



Smooth C 9



Smooth C 9

Preparing Compressor Maps for Gas Turbine Performance Modeling

by Joachim Kurzke

Smooth C 9

Joachim Kurzke is the principal author of Smooth C 9 and this manual. Additions have been made by the team of GasTurb GmbH.

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Foreword

Computer programs that calculate the performance of gas turbines or piston engines with turbocharger need as input a description of the compressor maps (sometimes called also compressor characteristics). These maps are either calculated or derived from a compressor rig test.

The accuracy of the compressor map representation is very important for precise cycle calculations. Remember, that 1% error in compressor efficiency can mean - dependant on engine type - up to 1% error in specific fuel consumption! It can easily happen, that such an error is introduced into the cycle calculation by use of a low quality compressor map. Both in case the data are scattered or if there are not enough speed lines in the map the interpolation of data is prone to errors.

The compressor characteristics are needed in performance calculation programs in a special format. To produce this format "by hand" is a cumbersome task that takes quite much time because of the scatter in the data. Moreover the data from the compressor rig test usually are not evenly distributed over the tested speed range or the distance between speed lines is big. Interpolation and extrapolation of the measured data are required.

The program Smooth C is a tool that quickly produces high quality compressor characteristics from measured data. Such characteristics can be used not only for performance calculations. One can also evaluate small differences between different compressor types, for example the effects of interstage bleed, Reynold's number, tip clearance, restaggered blades and vanes, distortion etc.

However, Smooth C is not only a valuable tool for dealing with measured data. It can also be used to check the quality of any compressor map. One can use, for example, existing compressor maps as input. Various crossplots offered by the program allow a judgment whether the map is a reasonable description of compressor physics or not. Deficiencies can be corrected and physical meaningful interpolations and extrapolations of the map are possible.

Instead of genuine measured data - which seldom are available outside industry and research facilities - one can also take data from figures published in literature. Even relativized compressor map data can be used as input.

The output of the program is tabulated data with the same number of equally spaced points for all speed lines. These data are suited as input into performance programs simulating gas turbines or turbocharged piston engines.

Joachim Kurzke is the principal author of Smooth C 9 and this manual. Additions have been made by the team of GasTurb GmbH.

The GasTurb Team

2021

1 Getting Started

1.1 Program Requirements and Installation

Requirements

For running the program Smooth C 9 you need a PC with a color monitor which has a screen resolution of 1024x768 or better. Windows 2000, Windows XP, Windows Vista, Windows 7, 8 and 10 are suitable operating systems. The license server, used for Floating and Site Licenses, can run on Windows, Max OS, Linux or Solaris.

Installation

Run setup for installing the program. A wizard will lead you through the details of the installation. Install Smooth C 9 in its own, new directory and do not install it in the directory of any previous program version you may have. Some of the files delivered with Smooth C 9 have the same file name as those of previous versions, but different file contents. Mixing the files from different versions of Smooth C will cause a program crash.

Installation on a Network

On a network you can store the program in a directory which everybody can access. The different users should store their private data in their own directories for maps. Note that the example maps delivered with the program must reside in the same directory as the program. You can store a copy of these files in any private component map directory.

A Microsoft security patch now prevents HTML Help .CHM files from being opened on network drives. When you call help, "Action canceled!" will be displayed instead of the topic text. This will happen with all HTML Help files that you open over a network connection (note, that local HTML Help files will not be affected).

The reason for this error is a new and more strict security policy for Microsoft Internet Explorer. Microsoft is permanently updating MSIE to fix potential or real security threats. In case of this error, the Microsoft Security Bulletin MS05-026 disables HTML Help files opened from a network drive. Learn more about the security threat in the Microsoft Knowledgebase Article KB896358.

When you install the program on a network, please ensure that the help file (file extension .CHM) gets installed on the local C: drive (this is recommended by Microsoft). If this is not possible or not desirable, you can explicitly register individual help files and folders to allow viewing them over the network or edit the Windows registry to make the security settings less strict in general. Microsoft describes the necessary steps in detail in the knowledge base article KB 896054.

Using a Working Directory

If you want to store your files in a directory different from the program, you need to start Smooth C 9 with a command line parameter. After the program call (separated by a space) add the path to your data. If your path name contains blanks, then you must enclose the path name with quotation marks.

If you have stored the program in directory C:\Program Files\GasTurb\Smooth C, for example, and want your data stored in directory C:\My Documents\Smooth C\Data, then you must start the program by the following command sequence:

```
"C:\Program Files\GasTurb\Smooth C\Smooth_C9.exe" "C:\My Documents\Smooth C\data"
```

1.1.1 License software

Additionally to Smooth C 9, you have to install a license software called CodeMeter Control Center®. This will be done automatically, if you check the respective box during the setup of Smooth C 9.

Moreover, in case you have a Floating or Site License, a license server has to be installed somewhere in your local network. Details about the installation of the license server and the activation of licenses can be found in a guide you have received together with your license information via email.

If you experience any kind of problems during the installation, please contact the support.

1.2 What's New in Smooth C 9

Enhanced Map Extending Capabilities

The most important added feature of Smooth C 9 is the enhanced map extension capability which supports the generation of compressor maps suitable for starting and windmilling simulations. The physics based methodology is described in detail in Ref. [7] by the inventor of method. As explained later, for extending the map the [Speed Line Zero](#) is used. Extending the map towards lower speeds is performed by an interpolation between the lowest speed line available and the speed line zero. This yields better results than an extrapolation from the lowest speed line available, without taking into account the information given by the speed line zero.

The representation of the speed line zero is improved by using [correlations hidden in compressor maps](#). In order to incorporate compressibility effects, the use of the exit guide vane (EGV) throat Mach number has been implemented in Smooth C 9.

Plotting Improvements

To enable the user to handle the map extending capabilities, additional plots have been introduced in Smooth C 9. This for example includes the plot of the EGV throat Mach number over flow, isentropic [work coefficient](#) *is* over work coefficient or torque slope over EGV throat Mach number.

Many existing plots have been improved in order to give a better overview of the map concerning different physical quantities. This means more speed lines are shown and they have different colors making them more distinguishable.

Straight Line Function

The smooth speed and efficiency lines could be modified point by point or as a whole line in the previous program version. For mass flow it was possible to define vertical line sections when choking was reached. Now it is also possible to define straight sections on specific work or torque lines. This makes extending maps much more comfortable.

1.3 What's New in Smooth C 8.3

Point and Line Working Mode

The smooth speed and efficiency lines could only be modified point by point in previous program versions. Shifting a whole speed line required many mouse clicks. Now it is feasible to modify whole speed and efficiency lines in one go.

Map Output

The quality of the graphical output of maps is significantly improved.

β -Lines With Physical Meaning

In general, the β -lines in a compressor map are auxiliary coordinates which have no physical meaning. They are introduced for the sole purpose of reading the map unambiguously. However, the β -lines in compressor maps can be shaped in such a way that they approximate lines of constant work coefficient H/U^2 very well. Doing this was not easy with previous versions of Smooth C.

Smooth C 8.3 allows re-defining the β -line grid without losing the smooth map data which had been created before. A new plot shows how the work coefficient varies along the β -lines while the β -line grid is defined.

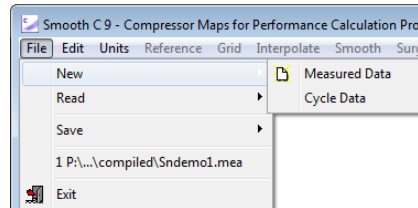
Enhanced Single Stage Fan Map

If the β -lines in a map of a single stage fan approximate lines of constant work coefficient H/U^2 then it is easy to create an additional table with values for the core stream efficiency as a function corrected speed and β . The theoretical background for this as well as how to use such an enhanced map is described in [Reference 6](#).

2 Data Input

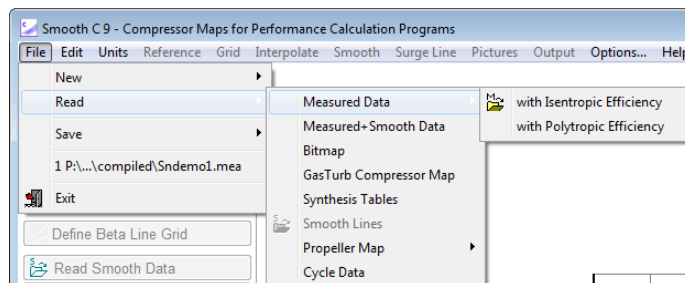
2.1 Input Options

You can select between several input options from the menu option *File/New*:



Selecting *File/New/Measured Data* opens the data input editor window in which you can [enter your data manually](#).

If you want to read data from file then select *File/Read*:



Selecting *File/Read/Measured Data* allows you to read input data, for which a smooth map is to be created, from file. [Measured data](#) are stored in a file with the file name extension MEA and may contain isentropic or polytropic efficiency values. Polytropic efficiency data will be converted to isentropic efficiency immediately after the data input process.

If the option *Measured+Smooth Data* is selected, then first a file with measured data is read and second the file with [Smooth Lines](#) (file name extension SMO).

If instead of numerical data only a picture of the map is available, then scan it and store it as a Windows bitmap (file name extension BMP). With Smooth C 9 you can read numbers from such a [Bitmap](#).

[Synthesis Tables](#) contain compressor map data in a special format which is required by some gas turbine performance simulation programs (file name extension SYN). A [GasTurb Map](#) has the format as required by the GasTurb program (file name extension MAP). Both the data read as Synthesis Tables or from a GasTurb Map are interpreted as measured data by Smooth C 9

A file with [Smooth Lines](#) does not contain measured data but the result of the map smoothing process. If you want to read a file with smooth lines as measured data, you can cheat the program: Modify the [map type indicator](#) in such a way, that the smooth data are marked as measured data. Furthermore it is recommended to change the file name extension to MEA.

Measured Data, Synthesis Tables, Cycle Data and Smooth Lines can be read in non-relativized and in relativized form. Relativized data will be converted to non-relativized data before the map smoothing process commences.

Besides a compressor map you can also read a [propeller map](#) either from a bitmap or from file.

[Cycle Data](#) are data from a gas turbine cycle calculation that can be viewed during the map smoothing process.

2.2 Units

The system of units that you select in the program main window affects directly the numbers for the corrected specific work and velocity:

| | SI system | US system |
|---------------------------------|-----------|-------------|
| Corrected Specific Work H/T_1 | J/(kg*K) | BTU/(lbm*R) |
| Velocity | m/s | ft/s |

The units for corrected speed and corrected mass flow are arbitrary. However, the numbers for all quantities which are derived from corrected speed or corrected mass flow depend on the units chosen:

| Quantity | Formula | Units |
|---------------------------|---|--------------|
| Corrected Specific Work | H/T_1 | ch |
| Corrected Mass Flow | $W*\sqrt{T_1}/P_1$ | cw |
| Corrected Speed | $N/\sqrt{T_1}$ | cn |
| Torque / $[W*\sqrt{T_1}]$ | $H/T_1 / N/\sqrt{T_1}$ | ch / cn |
| Torque / P_1 | $W*\sqrt{T_1}/P_1 * H/T_1 / N/\sqrt{T_1}$ | cw * ch / cn |

The program writes a neutral text near to the x- and y-axes of the graphs. You can [edit the text](#) and add the units that apply to your special map, for example.

2.3 Measured Data

A compressor rig test is run in such a way, that with a fixed throttle position the spool speed is set to a certain value, say 100% of the design speed. Then a scan is taken which stores all measured data in a file. With the help of the rig test analysis program the overall pressure ratio P_2/P_1 , the total corrected mass flow W_{corr} and the efficiency are evaluated.

A data point of a compressor map thus consists of four numbers:

1. [Speed](#)
2. [Pressure ratio](#)
3. [Mass flow](#)
4. [Efficiency](#)

After the first scan is taken, the throttle setting is modified while the spool speed is kept constant. Pressure ratio, mass flow and efficiency will change with the throttle setting. The next scan will yield a new data point. If the throttle is closed too much then the compressor will surge. The last scan just before compressor surge is a data point of the surge line.

The low pressure compressor of a turbofan is sometimes tested with two independent throttles. One deals with the flow entering the core engine and the other with that entering the bypass. Any scan in such a test yields the total mass flow, a pressure ratio and an efficiency value for each stream, and the bypass ratio. Thus a data point of a fan map consists of seven numbers:

1. Speed
2. Total mass flow
3. Primary pressure ratio
4. Primary efficiency
5. Secondary pressure ratio
6. Secondary efficiency
7. Bypass ratio

One of the streams must be selected as primary map. It is recommended to use the inner (core) stream for the primary map if the design bypass ratio is lower than 0.9 and otherwise the outer (bypass) stream.

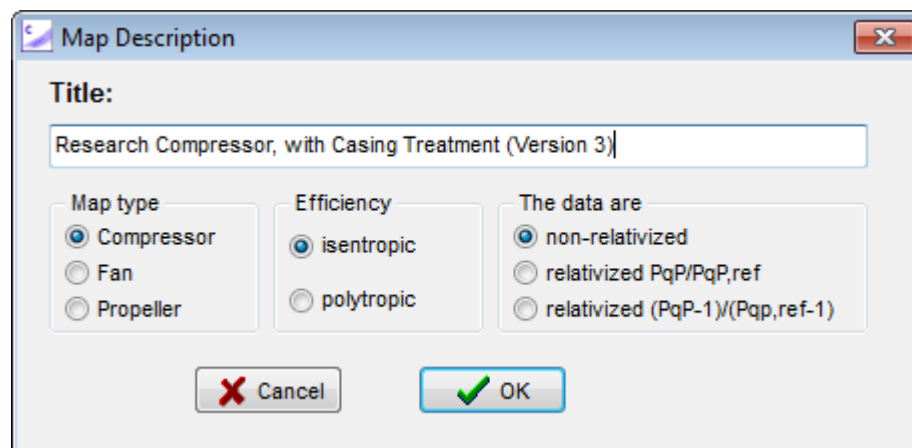
The bypass ratio is an optional input to Smooth C 9. If it is available, then besides the primary and the secondary maps also the mean map will be produced.

A data point of a propeller map consists of four numbers:

1. Propeller pitch
2. Power coefficient
3. Advance ratio
4. Efficiency

2.3.1 Manual Input

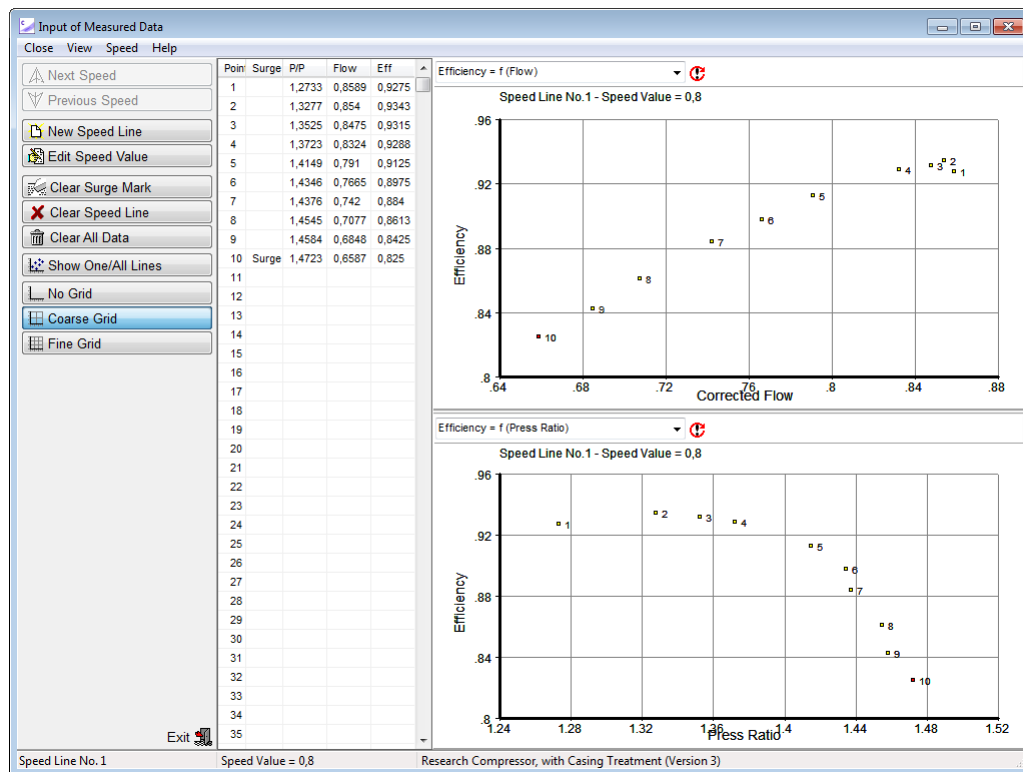
Before entering the actual data some information is requested:



The image shows a 'Map Description' dialog box with a title field and three groups of radio buttons. The title field contains 'Research Compressor, with Casing Treatment (Version 3)'. The 'Map type' group has 'Compressor' selected. The 'Efficiency' group has 'isentropic' selected. The 'The data are' group has 'non-relativized' selected. At the bottom are 'Cancel' and 'OK' buttons.

| Map type | Efficiency | The data are |
|---|---|---|
| <input checked="" type="radio"/> Compressor | <input checked="" type="radio"/> isentropic | <input checked="" type="radio"/> non-relativized |
| <input type="radio"/> Fan | <input type="radio"/> polytropic | <input type="radio"/> relativized $P_{qP}/P_{qP,ref}$ |
| <input type="radio"/> Propeller | | <input type="radio"/> relativized $(P_{qP}-1)/(P_{qP,ref}-1)$ |

Entering data manually is straightforward. Just type the measured values in the corresponding column and mark the surge point by double-clicking in the surge column. The sequence of the data is of no relevance. You can start with the data group for any speed value. Within a data group you can commence with the lowest, the highest or a medium pressure ratio point, for example.



2.3.2 Reading from File

The first line of a file with measured data must begin with an integer number which indicates the file contents. This is the **map type indicator**. After the map type indicator there must be one blank space. The rest of the line is reserved for the **map title**.

Also the second line must begin with an integer. This gives the number of speed lines to follow. After the number of speed lines there must be at least one blank space. Then either the word **relativized** or **non-relativized** must follow.

Next there is for each speed line a data group. It consists of the speed line header and the data lines. On the speed line header there must be three numbers, separated by at least one blank from each other. The first number is the speed value. The second number is the number of data lines to follow. The third number says, which of the data lines represents the surge point. If the surge point is not included in the data, then the third number must be 0 (zero).

A data line for a compressor map consists of three numbers and that for a fan map consists of five or six numbers. In any case the first three numbers are standing for pressure ratio, inlet mass flow and efficiency. In a fan map file the forth and fifth numbers are the secondary pressure ratio and the secondary efficiency. Optionally the bypass ratio can be given as the sixth number.

Note that efficiencies for a non-relativized map must be a number lower than 1 (except if the pressure ratio is below 1).

The sequence of the data within a file with measured data is of no relevance. You can start with the data group for any speed value. Within a data group you can commence with the lowest, the highest or a medium pressure ratio point, for example.

Have a look at the input file examples for a [compressor map](#) respectively a [fan map](#). Note that you can use . or , as [Decimal Separator](#) in your data input files.

2.4 Smooth Data

The [map type indicator](#) of a compressor map is 2 or 3. Map type indicators are 12 or 13 for fan maps with different pressure ratio and efficiency values in the core and bypass streams.

The maps of a single stage fan can be expanded after the map smoothing process by adding estimated values for core stream efficiency. The map type indicator is 33 for such an extended map.

The file format for smooth data is very similar to that for [measured data](#).

In files with smooth data there are on the second line the coordinates of the [map reference point](#) (speed and beta). On the third line there is the Mach number of the reference point and also the work and flow coefficients of the map reference point. These two lines with the map reference data exist only if the file was written by Smooth C 9. Previous versions of Smooth C did not write these lines; if they do not exist then you will be asked to enter reference point data before you can work with the program.

The number of data points is the same for all speed lines. The number of data points is repeated as a dummy surge point indicator.

Data for a [smooth surge line](#) are optional; they are appended at the end of the file.

Have a look at the file examples for a [smooth compressor map](#) respectively a [smooth fan map](#). Note that you can use . or , as [Decimal Separator](#) in your data input files.

2.5 Reading a Bitmap

2.5.1 Speed Lines

Choose the menu option *File/Read/Bitmap* from the program opening window. Before you can load a bitmap you will be asked for a title of this map, whether it is a relativized map and if isentropic or polytropic efficiency is shown in the picture.

In the window that opens after loading the bitmap there are two triangles and a square blinking. Click on the square with the left button of your mouse, keep the button pressed and move the square to the origin of the graph showing pressure ratio over corrected flow. When you release the button, a window opens in which you can enter the values for pressure ratio and corrected flow. Click OK to store the data of the origin.

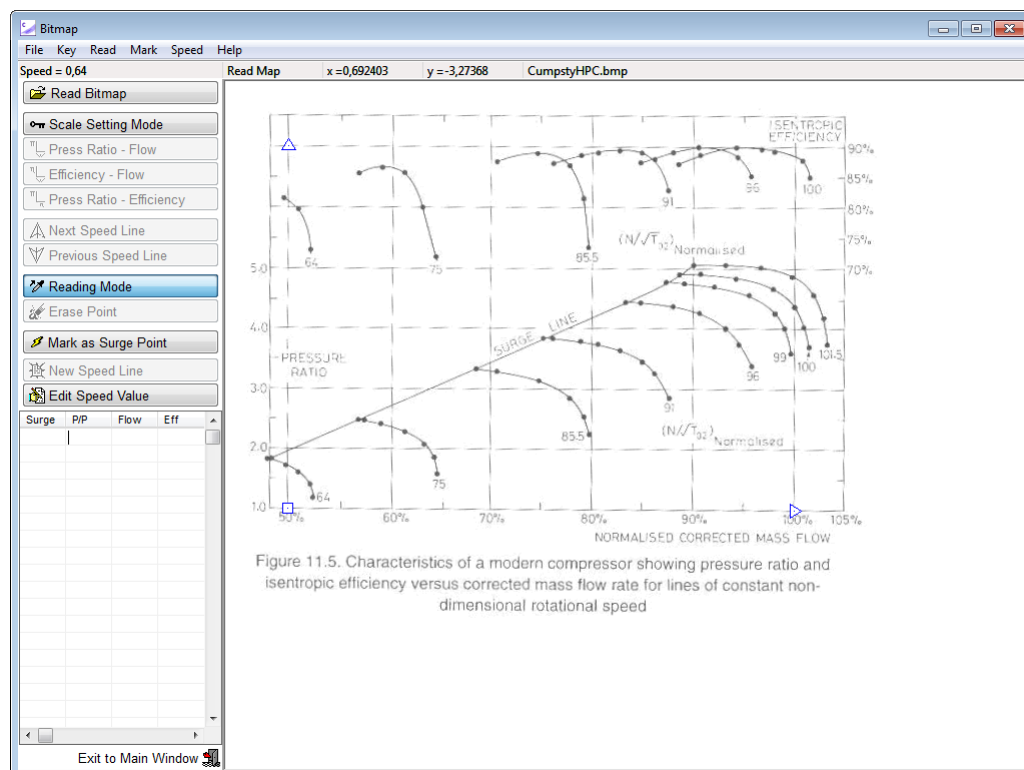
Click on the triangle pointing to the right and move it to a point on the x-axis. After releasing the button, you will be asked for the value of the corrected flow. The pressure ratio value is the same as for the origin.

Last click on the triangle pointing upwards and move it to a point on the y-axis. When you release the button, you will be asked for the value of the pressure ratio. The corrected flow value is the same as for the origin.

Actually it does not matter which of the blinking symbols you move first to the proper location. You can move the symbols in several steps, and use the scrollbars of the window in between, for example, before you click the *OK* button.

As soon as you have set all three symbols, you will be asked for the speed value of the first line. When this is done, you can move around with the crosshair cursor on the bitmap. In the status line the true coordinates are shown as evaluated from the mouse position.

Now move the mouse to a point on the first speed line and click. The coordinates of this point will show up in the table on the left. Add the next point to the table by clicking on another point on the speed line. The sequence of the points on a speed line is of no importance.



When you have placed a point by accident incorrectly, then you can delete this point by clicking on the *Erase Point* button. Note, however, that you can only delete the latest point.

To mark a point as surge point click first in the corresponding line of the table and then on the *Mark as Surge Point* button or on the menu option *Mark*.

When you are finished with the first speed line, then click on *Speed/New Line*. Enter the next speed value and proceed. The sequence of the speed lines is of no importance.

2.5.2 Efficiency

After all speed lines have been read from the bitmap, then the efficiency values can follow. If the efficiency is not on the same bitmap as the speed lines, then select from the menu option *Read* or click the *Read Bitmap* button. Click on the menu option **Key** or the *Scale Setting Mode* button to redefine the system of coordinates.

Efficiency may be given as graph in two formats (or as *contour lines*):

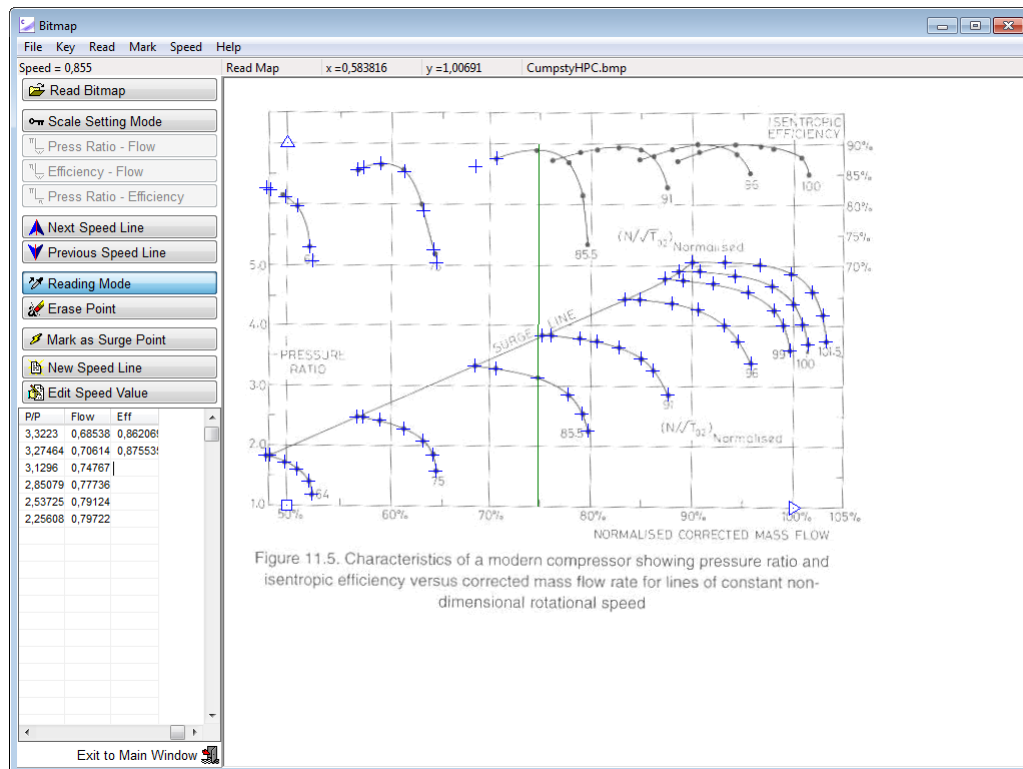
- Efficiency as y-axis and Corrected Flow as x-axis
- Pressure Ratio as y-axis and Efficiency as x-axis

Reading a Bitmap

When the correct bitmap is on your screen, click the *Efficiency-Flow* or the *Press Ratio - Efficiency* button dependant on the content of your figure. The three symbols for the definition of the origin and the maximum values of the x- respectively y-axis will appear and blink. Place these symbols as required and enter the corresponding values.

Note that Smooth C 9 requires efficiency values as relative numbers normally in the range from 0 to 1.0. Do not use percentage.

