

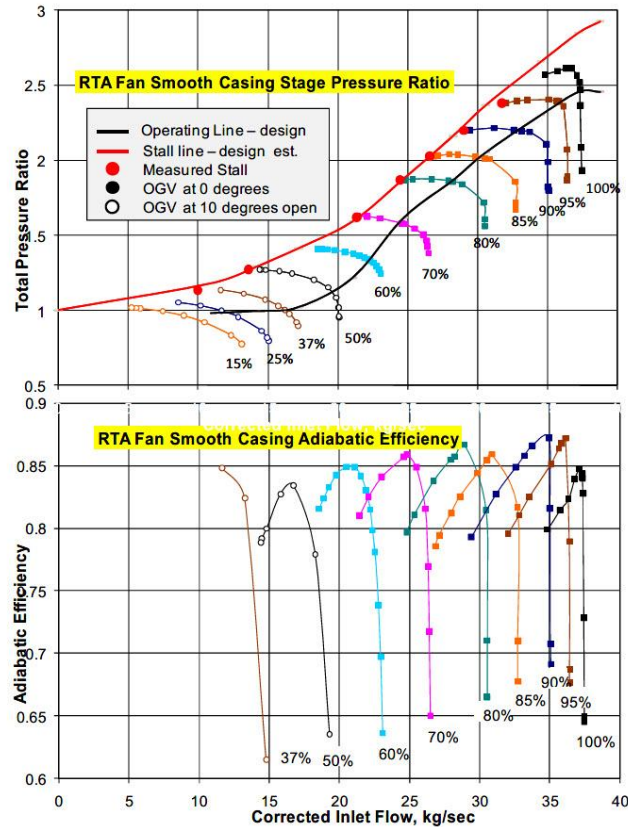
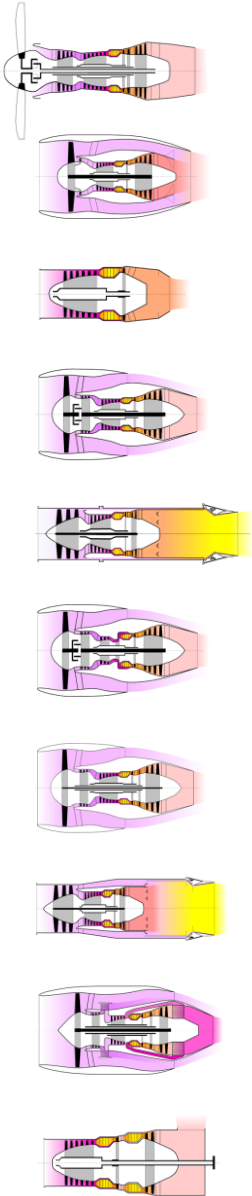


MONTREAL
2026 NORTH
AMERICA

September 9 -11

Generating Physically Accurate Compressor Maps

Joachim Kurzke
Gas Turbine Performance Consultant



Outline

The task

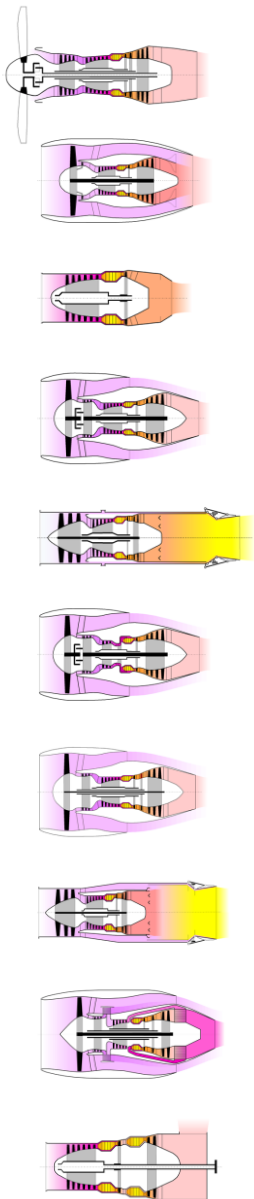
Methodology

Mathematical smoothing methods

Physics based smoothing

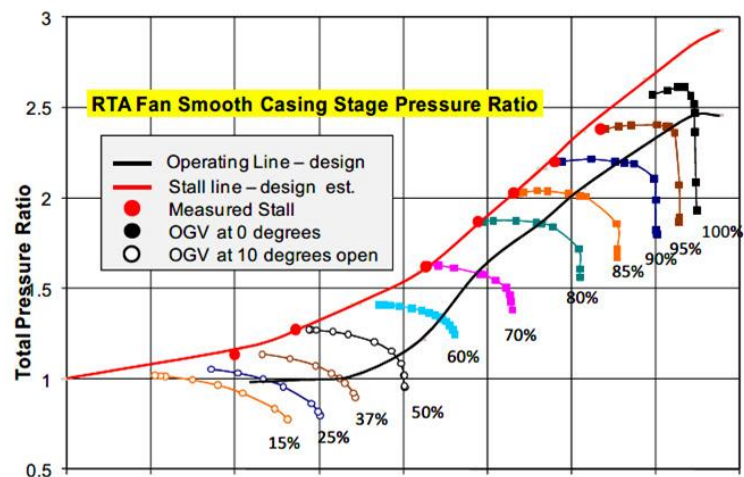
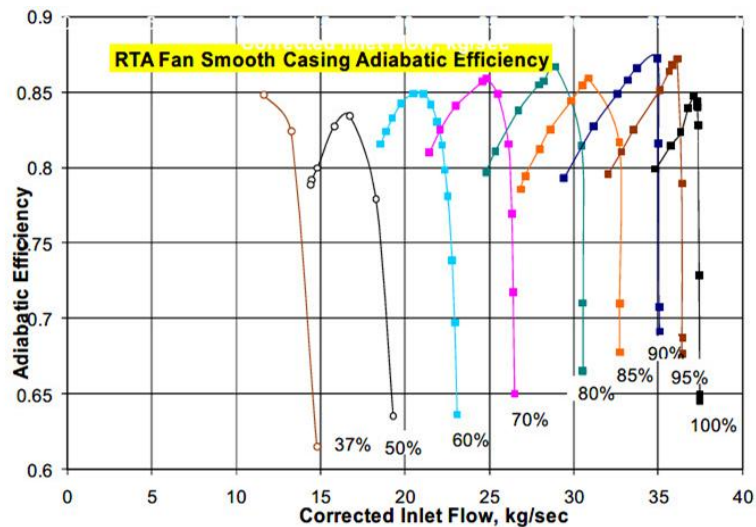
Checking the applicability

Recommendation



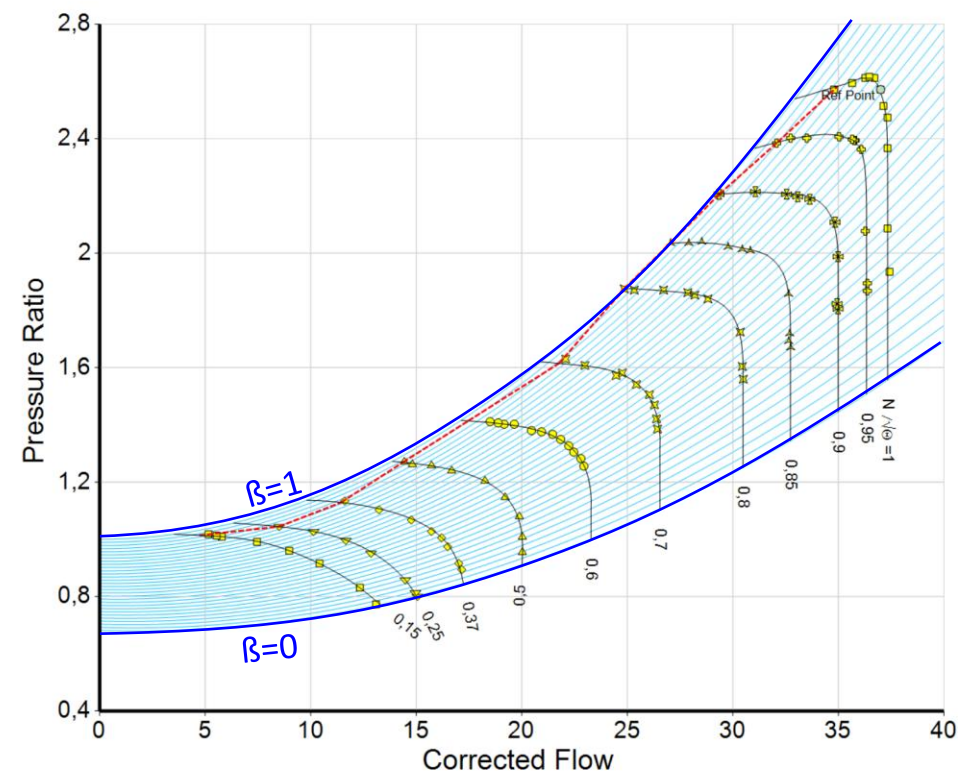
The Task

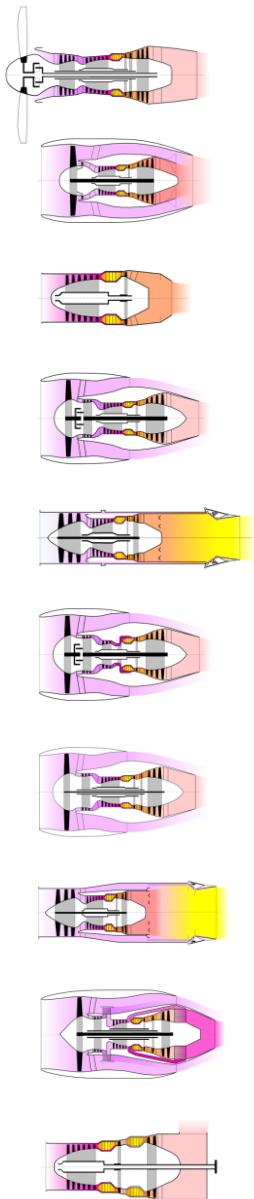
Generate a map with auxiliary coordinates (β -lines) from measured data as required for performance programs



Parabolic β -lines

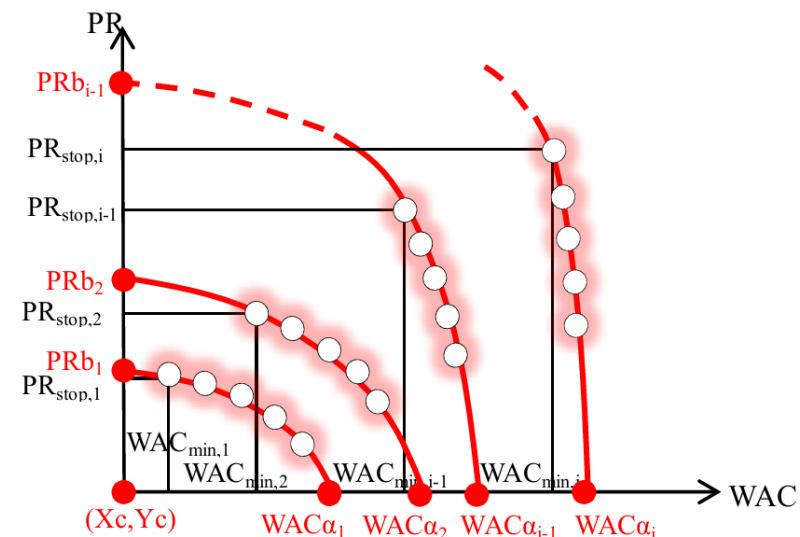
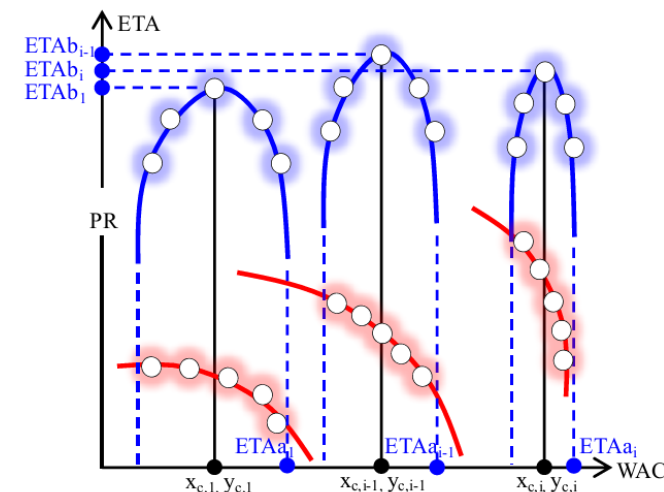
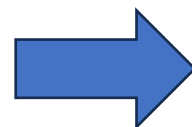
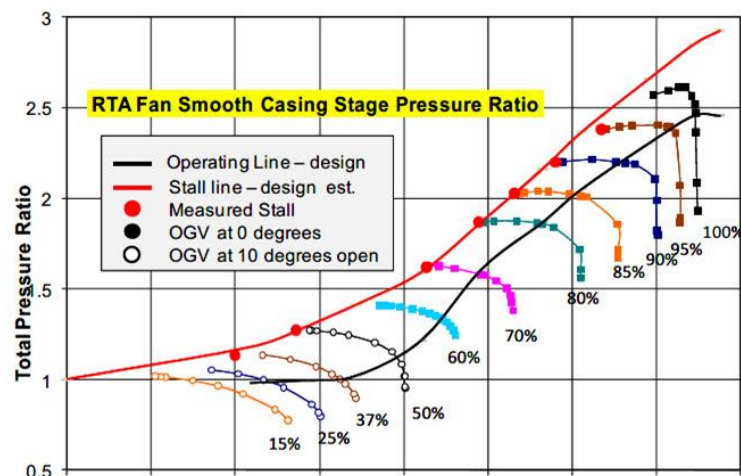
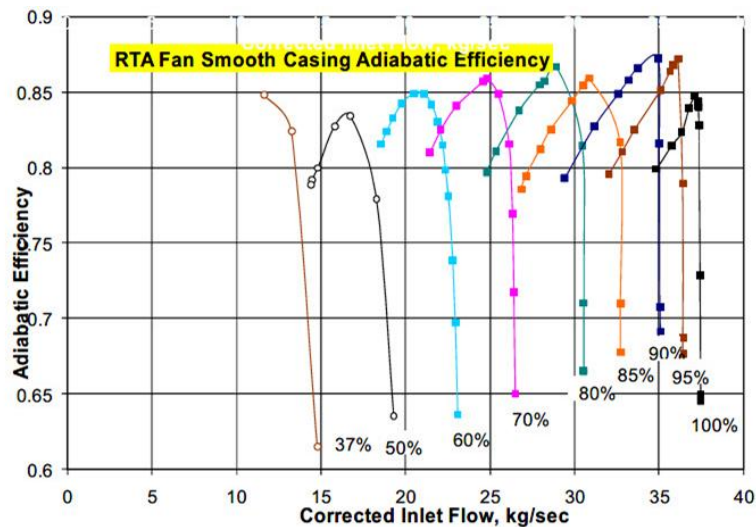
Advanced Fan Stage GT2010-22825 ©J.Kurzke 2026





