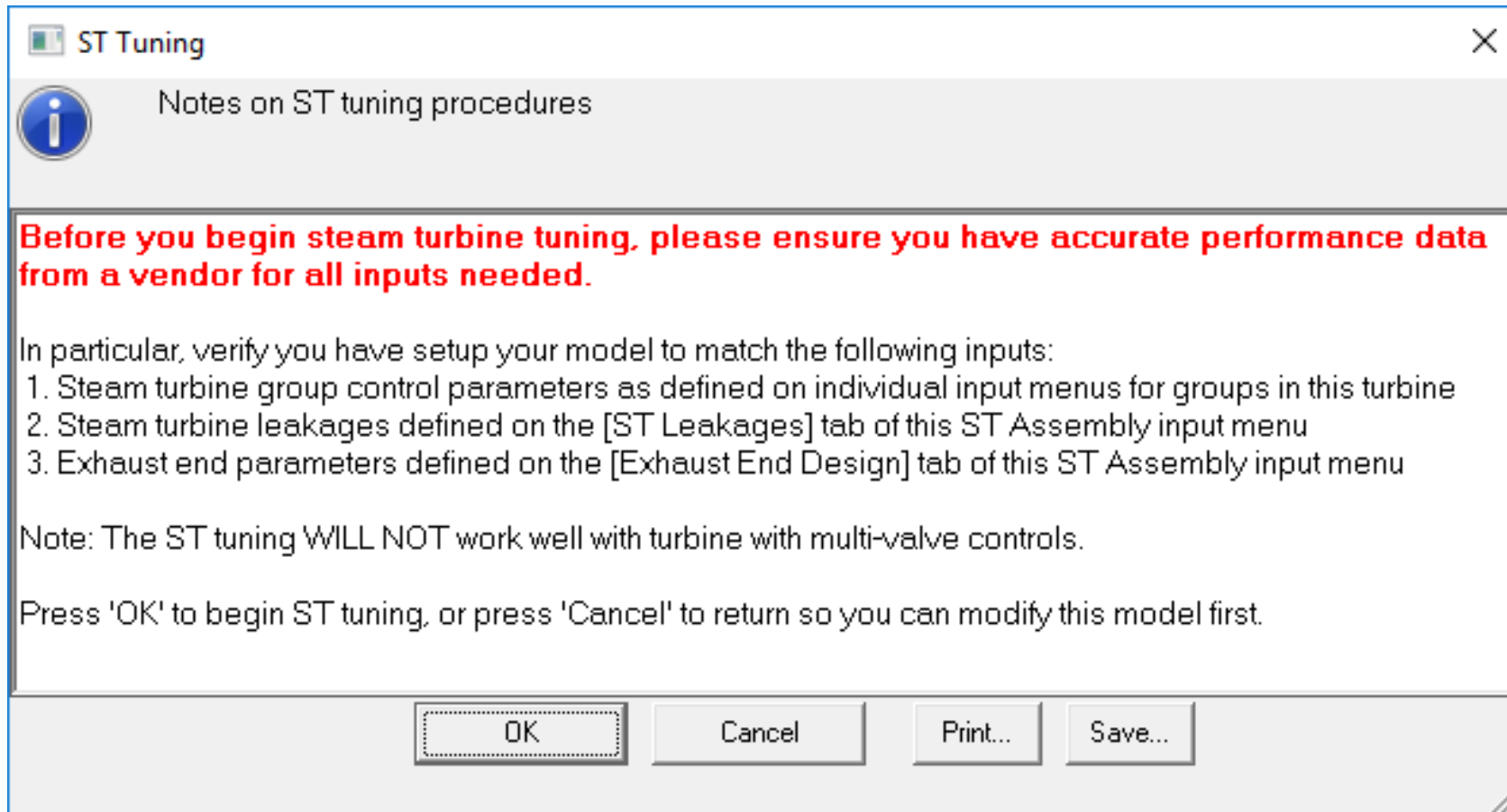
Resulting Adjustment Factors for nozzle area and efficiency

Data entered via [Tune ST Model] at the Model Adjustments tab of the menu for the ST Assembly

ST Tuning in THERMOFLEX - Results



ST Tuning – Reminder...



Q & A Session

- Please forward your questions on the WebEx Chat
- Further questions by email to: info@thermoflow.com

- PP Presentation will be available on the Website / Tutorials
- Video will be available on the Service Center

Thank you!

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