When the coordinates have been set, then you can click a line in the table on the left side. This will draw a line for the corrected flow respectively the pressure ratio in the efficiency graph. Next move the crosshair cursor to the bitmap and pick the efficiency value by clicking at the right place.



Click on one line after the other in the table and pick the efficiency values from the bitmap. Go to the other speed lines and complete the map reading.

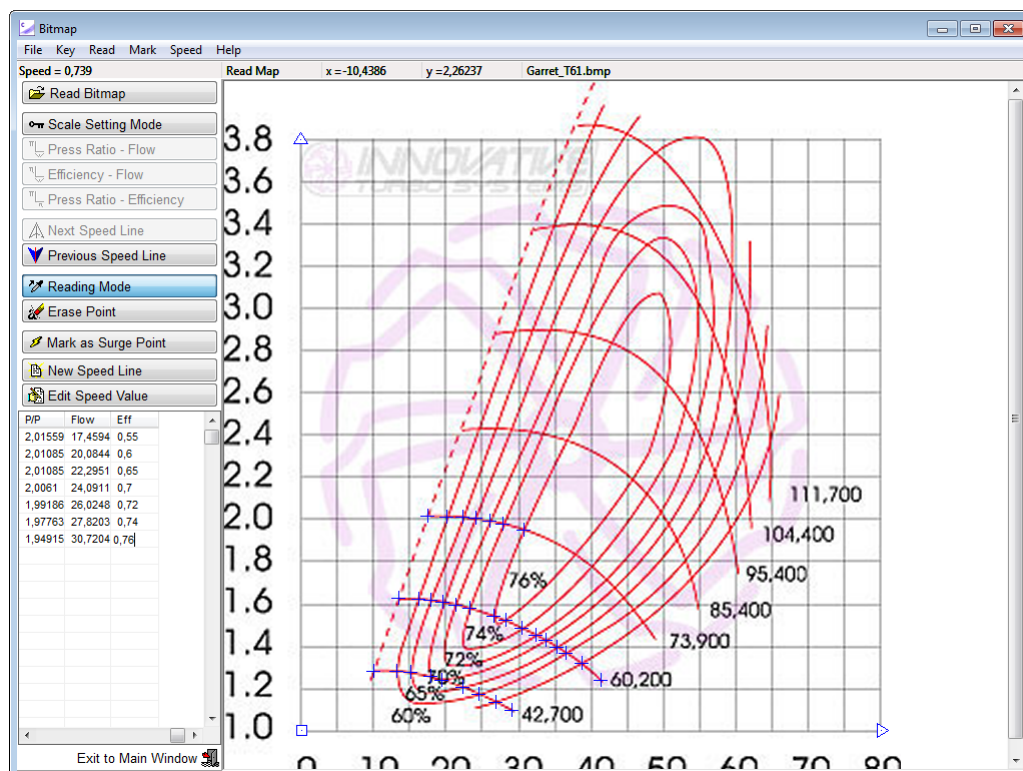
Note that you can redefine the efficiency coordinate system at any time. Thus you can use both types of efficiency graphs as required.

2.5.3 Efficiency from a Map with Contour Lines

In the window that opens after loading the bitmap there are two triangles and a square blinking. Click on the square with the left button of your mouse, keep the button pressed and move the square to the origin of the graph showing pressure ratio over corrected flow. When you release the button, a window opens in which you can enter the values for pressure ratio and flow.

Click on the triangle pointing to the right and move it to a point on the x-axis. After you releasing the button you need to enter the value of the corrected flow. The pressure ratio value is the same as for the origin. Last click on the triangle pointing upwards and move it to a point on the y-axis. When you release the button, you will be asked for the value of the pressure ratio. The flow value is the same as for the origin.

Actually it does not matter which of the blinking symbols you move first to the proper location. You can move the symbols in several steps, and use the scrollbars of the window in between, for example, before you click the *OK* button.



As soon as you have set all three symbols, you will be asked for the speed value of the first line. When this is done, you can move around with the crosshair cursor on the bitmap. In the status line the true coordinates are shown as evaluated from the mouse position. Move the mouse to a point on the first speed line where it crosses an efficiency contour line and click. The coordinates of this point will show up in the table on the left. Then move your mouse to the column with the heading "Eff" and enter the efficiency value into the table. Note that Smooth C requires efficiency values as relative numbers normally in the range from 0 to 1.0. Do not use percentage.

Add the next point to the table by clicking on another point on the speed line. The sequence of the points on a speed line is of no importance. When you have placed a point by accident incorrectly, then you can delete this point by clicking the *Erase Point* button. Note, however, that you can only delete the latest point.

After you are done with the first speed line, then click on Speed|New Line. Enter the next speed value and proceed. The sequence of the speed lines is of no importance.

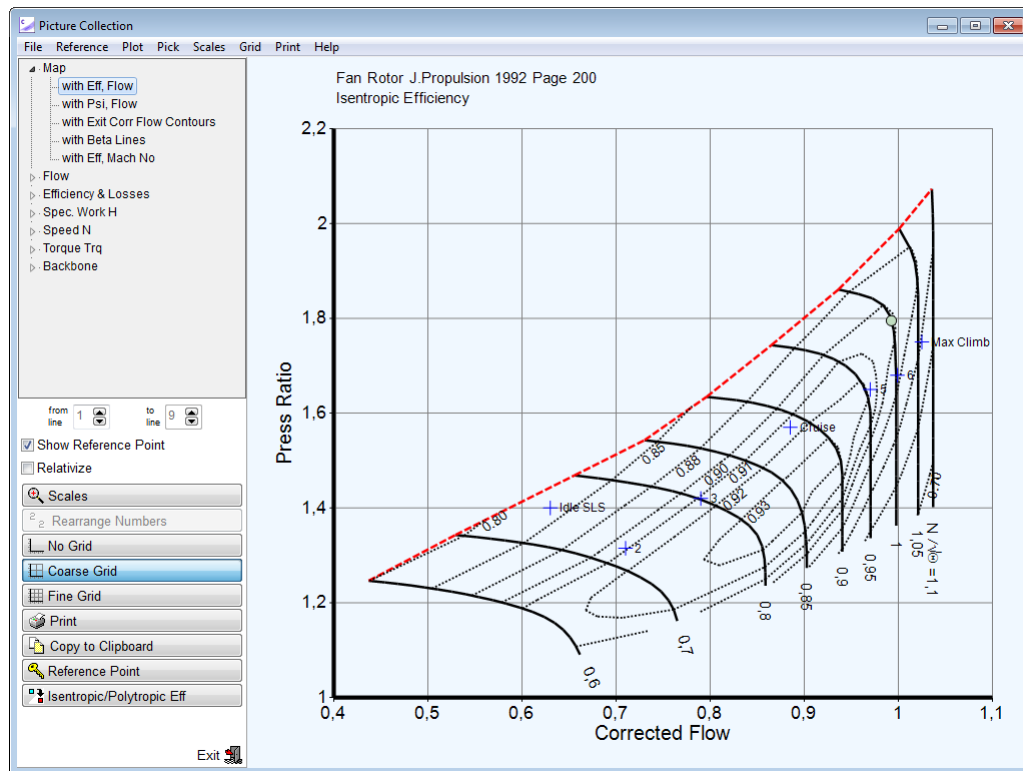
2.6 Cycle Data

You can plot data that were calculated with a cycle program, for example, in many graphs. The cycle data may be entered manually (choose File|New|Cycle Data) or they can be read from a file (choose File|Read|Cycle Data). For the file format please have a look at the [example](#).

In the picture catalog you can switch between graphs with or without the cycle data points. Select Plot|Cycle Data in the menu to toggle between the options.

Cycle Data

While you are working on the speed lines or the efficiency there will be those cycle data points shown as a blue crosses that have a speed value near to the one you are working on.



2.7 File Reading Error

If something in your data input file format is incorrect then an editor will open. You can correct the error, and write back the file to disk. After saving try again to read the file.

If you are unclear about the error message then have a look at the file format description for [measured data](#) respectively [smooth data](#).

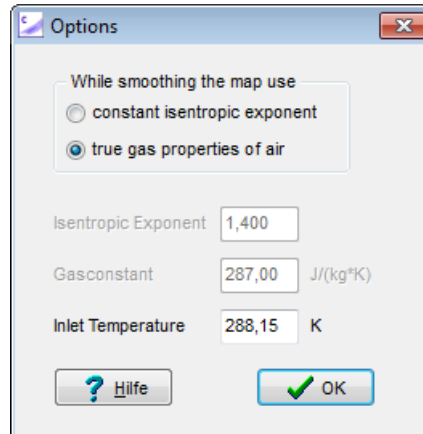
3 Compressor Maps

3.1 Gas Property Options

For calculating specific work or torque from pressure ratio and efficiency the gas properties are required. There are two options for the gas properties:

1. Constant isentropic exponent and gas constant
2. Properties of dry air as a function of temperature

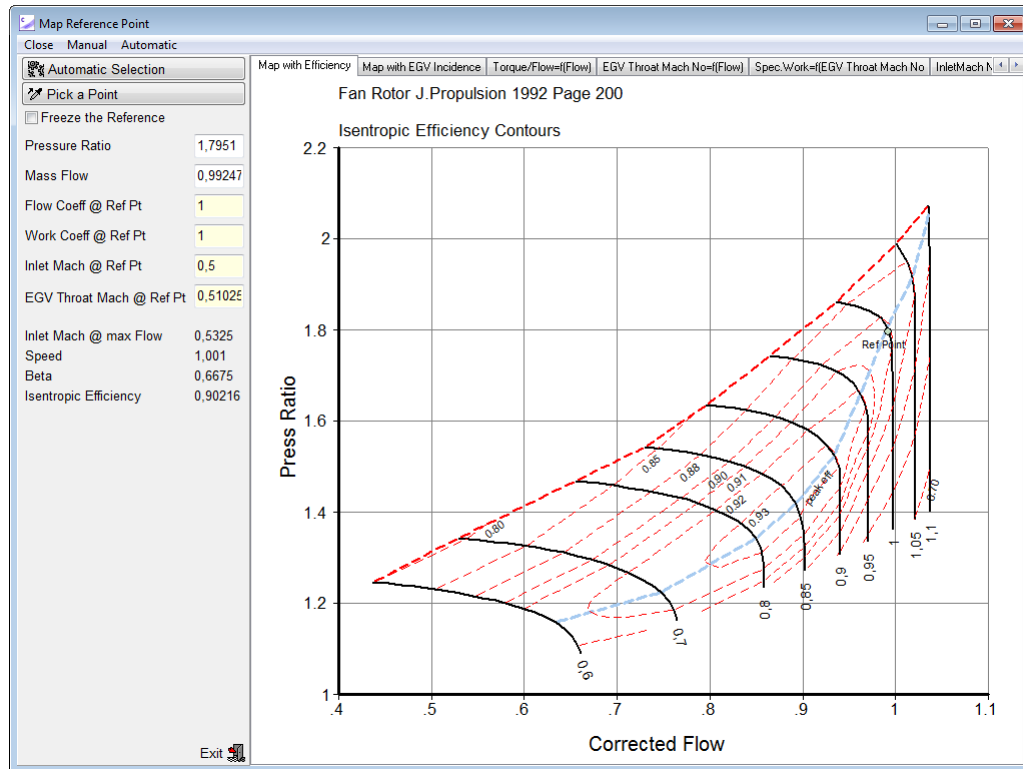
Switching between these options will affect the graphical and the synthesis table output for specific work and for torque.



Older versions of Smooth C have used option 1 with isentropic exponent $\gamma = 1.4$ and gas constant $R = 287 \text{ J/(kg}\cdot\text{K)}$ during the map smoothing process and for the graphical output while option 2 with $T_1 = 288.15\text{K}$ was employed for the table output.

3.2 Map Reference Point

In Smooth C 9 a map reference point must be selected before smoothing the map. For this reference point the Mach numbers at the inlet of the compressor and at the throat of the exit guide vane (EGV) must be given as well as values for the flow and work coefficients. It is desirable to use the true compressor design point as map reference point, however, that is not mandatory. A reasonable estimate for the flow Mach number is sufficient if an exact number is not known; in this case for the work and flow coefficients $ref=1$ and $ref=1$ can be used.



Assigning a inlet Mach number to the corrected flow value of the map reference point allows calculating the inlet Mach number for every other point in the map. Additionally, the compressor inlet flow velocity V_{ax} can be calculated. This velocity, divided by speed, yields a number proportional to the **flow coefficient** . If an absolute number for the flow coefficient at the map reference point is known, then the true flow coefficient can be evaluated for every point in the map. If the true flow coefficient at the reference point is not known and ref is set to 1.0, then one can observe at least how the flow coefficient varies throughout the map.

Similarly, the true **work coefficient** can be found if its value at the map reference point is known. Relative values for are produced if $ref=1$ is used.

The EGV throat Mach number is of interest because towards higher mass flow the EGV throat area finally can limit the mass flow through the compressor. For more information on this topic consider the [correlations hidden in compressor maps](#).

While smooth data are not available, the reference point can be selected from the available measured data points. After having a first guess of the smooth lines the map reference point can be selected arbitrarily.

The reference point coordinates can be selected automatically employing the following rules:

- If one of the speed lines is labeled 1 in the original map, then this speed is selected.
- Otherwise, the speed with the highest value of Mass Flow/Speed on the peak efficiency line will be chosen. The background of this criterion is the observation, that for many compressors, from which we know the design point, the maximum value of Mass Flow/Speed is reached at or near

to the design speed. This is especially true for compressors with variable geometry, when the inlet guide vanes are opened with increasing speed, but remain fixed (at a mechanical stop, for example) above the design speed.

- However, the maximum value for the corrected flow on the reference speed line must not be lower than 95% of the highest value for the corrected flow in the map. This criterion must be applied to the maps from fan rotors, for example. Otherwise one gets non-typical low reference pressure ratios.
- Speed lines for which the peak efficiency value is lower than 90% of the highest efficiency value in the map are not taken into account when the maximum corrected flow is determined. This rule prevents, that in maps that contain speed lines for very high speed values the reference point gets a non-typical low efficiency.
- On the selected speed line the reference point is placed at the point with the highest efficiency.

Alternatively to the automatic selection of the map reference point you can pick a point from the map with your mouse or enter numbers for Pressure Ratio and Mass Flow to fix a point. If you are working on a map to be used with GasTurb for creating a model that fits to given data, then you should use the map scaling point of GasTurb as the reference point.

The Mach number at the reference point can not be selected arbitrarily: the Mach number at the highest corrected flow value found in the map does depend on the Mach number at the reference point and can not exceed 1. In reality, it will definitely be below 1 and not exceed 0.75...0.8.

If the [Freeze Reference](#) box is checked then the smooth lines cannot be unintentionally modified in close vicinity to the reference point.

Further plots are available to define values as precise as possible at the reference point.

3.2.1 Why Freeze the Reference Point ?

Freezing the reference point is helpful if this point is employed in GasTurb as the map scaling point which is the location of the GasTurb cycle design point in the map. If the reference point is frozen during the map smoothing process, then the map scaling factors employed in GasTurb will remain unaffected by the modifications made in other parts of the map. This makes it easier adapting a map to given off-design data.

Map scaling in GasTurb is done in such a way, that Pressure Ratio, Mass Flow and Efficiency are factored with the aim that at the map scaling point the respective values of the cycle design point are equal to those read from the map. Moreover, all speed values are factored to such an extent that the speed value for the map scaling point is equal to 1.0.

For a more detailed explanation of the problem let us assume, for example, that the cycle efficiency is 0.85 and the efficiency in the unscaled map is at the reference point equal to 0.83. While in GasTurb the map is scaled, all efficiency values in the map are factored up by $f = 0.85/0.83 = 1.024$.

Let us further assume that from the scaled map at the off design point "A" an efficiency value of 0.9 is read, but the given data to be reproduced with GasTurb say that efficiency there is only 0.89.

In this case the unscaled map must be modified in such a way, that after scaling the efficiency at point "A" is 0.89. In the unscaled map the efficiency at this point is $0.9/1.024 = 0.879$. For getting there in the scaled map $= 0.89$ the efficiency in the unscaled map must be reduced to $0.89/1.024 = 0.869$ which is easily done with Smooth C.

However, that yields the desired effect only if the data of the reference point remain unchanged, i.e. the reference point is frozen. If the reference point is not frozen and the efficiency at the reference point would be changed to 0.825, then the efficiency scaling factor (which is applied in GasTurb to all values in the map) would become $f = 0.85/0.825 = 1.03$. The efficiency at point "A" would be

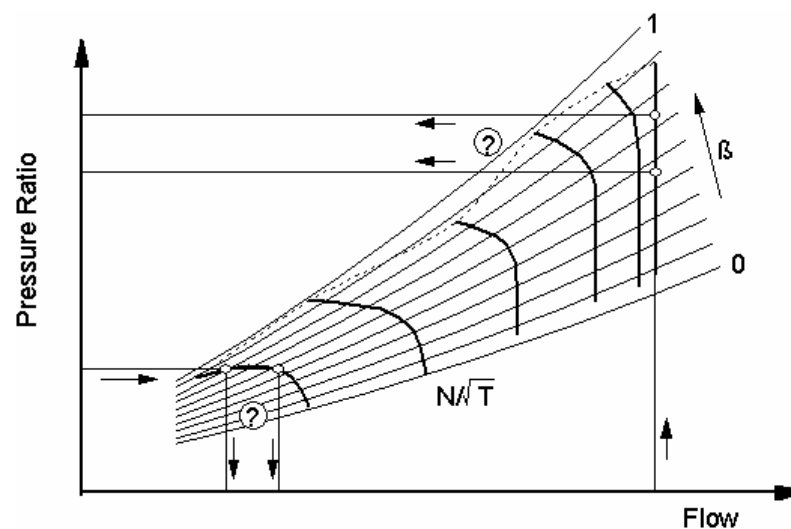
affected as every point and the scaled map would show at point "A" the value $0.869 \cdot 1.03 = 0.895$ instead of the desired value of 0.89.

The described unpleasant side effect of modified reference point data can be avoided by "freezing" it.

3.3 Defining the Beta Line Grid

After reading the measured data the so-called β -line grid must be defined which is a net of equally spaced auxiliary coordinates. β -lines are used in performance computer programs to locate the operating point in the map. This is convenient and avoids a fundamental problem:

1. One can not read the pressure ratio from a compressor map when speed and mass flow are given because at high speeds the speed lines are vertical.
2. One can not read the map with speed and pressure ratio given either because at low speeds the speed lines are often horizontal.



The β -lines are crossing the speed lines at unique cross-points and avoid thus ambiguity in map reading. From principle the beta-lines can be of any shape; In this program the β -lines are parabolas. Note that straight lines are also parabolas - only special ones! Straight β -lines are called m-lines.

In the program main window click the *Define Beta Line Grid* button to open the beta grid editor. The grid can be defined [graphically](#) or by the input of the [parabola coefficients](#).

If the map is intended to be used in ground starting simulations or for windmilling and relight simulations the use of 30 β -lines is recommended. The parabola for β -line=0 should pass through the point where mass flow is zero and the pressure ratio is 0.9. The parabola for β -line=1 in maps to be used for simulating engine with GasTurb must pass through the point with pressure ratio 1 and mass flow zero. If the map will be used for windmilling and relight simulations, where pressure ratios less than one can occur in the fan, the β -line=0 should be a line with of constant pressure ratio of 0.9. The b_0 coefficient of β -line=0 in both cases has to be zero or bigger than zero.

3.3.1 Define Beta Line Grid Graphically

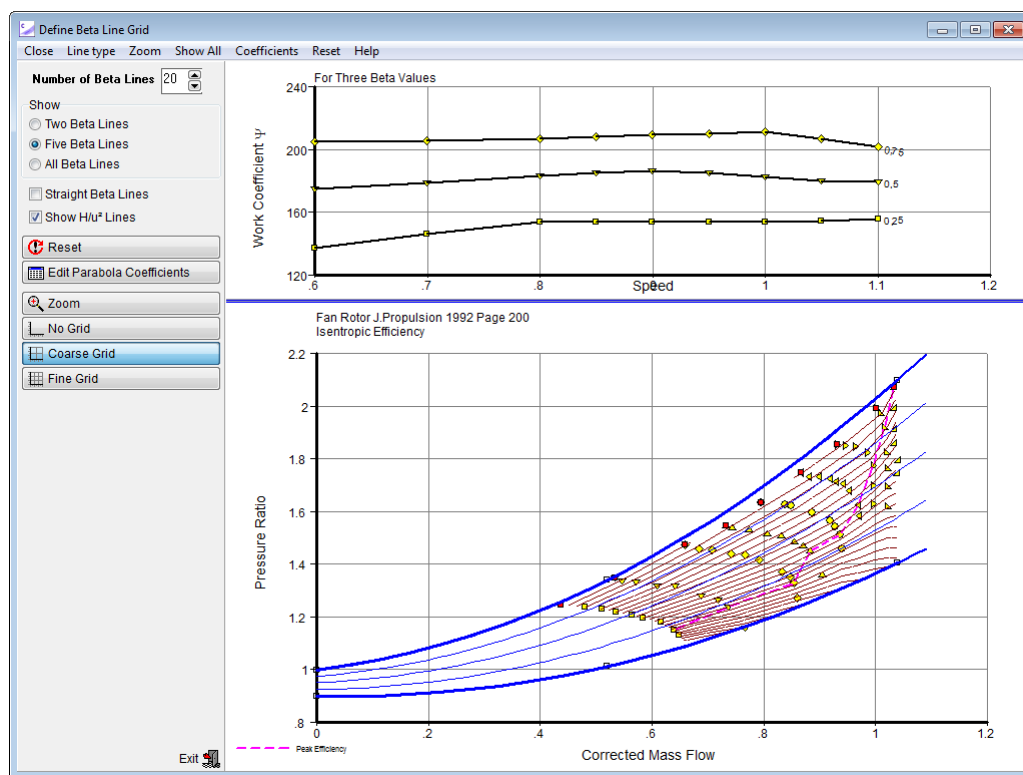
You get a proposal for the auxiliary coordinates on your screen. The lower line is for $\beta=0$, the upper line is for $\beta=1$.

If you are not happy with the shape of the β -lines as proposed by the program you can modify the shape easily. On both the upper and the lower β -line you will see three square. If you have selected straight lines then there are only two squares.

From school you will remember, that a parabola is fully defined by three points. If you change the position of a point then the shape of the parabola passing through that point will be modified.

You can change the position of each of the six points with the mouse. Click one of the squares and move it while holding the mouse button down. After you have released the button, the beta line will be redrawn

The final map will contain only data on and between the lowest ($\beta=0$) and the highest ($\beta=1$) line. Be careful and enclose all your measured data points with the two parabolas. Make sure that the parabola for $\beta=0$ is below the other parabola. If you can avoid the parabolas crossing each other on the screen then it's fine. Otherwise make sure that the cross-point is as far away as possible from your data points.



In the map on the screen there is also the peak efficiency line shown. The β -lines should follow the trend of this line as good as possible. This will minimize the [interpolation errors](#) when reading data from the smoothed map.

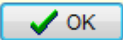
Furthermore you should fix the line for $\beta=1$ in such a way that it passes through the point with pressure ratio one and mass flow zero. Then the graphs of [mass flow over speed](#) and [specific work over speed²](#) can be assessed more easily: are they in line with the laws of physics?

3.3.2 Input of Parabola Coefficients

You can define and edit the beta line parabola coefficients directly after clicking the *Edit Parabola Coefficients* button.

Parabola Coefficients $y = a \cdot x^2 + b \cdot x + c$

| | a | b | c |
|----------|---------|-----------|---------|
| beta = 0 | 0,52277 | -0,058791 | 0,9007 |
| beta = 1 | 0,77558 | 0,25221 | 0,99895 |

 OK

The input of the parabola coefficients is convenient if you want to use the same beta line grid for two or more maps. Employing the same beta line grid makes it easy to evaluate the differences between two maps.

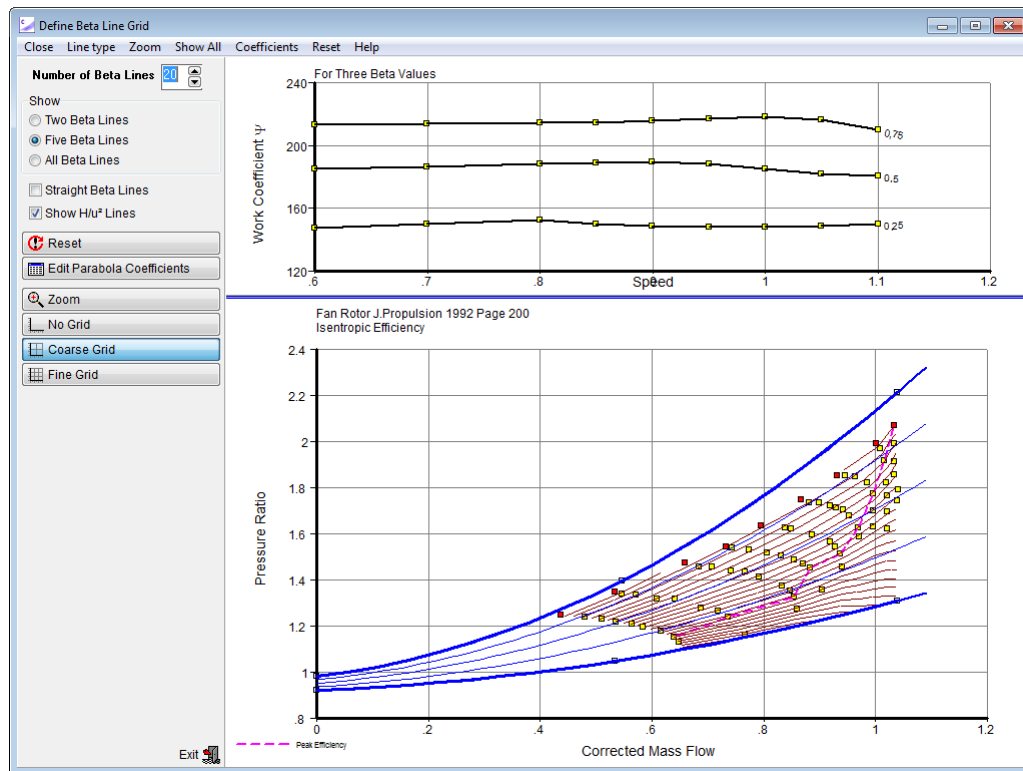
3.3.3 Beta lines for Constant Work Coefficient

β -lines are required for unambiguously reading a map. In general they have no meaning in terms of physics. However, one can define the β -lines in such a way that they represent fairly accurately the work coefficient.

If you begin with a new compressor map you do not know the shape of the lines with constant work coefficient. Therefore you cannot immediately create the β -lines as lines of constant work coefficient. Select the preliminary β -line grid in such a way that it covers all the measured data with some margin. Close the β -line definition window and create a smooth map. When you are done with smoothing the speed and efficiency lines then the position of constant work coefficient lines is known.

Go back to the β -line definition window which now shows additional information. The lower picture shows the measured data with the two parabolas for $\beta=0$ and $\beta=1$. Additionally there are lines for constant work coefficient which origin from the previously smoothing process. Above the map there is a picture which shows the work coefficient for the three β -values 0.25, 0.5 and 0.75.

Now re-define the β -line grid in such a way that all three lines in the upper picture are - as far as possible - straight horizontal lines. With such a β -line grid definition the β -lines are approximately lines of constant work coefficient.



Close the Beta Line Definition Window and check the smooth map again. If you have done a good job in the first pass then only minor corrections will be required.