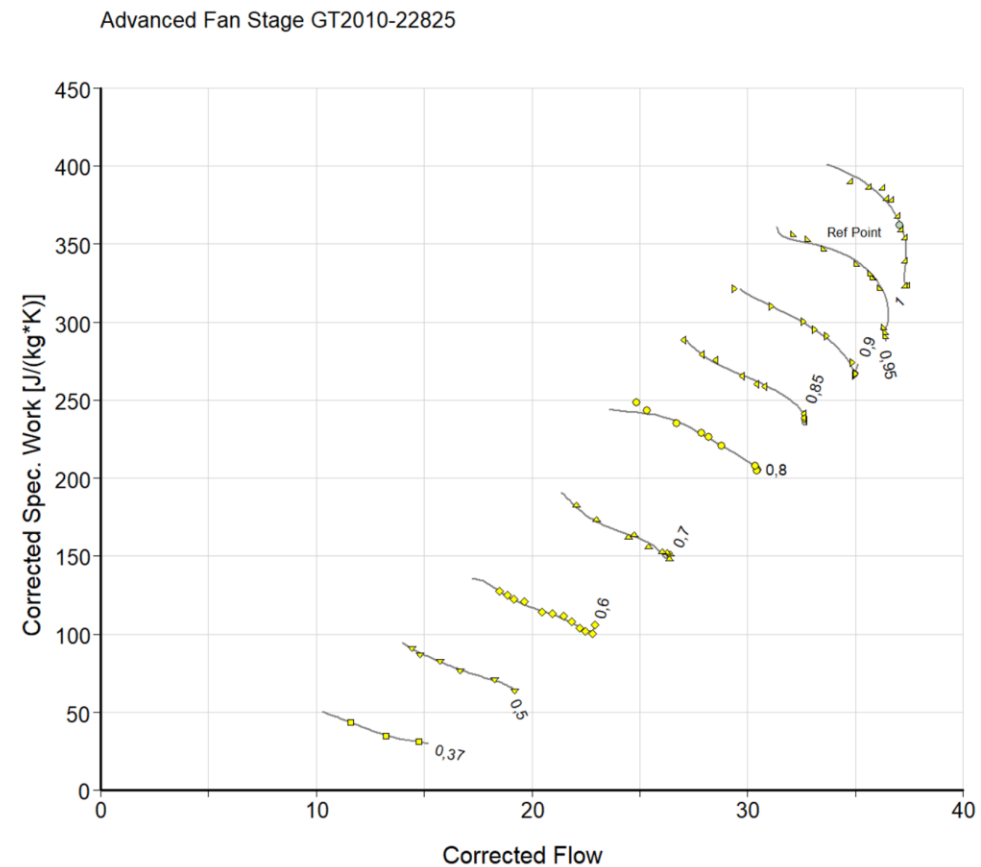
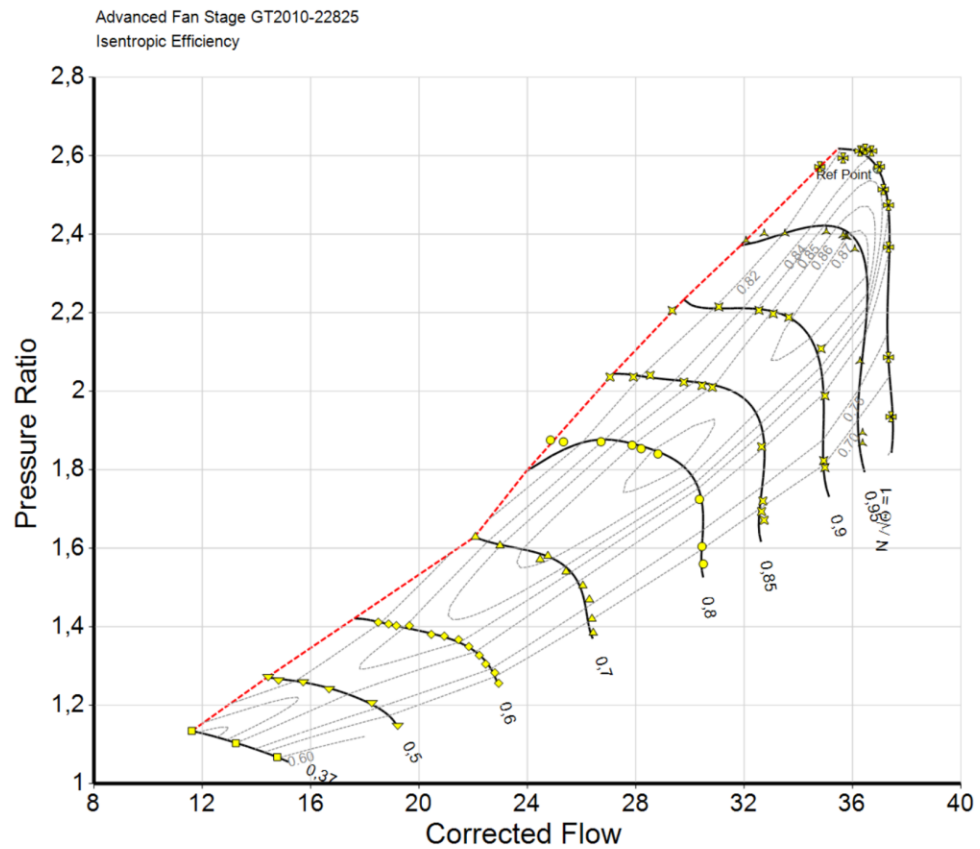
An example of what others have done...

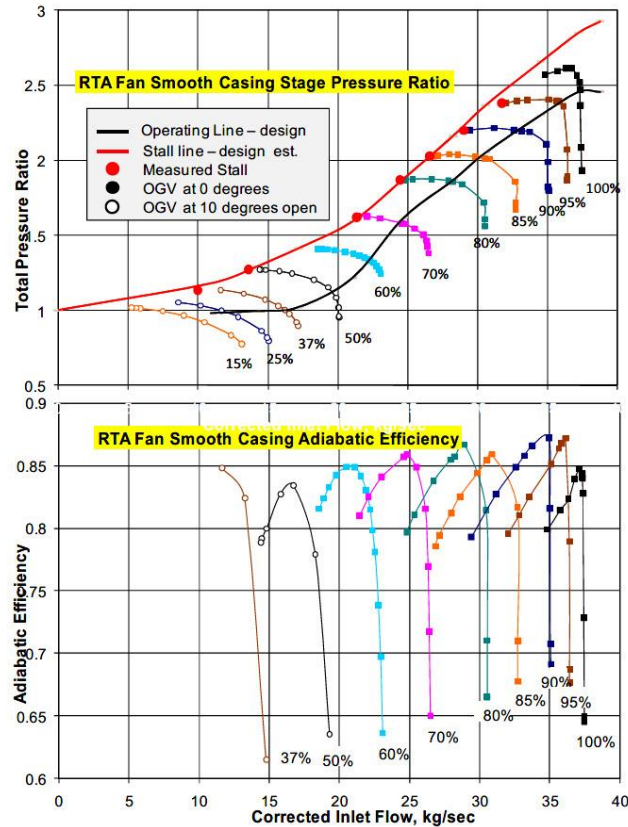
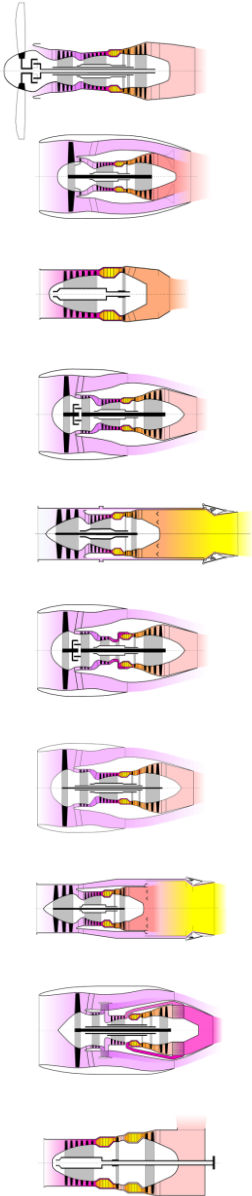
Represent efficiency and pressure ratio as a function of mass flow and speed using mathematical functions, here ellipses



Automatic smoothing example

5th order Chebyshev polynomials





Outline

The task

Methodology

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Physics based smoothing

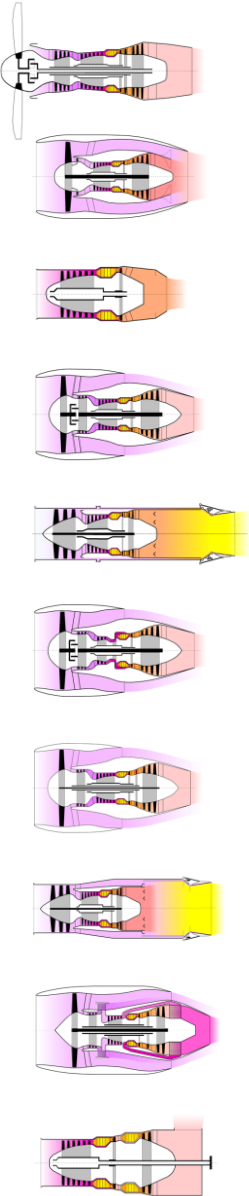
Checking the applicability

Recommendation

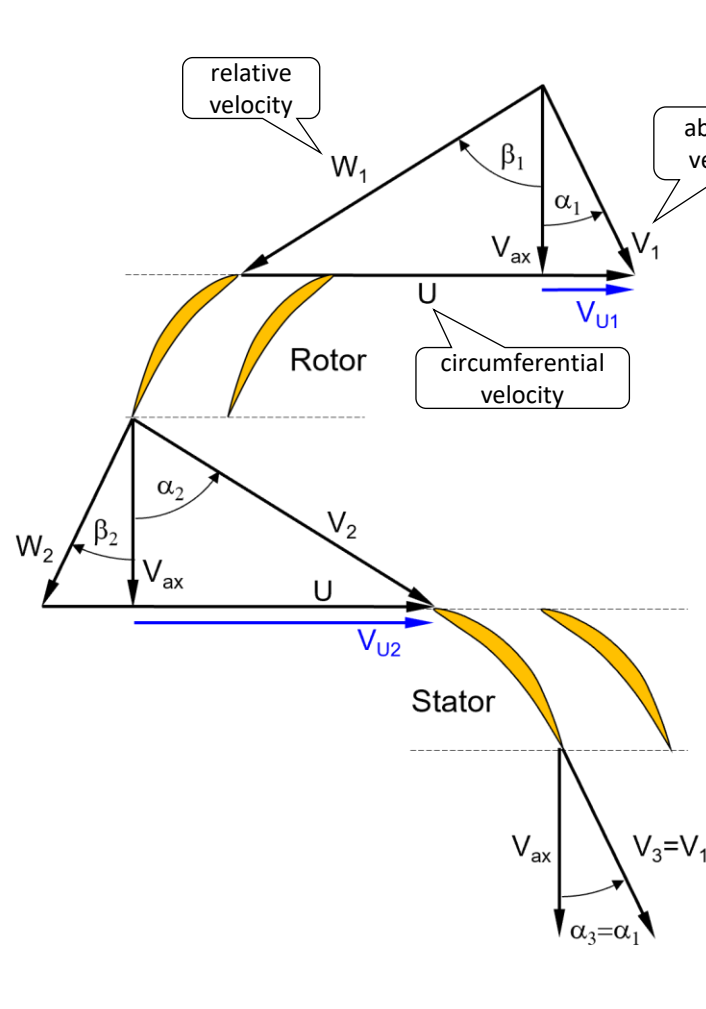
Engine performance calculations

Compressor maps

- What is important for a physics based smooth map...
 - That the lines of $\text{PressRatio} = f(\text{Flow}, \text{Speed})$ look nice?
 - That the efficiency contour lines look smooth?
- That is not sufficient.
- Important for the cycle calculation are
 - Compressor exit pressure and temperature
 - The power needed for driving the compressor
- There are no laws of physics about the shape of efficiency lines
- However,
there are laws of physics about the shape of specific work lines!