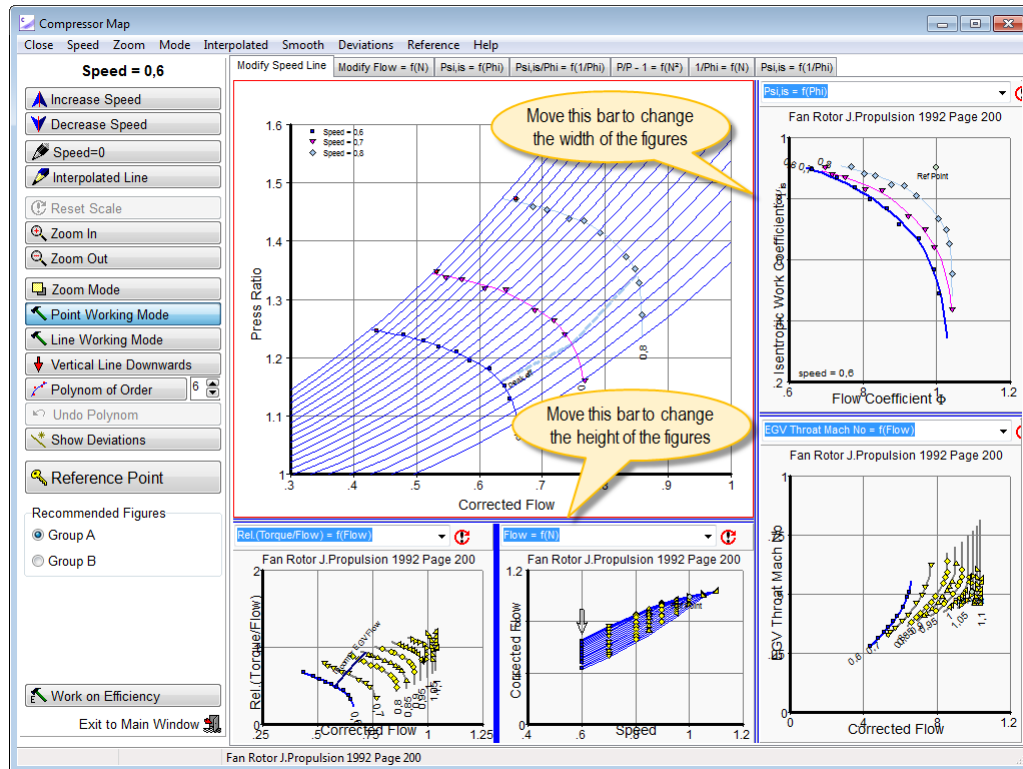
3.4 Smoothing the Speed Lines

When measured data are available, and the beta line grid is defined, then you can smooth the speed lines. The term speed line is in this program used for the smooth lines passing through the measured data in the graph pressure ratio over mass flow.

Click the *Work on Mass Flow* button or select the menu option *Smooth/Speed* to open the speed line smoothing window. This window shows in the top left figure the data points of the first three speed lines and all β -lines. The lowest speed line is illuminated which indicates, that this speed line is now the active one. The other two speed lines are shown for cross reference and comparisons.

The other three figures show alternative views on the speed line data and also several versions of the complete map.

Clicking the tabs above the pictures will show the most important correlations in full size. Note that you can resize the individual pictures on the Modify Speed Line page with your mouse: click one of the small blue bars between them, hold the mouse button down and move it as required. After releasing the button all figures will be refreshed.



There are three operating modes: the **zoom mode**, the **point working mode** and the **line working mode**. You can switch between these modes by clicking the corresponding button.

In the first round the plots $\text{Flow} = f(\text{Speed})$ and $P/P - 1 = f(\text{Speed}^2)$ are the most important ones. You should get these graphs right before proceeding with efficiency. If you are especially interested in the low speed part of the map then also the other correlations are of interest.

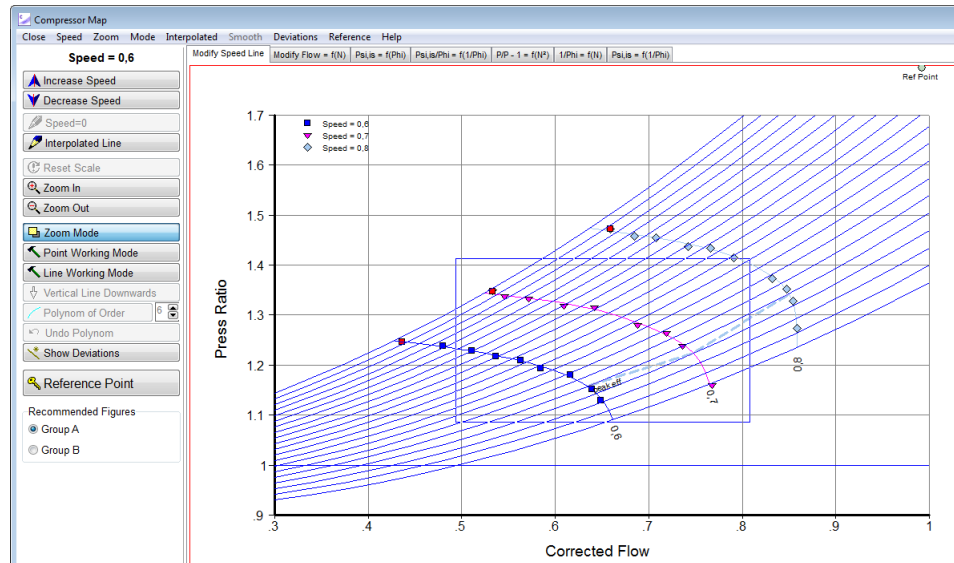
3.4.1 Zoom Mode

Change the content of the top left picture in Zoom Mode. Zooming out will give you a better overview while zooming in will give you more details and an improved accuracy of your numbers.

You can draw a rubber rectangle (press the left button and hold it down while selecting an area) to enlarge a part of the compressor map while the cursor has the zoom shape. Another way to change the view is by selecting from the menu option *Zoom/In* or *Zoom/Out*.

While you modify the speed line in the upper left graphic you can simultaneously look at the implications which your modification has on other views. Select between different options from the drop down boxes above each graph. If you move your mouse away from the top left graph then the cursor is configured as zooming tool: you can draw a rubber rectangle to enlarge a part of the graphic. To go back to the default view, click the *Reset Scale* button above the respective graph.

If you have difficulties restoring the normal size then switch to a different speed line and back to the speed line you want to deal with. To do this select the menu option *Speed/Incr* or *Speed/Decr* to increase respectively decrease the speed value. Alternatively you can click the *Increase Speed* or *Decrease Speed* button.



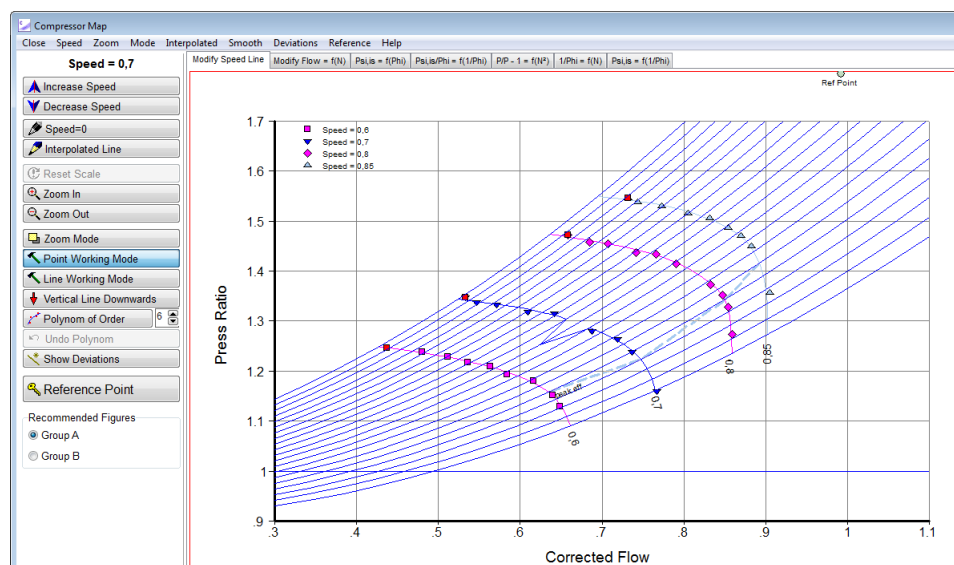
Click the right mouse button while pointing to the top left picture for a pop up menu which allows you to switch to **working mode**.

3.4.2 Working Mode

There are different options for modifying the smooth speed lines. First of all there is the option to modify single points on the speed line. Additionally there is the option to modify the whole line at once and the third option is to make a vertical line downwards at high mass flow.

Point Working Mode:

Click the Point Working Mode button first. Move your mouse pointer to the location where you want to modify, press the left mouse button and hold it down while modifying the speed line at a beta value. Note that the selected point of the smooth line moves along the β -line to which it belongs. Release the button when the line is at the right place. In the example figure below the active line has been distorted intentionally for demonstration purposes.



While you are modifying a speed line, the new numbers for mass flow and pressure ratio are derived from the pixel coordinates on the screen. If the graph in which you are working is small, then the number of pixels that make the x-axis, for example, is also small. The conversion process from the

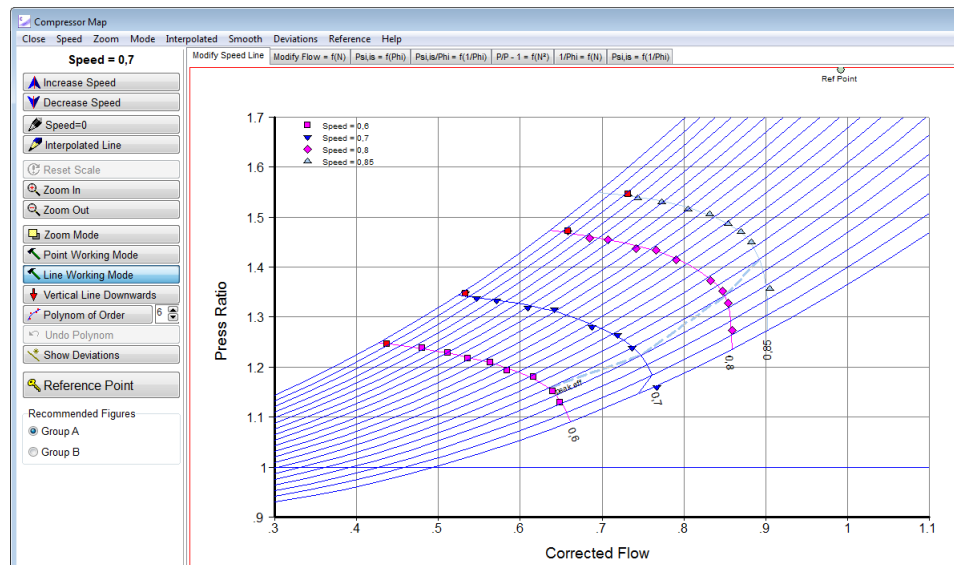
Smoothing the Speed Lines

pixel coordinates to the true mass flow numbers is not very accurate in such a case. Therefore it is recommended to make the graph in which you are working as big as practical.

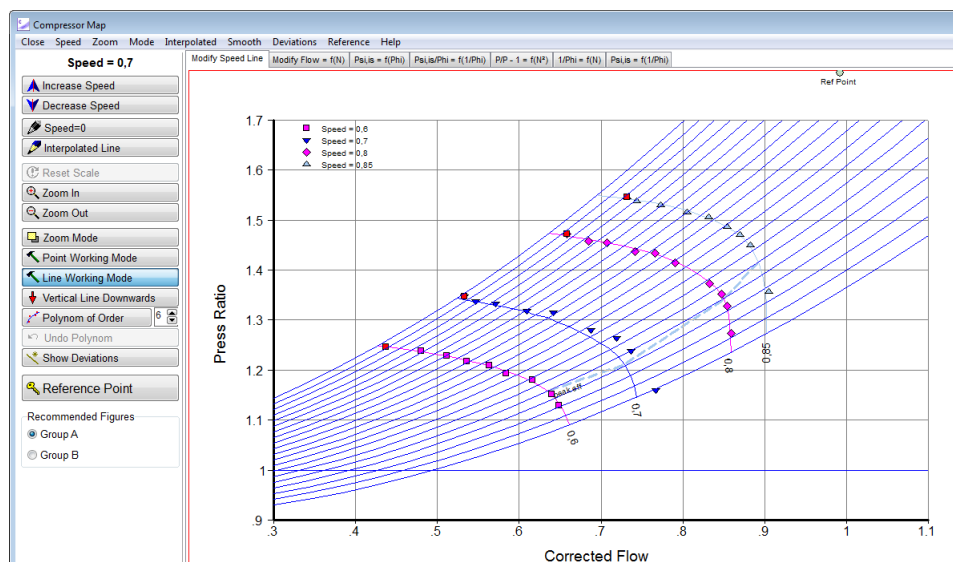
Line Working Mode:

The speed line is modified in Point Working Mode only at one point. In Line Working Mode the whole speed line is affected.

Click the Line Working Mode button first. Move your mouse pointer to the β -line where you want to modify, press the left mouse button and hold it down while moving your mouse. The selected point of the smooth line moves along the β -line to which it belongs:



Release the button when the point is at the right place. The complete speed line is modified as shown in the next figure.



In this example the line was re-shaped in such a way that the $\beta=1$ point remains at its place and the $\beta=0$ point moves to the place selected with your mouse. If you modify the line at an intermediate β -value then both the $\beta=0$ and the $\beta=1$ points remain fixed.

While modifying a speed line you can employ as guide a line which is linearly interpolated between the two neighboring speed lines. Click the *Interpolated Line* button to make it visible. Since

compressor physics is a non-linear science, the true speed line will not be identical to this guide line. Nevertheless the interpolated line can be of help for shaping the true line, especially if only a few measured data points are available.

You need not to make the shape of a line very smooth manually. You can use for the final smoothing the menu option *Smooth|Poly Line* or click the button *Polynom of Order* and a best fit polynomial will be found based on the breakpoints of the speed line. Note that the measured data are not taken into account for finding this polynomial. Try with different order polynomials (the order is selected with the spin box to the right of the *Polynom of Order* button) if the shape of the smoothed speed line does not satisfy you. Use the *Undo Polynom* button or the menu option *Smooth|Undo Line* to go back if necessary.

Vertical Line Downwards:

The speed line can be partially or completely vertical at high corrected speeds. Describing such a shape with a high order polynomial is difficult. However, there is another tool which makes drawing a vertical line easy: click the *Vertical Line Downwards* button or the menu option *Smooth|Const Flow*. The cursor will change its shape to a double headed arrow. Now move it (near to the speed line) to the pressure ratio below which the corrected flow is constant, press the left button and move the mouse sideways while holding the button down. Release the button when you have found the best place of the vertical part of the speed line. Note that the *Undo Polynom* button works only for polynomials, not for the vertical line drawing tool.

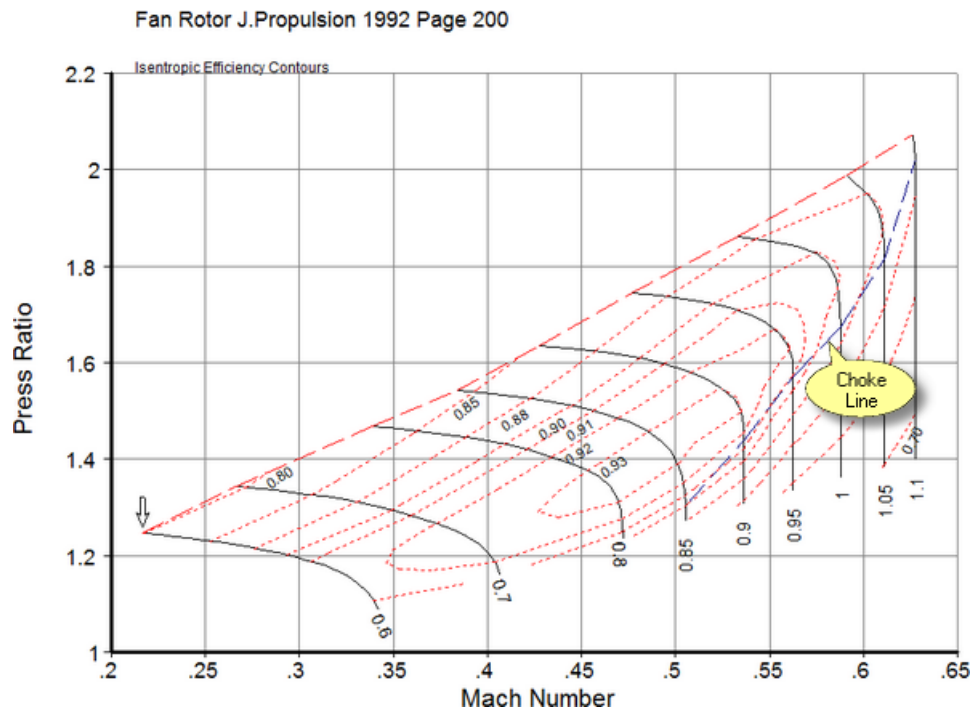
A smooth speed line represents measured data that have some scatter. Most of the measured data will not be part of the smooth line, there will be deviations. Click the *Show Deviations* button or select the menu option *Deviations|Show* to get a table with numbers for the deviations of the measured data from the smooth line. Deviations lower than the threshold - which you can select depending on the scatter in your data - will not be listed.

3.4.3 Some Advice

A plot of the complete map is offered in the drop down lists in two versions, with corrected mass flow and with Mach number as x-axis. The shape of the map with Mach number as x-axis depends on the Mach number at the [map reference point](#).

The maximum mass flow for a given speed is limited by choking of the flow. In the choked region of the map the speed lines are vertical. While for the upper speed range test points with choked flow are often measured, this is mostly not so for low speeds. In the figures that show the complete map the Choke Line connects pressure ratio values below which the speed lines are vertical.

Choking of the flow can also be visible in the plot [specific work over pressure ratio](#). If the compressor exit is choked, then from a certain pressure ratio downwards there will be no change of the internal flow field if the throttle is further opened. That implies, that there will be no change in specific work. Therefore at very low pressure ratios the line *specific work over pressure ratio* can become horizontal.



Note that there is an option for [freezing](#) the data of the map reference point. With this you can make sure that the data of the map reference point remain unchanged during smoothing.

3.5 Smoothing Efficiency Lines

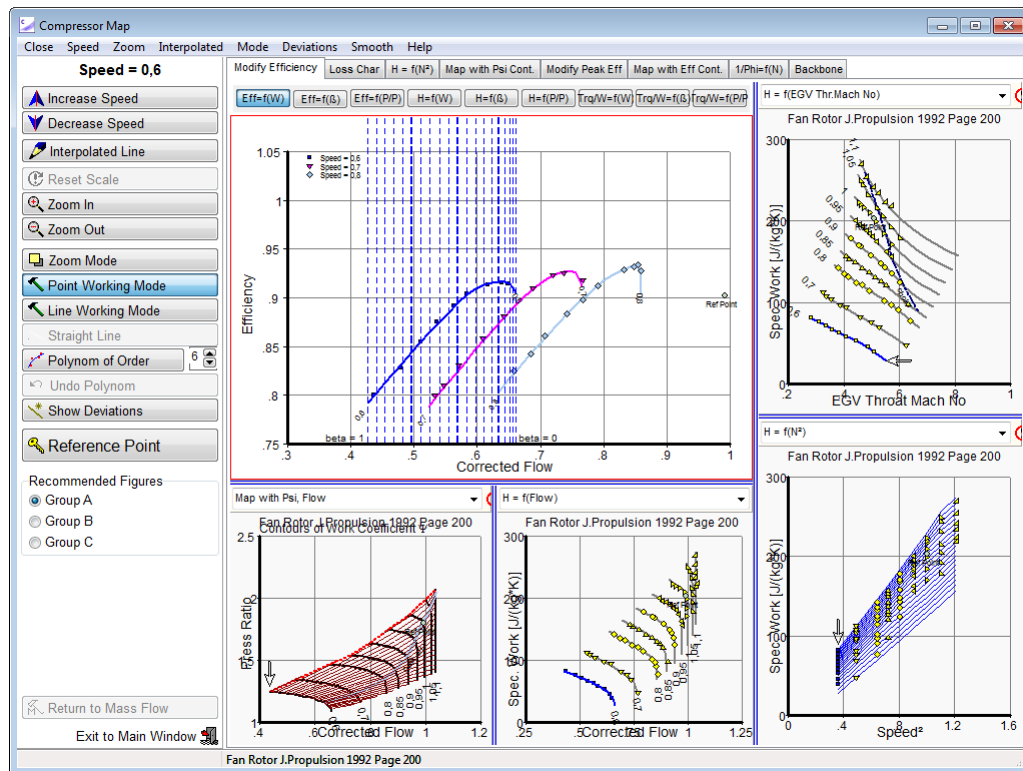
It is strongly recommended to begin with smoothing efficiency lines only after the speed lines are smooth, otherwise you are unable to make the efficiency and the specific work lines smooth at the same time.

Click the *Work on Efficiency* button or select the menu option *Smooth|Efficiency* in the program main window.

Now you get a graph on your screen that shows in the top left figure the data points of the first three efficiency lines and all β -lines. One of the lines is illuminated which means that this line is now the active one.

There are nine versions of the top left picture in which the β -lines are always vertical. This is because the position of any β -line is fixed by the intersection of the β -line with the speed line in the graph [Pressure Ratio = f\(Mass Flow\)](#).

It depends on the shape of the speed lines which of the nine graphs is most convenient for smoothing the efficiency line. You can switch between the various graphs at any time. For getting a line roughly right use specific work or torque. For the fine trim smoothing efficiency is more convenient. As in the speed line smoothing window there are three operating modes: the Zoom Mode and the Point Working Mode and the Line Working Mode. You can switch between them by clicking the corresponding button.



If there are cycle data available then those cycle data points that have a speed value near to the one you are working on will be shown as a blue crosses. Note that the cycle data values which are shown in the top left picture are not the true values. The values shown are from points that are shifted along a β -line to the point where the β -line crosses the speed line in the pressure ratio - mass flow picture.

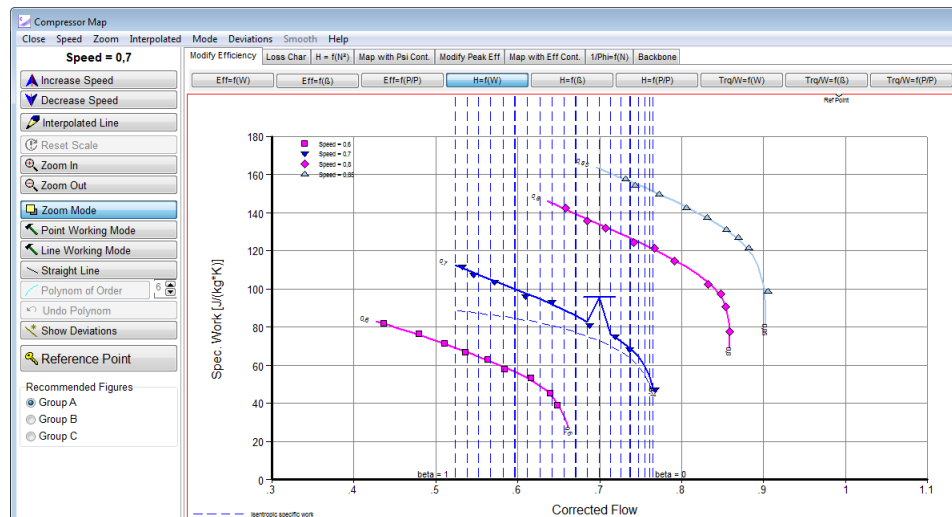
In the subsonic flow region the correlations of specific work = $f(\text{mass flow})$ and torque/mass flow = $f(\text{mass flow})$ theoretically are straight lines. The straight part of the torque/mass flow = $f(\text{mass flow})$ correlation of the lowest speed line later is used for extending the map.

3.5.1 Straight Line Function

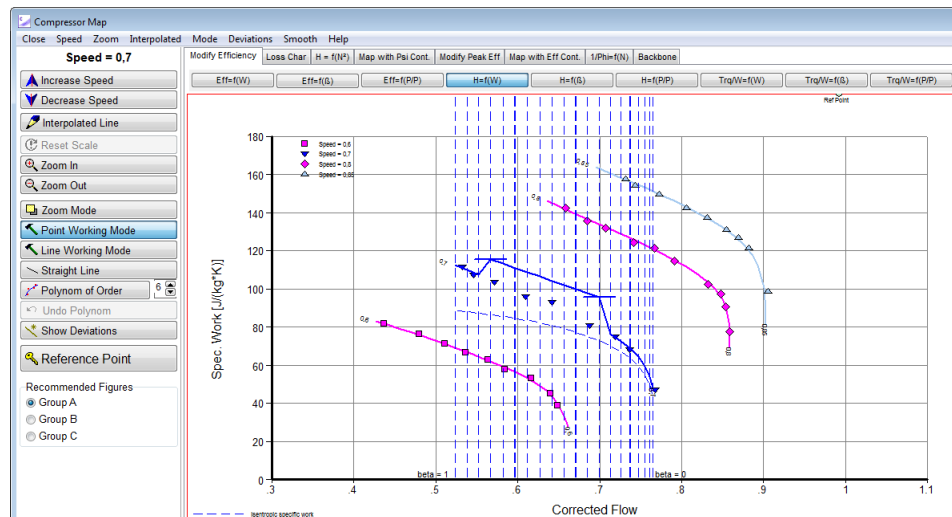
With the Straight Line Function a distinct section of a speed line can be made straight. This function is available at plots of specific work and torque where straight sections might appear.

Click at the *Straight Line* button first. Now like in the Point or Line Working Mode move your mouse pointer to the β -line where you want to start the straight section. Press the left mouse button and hold it down while moving the mouse. The selected point of the smooth line moves along the β -line to which it belongs. Release the button when the point is at the right place. You can also release the button without having moved the mouse, if the starting point is already in the desired position. The starting point always is marked by a short horizontal line:

Smoothing Efficiency Lines



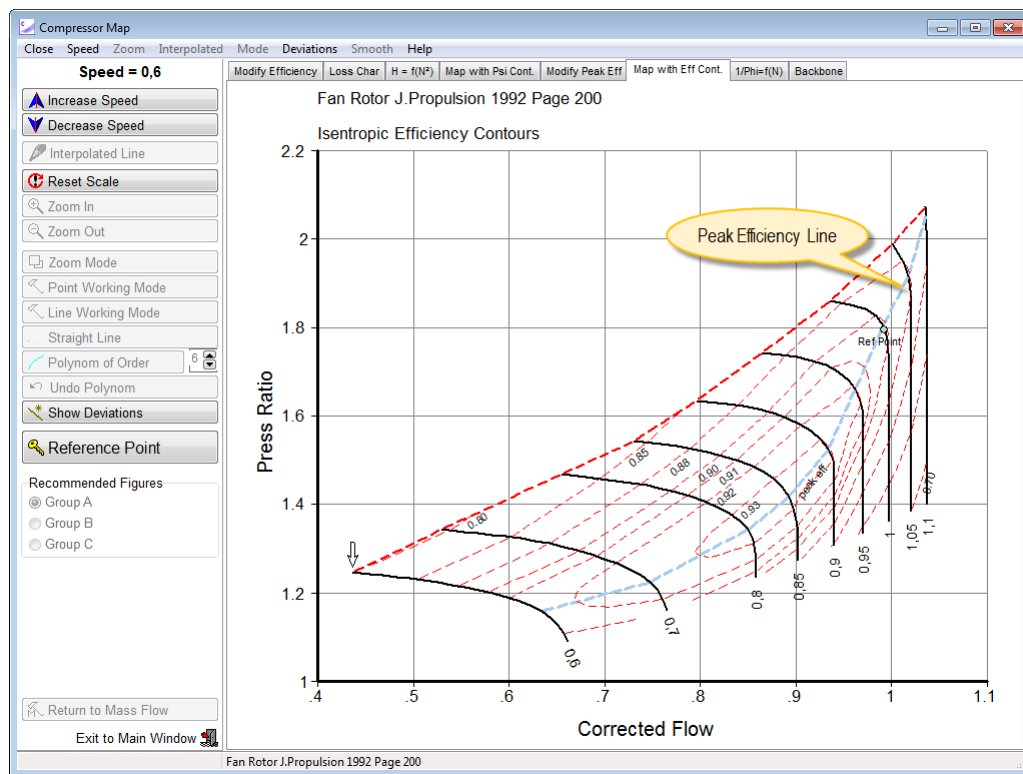
Then move the mouse pointer to the where you want to end the straight section. Press the left mouse button and hold it down while moving the mouse. The section to be modified moves according to the mouse movement. This way the change in slope of the modified line section can be observed.



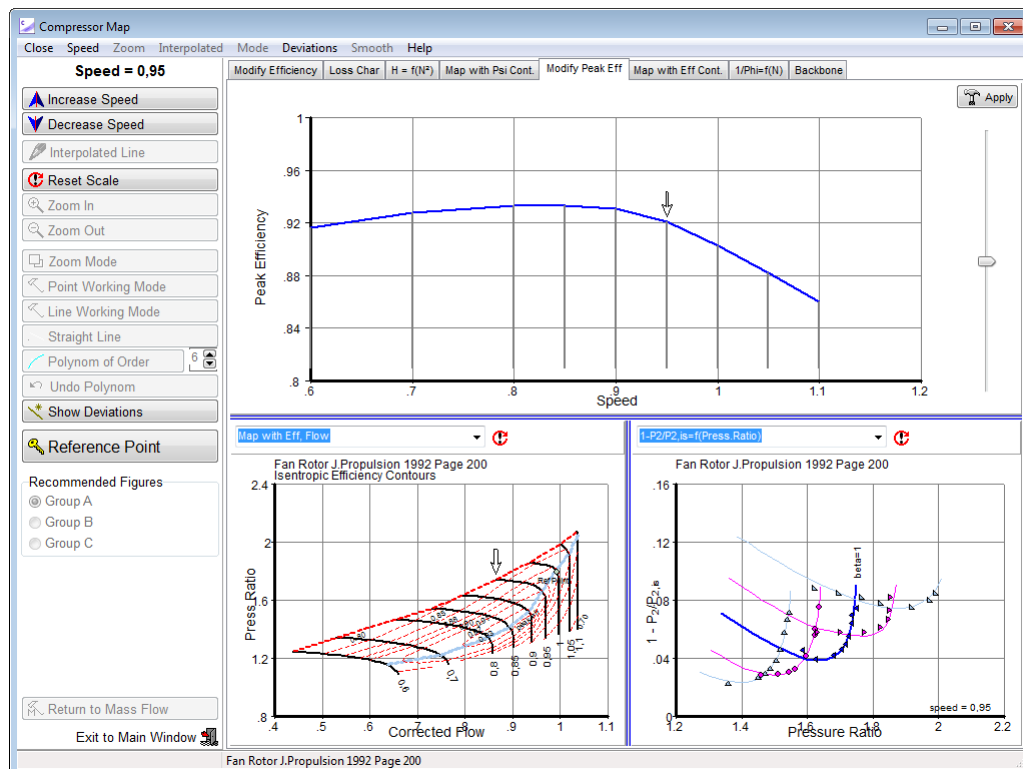
Release the mouse in the position required. Afterwards a second short horizontal line indicates the end position of the straight line section. The start and end positions are obvious in the given example, but in practice they are often hard to recognize without any mark. The marks disappear by conducting the next action or changing the view.

3.5.2 Peak Efficiency

The Peak Efficiency Line is a line which connects the points with the highest efficiency on each speed line. This line is also called the Backbone of the map.



In the Peak Efficiency plot the efficiency along the backbone of the map is shown over speed. The peak efficiency line in the map passes through the point {mass flow = 0; pressure ratio = 1}.



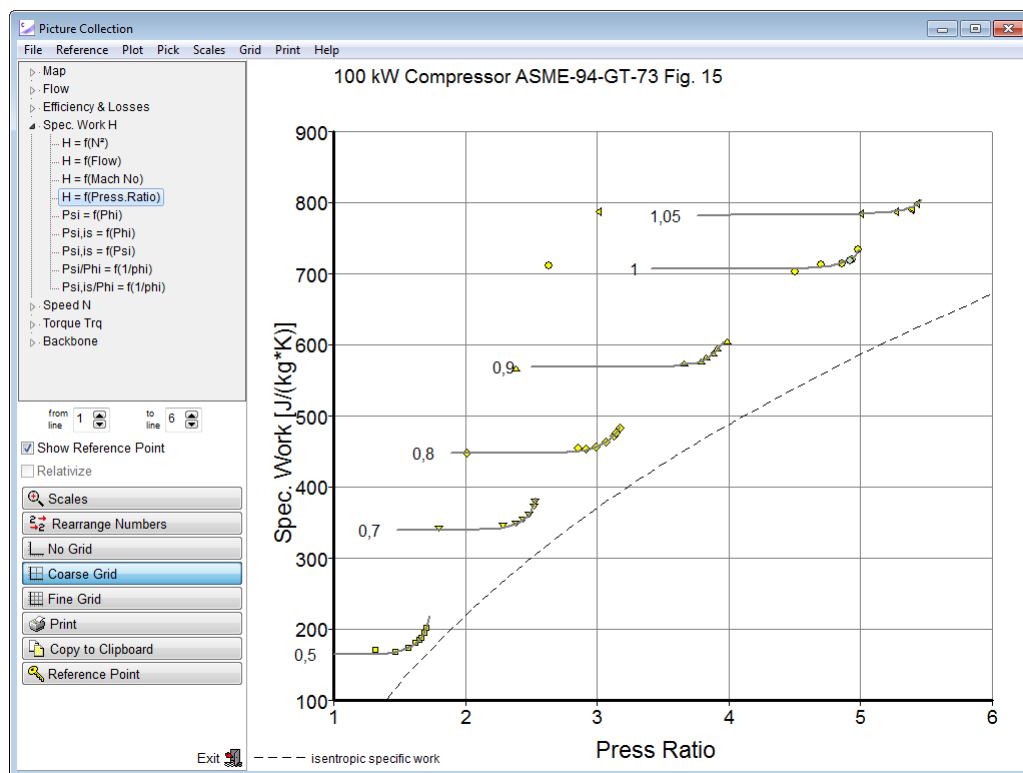
3.5.3 Finetuning Efficiency

For many problems, and especially interpolation and extrapolation of speed lines, the specific work is a very helpful parameter to use. However, because of the limited resolution on the screen, the required accuracy in efficiency cannot be achieved in all cases by using the specific work alone. After smoothing specific work it is a good idea to check the different efficiency plots and the [loss characteristics](#). Fine-tuning efficiency will not change specific work significantly, but is worthwhile doing it.

You need not to make the shape of the efficiency respectively specific work line very smooth manually. You can use for the final smoothing the menu option *Smooth|Poly Line* and a best fit polynomial will be found based on the breakpoints of the smooth line. Note that the measured data are not taken into account for finding this polynomial. Try with different order polynomials (the order is selected with the spin box to the right of the *Polynom of Order* button) if the shape of the smoothed line does not satisfy you. Use the *Undo Polynom* button or the menu option *Smooth|Undo Line* to go back if necessary.

3.5.4 Work - Pressure Ratio

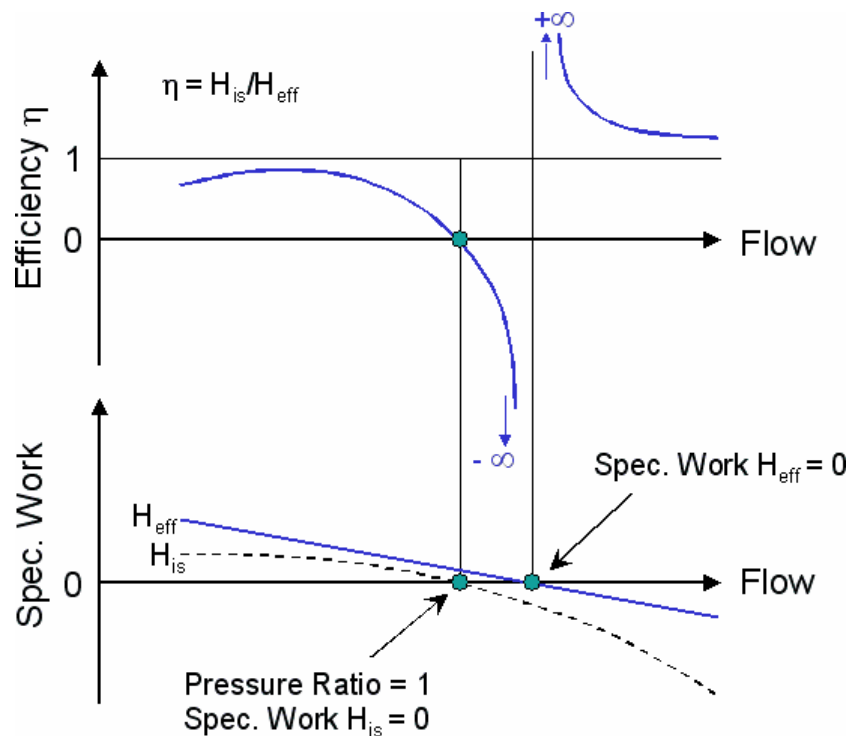
This is the map from a centrifugal compressor. At any given speed there is a pressure ratio below which the specific work is constant. This phenomenon can be explained by choking of the exit guide vanes. Imagine a test in which at constant speed - beginning at a high pressure ratio - the back pressure is decreased. This results in an increase of the Mach number at the inlet to the exit guide vanes. As soon as the exit guide vane is choked, further decreasing of the back pressure will no longer affect the flow field in the rotor, only the pressure losses in the exit guide vane. Since work is done only in the rotor, the work input required for driving the compressor will remain constant.



3.5.5 Pressure Ratio 1

Drawing efficiency along a speed line becomes difficult when the speed line (i.e. the line pressure ratio over flow) passes through pressure ratio = 1. There the efficiency changes from +infinity to -infinity. In this part of the map it is better to work with the lines for specific work and use the plot specific work over mass flow for defining efficiency implicitly. Make sure, that actual specific work is always higher than the isentropic specific work. Otherwise, you imply a drop in entropy which would be against the second law of thermodynamics.

For checking the map in this region look at the [torque](#) characteristics.



For extrapolating a map to lower speeds it might be helpful to consider some thoughts about the [speed line zero](#).

3.5.6 Some Advice

Do not begin with smoothing efficiency lines before you have smoothed the speed lines in the graph Pressure Ratio over Mass Flow. This is because the pressure ratio fixes the isentropic specific work. If the isentropic work lines are not smooth, then you can never achieve smooth lines for actual specific work and efficiency at the same time.

Drawing efficiency along a speed line becomes difficult when the speed line *pressure ratio over flow* passes through [pressure ratio = 1](#), see previous section.

For extrapolation of the map to very low speeds you should think of the shape of the [speed line for speed = 0](#). This specific speed line must pass through the point {mass flow = 0; pressure ratio = 1} and will in all other parts have a pressure ratio lower than one. Specific work is exactly = 0 along all of the line. The mass flow range is from negative choking mass flow to positive choking mass flow. The speed line in terms of *pressure ratio over flow* will not be symmetrical around the point {mass flow = 0; pressure ratio = 1}, but there will be a horizontal tangential at this point.

3.6 Extending the Map

3.6.1 Map Calculation

Calculating compressor maps requires knowledge about many geometrical details which are rarely available outside the OEM companies. Even if the geometry is known the calculation results are often of dubious quality and will not be consistent with measured rig data. Thus map calculation is not a practical procedure for supplementing existing maps.

3.6.2 Correlations Hidden in Compressor Maps

Work and Flow Coefficients

One of the basic correlations that may be used for extending the map is the correlation between the [work coefficient](#) and [flow coefficient](#). It is described in detail in the section [work and flow coefficients theory](#). The main insight is, that for a single stage axial compressor it can be concluded from a velocity diagram analysis (see for example Reference 5) that in the ideal case the relationship between the [work coefficient](#) and [flow coefficient](#) is linear:

$$\Psi = 1 - k \cdot \Phi$$

The magnitude of the constant k depends on the blade and vane exit flow angles that are determined by the respective profile geometry. For further details concerning this correlation please refer to the section [work and flow coefficients theory](#) mentioned above.

The verified part of the $\Psi - \Phi$ correlation is relatively small and restricted to the map region with pressure ratios above 1. However, the range of flow coefficient values needed for extrapolated speed lines increases enormously with decreasing speed. Thus the correlation is useless for estimating the speed line zero.

Extrapolation is based on two speed lines in the map. The base speed lines can contain compressibility effects which differ between the two speeds. If the compressibility effects are not considered, in the high flow coefficient region peculiar results will appear. In order to gain correct extrapolation results the $\Psi - \Phi$ correlation can be improved by adding empirical correction terms.

Torque

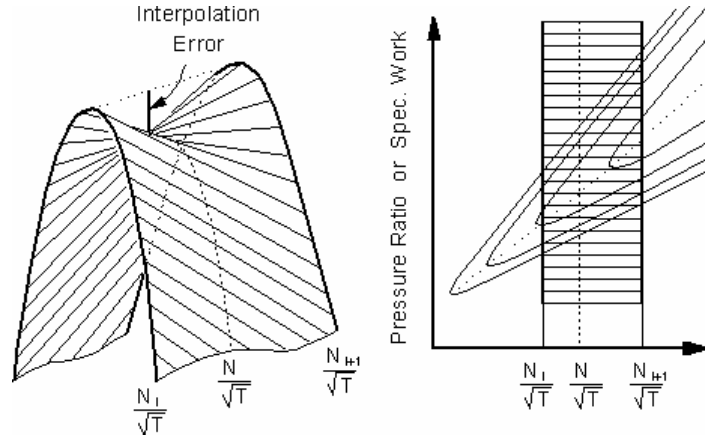
The speed line zero cannot be described with a $\Psi - \Phi$ correlation. Describing the performance for speed zero in terms of torque and total pressure loss is the way out of this dilemma. However, extrapolation based on the $\text{torque} = f(\text{flow})$ correlations along the two lowest speed lines will not yield reasonable values for speed line zero.

EGV Throat Mach Number

The EGV throat Mach number is of interest because the geometric EGV throat area is the smallest passage within the compressor annulus. Towards higher mass flow the EGV throat area finally can limit the mass flow through the compressor. The EGV throat area can be calculated from an assumed EGV throat Mach number at a reference point, which usually is the design point. At the throat of the EGV the total pressure is slightly higher than the compressor delivery pressure and the total temperature equals the compressor delivery temperature. From a known EGV throat area, the EGV Throat Mach number can be calculated for any point in the map.

3.6.3 Interpolation and Extrapolation

If the speed lines are not narrowly spaced and if the β -lines are not approximately parallel to the peak efficiency line then a linear interpolation of the final map in the program that employs the smooth map can result in a significant interpolation error:



Therefore it is recommended to interpolate additional speed lines with the help of Smooth C 9.

Select the menu option *Interpolate* from the program opening screen and enter the desired speed values. However, you should first smooth all the speed and efficiency lines before you do that. The automatically generated speed line proposal will have a poor quality if the existing lines from which it is derived are not smooth.

3.6.4 Speed Line Zero

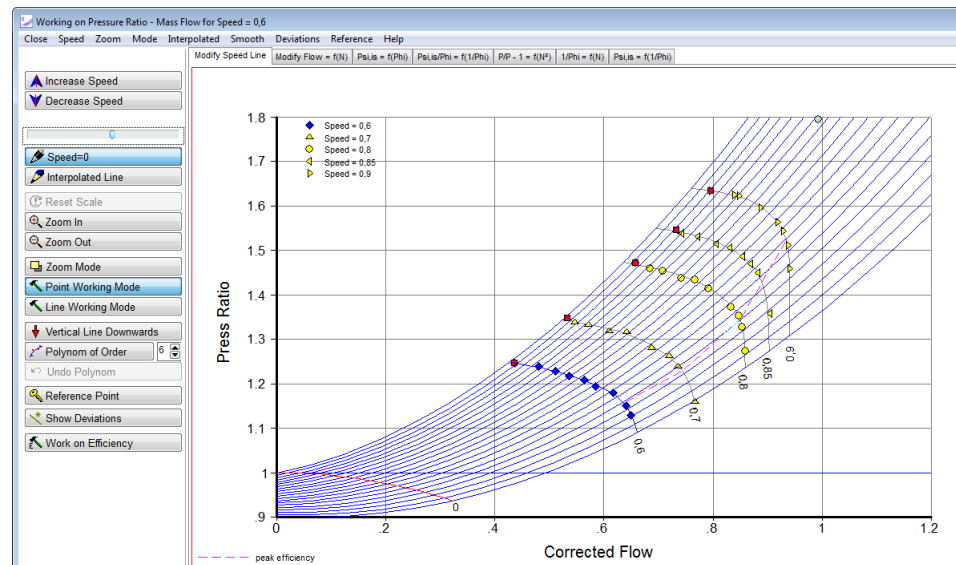
The speed line zero has several interesting features which make this line very interesting for the extrapolation of a compressor map towards very low speeds. The line passes through the point {Pressure Ratio = 1, Mass Flow = 0} and has a slope of zero at that point. Blowing through the compressor will yield a corrected mass flow > 0 and a pressure ratio < 1 . The specific work remains zero for any value of mass flow and pressure ratio, but there will be some force (torque) required to prevent the rotor from turning if the mass flow is not zero.

For moderate corrected flow, if the Mach number is everywhere in the compressor lower than say 0.5, the pressure loss through the compressor will be proportional to dynamic head. Since density ρ and the gas constant R are invariable it holds

$$\frac{P_2}{P_1} = 1 - k_p' \cdot \left(\frac{W \cdot \sqrt{T_1}}{P_1} \right)^2$$

Extending the Map

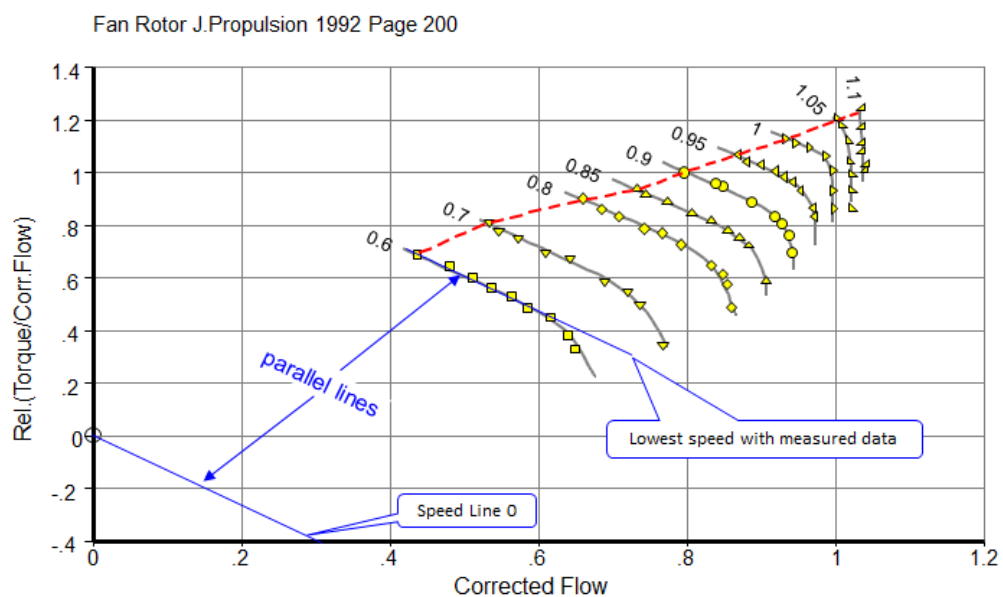
Thus for moderate corrected flow the speed line zero is a parabola passing through the point {Pressure Ratio = 1, Mass Flow = 0}.



Click the *Speed=0* button to get a parabola as speed line zero proposal. Reshape it employing the slider above the button to make it consistent with your map. Note that the actual speed line zero will deviate from the parabola at high flow values respectively Mach numbers. Using the button and the slider enables the output of the Speed Line Zero in a [GasTurb Map](#).

Between the line for the lowest speed for which you have data and the speed line zero proposal you can interpolate additional speed lines. Note that you can not create a line for exactly speed=0 in Smooth C 9 because efficiency and other quantities like work and flow coefficients are unsuitable if $N=0$.

In the torque/flow over flow diagram the speed line zero is a straight line intersecting the origin. In direction of decreasing mass flow the lower speed lines become straight. The slope of the lowest known speed line can be used as an indication of the slope of the speed line zero in the torque/flow over flow diagram.



Note that the considerations above are only strictly valid as long as the Mach number remains moderate everywhere within the compressor. If the flow is increased more and more by, for example,

decreasing the compressor exit pressure with constant P_1 , then the Mach numbers will increase until finally somewhere - most probably at the inlet of the EGV of the compressor, the flow becomes sonic. Further decreasing the exit pressure will no longer increase the mass flow, the speed line plotted as the *pressure ratio - mass flow* will become vertical.

3.6.5 Extending the map towards low speeds

For extending a map to lower speeds the special properties of the [speed line zero](#) are helpful. Interpolation is inevitably more reliable than extrapolation. For that reason for extending the map the speed line zero is used to convert the extrapolation task to an interpolation task.

3.6.6 Implementation in Smooth C 9

In order to extend a map with Smooth C 9 it is required to follow a sequence of several steps. The steps must be executed in the given sequence. Otherwise the process of extending a map might become cumbersome. The necessary steps are described in the following.

Preparing the Baseline Map

First of all, the baseline map should be prepared according to the intended purpose. This means that, depending whether a ground starting or a windmilling simulation has to be conducted, the beta line grid is defined as recommended in the section [defining the beta line grid](#).

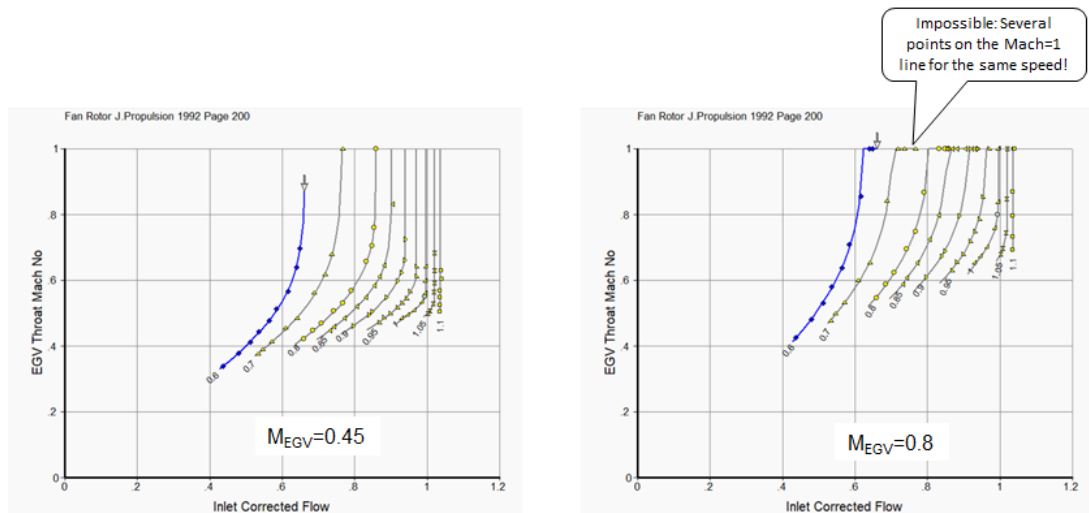
Create a Smooth Map

After the beta lines are defined, it is necessary for the map to be smoothed. This should be performed in the following sequence of steps:

1. Start with working on the graph [Pressure Ratio = f\(Mass Flow\)](#). Do **not** use the option „Vertical Line Downwards“ yet. This option can be used later in the process. Check whether the *is*-correlation is correct. When pressure ratio over mass flow is smooth, on each speed line, go to „Work on Efficiency“.
2. Eliminate any big kinks in the $H=f(\beta)$ plot. Remember that β has no meaning in terms of physics.
3. Now do the raw tuning in the plots $H=f(W)$ and $H=f(P/P)$.
4. Afterwards the fine tuning in the plots $=f(W)$ and $=f(P/P)$ should be done.
5. Switch to the plot $Trq/W=f(W)$. Make the low mass flow section of the line for the lowest speed straight. This can be done easily by using the new [Straight Line Function](#).
6. After having made the straight section go back to Pressure Ratio = f(Mass Flow). Now you can use the option „Vertical Line Downwards“ if appropriate. This function yields as a by-product horizontal lines in the diagram $H=f(P/P)$.
7. Go to „Work on Efficiency“ again. Now fine trim $H=f(P/P)$ respectively $Trq=f(P/P)$. Make the $H=f(N^2)$ correlation smooth and check the H/N^2 contour lines. It might also be helpful to go through the picture catalog after smoothing a map.

Adapt Reference Point

Now the Mach number at the throat of the EGV at the [map reference point](#) should be adapted, in a way that the Mach number at the throat of the EGV is sensible in every operating point. Assuming an unrealistically high Mach number at the map reference point leads to clearly impossible Mach numbers in the map. This can be checked in the EGV Throat Mach No plot which is selectable in the mass flow definition window.

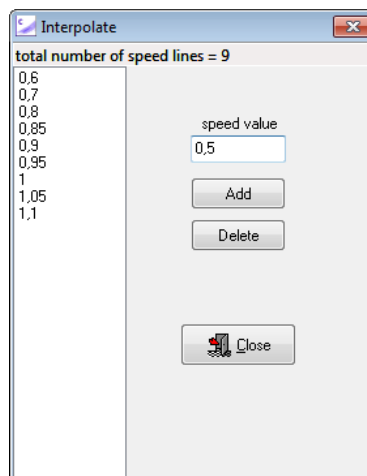


Adapt the Speed Line Zero

As described in the section [Speed Line Zero](#), the shape of the line can be adapted by using the slider at the on the graph [Pressure Ratio = f\(Mass Flow\)](#). First click the *Speed=0* button. This way a parabola as speed line zero is proposed. Remember that the actual speed line zero deviates from the parabola at high flow values respectively Mach numbers. The parabola can be reshaped by using the slider above the button. This is needed to be done in order to make the Speed Line Zero consistent with your map. Since the following interpolation is based on the lowest given speed line and the Speed Line Zero, both of them have to be reasonable. The compressibility correction of the interpolated line will be carried out later.

Add a Speed Line

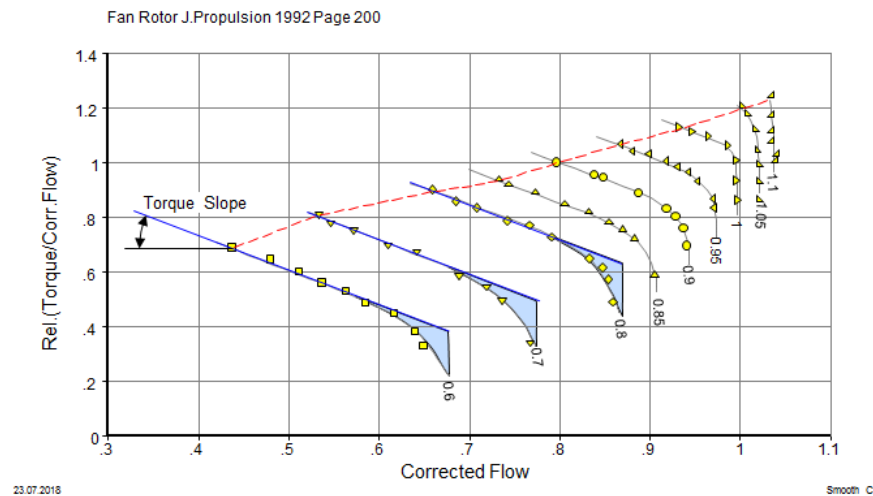
If the Mach Numbers are realistic you can click the button *Add Interpolated Line* in the main window. For extending a map towards low speeds it is recommended to take small steps, not exceeding 10% of the design speed, starting from lowest speed line existing. Add only one speed line at a time and execute the following steps on it, since the extension is based on lowest speed line. Also adding more than five speed lines at once might result in program instabilities.