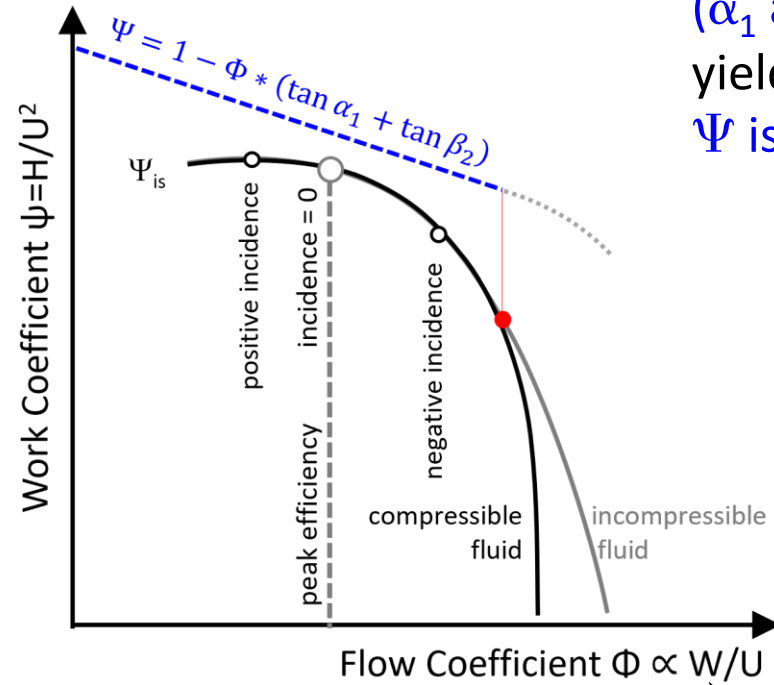
Simple compressor theory



specific work

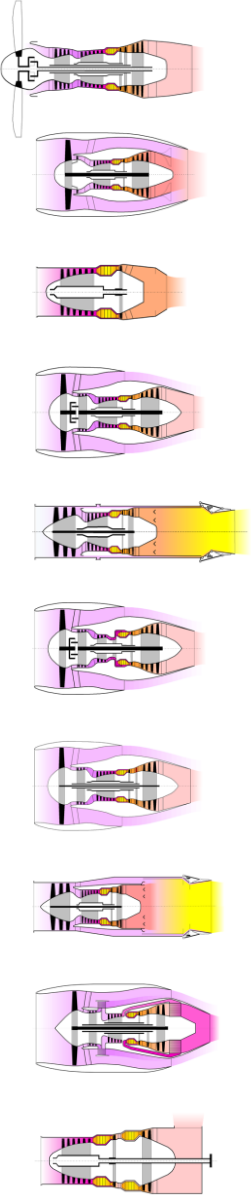
$$H = U \cdot (V_{u2} - V_{u1})$$

$$H/U^2 = 1 - V_{ax}/U (\tan \alpha_1 + \tan \beta_2)$$



Euler's law
plus hypothesis
flow angle = metal angle
(α_1 and β_2 are constant)
yields
 Ψ is a linear function of Φ

mass flow



Some equations

$$\psi = 1 - \Phi \times (\tan \alpha_1 + \tan \beta_2)$$

Euler + hypothesis (flow follows the blade trailing edge)

$$\psi = 1 - c_1 \times \Phi$$

Work coefficient Ψ is a linear function of flow coefficient Φ

$$PW = W \times H = \omega \times Trq$$

Two expressions for shaft power

$$\frac{Trq}{W^2} = c_2 \frac{H}{U^2} \frac{U}{W}$$

Introducing work coefficient $\Psi = H/U^2$
and flow coefficient $\Phi = W/U$

$$\frac{Trq}{W^2} = c_2 \frac{1 - c_1 \Phi}{\Phi} = c_2 \frac{1}{\Phi} - c_1 c_2$$

Replace Ψ by $1 - c_1 \times \Phi$ and re-arrange

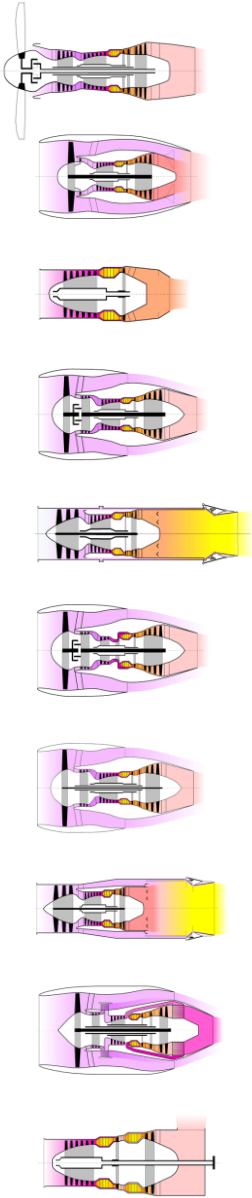
$$Trq/W = c_2 U - c_1 c_2 W$$

Multiplying by W yields a linear equation for $Trq/W=f(W)$

$$\frac{\partial(Trq/W)}{\partial U} = c_2$$

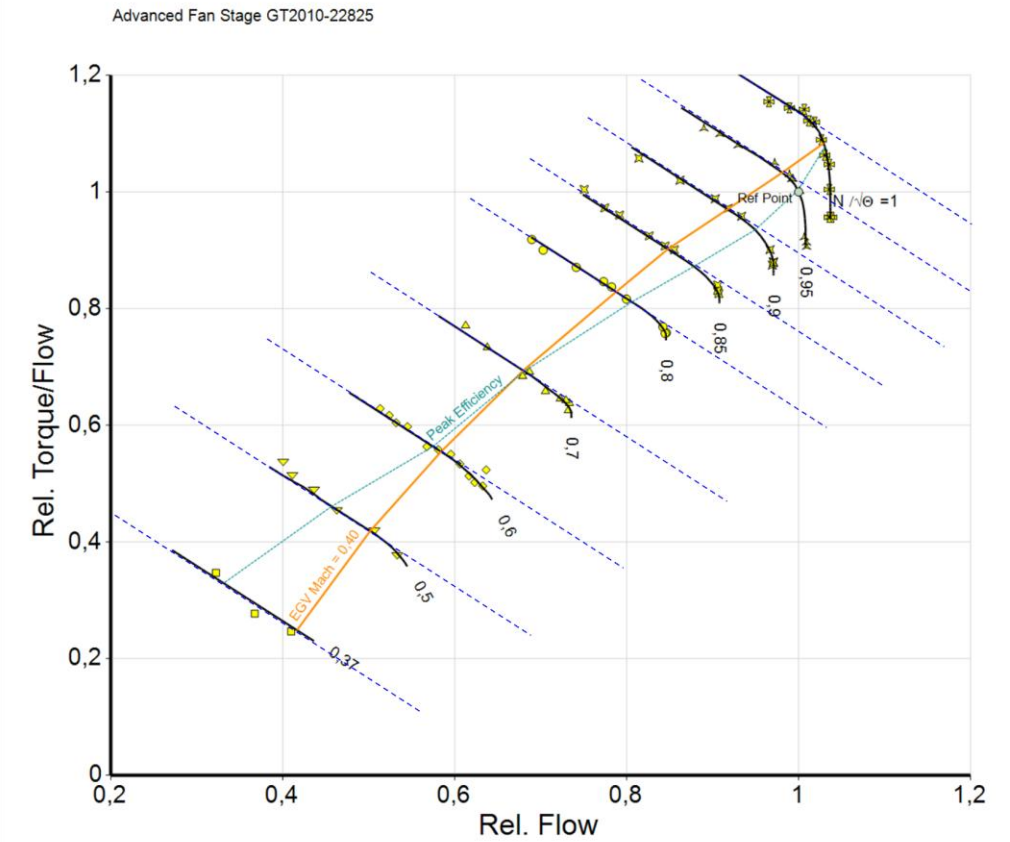
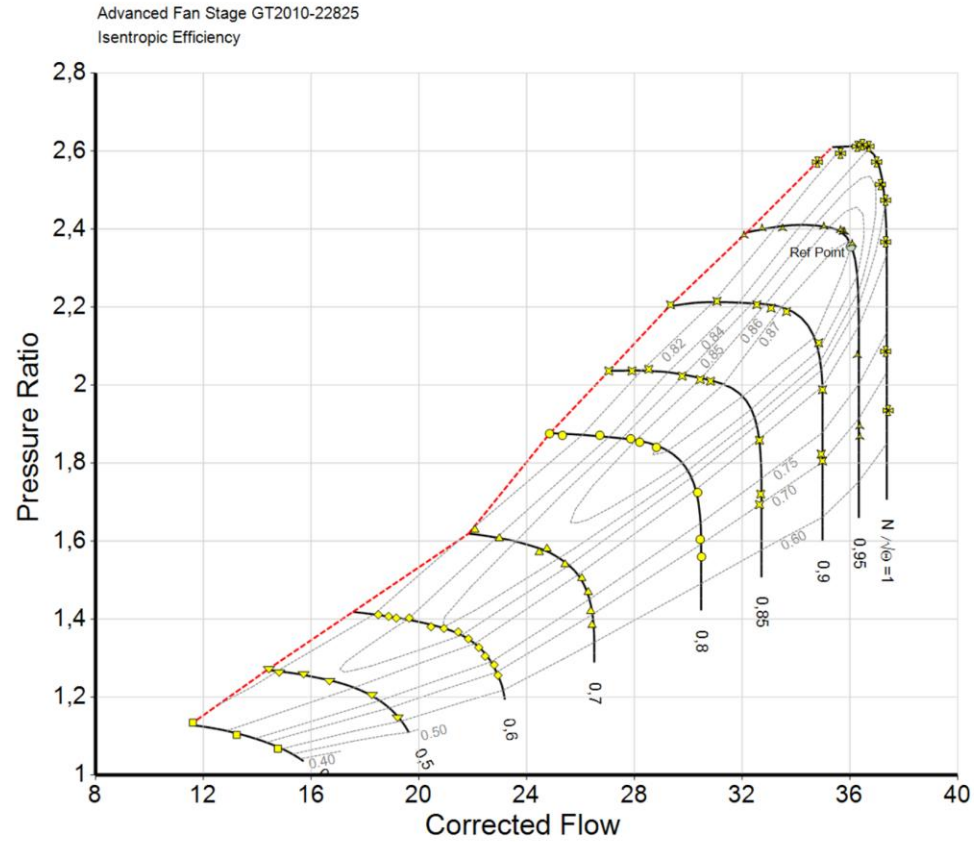
The slope of $Trq/W = f(W)$ is independent from speed

Conclusion: The lines $Trq/W=f(W)$ are parallel straight lines

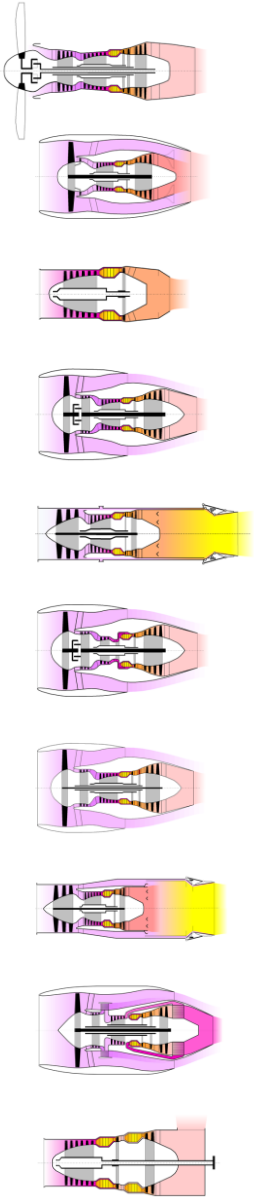


Map smoothing

The $\text{Trq}/W=f(W)$ lines are straight and parallel in the upper left map region