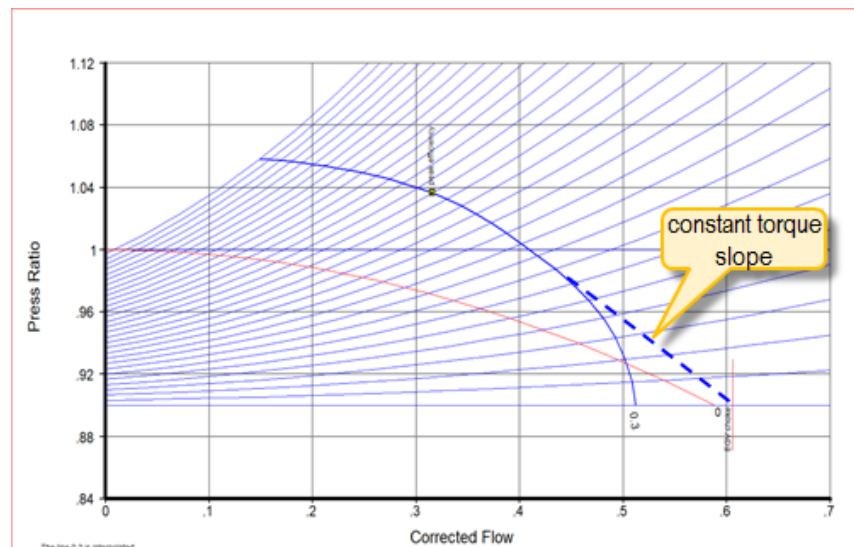
On the top left in the working on pressure ratio window a slider is provided. Use the slider to adapt the shape of the lowest interpolated speed line. This only affects the lowest interpolated speed line. The slope of the torque will remain constant and parallel to the next existing speed line while moving the slider. Check whether the plots [isentropic work coefficient](#) is over [work coefficient](#) and [Efficiency over flow coefficient](#) look reasonable before moving on to the compressibility correction.

Compressibility Correction

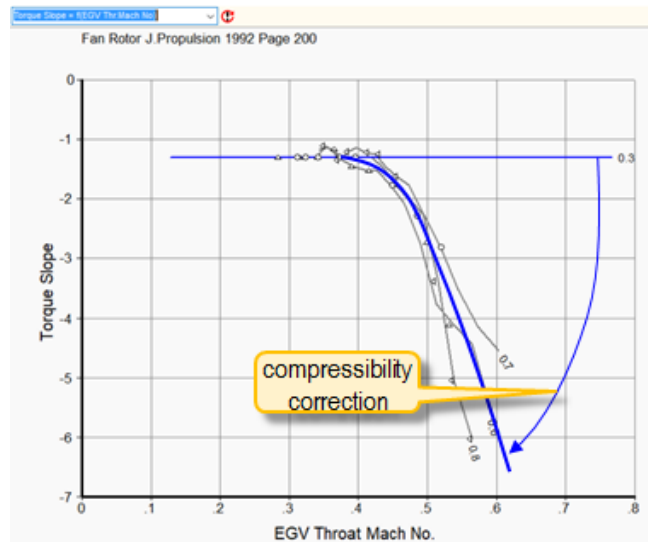
The torque/flow correlation is a straight line only in the left sections of the speed lines. The right sections of the speed lines are increasingly steeper.



The use of the slider on the graph $\text{Pressure Ratio} = f(\text{Mass Flow})$ creates an interpolated speed line with a constant torque slope. Now you can adapt the high mass flow region of the interpolated speed line if necessary. In the following picture the curve of the original interpolated line is shown with a dashed line and the speed line with compressibility correction can be seen in comparison.



The result can be checked by the plot $\text{Torque Slope} = f(\text{EGV Throat Mach No.})$. There the curve of the interpolated speed line should look similar to the existing ones, which is shown in the next image.



Check Efficiency

The last step is to check the efficiency of the interpolated speed line. Switch to „Work on Efficiency“ and check the speed line. If the speed line is smooth, make a check of the peak efficiency plot and adapt it when necessary. Thereby the required steps for adding a speed line are completed.

3.7 Adapting a Map to Cycle Data

You can use Smooth C 9 for more than drawing smooth lines through measured or calculated compressor data. It is also feasible to adapt an estimated compressor map to the data you might have from a cycle calculation program or from the output of a computer deck as delivered to customers by an OEM. Thus you can re-engineer the map which was used within the cycle code.

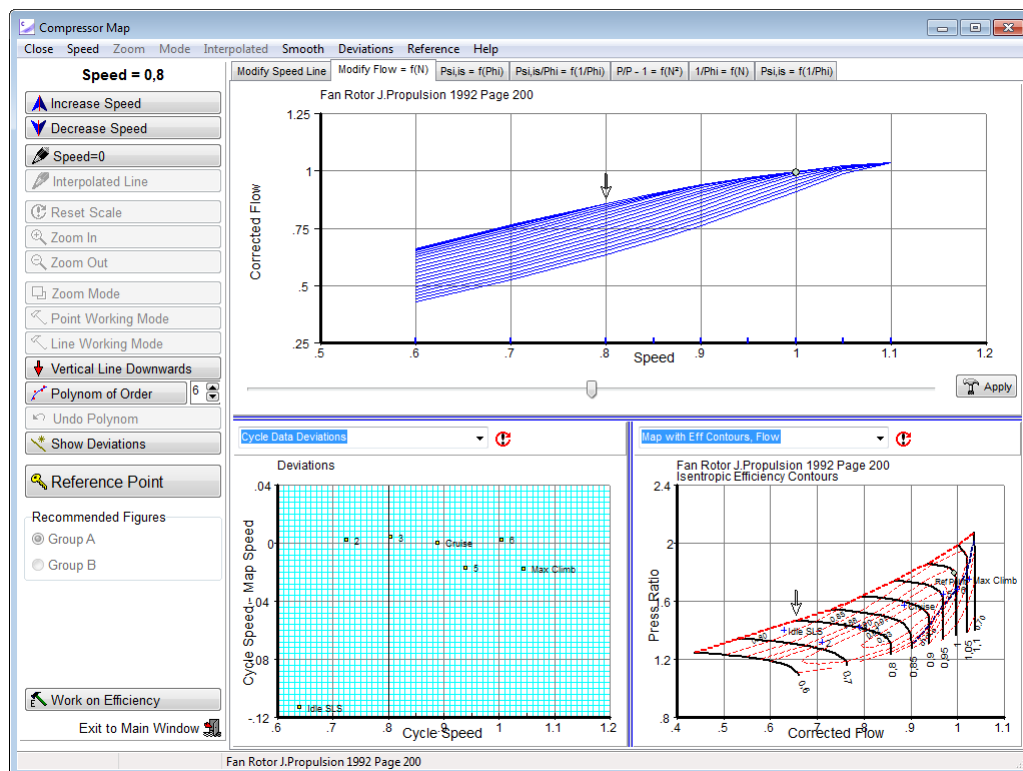
Usually the compressor operating points from a full engine simulation do not cover all regions of the map - especially not the region near to the surge line. However, it is most important and often sufficient to get only the given compressor operating points right.

Note that in Smooth C 9 you can modify the speed lines without any side effect on the efficiency. This is a new program behavior: In early versions of the program, specific work was held constant and efficiency did change while a speed line was being modified.

3.7.1 Mass Flow

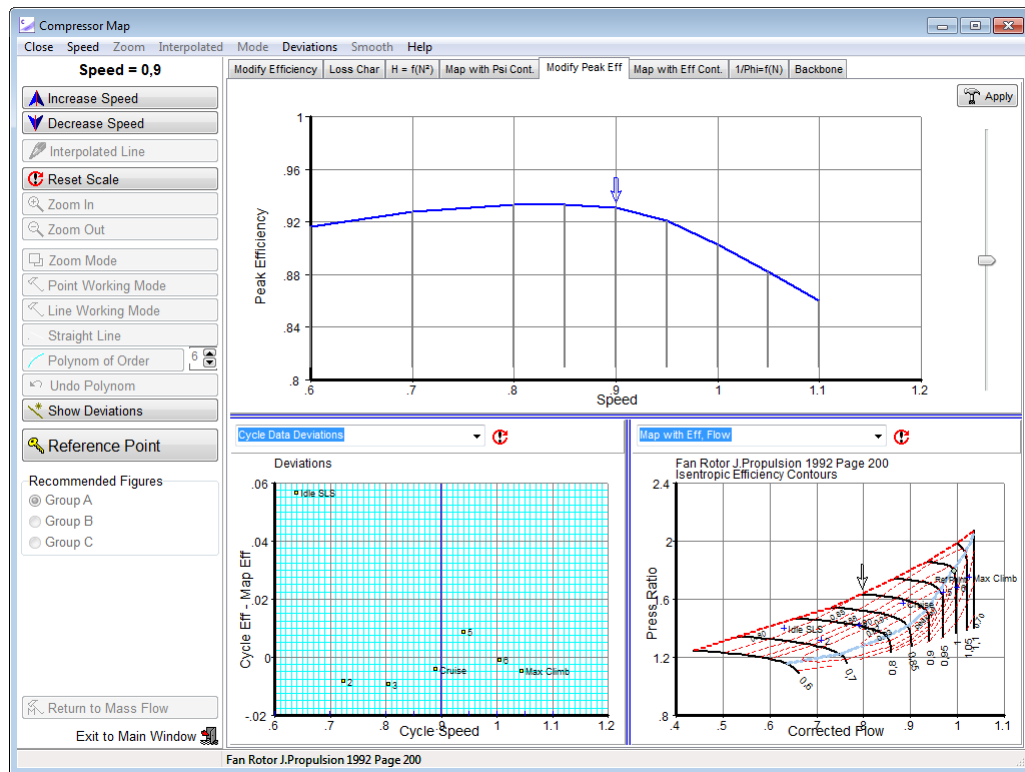
In the mass flow definition window there is the opportunity for adapting the speed - flow relationship. Choose the **Modify Flow=f(N)** page for a crude match with the given data by re-labeling the speed lines of the estimated map.

Move the slider and observe how the difference between the given speed values from the cycle program and the map values is affected by doing that. With the default picture selection the deviation between the given cycle data and the values read from the map are shown in the lower left picture while in the lower right picture the cycle points are shown in the map. It can happen that two points (point #2 and the Idle SLS points in the example picture) have very different speed values in the cycle data (see lower left picture), but in the map they are seemingly nearly on the same speed line, then it is impossible to get both points right simultaneously by moving the slider. In this case the shape of the speed line in the pressure ratio - mass flow plane must be modified.



3.7.2 Efficiency

In the efficiency definition window there is the opportunity for adapting all efficiency values at a given speed simultaneously on the **Modify Peak Eff** page for a crude match with the given data. Use the slider on the right side and observe how moving it affects the match between the cycle data and the map. If at the same map speed more than one cycle point is available and the efficiency deviation of these cycle data from the map is different, then it is impossible to get a good line-up alone by moving the slider. In such a case the shape of the efficiency = $f(\beta)$ must be modified for getting a satisfactory match.



4 Fan Maps

4.1 Split Fan Map

The fan map is a very important element for off-design turbfan performance simulations. Applying the data read from a normal compressor map to both the core and the bypass stream is inaccurate because the transonic flow field of the bypass stream is very different to the subsonic flow field of the core stream.

For more accurate simulations two maps may be employed, one for the core and another one for the bypass stream. The total mass flow of the fan is the same in these two maps while pressure ratio and efficiency are different for the two streams. The data for each point in this so-called "Split Map" are valid for a pre-defined bypass ratio.

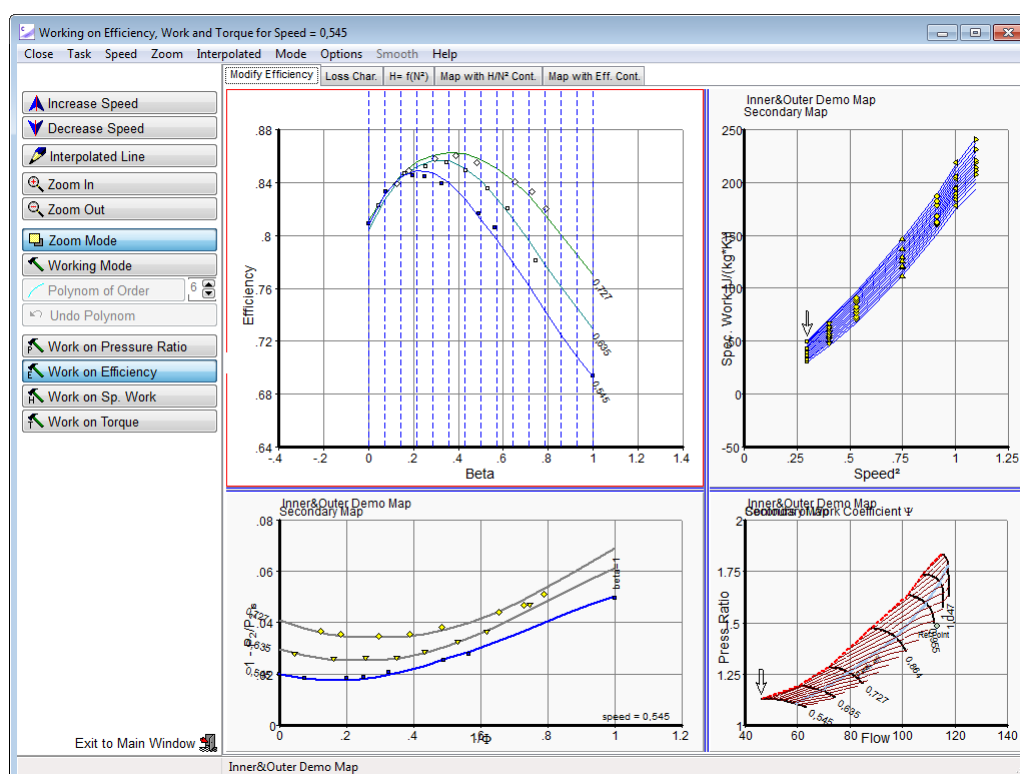
For smoothing a split map one stream must be selected as primary map. It is recommended to use the inner (core) stream for the primary map if the design bypass ratio is lower than 0.9 and otherwise the outer (bypass) stream. Make the primary map smooth as any other compressor map. You should finish the work on the primary map before switching over to the secondary map.

Input of data is as for single maps with the exception that for each data point you have to enter two pressure ratios and two efficiencies.

For each data point there are five or six numbers on a line, separated by at least one blank from each other. After the primary pressure ratio, the mass flow, and the primary efficiency there follow the secondary pressure ratio and the secondary efficiency.

As last number on the line there is the optional bypass ratio. If it is available, then smooth lines for the bypass ratio will be produced. Moreover, the mean map will be calculated with efficiency and pressure ratio as mass-averaged values.

Do not click the *Go to Secondary Map* button before you are finished with the primary map. In the new window that opens you can select between working on efficiency, pressure ratio, specific work and bypass ratio of the secondary map.



4.2 Single Stage Fan

Modern high bypass turbofan engines have single stage fans with a low hub-tip radius ratio. The variability of the bypass ratio can be taken into account with a split map. However, getting the data for a split map is a complex and expensive task.

An alternative single stage fan performance description employs the hypothesis that the overall fan performance is not affected by variations in bypass ratio. The overall fan performance map is completed by an additional table with core stream efficiency.

The enhanced single stage fan map is used as follows:

During cycle design calculations, when scaling the map, the bypass ratio as well as the pressure ratio and efficiencies for the core and bypass streams are known. Given or assumed values for fan tip speed, hub-tip radius ratio and fan inlet Mach number yield the core stream velocity triangle. The rotor blade exit flow angle from this triangle remains the same in all other operating conditions.

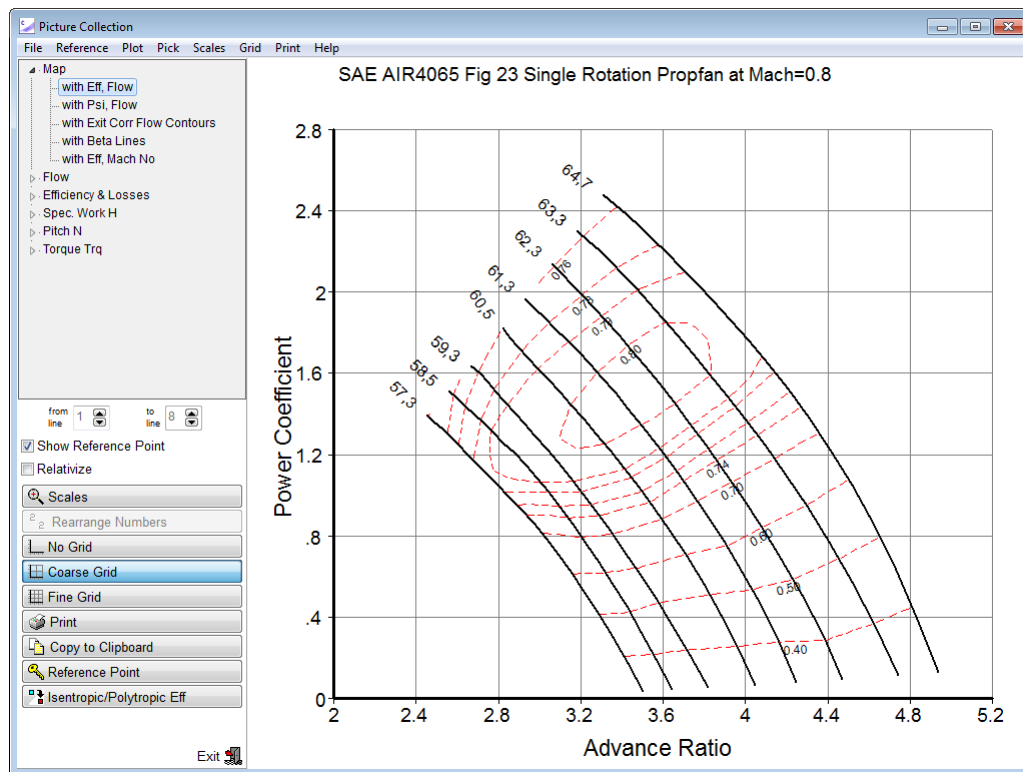
During off-design simulations, the core flow velocity triangle analysis with known rotor blade exit angle yields the work done on the core stream. The pressure ratio is calculated from this work and the efficiency read from the core stream efficiency table mentioned above. Finally, the bypass stream pressure ratio and efficiency are calculated from the overall map and the core stream data employing the actual bypass ratio.

Smooth C 9 makes the creation of a core efficiency table simple. After smoothing the overall fan map click the *Go to Secondary Map* button. You will get an estimate for the core efficiency map which you can modify easily. Due to the low Mach numbers the core stream efficiency values will be higher than the overall efficiency of the fan. Furthermore, the efficiency islands will be wider.

More details about this enhanced fan performance model can be found in [Reference 6](#).

5 Propeller Maps

In a propeller map the **Advance Ratio** replaces the Mass Flow, the **Power Coefficient** is used instead of the Pressure Ratio and the Speed is substituted by the **Propeller Pitch**.



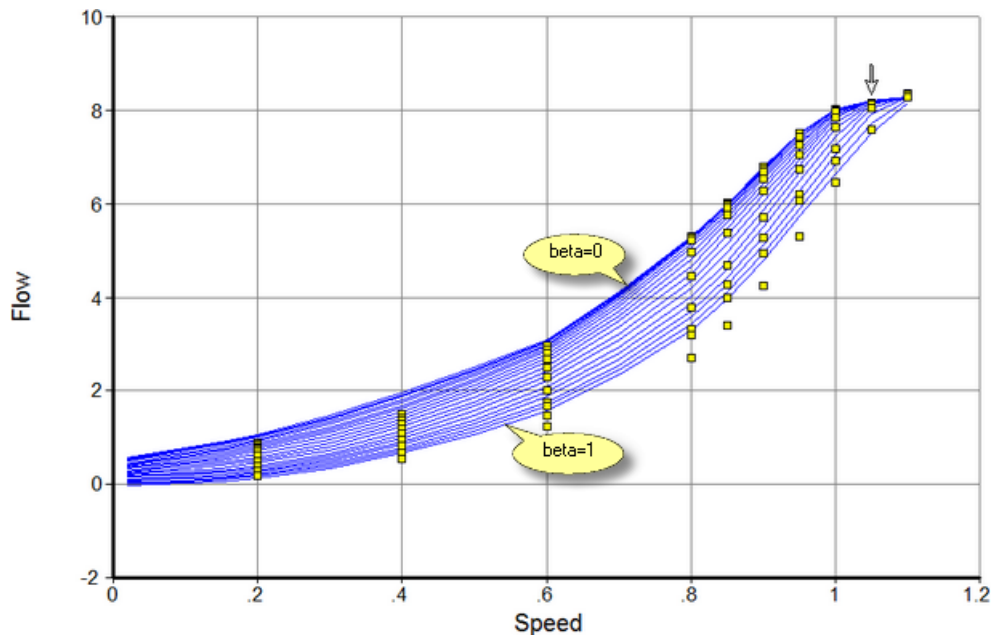
After reading the propeller map input data the numbers for the power coefficient are converted to dummy pressure ratio numbers assuming that the power coefficient is proportional to specific work. After this conversion all the tools that are adequate for compressor maps can be used for the map smoothing process. After smoothing the map - before writing the output tables - the dummy pressure ratio numbers are converted back to power coefficient numbers.

Some of the correlations originally invented for compressor maps make sense for propeller maps also - others don't. In any case the graphical output can be used for judging whether the map is smooth or not.

6 Checking a Map

6.1 Speed-Flow Relationship

The lower part of the speed-flow relationship along a β -line will look almost like a parabola. The exact shape depends not only on the compressor data, but also on the definition of the β -line grid which can be defined in many different ways. In addition to the speed-flow plot there is also a *speed-Mach no plot* available.



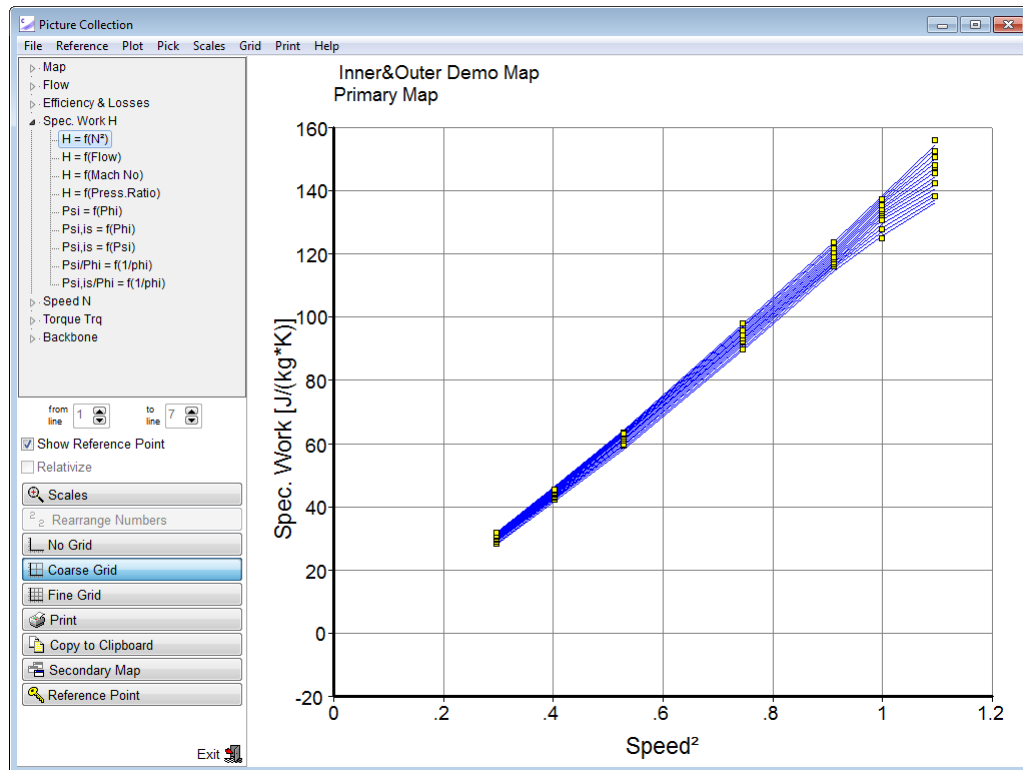
In the upper speed range the speed lines in the map can be vertical, the mass flow is constant for a given speed. In the plots flow over speed and Mach no over speed all β -lines will collapse into a single line.

6.2 Speed-Work Relationship

According to incompressible compressor theory the specific work is proportional to speed squared. Specific work for a constant β plotted over speed squared therefore will be straight lines over most parts of the map. However, the exact shape of the β -lines in the Speed-Work plot depends also on the definition of the β -line grid.

Before drawing conclusions from the plot $H=f(N^2)$ make sure that the speed - flow relationship is smooth and consistent with physics, see the previous section.

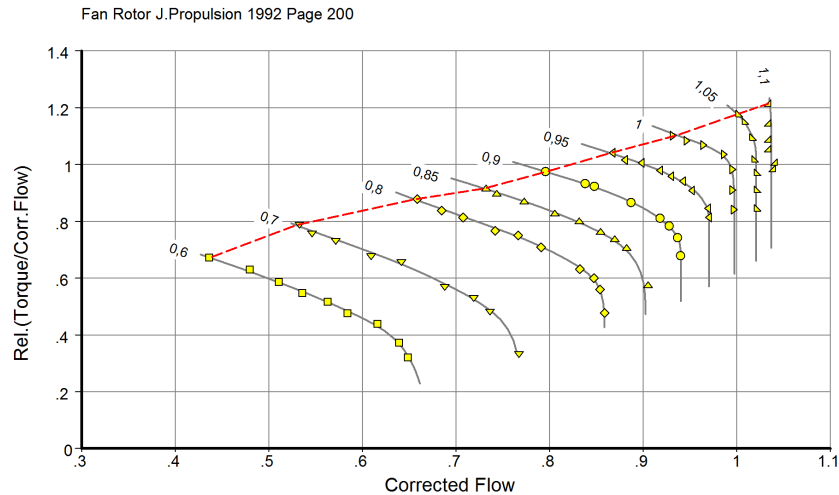
Since for speed zero the specific work is zero, all the β -lines must pass through the origin of the speed-work plot. Note that at very low speed the specific work can become negative - the compressor is operating as a windmill in this case. Therefore the lines for lower β -values can pass through an area with negative specific work before reaching the origin.



The speed-work relationship can also be checked in the map with $\beta = H/N^2$ contours. The contours in this plot are relativized with the maximum value found in the map. In case of compressors without variable geometry the lines for $\beta = \text{constant}$ are more or less straight.

6.3 Torque-Flow Relationship

In subsonic flow regions the correlation between torque/mass flow and mass flow is a straight line, since in incompressible compressor theory torque is proportional to mass flow squared. The slope of the straight sections in the subsonic regions is constant over the speed lines. Thus these sections are parallel. This circumstance also is used for defining [Speed Line Zero](#) and for extending the map towards low speeds.