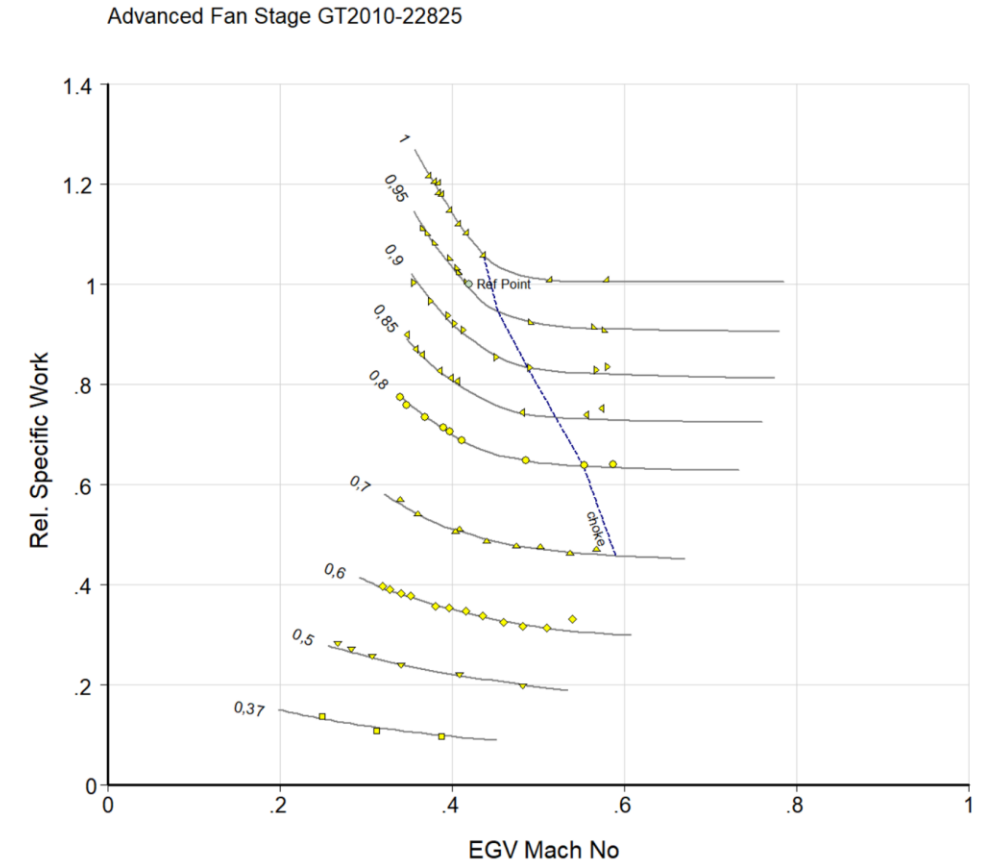
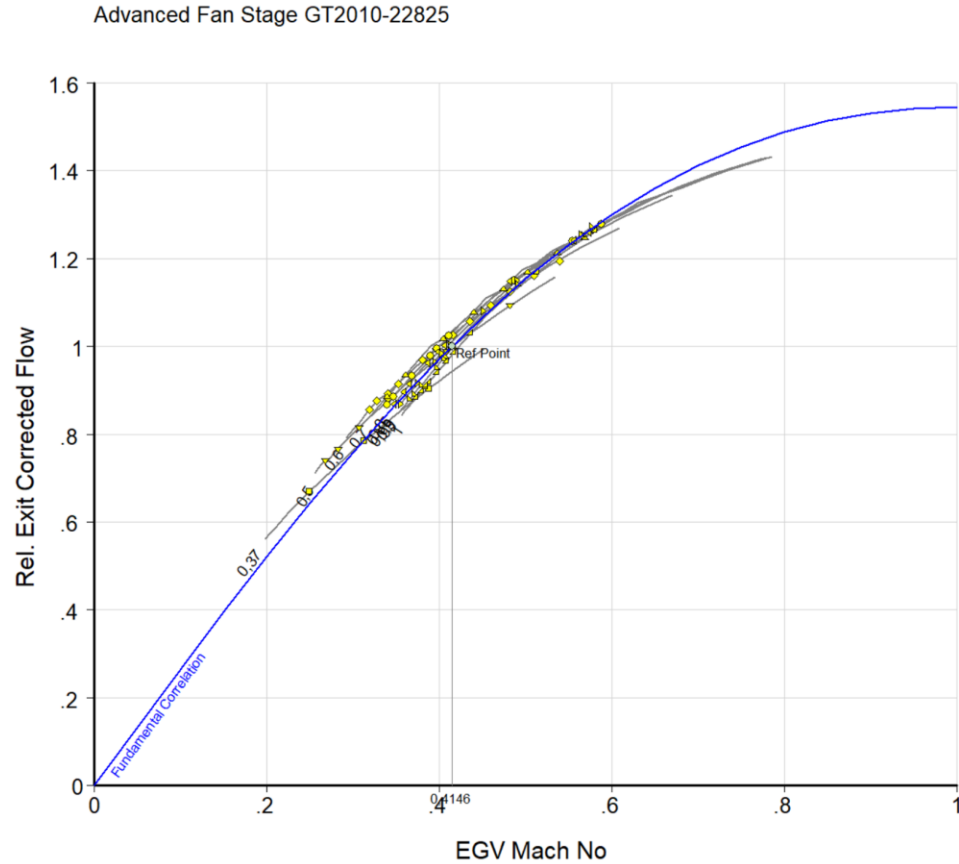


Generated with a derivative of Smooth C 9

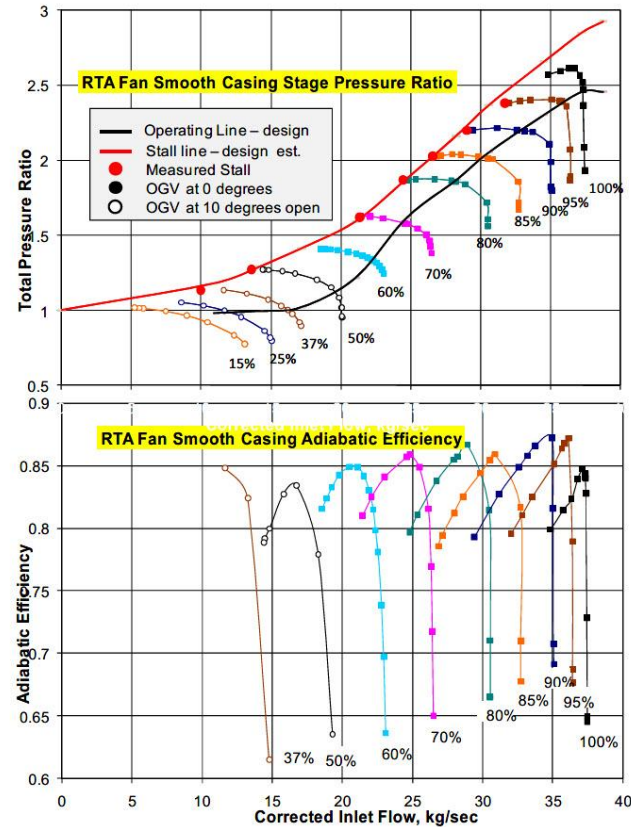
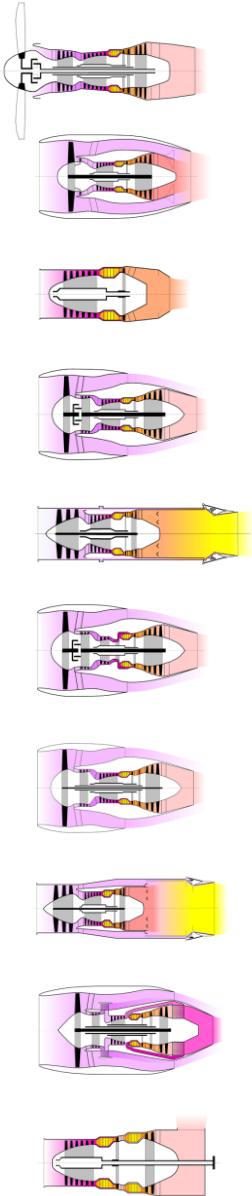


Map smoothing

Considering the exhaust guide vane Mach No helps in the lower right region



See Kurzke J. Generating Compressor Maps to Simulate Starting and Windmilling. *ISABE-2019-2499*, 2019



Outline

The task

Methodology

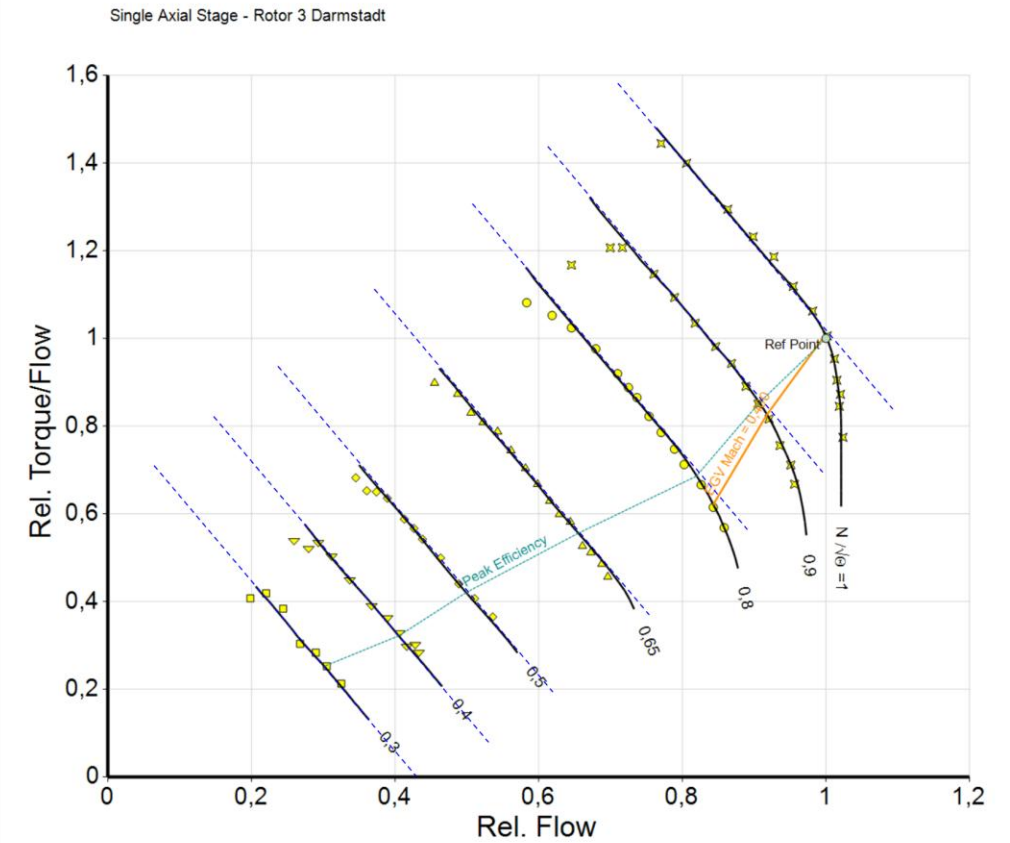
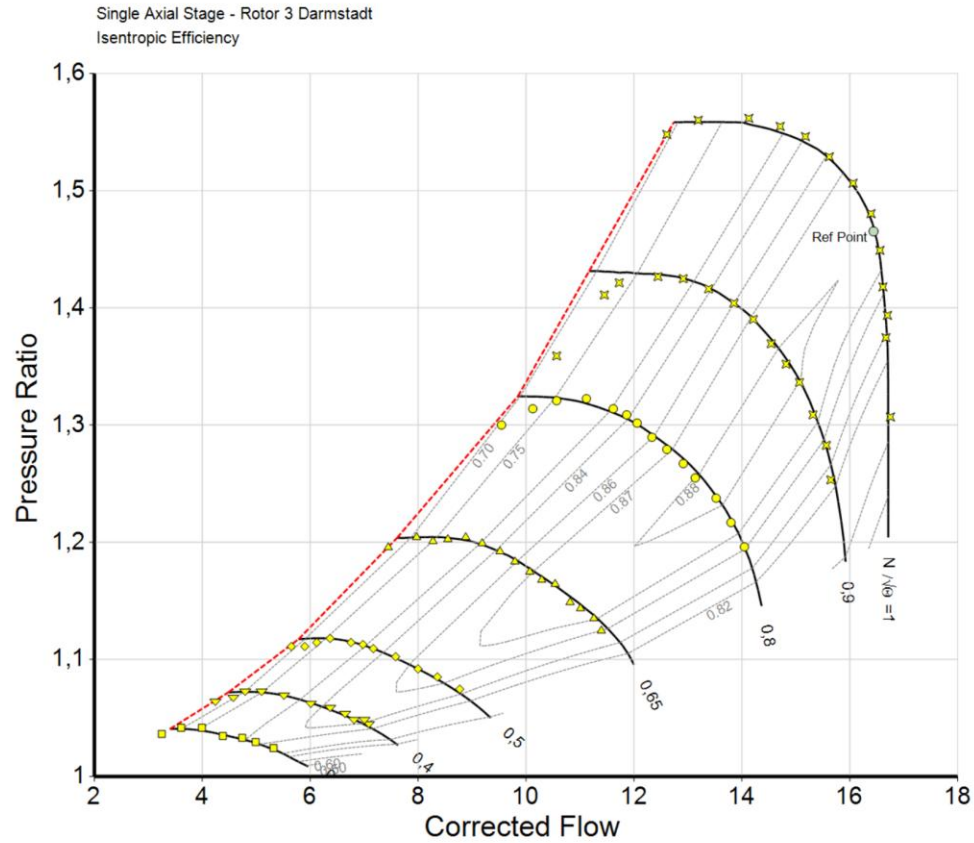
Mathematical smoothing methods