6.4 Work and Flow Coefficients

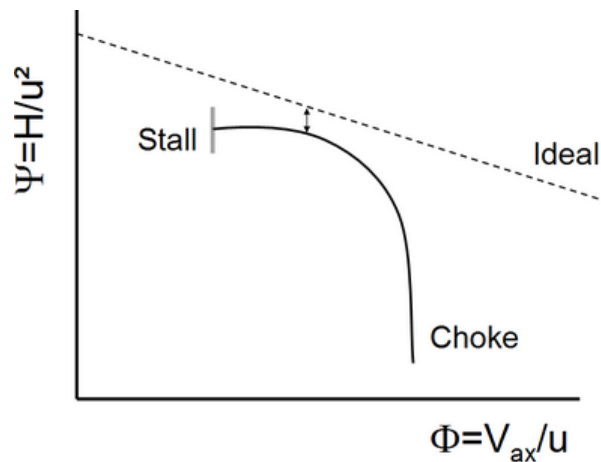
6.4.1 Theory

For a single stage axial compressor it can be concluded from a velocity diagram analysis (see for example Reference 5) that in the ideal case the relationship between the **work coefficient** and **flow coefficient** is linear:

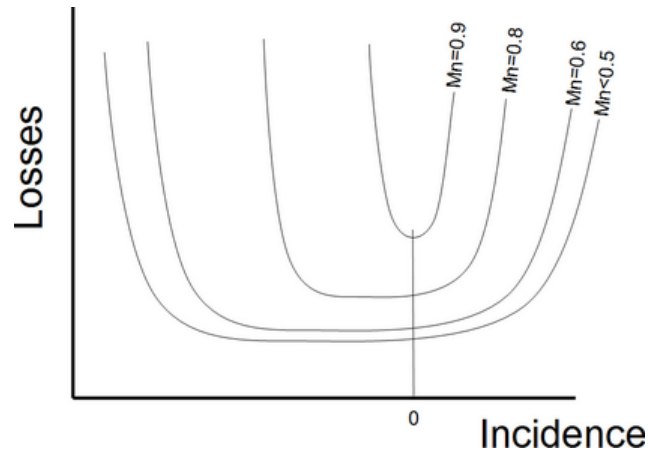
$$\Psi = 1 - k \cdot \Phi$$

The magnitude of the constant k depends on the blade and vane exit flow angles that are determined by the respective profile geometry.

In reality there are losses and the total pressure rise will be less than ideal even if the inlet flow angles to the blade rows are as designed (zero incidence). During off-design operation the inlet flow angles deviate from their optimum value (incidence $\neq 0$) which causes an increase of the losses. Moreover, the blade and vane exit flow angles will not remain constant while the incidence varies, especially if the flow detaches. The shape of the Ψ - Φ -relationship resembles more a parabola than a straight line.



As long as the Mach number of the incoming flow to a blade row is low, the total pressure loss and the incidence range without flow detachment will be independent from Mach number. With higher Mach number, however, the losses increase and the useful incidence range narrows down.



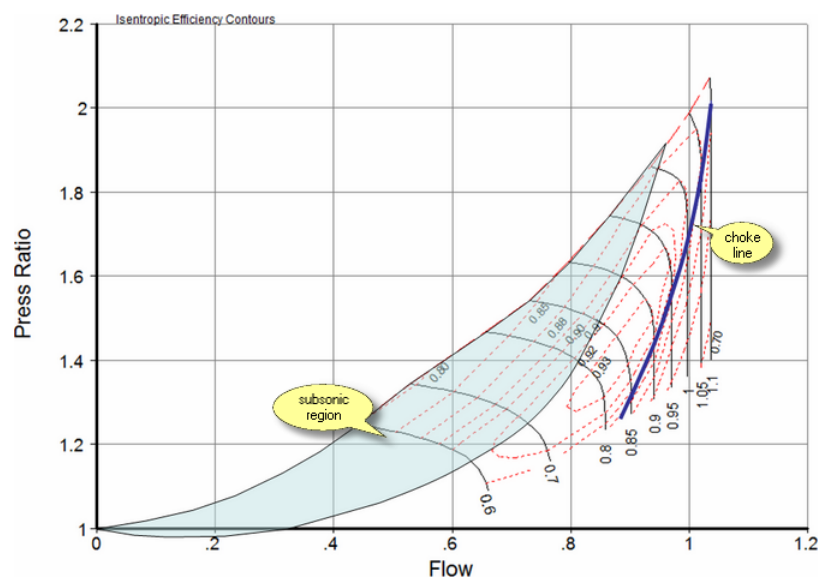
If the losses are independent from Mach number, then a single η -relationship describes the off-design performance of single stage compressors for all speeds. In multistage compressors the conditions are not so simple because the matching of the stages at off-design conditions deviates from the design case.

6.4.2 Application

In the user interface of Smooth C 9 some Greek symbols are employed. The work coefficient can be identified as ϕ or as H/N^2 and the flow coefficient as ψ respectively V_{ax}/N . In addition to the plots with ϕ there are alternative plots employing $1/\phi$ as x-axis. These are useful at extremely low speeds where the numbers for ϕ become very big; In contrast, the numbers for $1/\phi$ remain in a reasonable range.

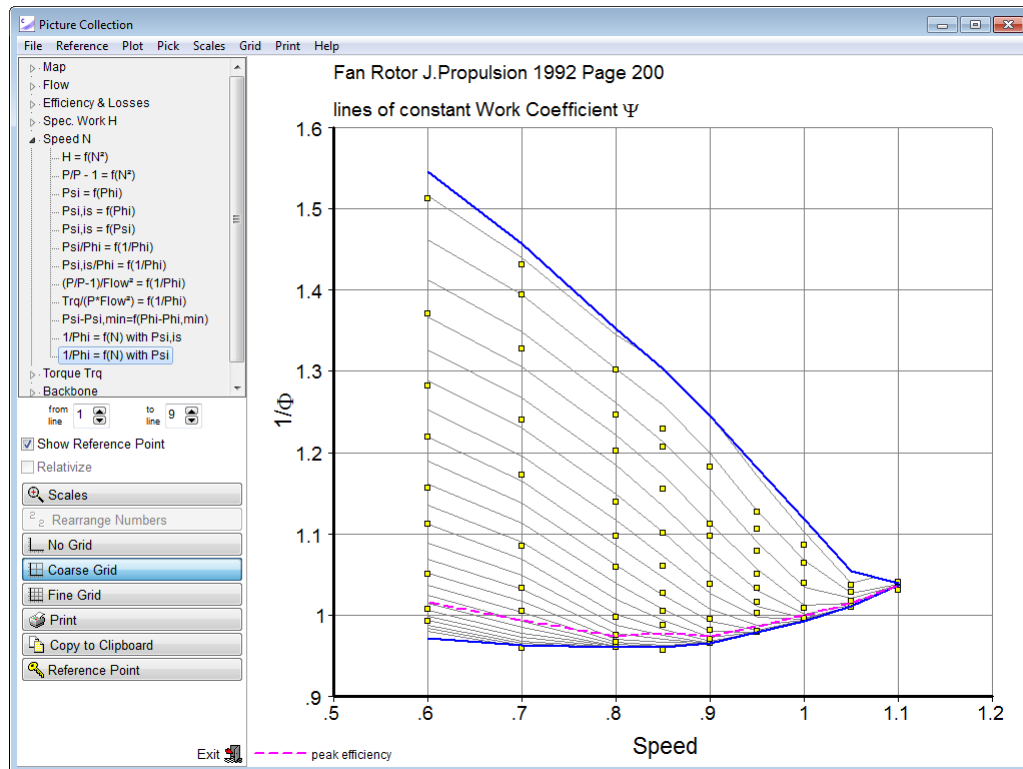
The plot $H_{is}/(N^2 V_{ax}) = f(N/V_{ax})$ shows $\eta_{is}/\phi = f(1/\phi)$. In the ideal case η_{is}/ϕ is proportional to $1/\phi$ and thus the correlation $\eta_{is}/\phi = f(1/\phi)$ tends to be linear.

Correlations between flow and work coefficients are helpful for inter- and extrapolating maps in the subsonic flow region. Note that high Mach numbers can be encountered also at low speeds if the flow coefficient $\psi = V_{ax}/N$ is high.



6.4.3 Flow Coefficient = f(Speed, Work Coefficient)

This is a special plot which is intended to help with extrapolation of a map towards lower speed.

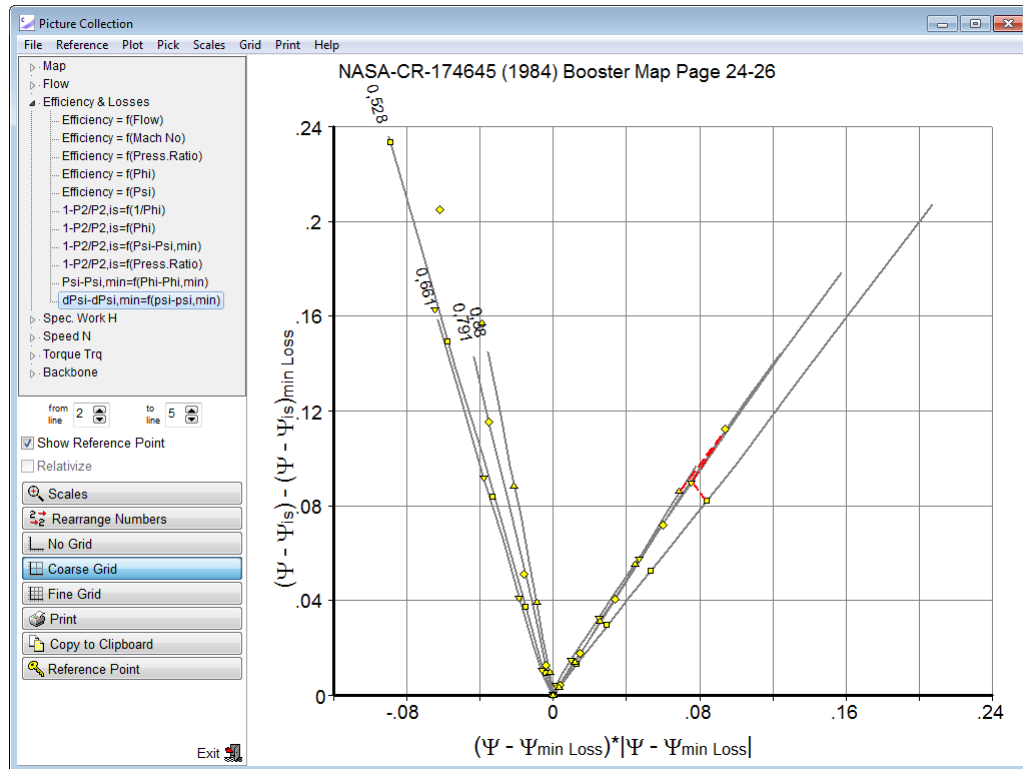


The $\Psi = H/N^2$ lines from the area covered by measurements can be continued, beginning with the gradient of the Ψ lines at the lowest speed with measured data. At speed=0 the gradient of the lines is zero in this plot which postulates that the correlation between the flow coefficient ϕ and the work coefficient Ψ is independent from speed.

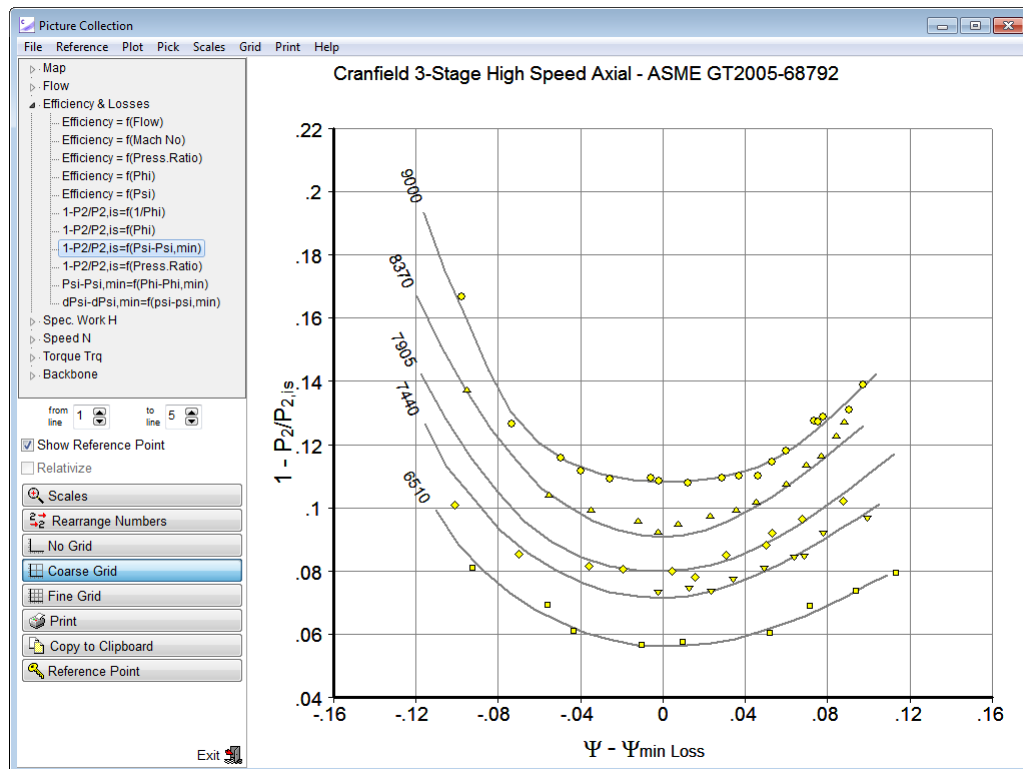
6.5 Loss Characteristics

With the help of this graph you can check whether your map makes sense in terms of physics. There are three versions of the loss characteristics:

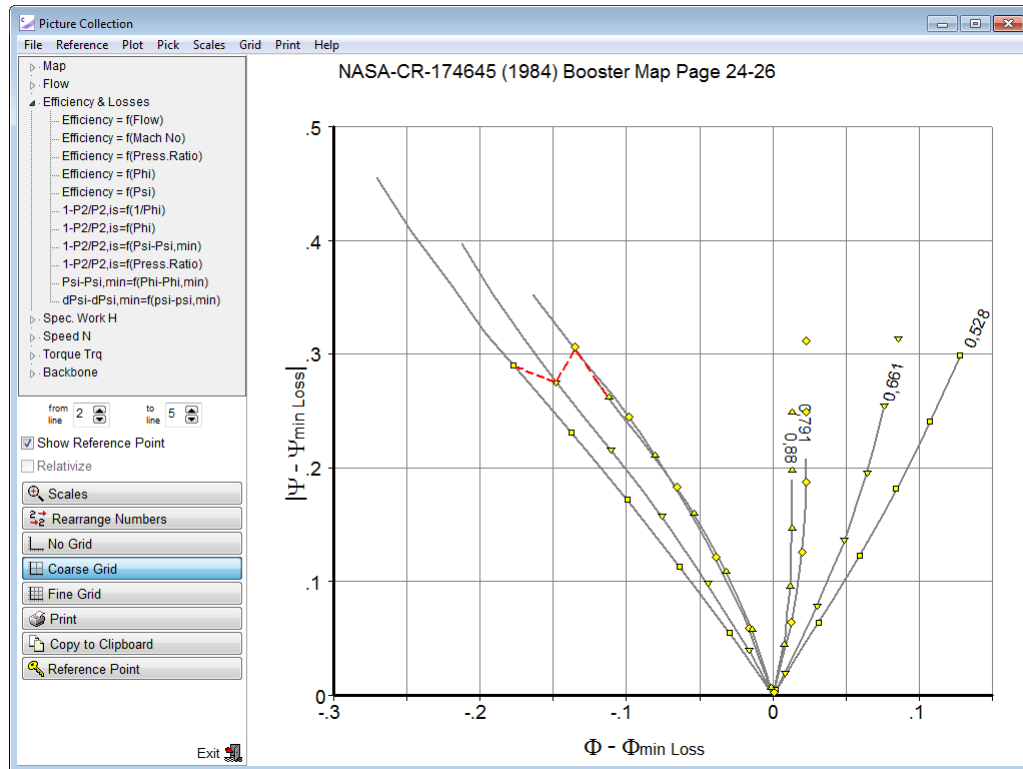
In the first loss characteristic the x-axis values are a measure of the distance from the peak efficiency point, expressed as difference in Ψ values. On the y-axis there are the losses $1 - \eta$, compared to those of the point with the minimum losses. This loss characteristic is very well suited for the normal speed range. However, for low speed values it becomes extremely sensitive to small changes.



The second option for describing the losses works very well over the full speed range. Here the losses are described as a total pressure loss from the pressure $P_{2,is}$ - which would be achieved by an isentropic process with the actual work input - to the real delivery pressure P_2 .



The third method of describing the losses shows $1 - P_2/P_{2,is}$ over $\Psi - \Psi_{\min \text{ Loss}}$ which is flow coefficient difference from the location with minimum losses. This method works fine for maps in which the speed lines are not vertical.

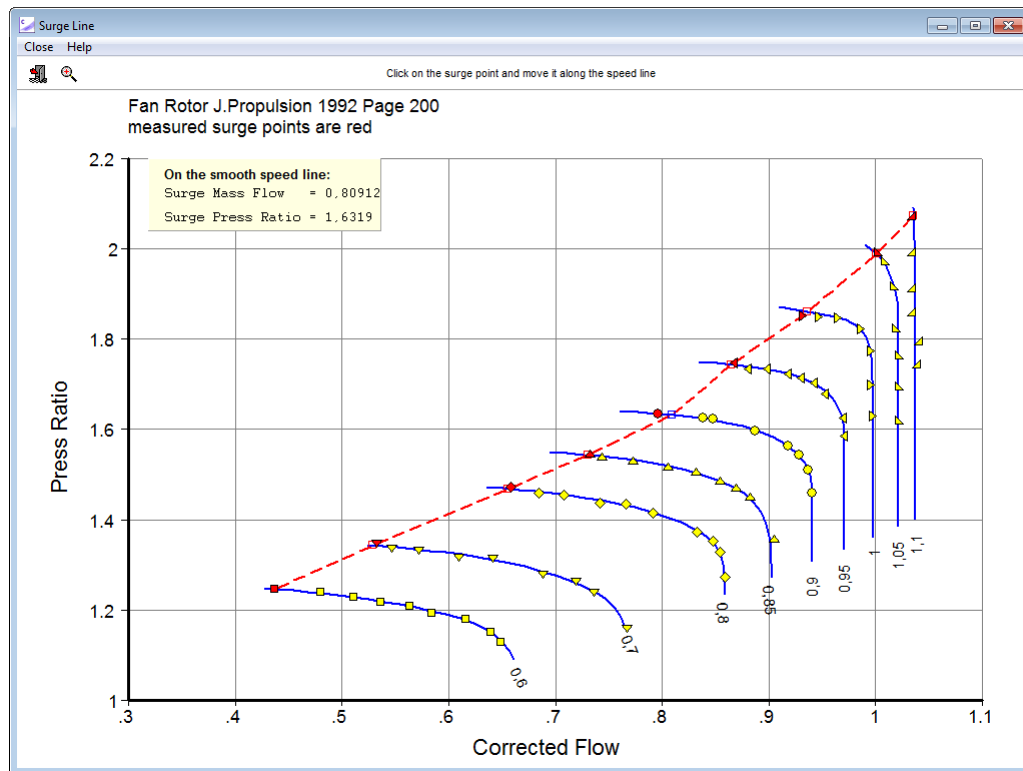


6.6 Checking the Surge Line

The measured surge line information is given with the [measured data](#) and the smooth surge line information is given with the [smooth data](#). If as input to the program [GasTurb Maps](#) or [Synthesis Tables](#) are used then the surge line information is read from a table.

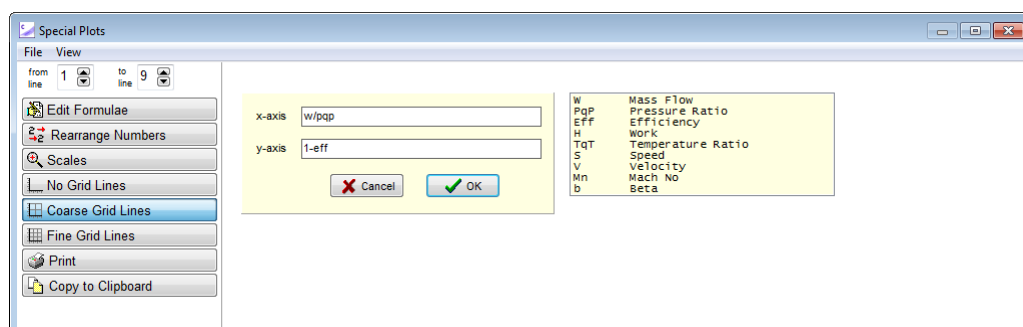
The surge line may not be known at all. Also in such a case Smooth C 9 will work fine, however, no surge line output will be generated.

If the surge line is only partially known - i.e., for some of the measured speeds the number of the surge point is 0 in the data input file - the program will interpolate the missing surge points. You should check the surge line after clicking the *Check Surge Line* button or after selecting *Surge Line* from the menu in the program opening window. In the figure below you can click on a square and move it along the speed line while the mouse button is down. Thus you can correct the surge line as required.

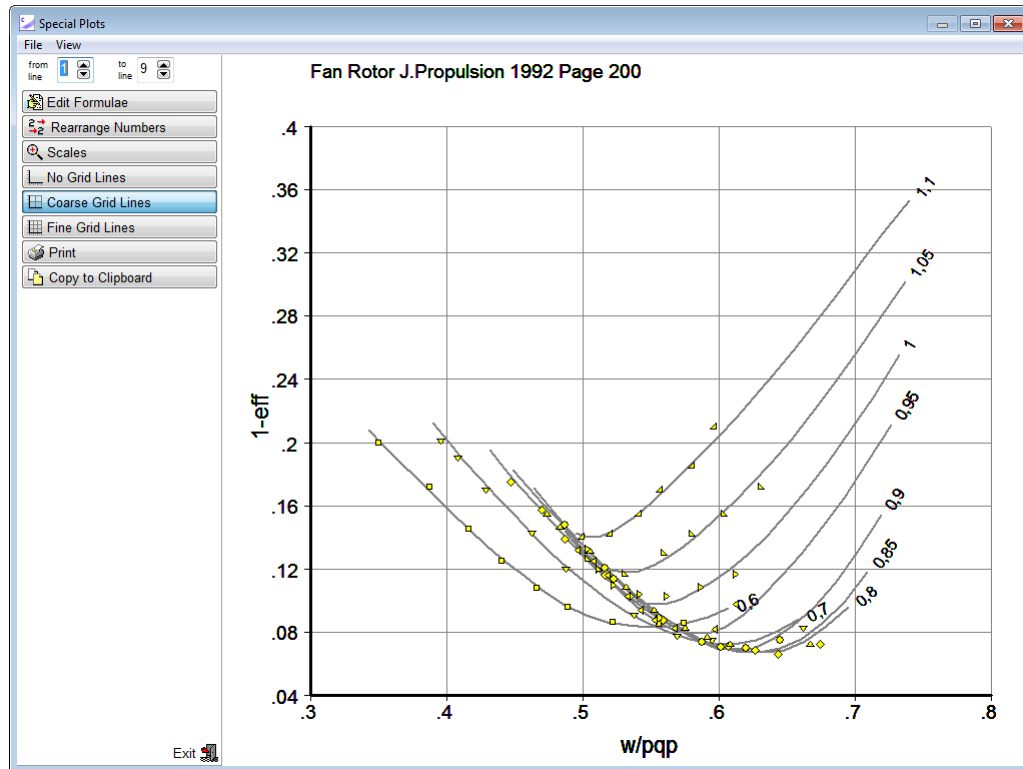


6.7 Special Plot

If you are missing a special plot in the picture catalog, then you can define yourself a special graph. Select *Plot/Special* from the menu in the picture catalog and enter formulae for the x and the y axes. The list of property names which may be used is shown to the right of the formula editor. You can use the operators $+$, $-$, $*$, $/$ and $^$ in the formula, and also brackets.



The example input above will yield the following graph:

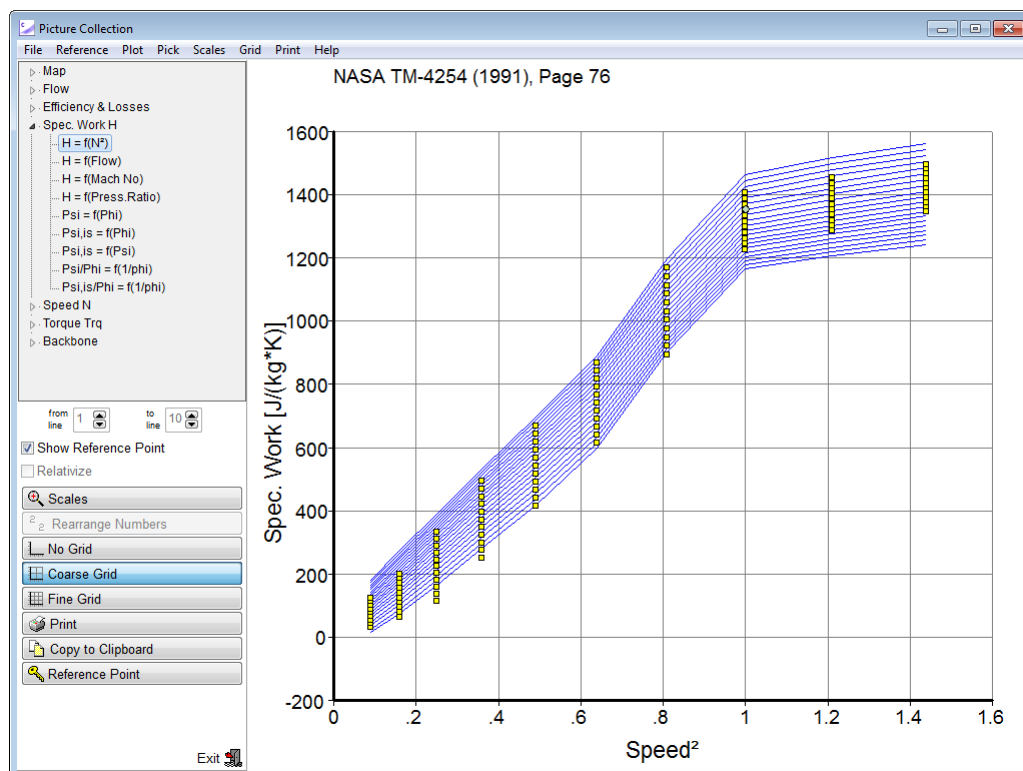
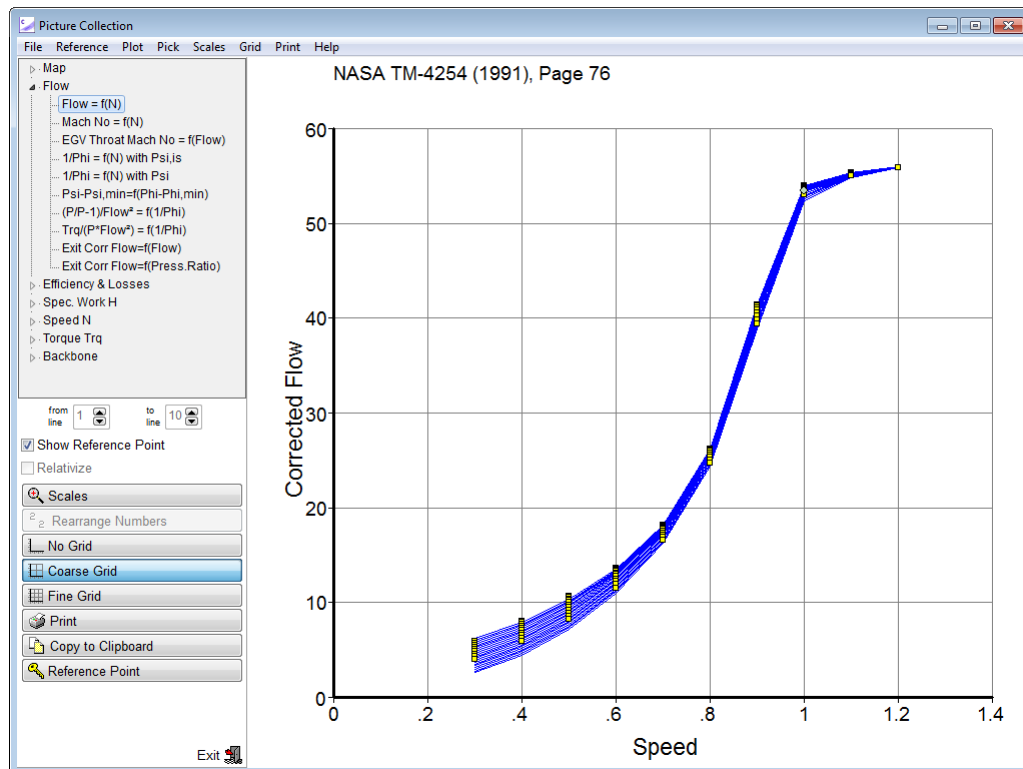


6.8 Variable Geometry

Variable geometry has a severe influence on the compressor characteristic. A complete description of a compressor with variable guide vanes or variable blade pitch setting requires a set of several maps, each for a clearly defined variable geometry setting.