Physics based smoothing

Checking the applicability

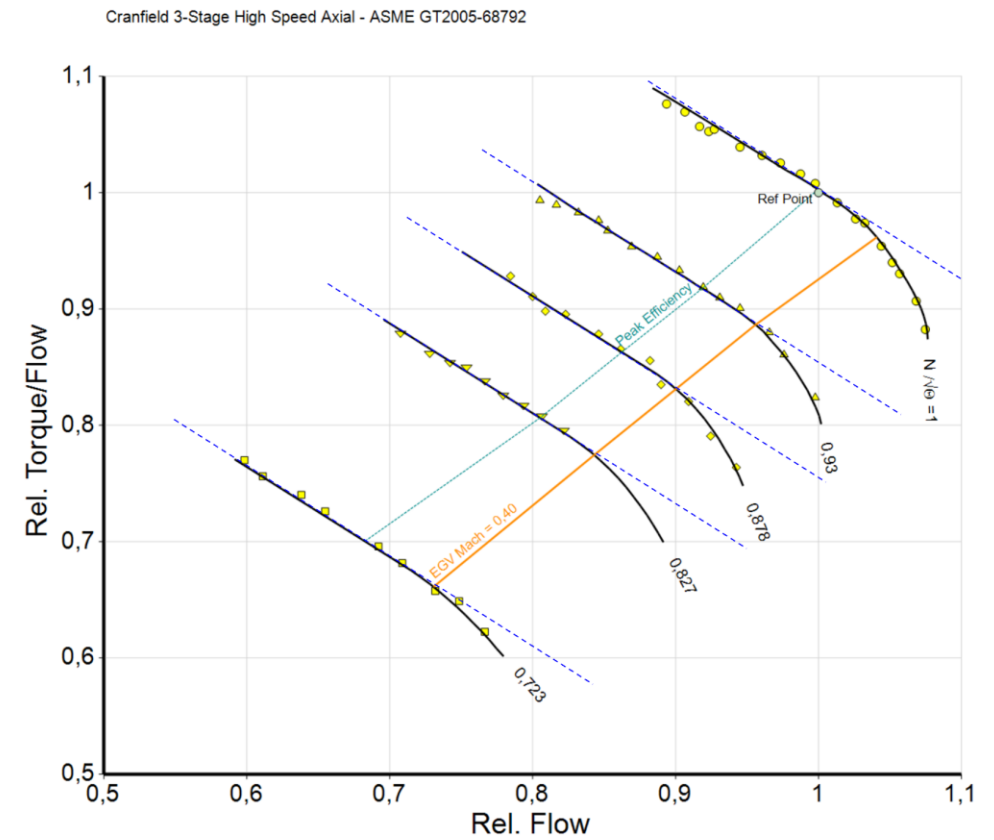
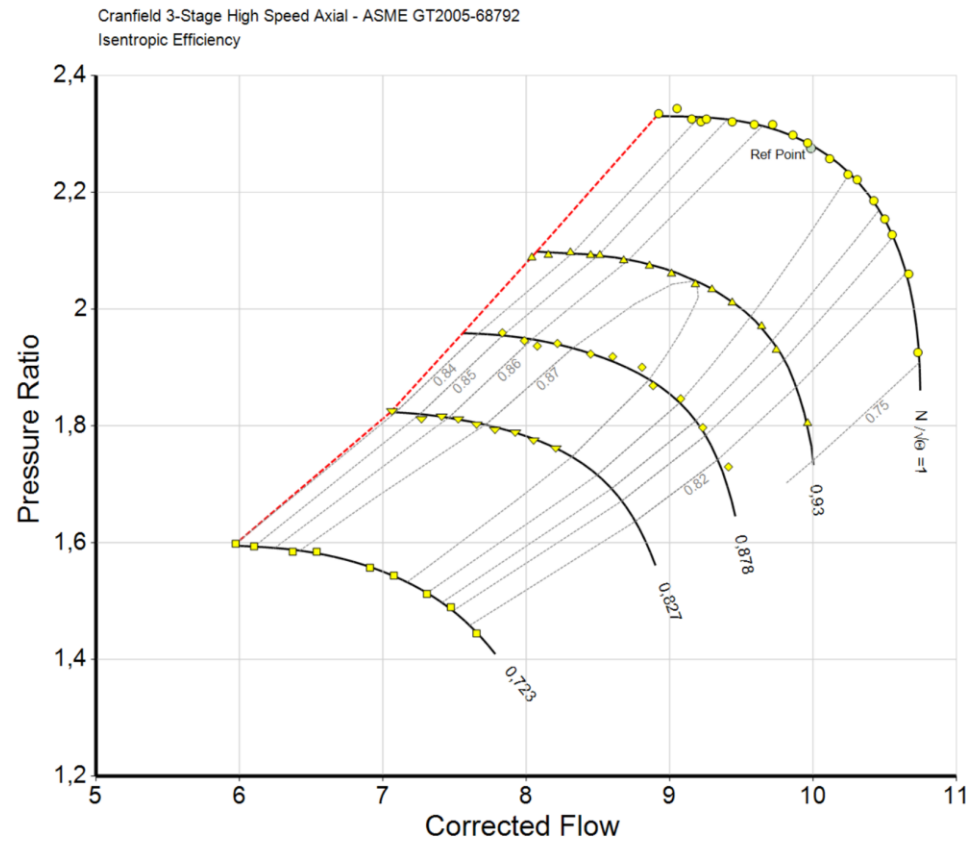
Recommendation

Trq/Flow = f(Flow) lines in the map of a ... Single-stage transsonic compressor

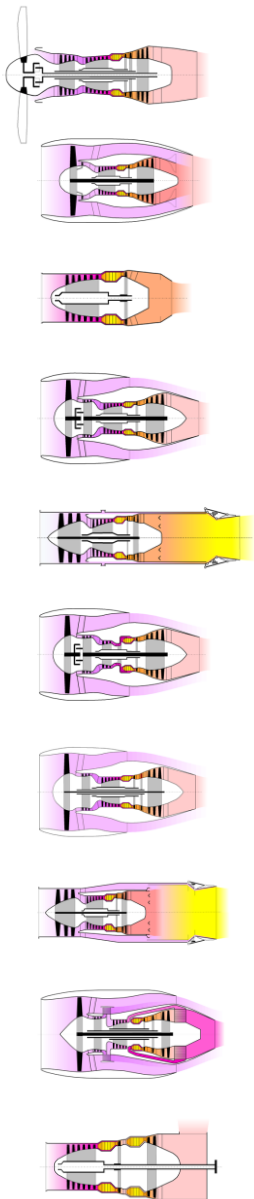


Example #2

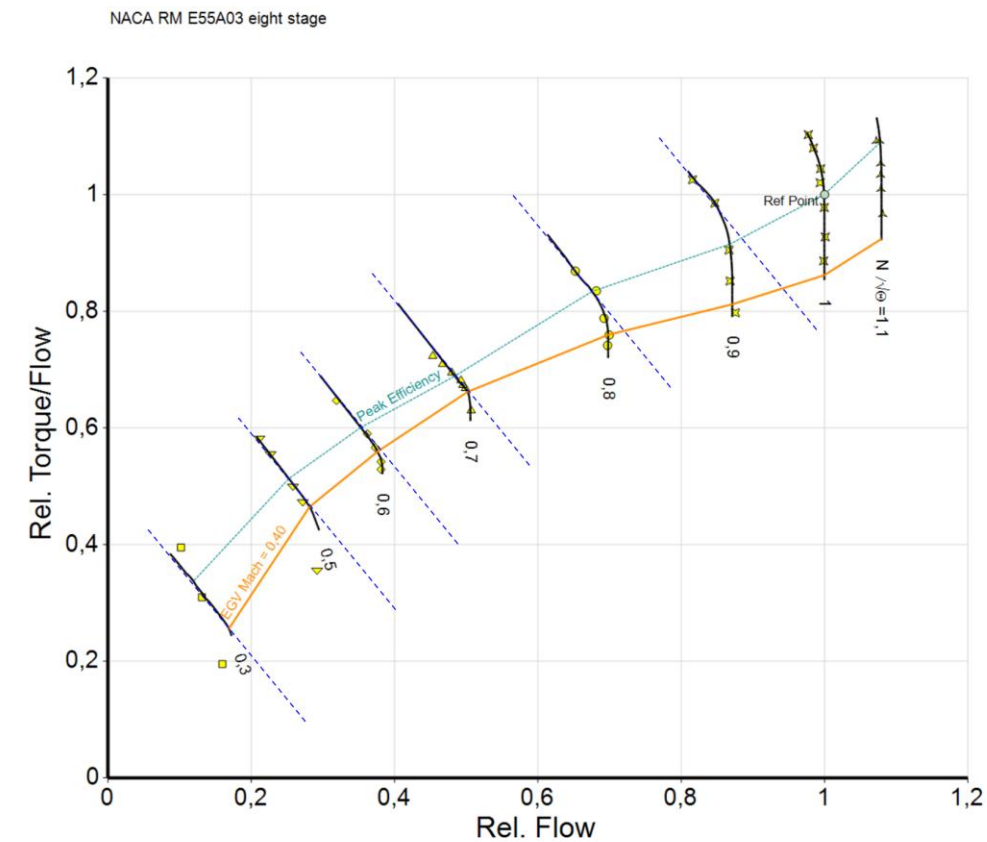
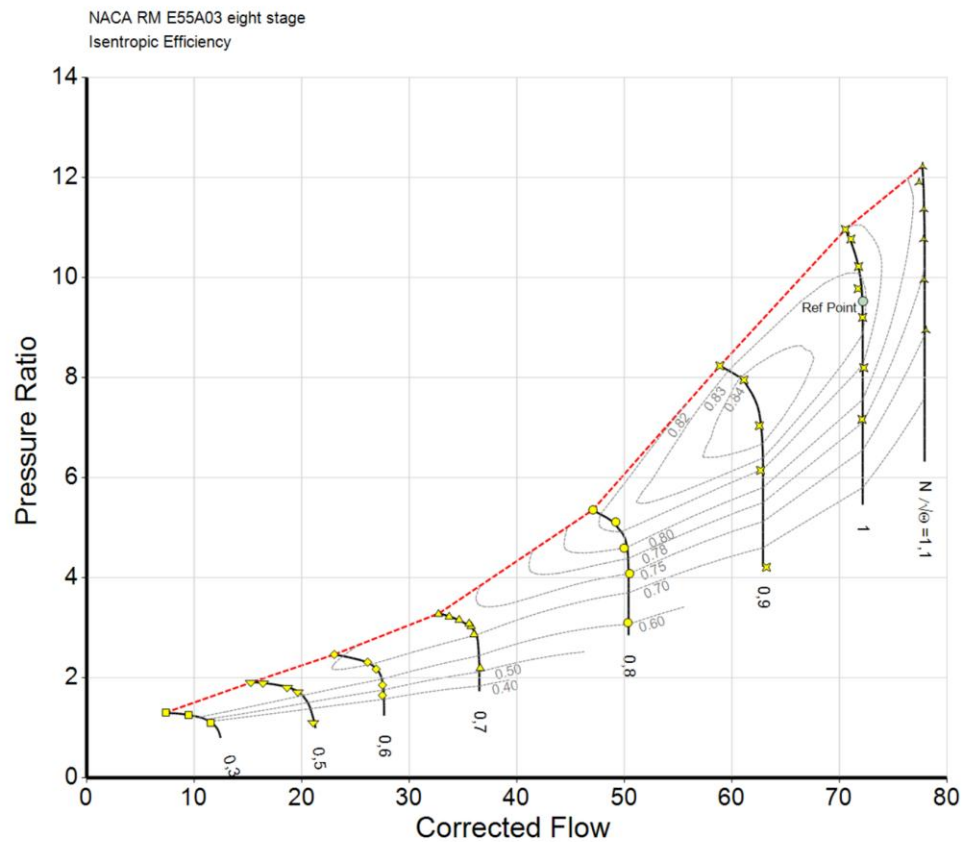
Trq/Flow = f(Flow) lines in the map of a ... Three-stage subsonic compressor



Example #3

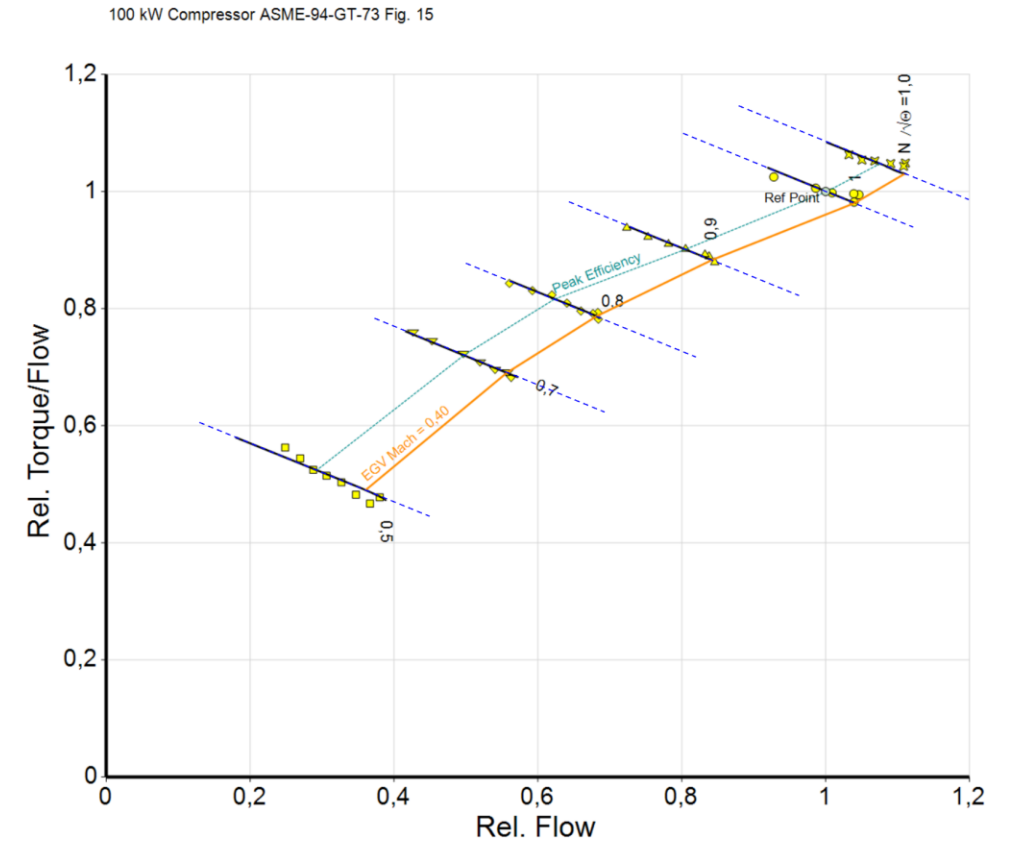
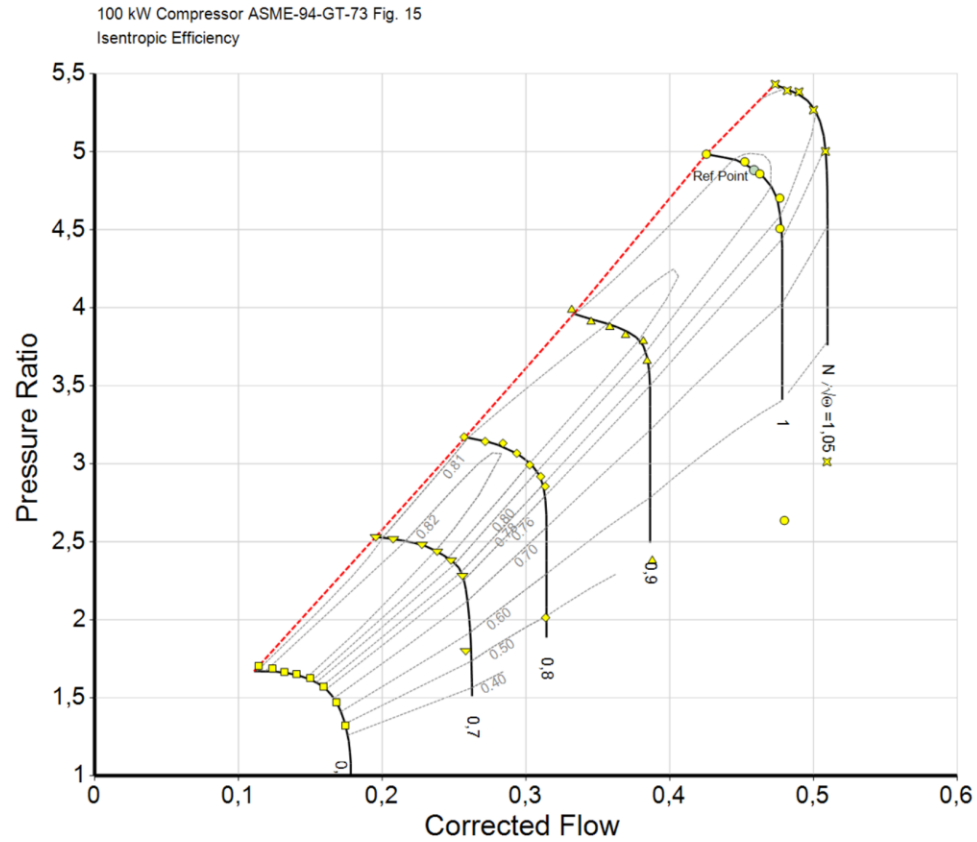


$\text{Trq/Flow} = f(\text{Flow})$ lines in the map of a ... **Eight-stage axial compressor (no VGV's)**

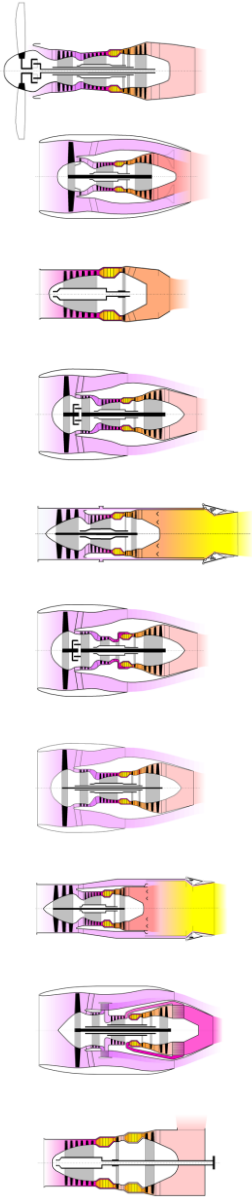


Example #4

Trq/Flow = f(Flow) lines in the map of a ... Single-stage radial compressor

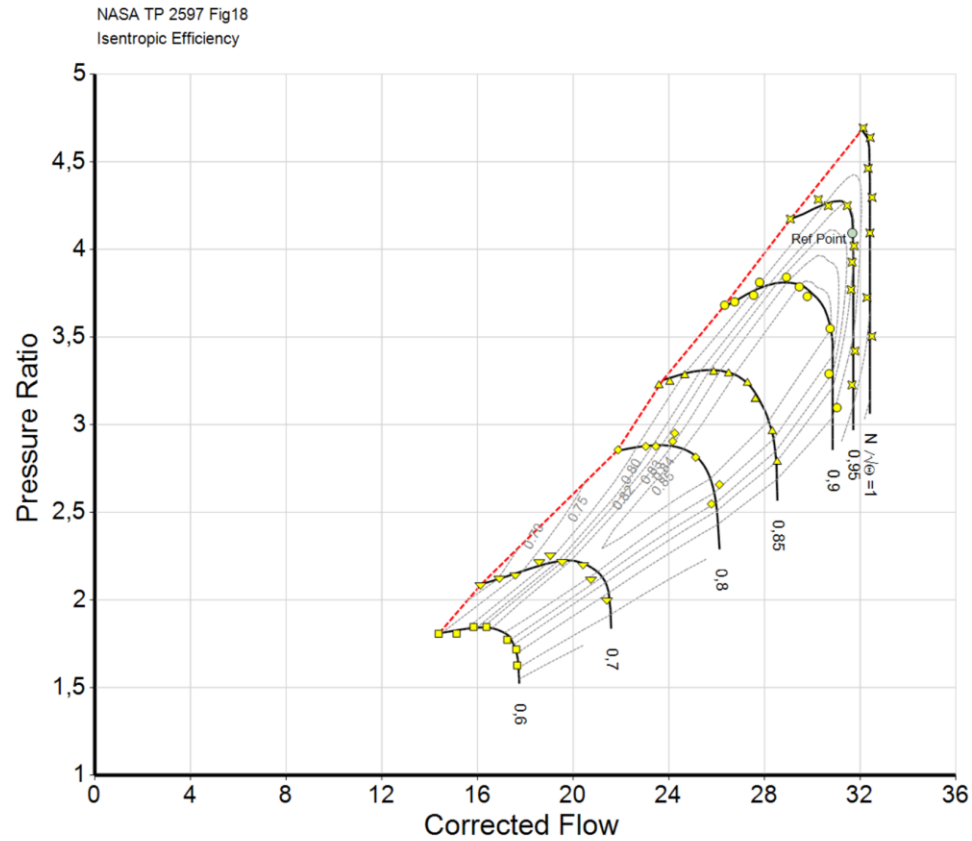


Example #5

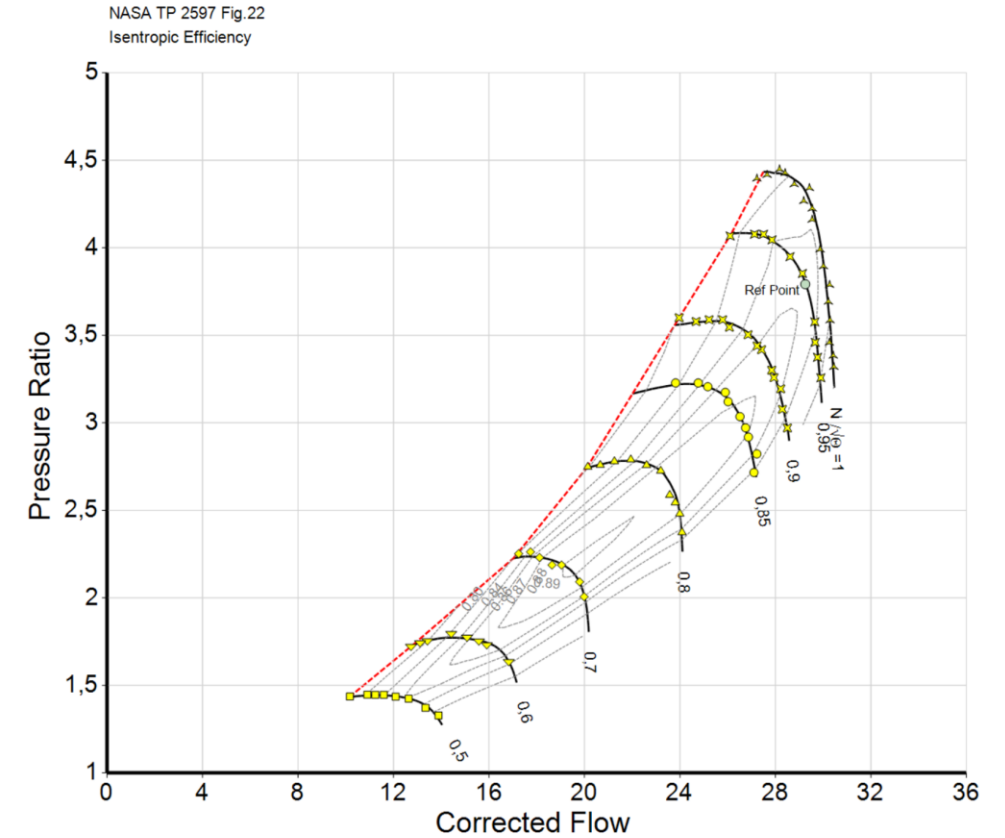


Warning: Maps of a Compressor With VGV's Are Not Smooth !