However, in many practical applications the variable guide vane position is scheduled as a function of corrected speed. Then for each speed line there is a defined geometry setting and all the speed lines can be combined again in one map. Such a map is not necessarily a smooth map.

In contrary: each bend in the variable geometry schedule will show up as a bend in the speed - flow relationship and in the plot *specific work over speed*². In the efficiency plots the bends can also exist, but they are normally not very pronounced.

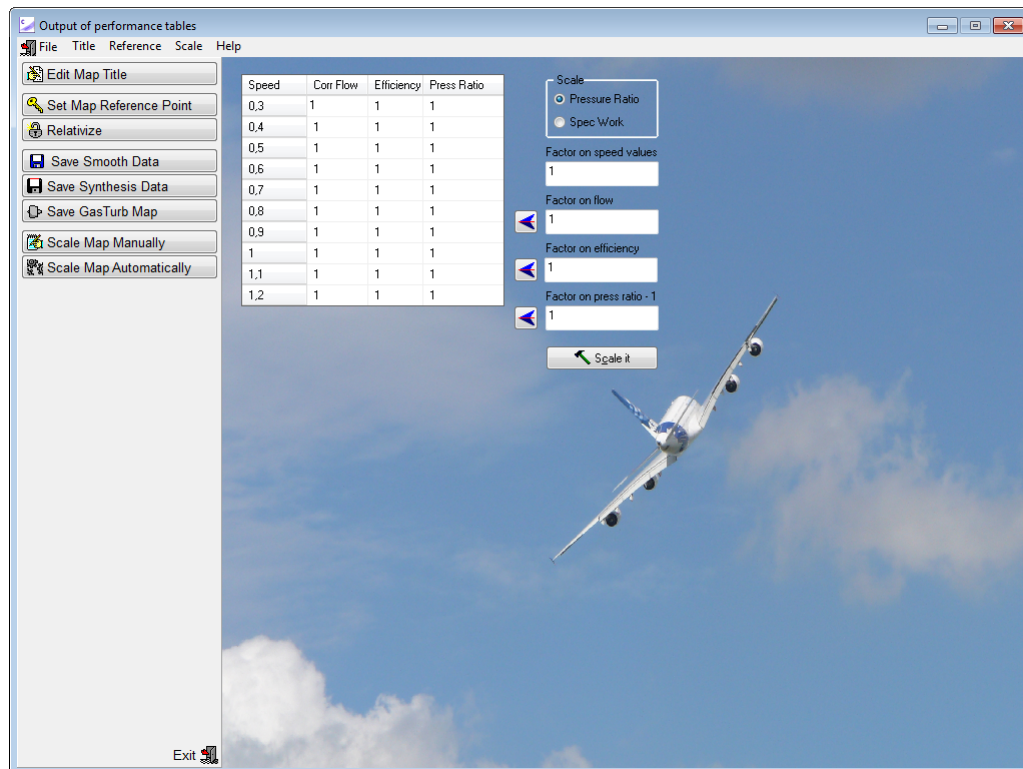


So be careful, while smoothing a map from a compressor with variable geometry: If there are bends in the schedule, then the map must not be smooth! Make sure that you include those speed lines in your map at which the geometry schedule plotted over corrected speed has a bend. If these speed lines were not measured, then they need to be interpolated.

7 Map Scaling

7.1 Manual Map Scaling

To scale a compressor map manually you can decide between pressure ratio scaling and specific work scaling. Often you will scale the map with constant factors. Enter these factors in the boxes to the right of the table and transfer the numbers to the table by clicking the buttons with the arrows; finally click the *Scale It* button.



For each of the speed lines you can apply a different scaling factor by editing the numbers in the table. Note, however, that by doing this you can easily produce a map which violates the laws of physics.

GasTurb accepts only maps with relative speed, and all speed values must be lower than 1.5. If you have used absolute speed values during the map smoothing process then you can convert the speed numbers by manual scaling.

Map scaling is performed in the following sequence of steps:

1. Speed
2. Mass flow
3. Efficiency
4. As selected:
 - 4.a. "Pressure ratio - 1" scaling:
 - i. Scale pressure ratio
 - ii. Calculate specific work from pressure ratio and scaled efficiency
 - 4.b. "Specific work" scaling:
 - i. Scale specific work
 - ii. Calculate pressure ratio from specific work and scaled efficiency
5. Calculate torque from new specific work and scaled speed

Consequently scaling speed affects also torque, and scaling specific work affects also pressure ratio and torque, for example. It is highly recommended to go through the picture catalog after scaling a map.

7.2 Automatic Map Scaling

The traditional methods of scaling maps can lead to significant errors in component representations. This was recognized many years ago and led to the development of a program which generates from only a few design point data typical maps for fans, boosters and high pressure compressors ([Reference 1](#)).

Alternatively to the calculation of a series of maps one can also apply more sophisticated scaling rules to an existing map. Such scaling rules were derived from a statistical analysis of many compressor maps with the help of Smooth C and published at the IGTI conference 2000 ([Reference 2](#)). This paper got the “Best Paper Award” from the ASME Aircraft Engine Committee.

When you select *Scale/Automatic* then the scaling method described in [Reference 2](#) will be applied. Thus you can produce a family of maps, all scaled from the same original map, which allows you to do a representative parametric cycle study, for example.

You can also do your own statistical evaluation of compressor maps with the methodology described in [Reference 2](#). For that purpose you find in the picture catalog graphs that show the characteristic properties of a map as a function of flow and speed.

8 Data Output

8.1 Output Options

A list of predefined graphics is offered in the picture catalog for printing and copying to the Windows clipboard. If you do not find your favorite graph there, then you can create it as a [special plot](#).

The program produces three types of output data files:

| File content | File extension |
|------------------|----------------|
| Smooth data | *.SMO |
| Synthesis tables | *.SYN |
| GasTurb map | *.MAP |

The file format for smooth data is the same as that of measured data. You can save the smooth lines by clicking on the *Save Smooth Data* button or from the menu *File/Save/Smooth Data* in the program opening window.

Synthesis tables and GasTurb maps are only produced from the output window (activate it from the menu option *Output* or with a click on the *Output Map* button in the program opening window).

Smooth lines and synthesis tables can be produced in non-relativized and in [relativized](#) form. You can produce relativized data only after you have entered [reference data](#) for the map.

Before writing output files you have the option to scale the map either [manually](#) or [automatically](#).

If data of the Speed Line Zero is available the user will be asked whether they should be included in the output. If speed is zero, then specific work is zero. Since the map is interpolated by GasTurb using specific work, efficiency is not needed.

8.2 Scales in Graphics

The program selects the scales of the graphics automatically with round numbers on both the x- and y-axis. You can easily modify the scales by using the menu option *Scale*. In this way, you can produce a series of plots with the same scale. If you modify the scale of a plot, the program will accept your input only if your wish implies round numbers for the x and y-axis.

You can also zoom into a picture: Press the left mouse button and hold it down while moving the mouse. Enclose with the rubber rectangle the region you are interested in and release the button to initiate repainting the figure. With a click on the right button of your mouse you will zoom out to the standard scaling.

If the range of values is very small, an appropriate number will be subtracted from the values and noted separately at the axis. If for example all values are between 32000.3 and 32000.4 the scale will begin with 0.3 and end with 0.4. Near to the axis the string +32000 will be written.

You can produce graphs with or without grid lines. From a figure with fine grid lines you can read numbers without the help of a ruler. Reading numbers from a plot without grid lines is a cumbersome task because the spacing between grid lines on paper will not be even centimeters or inches. While running Smooth C you can easily read numbers from a map: Go to the Picture catalog and select *Pick* from the menu.

8.3 Text on Axes

In the picture catalog you can edit most of the text which is written near to the x- and y-axes, select *Plot/Text on Axes* for that. You can add the unit for the corrected mass flow, for example. Be careful with your modifications: the program will not check if the text at an axis is according to the content of the graph or not.

Your new text can contain the font control characters #, \$ and §. These font control characters will not be printed, they control the format of the output as follows:

| | |
|-----|--|
| # | Begins a new piece of text with Arial font (normal size) |
| #\$ | Begins a new text piece with Symbol font (normal size) |
| #§ | Begins a new text piece with Arial font (index size) |

The text must contain only ASCII characters. Characters to be printed with Symbol font have the same ASCII code as given in the text string. Thus the uppercase greek letter F must be given in the text as #\$F (ASCII code 70) and Y as #\$Y (ASCII code 89).

8.4 Synthesis Tables

A smooth map is described with a set of [tables](#). A compressor map as produced by Smooth C 9 consists of 8 tables stored in one file. The default extension to the file name is "SYN".

Note: the explanations (text in blue/italic) are not part of an actual file and tables are abbreviated by the *Table: ...>* statement, followed by the argument, the parameter and finally the function value!

Map Type *Map Title*
99 Arbitrary Text

Table Content Keyword
Mass Flow
<Table: β, Speed, Mass Flow>

Efficiency
<Table: β, Speed, Efficiency>

Pressure Ratio
<Table: β, Speed, Pressure Ratio>

Specific work dH/T
<Table: β, Speed, Specific Work>

Isentropic specific work dH_{is}/T
<Table: β, Speed, Isentropic Specific Work>

Torque/($W1 \cdot N / \sqrt{T1}$)
<Table: β, Speed, Torque/($W1 \cdot N / \sqrt{T1}$)>

Surge Line

<Table: Surge Point Mass Flow, 1.0 , Surge Point Pressure Ratio>

Surge Line with Specific work

<Table: Surge Point Mass Flow, 1.0, Surge Point Specific Work>

Synthesis tables can be read by Smooth C as "measured data". The tables with Mass Flow, Efficiency and Pressure Ratio are mandatory while the tables with Specific Work and the Surge Line are optional. Note that the Surge Line with Specific Work will be ignored while reading a synthesis map.

A synthesis map for a fan as produced by Smooth C consists of 15 tables stored in one file. The default extension to the file name is "SYN".

| Map Type | Map Title |
|----------|----------------|
| 99 | Arbitrary Text |

Table Content Keyword

Mass Flow

<Table: β , Speed, Mass Flow>

Efficiency

<Table: β , Speed, Efficiency>

Pressure Ratio

<Table: β , Speed, Pressure Ratio>

Specific work dH/T

<Table: β , Speed, Specific Work>

Isentropic Specific work dH_{is}/T

<Table: β , Speed, Isentropic Specific Work>

Torque/($w_1 \cdot N / \sqrt{T_1}$)

<Table: β , Speed, Torque/($w_1 \cdot N / \sqrt{T_1}$)>

Surge Line

<Table: Surge Point Mass Flow, 1.0, Surge Point Pressure Ratio>

Surge Line with Specific work

<Table: Surge Point Mass Flow, 1.0, Surge Point Specific Work>

Second Efficiency

<Table: β , Speed, Second Efficiency>

Second Pressure Ratio

<Table: β , Speed, Second Pressure Ratio>

Second Specific work dH/T

<Table: β , Speed, Second Specific Work>

Second Isentropic Specific work dH_{is}/T

<Table: β , Speed, Second Isentropic Specific Work>

Second Torque/($w_1 \cdot N / \sqrt{T_1}$)

<Table: β , Speed, Second Torque/($w_1 \cdot N / \sqrt{T_1}$)>

Second Surge Line
<Table: Surge Point Mass Flow, 1.0, Second Surge Point Pressure Ratio>

Second Surge Line with Specific work
<Table: Surge Point Mass Flow, 1.0, Second Surge Point Specific Work>

8.4.1 Propeller Map

If a propeller map is created then there will be only two synthesis tables produced: one with the power coefficient and one with efficiency numbers. The map arguments are the beta values, the map parameters the propeller pitch.

Note: the explanations (text in blue/italic) are not part of an actual file and tables are abbreviated by the *Table: ...>* statement, followed by the argument, the parameter and finally the function value!

| Map Type | Map Title |
|----------|----------------|
| 99 | Arbitrary Text |

Table Content Keyword
 Power Coefficient
<Table: β , Pitch, Advance Ratio>

Efficiency
<Table: β , Pitch, Power Coefficient>

Smooth C cannot read synthesis tables containing a propeller map.

8.5 GasTurb Map

A GasTurb Map is described with a set of 4 tables stored in one file. The extension to the file name is "MAP".

Note: the explanations (text in blue/italic) are not part of an actual file and tables are abbreviated by the *Table: ...>* statement, followed by the argument, the parameter and finally the function value!

| Map Type | Map Title |
|----------|----------------|
| 99 | Arbitrary Text |

Reynolds correction data:
 Reynolds: $RNI=x1 \ f = y1 \ RNI = x2 \ f = y2$

Table Content Keyword
 Mass Flow
<Table: β , Speed, Mass Flow>

Efficiency
<Table: β , Speed, Efficiency>

Core Efficiency
<Table: β , Speed, Core Efficiency>

Pressure Ratio

<Table: β , Speed, Pressure Ratio>

Surge Line

<Table: Surge Point Mass Flow, 1.0, Surge Point Pressure Ratio>

The Core Efficiency table is optional. GasTurb Maps can be read by Smooth C 9 as "measured data".

The Reynolds correction data are described in detail in the GasTurb manual. They are of no relevance for Smooth C 9.

Note that the [speed](#) values in a GasTurb Map must be numbers in the range 0...1.5, i.e. you must use relative speed values. Moreover, the number of speed lines is limited depending on the GasTurb program version.

If a propeller map is created for GasTurb, then the line with the Reynolds number data remains empty. Instead of the Mass Flow numbers one gets the Advance Ratio and the Pressure Ratio numbers are replaced by the Power coefficient values. Only two tables are produced, the static propeller performance data need to be added manually before using the map with GasTurb.

8.6 Surge Line Output

The surge line is part of the standard [GasTurb](#) and [Synthesis Table](#) output. When you save [smooth lines](#) to a file from the map output window then the surge line will be appended at the end of the file with smooth data.

8.7 Relativizing a Map

You can relative the map which means that you replace in the output the pressure ratio P_2/P_1 by the relative pressure ratio $(P_2/P_1 - 1) / [(P_2/P_1)_{ref} - 1]$, the mass flow by the relative mass flow W/W_{ref} , the speed by N/N_{ref} and the efficiency by η/η_{ref} .

Note that you cannot use relativized maps with GasTurb. If you have only relativized data of a compressor, then read the relativized map into Smooth C, guess the compressor design data, and output the map in non-relativized format for GasTurb.

9 References

- [1] Extended Parametric Representation of Compressors, Fans and Turbines Vol I
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- [3] Some Aspects of Modeling Compressor Behavior in Gas Turbine Performance Calculations
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- [6] An Enhanced Off-Design Performance Model for Single Stage Fans
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10 Appendix

10.1 Nomenclature and Definitions

10.1.1 Symbols

| | |
|---------------------|------------------------------------|
| a | Velocity of sound |
| A | Area |
| H | Specific work |
| Mn | Mach number |
| N | Spool speed |
| $N/\sqrt{\theta_1}$ | Standard day corrected spool speed |
| P | Total pressure |
| P _s | Static pressure |
| P _W | Power |
| R | Gas constant |
| T | Total temperature |
| Trq | Torque |
| T _s | Static temperature |
| U | Circumferential speed |
| V _{ax} | Axial velocity |
| W | Mass flow |
| γ | Isentropic exponent |
| δ | $P / 101.325\text{kPa}$ |
| θ | $T / 288.15\text{K}$ |
| ρ | Density |
| Φ | Flow coefficient |
| Ψ | work coefficient |

10.1.2 GasTurb

GasTurb is a cycle program for design and off-design performance of many gas turbine configurations, see www.gasturb.com. With the help of Smooth C 9 you can produce the compressor map format needed by GasTurb.

10.1.3 Map Type Indicator

The map type indicator is an integer number which indicates numerically the contents of a file. The following map type indicators are defined:

Compressor maps:

- | | |
|---|---|
| 1 | Measured data |
| 2 | smooth data (retained for consistency with previous versions) |
| 3 | Smooth data |

Fan maps (split maps):

- | | |
|----|---|
| 11 | Measured data |
| 12 | smooth data (retained for consistency with previous versions) |
| 13 | Smooth data |

Single stage fan maps:

- | | |
|----|---|
| 33 | Smooth data with an additional column for core efficiency |
|----|---|

Propeller maps:

| | |
|----|---------------|
| 21 | Measured data |
| 23 | Smooth data |

Any map:

| | |
|----|----------------------------------|
| 99 | GasTurb Map and Synthesis Tables |
|----|----------------------------------|

10.1.4 Map Title

The map title is an arbitrary text which describes the map. It will be printed with any graphical output and also stored with the files produced by Smooth C 9.

10.1.5 Speed

A speed line in Smooth C 9 is a line of constant corrected spool speed in a plot with Pressure Ratio over Mass Flow.

The term speed is actually a shortcut for the corrected spool speed $N/\sqrt{T_1}$ which is a measure of the circumferential Mach number at the inlet to the compressor:

$$Mn_u = \frac{u}{a} = \frac{const \cdot N}{\sqrt{\gamma \cdot R \cdot T_s}} = \frac{const \cdot N}{\sqrt{\gamma \cdot R \cdot T} \cdot \sqrt{T_s/T}}$$

As can be seen from the formula above - since T_s/T is only a function of Mach number and isentropic exponent - it holds:

$$\frac{N}{\sqrt{T}} = f(\gamma, Mn_u)$$

Instead of using $N/\sqrt{T_1}$ it is more convenient to use the standard day corrected speed $N/\sqrt{\Theta_1}$ which is expressed in rpm (revolutions per minute).

Actual numbers for $N/\sqrt{\Theta_1}$ are often very big and this can cause undesired effects (overlapping of numbers, for example) in the graphical output of Smooth C 9. Therefore it is recommended to use relative corrected speed values as they are also used in GasTurb:

$$\left(\frac{N}{\sqrt{\Theta}} \right)_{rel} = \frac{\frac{N}{\sqrt{\Theta}}}{\left(\frac{N}{\sqrt{\Theta}} \right)_{ref}}$$

10.1.6 Mass Flow

In Smooth C 9 the term mass flow stands for the corrected mass flow which is a measure of the axial Mach number at the inlet to the compressor.

$$Mn_{ax} = \frac{V_{ax}}{a} = \frac{W}{A \cdot \rho \cdot \sqrt{\gamma \cdot R \cdot T_s}} = \frac{W \cdot R \cdot T_s}{A \cdot P_s \cdot \sqrt{\gamma \cdot R \cdot T_s}} = \frac{W \cdot \sqrt{R \cdot T/\gamma} \cdot \sqrt{T_s/T}}{A \cdot P \cdot (P_s/P)}$$

As can be seen from the formula above - since T_s/T and P_s/P are only functions of Mach number and isentropic exponent - it holds:

$$\frac{W \cdot \sqrt{R \cdot T}}{A \cdot P} = f(\gamma, Mn_{ax})$$

A frequently used shortcut of this formula is $W\sqrt{T}/P$. When using numbers then this term has units unfamiliar to most people. It is better to use standard day corrected mass flow which has in the SI system the unit kg/s:

$$\frac{W \cdot \sqrt{\Theta}}{\delta} = \frac{W \cdot \sqrt{T/288.15K}}{P/101.325kPa}$$

Note that Smooth C 9 works with both $W\sqrt{T}/P$ and $W\sqrt{\Theta}/\delta$, the units employed can be freely chosen.

10.1.7 Efficiency

Within Smooth C 9 normally the efficiency values are interpreted as isentropic efficiency.

$$\eta = \frac{H_{is}}{H}$$

The isentropic work H_{is} is calculated from the pressure ratio.

You can use polytropic efficiency while reading measured data from a file, a bitmap, or while you enter the data manually. The polytropic efficiency data will be converted to isentropic efficiency immediately after the data input process. In some of the plots in the picture catalog you can choose between polytropic and isentropic efficiency.

10.1.8 Pressure Ratio

The pressure ratio is defined as the total pressure P_1 at the exit of the compressor divided by the total pressure P_2 at the inlet to the compressor.

10.1.9 Specific Work

In Smooth C 9 the terms Specific Work and Work are in many places used as abbreviation for the Corrected Specific Work H/T_1 or $H/\sqrt{T_1}$ which is a measure of the work per unit of mass flow to drive the compressor divided by compressor inlet temperature.

During the map smoothing process the isentropic corrected specific work H_{is}/T_1 is calculated from the total pressure ratio P_2/P_1 . The actual corrected specific work H/T_1 is **calculated** from the isentropic corrected specific work H_{is}/T_1 and the efficiency.

10.1.10 Torque

The compressor shaft power PW is

$$PW = c \cdot N \cdot Trq = W \cdot \Delta H$$

with c as an unit conversion constant. This formula can be converted to

$$\frac{Trq}{W \cdot \sqrt{T_1}} = \frac{\Delta H / T_1}{c \cdot N / \sqrt{T_1}}$$

or

$$\frac{Trq}{P_1} = \frac{\frac{W \cdot \sqrt{T_1}}{P_1} \cdot \frac{H}{T_1}}{c \cdot \frac{N}{\sqrt{T_1}}}$$

10.1.11 Flow Coefficient

The flow coefficient $\phi = V_{ax}/U$ and the [work coefficient](#) $\psi = H/U^2$ are useful for describing compressor performance in the map region where the Mach numbers are low. The compressor inlet flow velocity V_{ax} at any point in the map can be calculated from the Mach number which in turn can be found from the correlation between corrected flow and compressor inlet Mach number at the [map reference point](#).

Note that in older versions of Smooth C corrected mass flow divided by speed was used as an expression for the flow coefficient. This was an approximation for which is valid for low Mach numbers only. The graphs created by Smooth C 9 show valid values for the flow coefficient over the full Mach number range.

Instead of circumferential speed U the speed value N may be employed for calculating a number which is proportional to the flow coefficient. If the true flow coefficient is known for the map reference point, then ϕ can be calculated for any point in the map. Setting $\phi_{ref}=1$ at the map reference point yields plots with relative ϕ values that are nearly as useful as those with the true data.

10.1.12 Work Coefficient

The parameters [flow coefficient](#) $\phi = V_{ax}/U$ and work coefficient $\psi = H/U^2$ are useful for describing the off-design performance of a compressor in the low Mach number region because there the influence of compressibility becomes negligible.

A number proportional to the work coefficient can be calculated as H/N^2 and the isentropic work coefficient ψ_{is} is proportional to H_{is}/N^2 .

$$\frac{\Delta H_{is}/T_1}{(N/\sqrt{T_1})^2} = \frac{\Delta H_{is}}{N^2} \cong \frac{\Delta H_{is}}{u^2} = \psi_{is}$$

If at the map reference point a value for the work coefficient is known, then ψ and ψ_{is} can be calculated for any point of the map.

10.1.13 Advance Ratio

In a propeller map the Advance Ratio replaces the mass flow of a compressor map.

10.1.14 Relativized Map

In a relativized map all data are referred to the reference conditions:

| | |
|----------------|--|
| Mass flow | True mass flow / Reference mass flow |
| Pressure ratio | (True pressure ratio - 1) / (Reference pressure ratio - 1) |
| Efficiency | True efficiency / Reference efficiency |
| Speed | True speed / Reference speed |

10.1.15 Format of a Table

A table is a set of numbers and contains argument values (A), parameter values (P) and function values (F):

| | | | | | |
|------|--------|--------|--------|--------|--------|
| Key | A[1] | A[2] | A[3] | A[4] | A[5] |
| P[1] | F[1,1] | F[1,2] | F[1,3] | F[1,4] | F[1,5] |
| P[2] | F[2,1] | F[2,2] | F[2,3] | F[2,4] | F[2,5] |
| P[3] | F[3,1] | F[3,2] | F[3,3] | F[3,4] | F[3,5] |

The first number of a table is the table key which is composed from the number of rows and columns of the table:

$$\text{Key} = \text{number of rows} + \text{number of columns}/1000$$

The number of rows is one more than the number of parameter values in the table and the number of columns is one more than the number of arguments in the table. The key for the table above would be 4.006, for example.

A table starts always on a new line and begins with the key. After the key follow the first four argument values, separated by at least one "blank" from each other. The rest of the argument values are on additional lines (five numbers per line). Only on the last line with argument values there may be less than five numbers.

Parameter values must always begin a new line and the first four function values follow on the same line. The rest of the function values are arranged as described for the argument values.

The data need not be in specific columns, but there must be at least one blank between each number. The length of the lines must not exceed 79 columns.

10.2 File Format Examples

10.2.1 Decimal Separator

Smooth C 9 will read files with . and with , as decimal separators. The decimal separator which is used as default for file output depends on your country settings in the Windows environment. Synthesis Tables and GasTurb Maps use always . as decimal separator.

10.2.2 File with Measured Compressor Map Data

The sequence of the data within a file with measured data is of no relevance. You can start with the data group for any speed value. Within a data group you can commence with the lowest, the highest or a medium pressure ratio point, for example.

Note: the explanations (text in blue/italic) are not part of an actual file!

Map Type Map Title

1 Fan Rotor J.Propulsion 1992 Page 200

of Speed Lines Keyword (relativized or non-relativized)

9 Non-Relativized Map

*Speed # of Points # of the Surge Point**

0.60000 9 1

Press Ratio Mass Flow Efficiency

1.24650 0.43660 0.80000 *<-Surge Point*

1.23860 0.47970 0.82800

1.22870 0.51110 0.85500

1.21780 0.53620 0.87500

1.20890 0.56330 0.89200

1.19400 0.58420 0.90450

1.18020 0.61620 0.91380

1.15148 0.63970 0.91500

1.12970 0.64890 0.91450

Next Speed Line

0.70000 9 1

1.34750 0.53290 0.79900 *<-Surge Point*

1.33760 0.54630 0.81000

1.33366 0.57160 0.83000

1.31780 0.60940 0.85750

1.31580 0.64170 0.88000

1.28020 0.68810 0.90950

1.26340 0.71910 0.92250

1.23860 0.73640 0.92500

1.15940 0.76740 0.91750

0.80000 10 1

1.47230 0.65870 0.82500 *<-Surge Point*

1.45840 0.68480 0.84250

1.45450 0.70770 0.86130

1.43760 0.74200 0.88400

1.43460 0.76650 0.89750

1.41490 0.79100 0.91250

1.37230 0.83240 0.92880

1.35250 0.84750 0.93150

1.32770 0.85400 0.93430

1.27330 0.85890 0.92750

0.85000 9 1

1.54550 0.73220 0.84500 *<-Surge Point*

1.53860 0.74360 0.85330

1.53070 0.77300 0.86880

1.51584 0.80570 0.89130

1.50590 0.83180 0.90630

File Format Examples

| | | |
|---------|---------|-----------------------|
| 1.48600 | 0.85460 | 0.91750 |
| 1.47030 | 0.86970 | 0.92300 |
| 1.45050 | 0.88240 | 0.92780 |
| 1.35740 | 0.90530 | 0.92750 |
| 0.90000 | 8 | 1 |
| 1.63460 | 0.79590 | 0.85250 <-Surge Point |
| 1.62480 | 0.83830 | 0.87950 |
| 1.62280 | 0.84810 | 0.88630 |
| 1.59700 | 0.88730 | 0.91130 |
| 1.56340 | 0.91830 | 0.92630 |
| 1.54360 | 0.92810 | 0.92950 |
| 1.51090 | 0.93700 | 0.93000 |
| 1.45840 | 0.94020 | 0.92500 |
| 0.95000 | 9 | 1 |
| 1.74850 | 0.86770 | 0.86800 <-Surge Point |
| 1.73370 | 0.88080 | 0.87500 |
| 1.73370 | 0.89870 | 0.88400 |
| 1.72370 | 0.91830 | 0.89750 |
| 1.71386 | 0.93040 | 0.90630 |
| 1.70400 | 0.94280 | 0.91250 |
| 1.67920 | 0.95260 | 0.91750 |
| 1.62470 | 0.96960 | 0.91830 |
| 1.58510 | 0.97060 | 0.90250 |
| 1.00000 | 7 | 1 |
| 1.85250 | 0.93140 | 0.86750 <-Surge Point |
| 1.85050 | 0.94610 | 0.88000 |
| 1.84750 | 0.96400 | 0.89000 |
| 1.82280 | 0.98590 | 0.89630 |
| 1.77320 | 0.99510 | 0.89750 |
| 1.69900 | 0.99510 | 0.89130 |
| 1.62970 | 0.99670 | 0.88300 |
| 1.05000 | 7 | 1 |
| 1.99110 | 1.00160 | 0.87400 <-Surge Point |
| 1.97128 | 1.00810 | 0.88000 |
| 1.91680 | 1.01630 | 0.88300 |
| 1.82280 | 1.01860 | 0.87000 |
| 1.76340 | 1.02120 | 0.85800 |
| 1.69410 | 1.02120 | 0.84500 |
| 1.61980 | 1.02120 | 0.82800 |
| 1.10000 | 6 | 1 |
| 2.07030 | 1.03430 | 0.86000 <-Surge Point |
| 1.99100 | 1.03430 | 0.85800 |
| 1.91190 | 1.03430 | 0.84500 |
| 1.85740 | 1.03430 | 0.83000 |
| 1.79310 | 1.04080 | 0.81500 |
| 1.74360 | 1.03920 | 0.79000 |

**use 0 when the surge point is not included*

10.2.3 File with Measured Fan Map Data

The sequence of the data within a file with measured data is of no relevance. You can start with the data group for any speed value. Within a data group you can commence with the lowest, the highest or a medium pressure ratio point, for example.