Three-stage axial compressor with VGV's



NASA TP 2597 Fig. 18: Nominal VGV settings



NASA TP 2597 Fig. 22: VGV setting for maximum efficiency at each speed

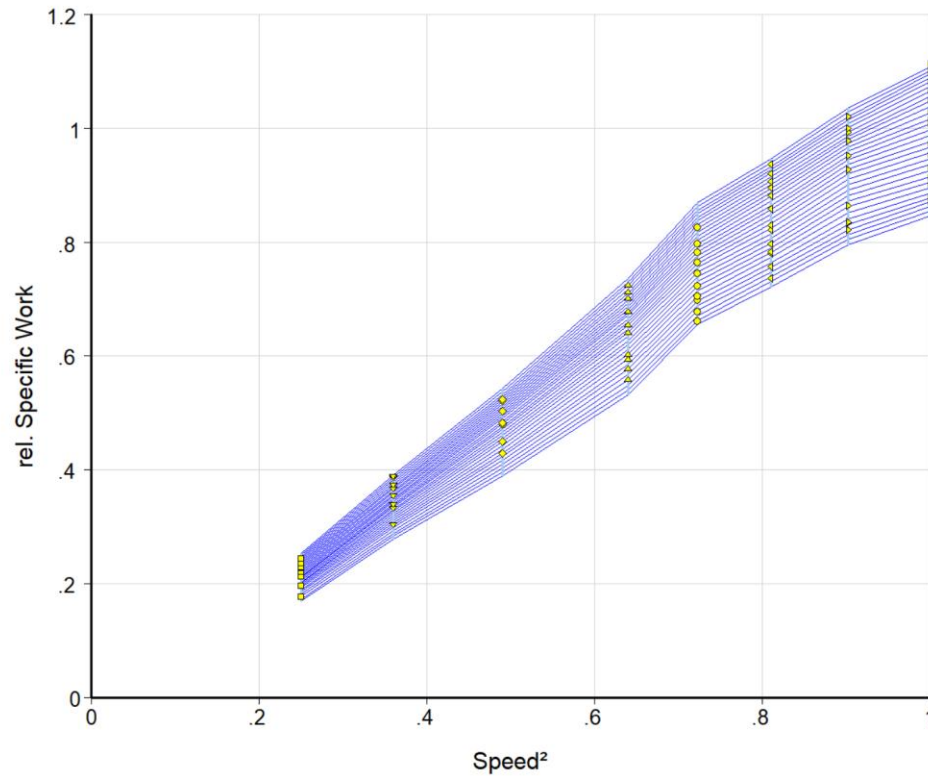
Examples #6 and 7

Maps of compressors with VGV's are not necessarily smooth...

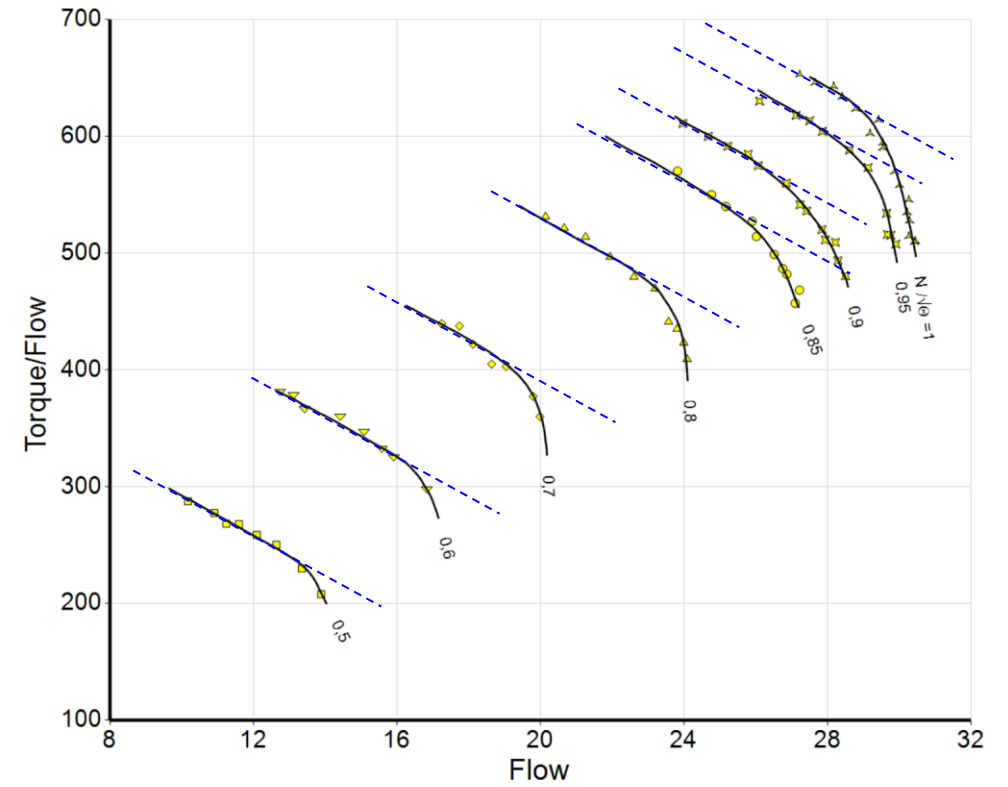


When parabolic β -lines are used, kinks in the VGV schedule are visible in the work-speed² correlation
Nevertheless, the $\text{Trq}/W=f(W)$ lines are straight and parallel

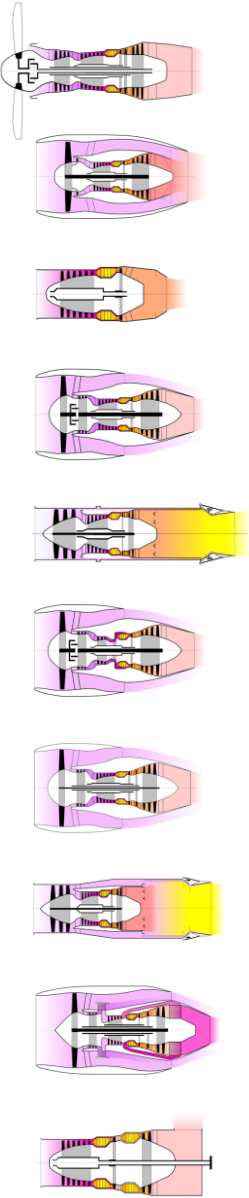
NASA TP 2597 Fig.22



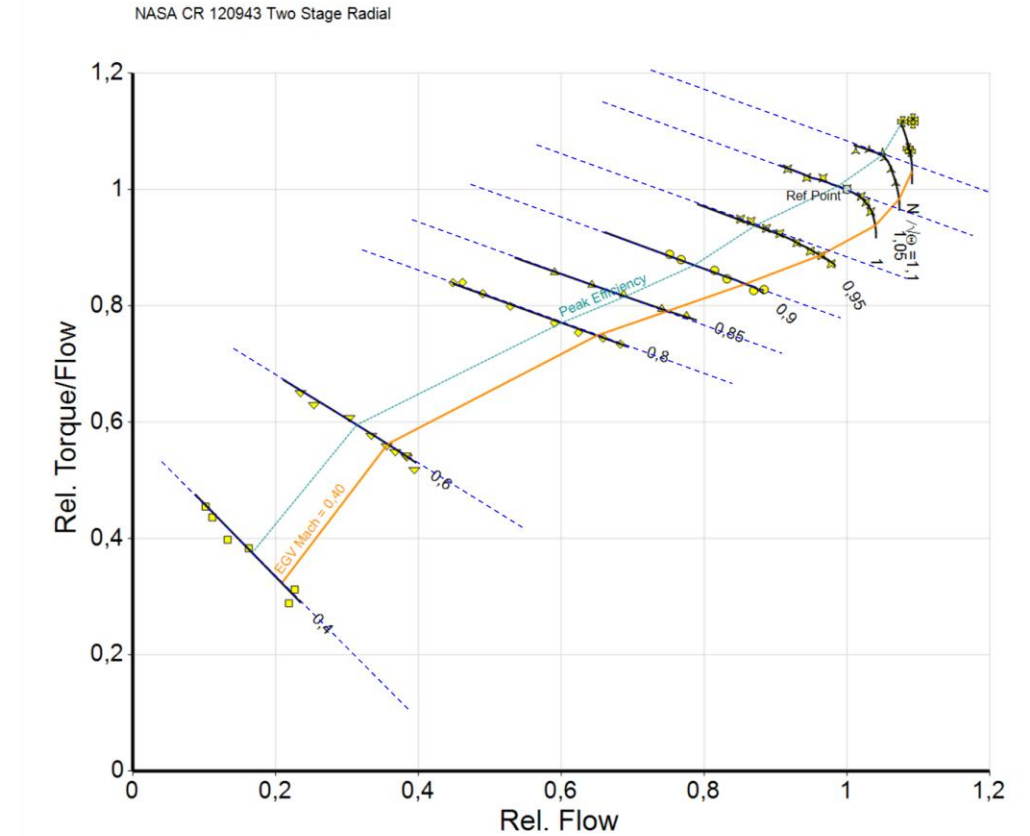
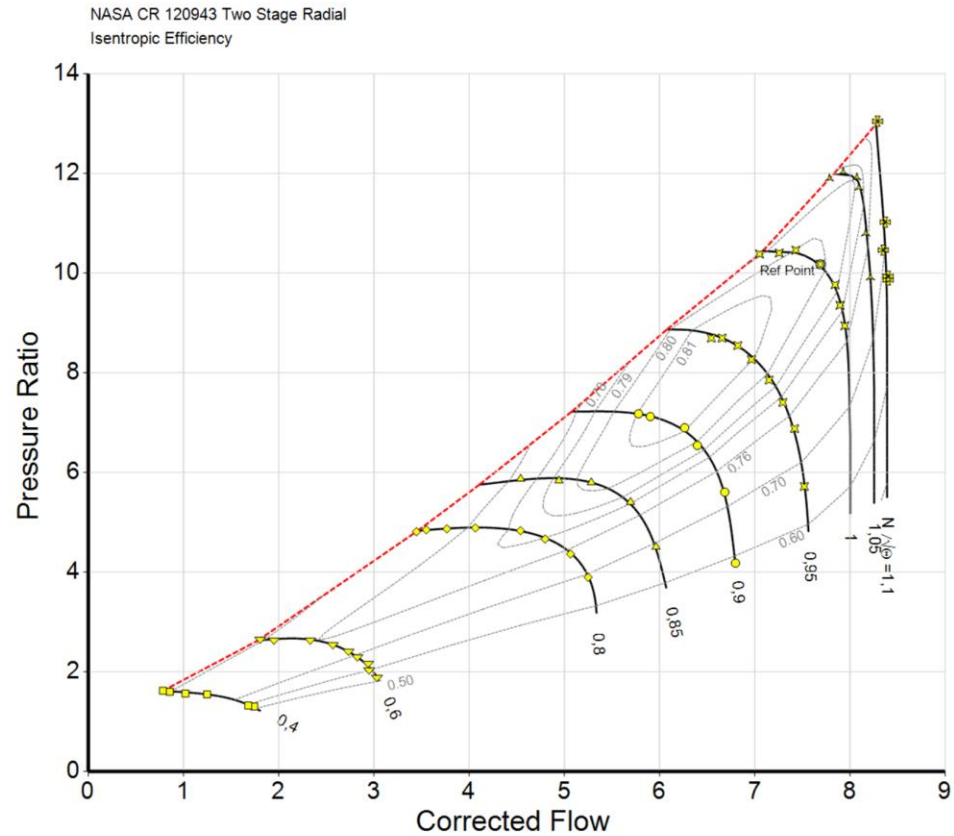
NASA TP 2597 Fig.22



Example #6

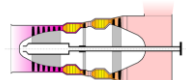
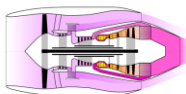
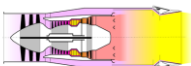
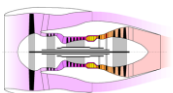
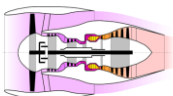
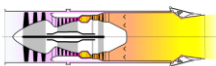
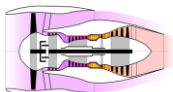
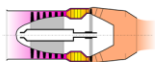
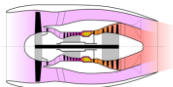
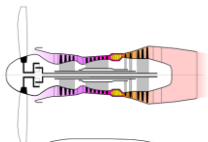


Trq/Flow = f(Flow) lines in the map of a ... **Two-stage radial compressor**



Example #8

Note: there is an interstage bleed valve that opens at speeds below 0.8



More examples ...

The screenshot shows a website interface. On the left, there are three engine diagrams: a standard turbofan, a 'Double Bypass Mode' turbofan, and a 'Single Bypass Mode' turbofan. To the right of these diagrams is a formula for Specific Fuel Consumption (SFC):

$$SFC = \frac{V_0}{\eta_{\text{therm}} \times \eta_{\text{prop}} FHV}$$

Further right is a schematic diagram of an engine system with four compressor stages (M) connected to a power section (PE) and a generator (G). At the bottom of the screenshot is a navigation menu with the following items: Home, My Services ▼, My Tools ▼, My Products ▼, and More... ▼.

Compressor Maps

Hello GasTurb, GSP, pyCycle, T-MATS, PROOSIS and NPSS users! You need compressor maps for your performance studies? I can generate them for you!

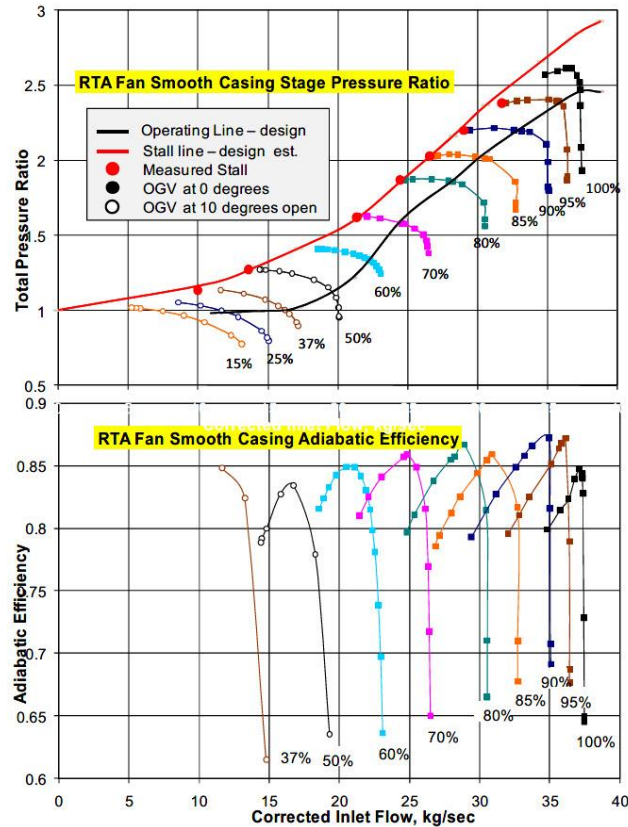
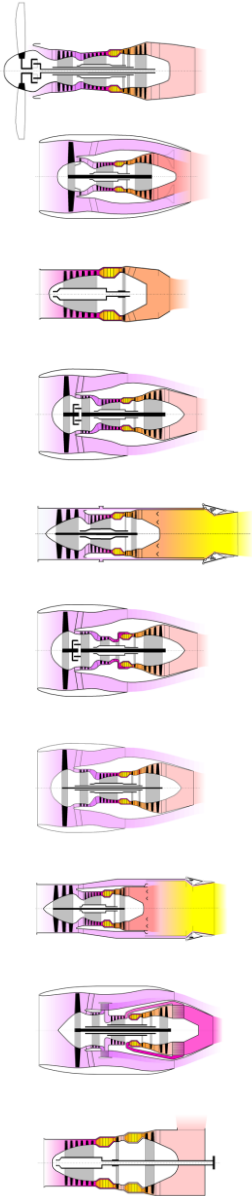
The source of your map may be a figure from a publication, calculated or measured data as text file, and input data from your favourite performance program. Extending the map down to 1% spool speed and to pressure ratios less than unity - as needed for starting and windmilling simulations - is not a problem.

The following maps were created or updated in the context of writing the paper entitled *Generating Physically Accurate Compressor Maps* which I will present at the GPPS conference in Montreal in September. You can see that the thesis that the torque/flow=f(flow) lines are parallel is true in a significant part of each of the maps.

The following maps are available for download in both [GasTurb](#) and NPSS format. Many of them have been extended down to 1% of the design spool speed, making them suitable for starting and windmilling simulations.

- [NASA Quiet Engine Program - Fan B Bypass](#)
- [NASA Quiet Engine Program - Fan B Core](#)
- [NASA Energy Efficient Engine - Fan Bypass](#)
- [NASA Energy Efficient Engine - Fan Core](#)
- [Single Stage Transsonic Compressor - Pressure Ratio 1.5](#)
- [Single Stage Fan - Pressure Ratio 1.7](#)
- [3 Stage Subsonic Compressor - Pressure Ratio 2.25](#)
- [Single Stage Fan - Pressure Ratio 2.47](#)
- [3 Stage Fan - Pressure Ratio 4](#)
- [3-Stage Transsonic Compressor - Pressure Ratio 4](#)
- [6-Stage HPC - Pressure Ratio 8](#)
- [8-Stage Compressor Without VGV's - Pressure Ratio 10](#)
- [Single Stage Radial Compressor - Pressure Ratio 5](#)
- [2-Stage Radial Compressor - Pressure Ratio 10](#)

All the compressor maps are licensed under **Attribution 4.0 International** (CC BY 4.0) See: <https://creativecommons.org/licenses/by/4.0/legalcode>



Outline

The task

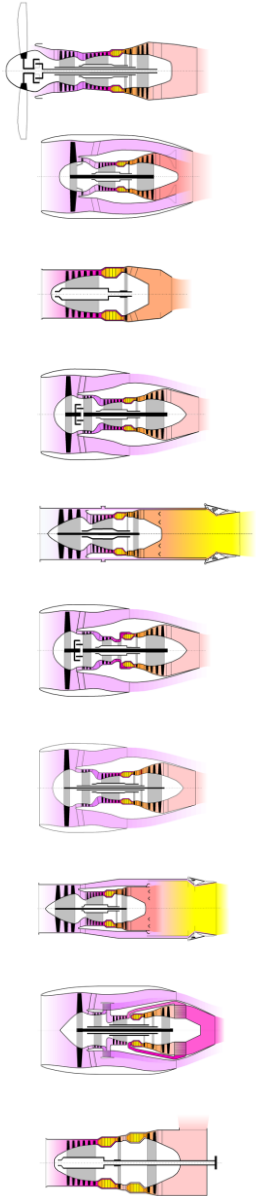
Methodology

Mathematical smoothing methods

Physics based smoothing

Checking the applicability

Recommendation



Recommendation: Check the quality of your compressor map!

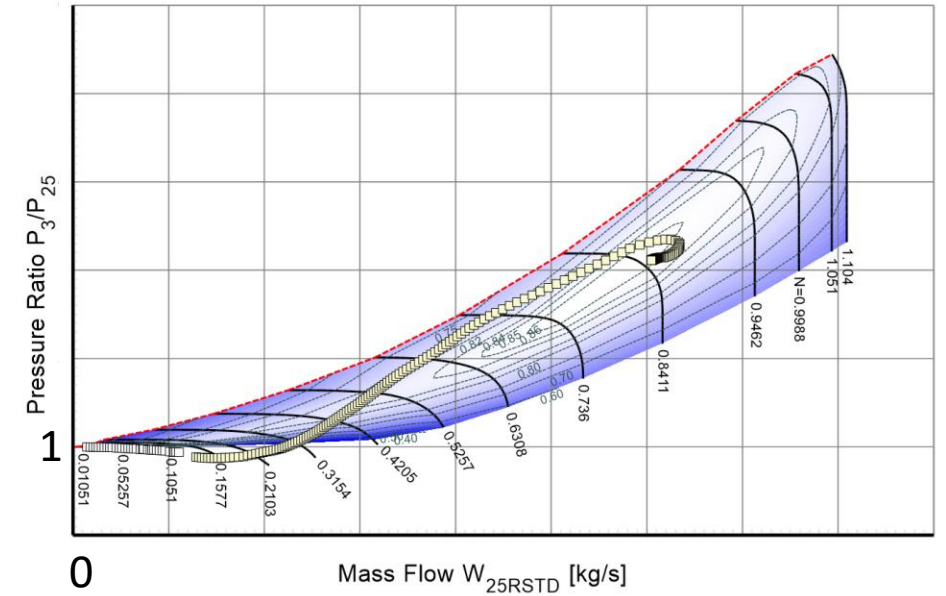
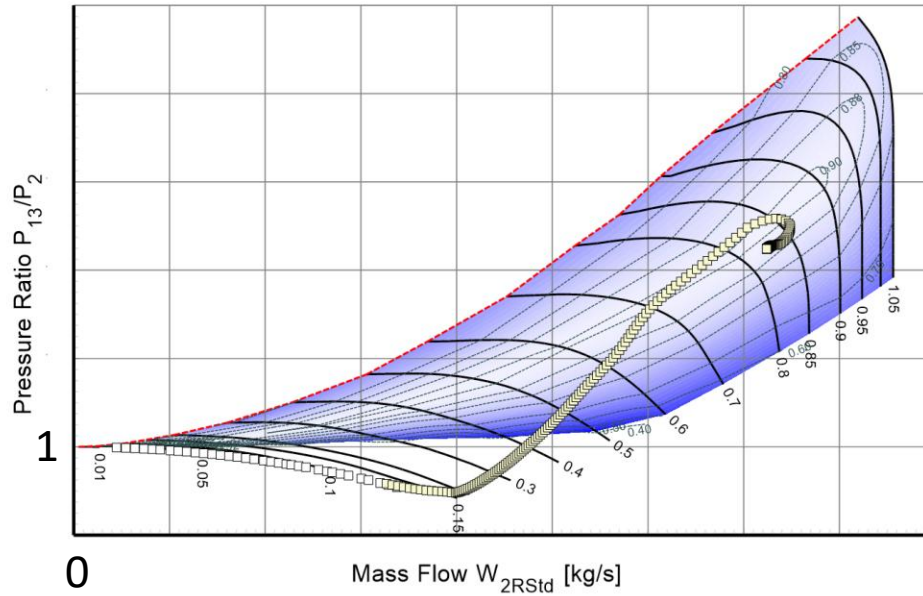
- It has been shown with 8 examples that $\text{Trq}/W = f(W)$ lines are straight and parallel in all compressor maps
 - More examples are published on my website
 - Exception: two stage radial compressors with interstage bleed

- No matter how you generate your compressor maps:

Check the shape of the $\text{Trq}/W = f(W)$ lines

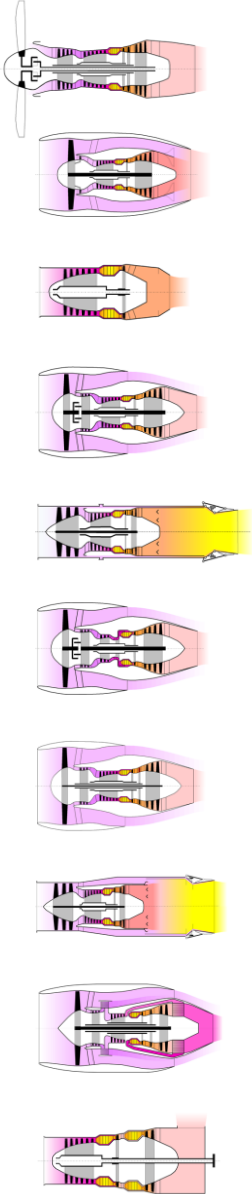
- If these lines are not straight or their slope changes with speed, the smoothed map does not align with first principles.

The reward for your efforts is...



Physically sound compressor maps allow you to simulate exotic operating conditions, such as starting an engine in flight.

Thank you for your attention



Are you looking for an alternative to Smooth C ?

The challenges of writing a fully automatic map smoothing program

- Compressors are different:
 - Subsonic – transonic – single stage – multi stage – axial-radial – single and multistage radial compressors, fan with bypass ...
- Generally, maps must be smooth
 - However, maps of compressors with variable guide vanes or interstage bleed are not necessarily smooth!
- The source of data differs:
 - Measured – calculated – from outside the company
- The format of the given data varies:
 - Tables
 - Map as figure with η contours
 - Separate figures for $\eta=f(\text{Flow})$ and $\eta=f(\text{Pressure Ratio})$
 - Efficiency may be isentropic or polytropic
 - Given data may be true or relativized values
- The number of available speed lines differs
- Identify and address outliers in measured data
- Create smooth lines through the given data
 - Add interpolated speed lines
 - Extend to high and low speeds
 - Extend the map down to 1% spool speed as needed for engine starting simulations
 - Extend the map to a pressure ratio of less than one as needed for the windmilling simulation
- Quality check
 - In a smoothed map, there are many correlations between parameters that all must be consistent with physics, for example specific work – pressure ratio – efficiency – Ψ – Φ – losses – EGV Mach number – ...
 - Are the $\text{Trq}/W = f(W)$ straight and parallel in the relevant map region?
 - Note that the correlations vary by compressor type
 - All correlations must be smooth – except those from compressors with variable geometry