Note: the explanations (text in blue/italic) are not part of an actual file!

Map Type Map Title

11 Inner&Outer Demo Map

of Speed Lines Keyword (relativized or non-relativized)

7 Non-Relativized Map

*Speed # of Points # of the Surge Point**

0.54500

8

8

Pressr. 1

Mass Flow

Eff. 1

Pressr. 2

Eff. 2 (BPR, opt.)

1.08992

63.24414

0.88688

1.08967

0.80916

1.09216

61.78282

0.89459

1.09824

0.83295

1.09478

59.25673

0.89695

1.10750

0.84538

1.09639

56.57575

0.89833

1.11769

0.83909

1.09987

53.86733

0.90720

1.12317

0.81653

1.10037

52.53317

0.90636

1.12610

0.80595

1.09536

58.07771

0.89871

1.11148

0.84477

1.10138

45.95931

0.88354

1.12557

0.69351-*Surge Point*

Next Speed Line

0.63500

8

8

1.13868

73.65559

0.90372

1.14235

0.82267

1.14138

71.36820

0.90580

1.15835

0.84666

1.14348

69.56079

0.91016

1.16786

0.85165

1.14591

67.92818

0.91174

1.17461

0.85522

1.14778

66.39177

0.91565

1.18163

0.84884

1.14912

64.50914

0.91575

1.18809

0.83509

1.15070

62.98027

0.91526

1.19050

0.82053

1.15022

60.35422

0.90279

1.19217

0.78062-*Surge Point*

0.72700

8

8

1.20106

83.36692

0.91274

1.22403

0.83913

1.20259

82.37521

0.91154

1.23433

0.84883

1.20703

80.65634

0.91432

1.24862

0.85779

1.20974

79.14765

0.91471

1.25977

0.86066

1.21199

77.49176

0.91314

1.26864

0.85466

1.21501

74.44290

0.91751

1.28117

0.84088

1.21668

73.20844

0.91603

1.28479

0.83303

1.21700

72.02835

0.92070

1.28439

0.81993-*Surge Point*

0.86400

8

8

1.31125

101.5804

0.90303

1.35863

0.82087

1.32207

99.02526

0.90925

1.40596

0.85505

1.32845

97.18973

0.91247

1.43132

0.86060

1.33311

95.86633

0.91351

1.44257

0.85388

1.33995

92.32283

0.91447

1.46539

0.84273

1.34648

88.15416

0.91006

1.47531

0.80190

1.32331

98.71577

0.90844

1.41185

0.85551

1.34617

88.07531

0.91001

1.47530

0.80601-*Surge Point*

| | | | | |
|---------|-----------|---------|---------|-----------------------------|
| 0.95500 | 11 | 5 | | |
| 1.41579 | 111.31018 | 0.90009 | 1.56881 | 0.85352 |
| 1.41920 | 110.29843 | 0.90237 | 1.58290 | 0.86947 |
| 1.42609 | 108.62289 | 0.90153 | 1.60386 | 0.86380 |
| 1.43621 | 105.59663 | 0.90645 | 1.62908 | 0.84479 |
| 1.44384 | 102.44201 | 0.90080 | 1.63978 | 0.81575- <i>Surge Point</i> |
| 1.41530 | 111.02465 | 0.90346 | 1.56465 | 0.85744 |
| 1.41686 | 110.48923 | 0.90023 | 1.57021 | 0.85734 |
| 1.41618 | 110.29318 | 0.90087 | 1.57207 | 0.85726 |
| 1.42194 | 108.68465 | 0.89885 | 1.59222 | 0.85173 |
| 1.43472 | 104.85144 | 0.90571 | 1.62674 | 0.84310 |
| 1.43835 | 103.19460 | 0.90421 | 1.63046 | 0.82738 |
| | | | | |
| 1.00000 | 10 | 10 | | |
| 1.43539 | 115.72994 | 0.87496 | 1.57682 | 0.78429 |
| 1.45541 | 115.50361 | 0.89065 | 1.64983 | 0.84289 |
| 1.46539 | 115.26773 | 0.88875 | 1.67281 | 0.85076 |
| 1.48109 | 113.79981 | 0.89418 | 1.70742 | 0.84983 |
| 1.48899 | 111.48915 | 0.89519 | 1.73304 | 0.83119 |
| 1.48650 | 111.92203 | 0.88986 | 1.73137 | 0.83889 |
| 1.47130 | 114.90859 | 0.88795 | 1.68277 | 0.85169 |
| 1.47593 | 114.26458 | 0.89004 | 1.70555 | 0.85233 |
| 1.48007 | 113.37487 | 0.88907 | 1.70365 | 0.84947 |
| 1.49133 | 107.45372 | 0.88547 | 1.73831 | 0.78734- <i>Surge Point</i> |
| | | | | |
| 1.04700 | 8 | 7 | | |
| 1.48134 | 117.71659 | 0.86508 | 1.71859 | 0.80933 |
| 1.50111 | 117.57032 | 0.86834 | 1.76559 | 0.82843 |
| 1.51574 | 117.32973 | 0.87224 | 1.75866 | 0.83375 |
| 1.52177 | 117.39257 | 0.87008 | 1.79597 | 0.83579 |
| 1.52854 | 117.12614 | 0.87509 | 1.79365 | 0.82852 |
| 1.54132 | 116.65128 | 0.87857 | 1.83000 | 0.82020 |
| 1.55220 | 115.11917 | 0.86279 | 1.84149 | 0.79645- <i>Surge Point</i> |
| 1.54936 | 115.22077 | 0.87927 | 1.84037 | 0.79393 |

**use 0 when the surge point is not included*

10.2.4 Example File with Smooth Compressor Data

Note: the explanations (text in blue/italic) are not part of an actual file!

Map Type Map Title

3 Fan Rotor J.Propulsion 1992 Page 200

Speed of the Map Reference Point Beta of the Map Reference Point

RefSpeed=1.0000000 RefBeta=0.6407091

Ref. Mach no Ref. ψ Ref. ϕ

RefMach=0.5000000 RefPsi=1.0000000 RefPhi=1.0000000

of Speed Lines Keyword (relativized or non-relativized)

9 Non-Relativized Map

Speed # of Points # of Points

| 0.60000 | 20 | 20 |
|----------------|------------------|-------------------|
| <i>Pressr.</i> | <i>Mass Flow</i> | <i>Efficiency</i> |
| 1.08307 | 0.66317 | 0.90115 |
| 1.10195 | 0.65900 | 0.90812 |
| 1.11996 | 0.65382 | 0.91238 |
| 1.13666 | 0.64714 | 0.91479 |
| 1.15193 | 0.63885 | 0.91639 |
| 1.16539 | 0.62849 | 0.91580 |
| 1.17711 | 0.61622 | 0.91447 |
| 1.18716 | 0.60212 | 0.91053 |
| 1.19608 | 0.58690 | 0.90451 |
| 1.20445 | 0.57132 | 0.89609 |
| 1.21178 | 0.55464 | 0.88512 |
| 1.21893 | 0.53796 | 0.87412 |
| 1.22512 | 0.52011 | 0.86140 |
| 1.23075 | 0.50156 | 0.84782 |
| 1.23625 | 0.48286 | 0.83377 |
| 1.24098 | 0.46286 | 0.81842 |
| 1.24543 | 0.44216 | 0.80326 |
| 1.24951 | 0.42041 | 0.78662 |
| 1.25315 | 0.39714 | 0.76882 |
| 1.25671 | 0.37263 | 0.74997 |
| | | |
| 0.70000 | 20 | 20 |
| 1.15776 | 0.76545 | 0.91053 |
| 1.17991 | 0.76243 | 0.91794 |
| 1.20020 | 0.75744 | 0.92436 |
| 1.21855 | 0.75056 | 0.92717 |
| 1.23474 | 0.74165 | 0.92757 |
| 1.24851 | 0.73052 | 0.92571 |
| 1.26116 | 0.71865 | 0.92221 |
| 1.27268 | 0.70603 | 0.91744 |
| 1.28234 | 0.69187 | 0.91068 |
| 1.29202 | 0.67818 | 0.90291 |
| 1.30059 | 0.66373 | 0.89414 |
| 1.30844 | 0.64889 | 0.88436 |
| 1.31527 | 0.63330 | 0.87358 |
| 1.32122 | 0.61707 | 0.86175 |
| 1.32635 | 0.60022 | 0.84877 |
| 1.33111 | 0.58319 | 0.83544 |
| 1.33536 | 0.56577 | 0.82180 |
| 1.33930 | 0.54813 | 0.80808 |
| 1.34288 | 0.53015 | 0.79323 |
| 1.34636 | 0.51206 | 0.77840 |
| | | |
| 0.80000 | 20 | 20 |
| 1.24008 | 0.85870 | 0.90614 |
| 1.26762 | 0.85844 | 0.91742 |
| 1.29448 | 0.85753 | 0.92619 |
| 1.31963 | 0.85506 | 0.93183 |
| 1.34207 | 0.85025 | 0.93287 |
| 1.36108 | 0.84260 | 0.93228 |
| 1.37688 | 0.83247 | 0.92992 |
| 1.39041 | 0.82078 | 0.92617 |
| 1.40265 | 0.80844 | 0.92115 |
| 1.41362 | 0.79545 | 0.91489 |

File Format Examples

| | | |
|---------|---------|---------|
| 1.42332 | 0.78182 | 0.90737 |
| 1.43176 | 0.76753 | 0.89930 |
| 1.43896 | 0.75260 | 0.89018 |
| 1.44523 | 0.73725 | 0.88000 |
| 1.45061 | 0.72152 | 0.86909 |
| 1.45560 | 0.70579 | 0.85765 |
| 1.46022 | 0.69006 | 0.84596 |
| 1.46426 | 0.67410 | 0.83404 |
| 1.46817 | 0.65829 | 0.82246 |
| 1.47189 | 0.64256 | 0.81018 |
| 0.85000 | 20 | 20 |
| 1.28353 | 0.90260 | 0.88888 |
| 1.31278 | 0.90247 | 0.90547 |
| 1.34117 | 0.90156 | 0.91711 |
| 1.36876 | 0.90000 | 0.92588 |
| 1.39442 | 0.89688 | 0.93068 |
| 1.41802 | 0.89221 | 0.93308 |
| 1.43909 | 0.88571 | 0.93289 |
| 1.45735 | 0.87727 | 0.93026 |
| 1.47302 | 0.86715 | 0.92556 |
| 1.48559 | 0.85500 | 0.91955 |
| 1.49660 | 0.84208 | 0.91263 |
| 1.50631 | 0.82857 | 0.90482 |
| 1.51431 | 0.81417 | 0.89609 |
| 1.52160 | 0.79963 | 0.88647 |
| 1.52798 | 0.78479 | 0.87684 |
| 1.53313 | 0.76935 | 0.86692 |
| 1.53743 | 0.75362 | 0.85639 |
| 1.54132 | 0.73788 | 0.84601 |
| 1.54482 | 0.72215 | 0.83534 |
| 1.54760 | 0.70612 | 0.82477 |
| 0.90000 | 20 | 20 |
| 1.32492 | 0.94184 | 0.86121 |
| 1.35580 | 0.94184 | 0.88182 |
| 1.38668 | 0.94184 | 0.89910 |
| 1.41757 | 0.94184 | 0.91240 |
| 1.44845 | 0.94184 | 0.92135 |
| 1.47803 | 0.94082 | 0.92792 |
| 1.50552 | 0.93827 | 0.93073 |
| 1.52926 | 0.93306 | 0.93113 |
| 1.54922 | 0.92535 | 0.92992 |
| 1.56633 | 0.91592 | 0.92559 |
| 1.58095 | 0.90510 | 0.91970 |
| 1.59327 | 0.89306 | 0.91318 |
| 1.60391 | 0.88026 | 0.90566 |
| 1.61220 | 0.86623 | 0.89739 |
| 1.61944 | 0.85187 | 0.88812 |
| 1.62509 | 0.83680 | 0.87845 |
| 1.62922 | 0.82105 | 0.86874 |
| 1.63275 | 0.80523 | 0.85859 |
| 1.63580 | 0.78941 | 0.84822 |
| 1.63840 | 0.77359 | 0.83769 |
| 0.95000 | 20 | 20 |

| | | |
|---------|---------|---------|
| 1.35726 | 0.97102 | 0.81987 |
| 1.38929 | 0.97102 | 0.84073 |
| 1.42133 | 0.97102 | 0.85526 |
| 1.45336 | 0.97102 | 0.86980 |
| 1.48540 | 0.97102 | 0.88183 |
| 1.51743 | 0.97102 | 0.89386 |
| 1.54946 | 0.97102 | 0.90388 |
| 1.58105 | 0.97070 | 0.91241 |
| 1.61194 | 0.96992 | 0.91867 |
| 1.63950 | 0.96694 | 0.92105 |
| 1.66292 | 0.96137 | 0.92070 |
| 1.68311 | 0.95395 | 0.91860 |
| 1.69946 | 0.94438 | 0.91439 |
| 1.71258 | 0.93310 | 0.90842 |
| 1.72322 | 0.92063 | 0.90000 |
| 1.73041 | 0.90638 | 0.89123 |
| 1.73651 | 0.89184 | 0.88145 |
| 1.74059 | 0.87640 | 0.87158 |
| 1.74457 | 0.86126 | 0.86140 |
| 1.74754 | 0.84583 | 0.85138 |
| 1.00000 | 20 | 20 |
| 1.38711 | 0.99696 | 0.77393 |
| 1.42020 | 0.99696 | 0.79336 |
| 1.45329 | 0.99696 | 0.81000 |
| 1.48638 | 0.99696 | 0.82576 |
| 1.51947 | 0.99696 | 0.83910 |
| 1.55255 | 0.99696 | 0.85183 |
| 1.58564 | 0.99696 | 0.86353 |
| 1.61872 | 0.99695 | 0.87356 |
| 1.65182 | 0.99696 | 0.88231 |
| 1.68490 | 0.99696 | 0.88968 |
| 1.71799 | 0.99696 | 0.89566 |
| 1.75005 | 0.99633 | 0.89995 |
| 1.78040 | 0.99469 | 0.90246 |
| 1.80698 | 0.99092 | 0.90263 |
| 1.82776 | 0.98393 | 0.90018 |
| 1.84157 | 0.97321 | 0.89439 |
| 1.85022 | 0.95989 | 0.88667 |
| 1.85708 | 0.94592 | 0.87930 |
| 1.86273 | 0.93163 | 0.87018 |
| 1.86818 | 0.91759 | 0.86105 |
| 1.05000 | 20 | 20 |
| 1.41597 | 1.02120 | 0.73195 |
| 1.45007 | 1.02120 | 0.75226 |
| 1.48417 | 1.02120 | 0.77030 |
| 1.51826 | 1.02120 | 0.78534 |
| 1.55236 | 1.02120 | 0.80113 |
| 1.58646 | 1.02120 | 0.81316 |
| 1.62056 | 1.02120 | 0.82444 |
| 1.65466 | 1.02120 | 0.83609 |
| 1.68875 | 1.02120 | 0.84511 |
| 1.72285 | 1.02120 | 0.85188 |
| 1.75695 | 1.02120 | 0.85977 |
| 1.79031 | 1.02076 | 0.86654 |

File Format Examples

| | | |
|---------|---------|---------|
| 1.82363 | 1.02032 | 0.87256 |
| 1.85639 | 1.01957 | 0.87782 |
| 1.88775 | 1.01809 | 0.88008 |
| 1.91809 | 1.01611 | 0.88158 |
| 1.94624 | 1.01304 | 0.88026 |
| 1.97086 | 1.00824 | 0.87675 |
| 1.98989 | 1.00071 | 0.87073 |
| 2.00549 | 0.99167 | 0.86391 |

| | | |
|---------|---------|---------|
| 1.10000 | 20 | 20 |
| 1.43517 | 1.03692 | 0.68436 |
| 1.46994 | 1.03692 | 0.70447 |
| 1.50470 | 1.03692 | 0.72457 |
| 1.53947 | 1.03692 | 0.74098 |
| 1.57424 | 1.03692 | 0.75602 |
| 1.60900 | 1.03692 | 0.76955 |
| 1.64377 | 1.03692 | 0.78158 |
| 1.67854 | 1.03692 | 0.79286 |
| 1.71330 | 1.03692 | 0.80338 |
| 1.74807 | 1.03692 | 0.81193 |
| 1.78283 | 1.03692 | 0.82068 |
| 1.81760 | 1.03692 | 0.82759 |
| 1.85237 | 1.03692 | 0.83311 |
| 1.88713 | 1.03692 | 0.83797 |
| 1.92190 | 1.03692 | 0.84011 |
| 1.95667 | 1.03692 | 0.84173 |
| 1.99111 | 1.03675 | 0.84173 |
| 2.02522 | 1.03642 | 0.83945 |
| 2.05896 | 1.03592 | 0.83573 |
| 2.09163 | 1.03492 | 0.82733 |

Surge Line

| <i>Speed</i> | <i>Press Ratio</i> | <i>Mass Flow</i> | <i>Efficiency</i> |
|--------------|--------------------|------------------|-------------------|
| 0.60 | 1.246477 | 0.4365782 | 0.7989637 |
| 0.70 | 1.343149 | 0.5287515 | 0.7920929 |
| 0.80 | 1.468887 | 0.6552594 | 0.8201060 |
| 0.85 | 1.543116 | 0.7298065 | 0.8405574 |
| 0.90 | 1.634555 | 0.7958678 | 0.8524758 |
| 0.95 | 1.743676 | 0.8646593 | 0.8637053 |
| 1.00 | 1.861099 | 0.9357553 | 0.8728305 |
| 1.05 | 1.989583 | 1.0008320 | 0.8708260 |
| 1.10 | 2.073170 | 1.0354850 | 0.8320776 |

10.2.5 Example File with Smooth Fan Data

Note: the explanations (text in blue/italic) are not part of an actual file!

| | |
|-----------------|----------------------|
| <i>Map Type</i> | <i>Map Title</i> |
| 13 | Inner&Outer Demo Map |

| | |
|---|--|
| <i>Speed of the Map Reference Point</i> | <i>Beta of the Map Reference Point</i> |
| RefSpeed=1.0000000 | RefBeta=0.6407091 |

| | | |
|---------------------|-------------------------------|-------------------------------|
| <i>Ref. Mach no</i> | <i>Ref. ψ</i> | <i>Ref. ϕ</i> |
| RefMach=0.5000000 | RefPsi=1.0000000 | RefPhi=1.0000000 |

of Speed Lines Keyword (relativized or non-relativized)

7 Non-Relativized Map

| <i>Speed</i> | <i># of Points</i> | <i># of Points</i> | | | |
|------------------|--------------------|--------------------|------------------|---------------|--------------------|
| 0.545 | 15 | 15 | | | |
| <i>Pressr. 1</i> | <i>Mass Flow</i> | <i>Eff. 1</i> | <i>Pressr. 2</i> | <i>Eff. 2</i> | <i>(BPR, opt.)</i> |
| 1.08992 | 63.24414 | 0.88559 | 1.08952 | 0.80822 | 0 |
| 1.09194 | 61.83673 | 0.89284 | 1.09634 | 0.83053 | 0 |
| 1.09367 | 60.40570 | 0.89736 | 1.10256 | 0.84461 | 0 |
| 1.09519 | 58.97959 | 0.90077 | 1.10795 | 0.84913 | 0 |
| 1.09644 | 57.55102 | 0.90231 | 1.11339 | 0.84728 | 0 |
| 1.09756 | 56.16327 | 0.90308 | 1.11774 | 0.84006 | 0 |
| 1.09851 | 54.81633 | 0.90286 | 1.12096 | 0.82795 | 0 |
| 1.09931 | 53.51020 | 0.90198 | 1.12339 | 0.81195 | 0 |
| 1.09991 | 52.24490 | 0.90039 | 1.12529 | 0.79666 | 0 |
| 1.10048 | 51.06122 | 0.89894 | 1.12652 | 0.77957 | 0 |
| 1.10085 | 49.91837 | 0.89659 | 1.12754 | 0.76178 | 0 |
| 1.10121 | 48.85714 | 0.89407 | 1.12791 | 0.74325 | 0 |
| 1.10138 | 47.83673 | 0.89113 | 1.12809 | 0.72514 | 0 |
| 1.10156 | 46.89796 | 0.88813 | 1.12763 | 0.70839 | 0 |
| 1.10176 | 46.04082 | 0.88527 | 1.12719 | 0.69314 | 0 |
| | | | | | |
| 0.635 | 15 | 15 | | | |
| 1.13676 | 74.35250 | 0.89821 | 1.13501 | 0.80460 | 0 |
| 1.13896 | 73.06122 | 0.90141 | 1.14589 | 0.82728 | 0 |
| 1.14087 | 71.72542 | 0.90444 | 1.15583 | 0.84332 | 0 |
| 1.14268 | 70.38961 | 0.90782 | 1.16369 | 0.85179 | 0 |
| 1.14457 | 69.09833 | 0.91112 | 1.17065 | 0.85689 | 0 |
| 1.14611 | 67.76500 | 0.91386 | 1.17625 | 0.85679 | 0 |
| 1.14769 | 66.47198 | 0.91533 | 1.18157 | 0.85079 | 0 |
| 1.14890 | 65.14286 | 0.91597 | 1.18551 | 0.84132 | 0 |
| 1.14989 | 63.81254 | 0.91542 | 1.18923 | 0.82807 | 0 |
| 1.15055 | 62.46382 | 0.91335 | 1.19112 | 0.81282 | 0 |
| 1.15102 | 61.12801 | 0.91072 | 1.19242 | 0.79580 | 0 |
| 1.15142 | 59.83673 | 0.90764 | 1.19351 | 0.77781 | 0 |
| 1.15165 | 58.57143 | 0.90434 | 1.19375 | 0.76107 | 0 |
| 1.15178 | 57.34694 | 0.90107 | 1.19355 | 0.74512 | 0 |
| 1.15201 | 56.20408 | 0.89807 | 1.19345 | 0.72948 | 0 |
| | | | | | |
| 0.727 | 15 | 15 | | | |
| 1.19512 | 85.03525 | 0.90253 | 1.20321 | 0.81106 | 0 |
| 1.19833 | 84.03340 | 0.90687 | 1.21581 | 0.83059 | 0 |
| 1.20157 | 83.03606 | 0.91077 | 1.22849 | 0.84549 | 0 |
| 1.20433 | 81.95918 | 0.91344 | 1.23929 | 0.85602 | 0 |
| 1.20672 | 80.82496 | 0.91566 | 1.24893 | 0.86032 | 0 |
| 1.20884 | 79.64948 | 0.91708 | 1.25722 | 0.86266 | 0 |
| 1.21072 | 78.43856 | 0.91813 | 1.26479 | 0.86152 | 0 |
| 1.21236 | 77.20123 | 0.91850 | 1.27087 | 0.85743 | 0 |
| 1.21383 | 75.94434 | 0.91832 | 1.27630 | 0.85065 | 0 |
| 1.21495 | 74.64564 | 0.91749 | 1.28026 | 0.84137 | 0 |
| 1.21616 | 73.38404 | 0.91628 | 1.28320 | 0.82968 | 0 |
| 1.21699 | 72.08020 | 0.91446 | 1.28519 | 0.81548 | 0 |
| 1.21749 | 70.74954 | 0.91163 | 1.28572 | 0.80043 | 0 |
| 1.21800 | 69.45083 | 0.90836 | 1.28570 | 0.78570 | 0 |

File Format Examples

| | | | | | |
|---------|----------|---------|---------|---------|---|
| 1.21829 | 68.15213 | 0.90493 | 1.28489 | 0.77003 | 0 |
| 0.864 | 15 | 15 | | | |
| 1.31125 | 101.5804 | 0.90304 | 1.35880 | 0.82101 | 0 |
| 1.31486 | 100.8275 | 0.90480 | 1.37410 | 0.83586 | 0 |
| 1.31845 | 100.0594 | 0.90676 | 1.38872 | 0.84697 | 0 |
| 1.32160 | 99.22449 | 0.90838 | 1.40293 | 0.85514 | 0 |
| 1.32483 | 98.38961 | 0.90996 | 1.41582 | 0.85997 | 0 |
| 1.32790 | 97.52134 | 0.91138 | 1.42786 | 0.86197 | 0 |
| 1.33055 | 96.58813 | 0.91268 | 1.43802 | 0.86186 | 0 |
| 1.33301 | 95.61781 | 0.91376 | 1.44580 | 0.86021 | 0 |
| 1.33541 | 94.63109 | 0.91440 | 1.45281 | 0.85545 | 0 |
| 1.33744 | 93.58389 | 0.91468 | 1.45796 | 0.85035 | 0 |
| 1.33952 | 92.53669 | 0.91440 | 1.46317 | 0.84340 | 0 |
| 1.34131 | 91.44312 | 0.91372 | 1.46733 | 0.83540 | 0 |
| 1.34303 | 90.33766 | 0.91271 | 1.47069 | 0.82579 | 0 |
| 1.34478 | 89.23220 | 0.91143 | 1.47335 | 0.81528 | 0 |
| 1.34617 | 88.07531 | 0.90991 | 1.47487 | 0.80459 | 0 |
| 0.955 | 15 | 15 | | | |
| 1.40392 | 112.3785 | 0.88541 | 1.49899 | 0.81222 | 0 |
| 1.40887 | 111.9221 | 0.89256 | 1.52744 | 0.83086 | 0 |
| 1.41287 | 111.3506 | 0.89736 | 1.54934 | 0.84500 | 0 |
| 1.41625 | 110.6963 | 0.90069 | 1.56838 | 0.85491 | 0 |
| 1.41918 | 109.9777 | 0.90258 | 1.58187 | 0.86055 | 0 |
| 1.42214 | 109.2467 | 0.90403 | 1.59301 | 0.86310 | 0 |
| 1.42482 | 108.4675 | 0.90506 | 1.60123 | 0.86308 | 0 |
| 1.42740 | 107.6623 | 0.90570 | 1.60820 | 0.86038 | 0 |
| 1.43012 | 106.8571 | 0.90588 | 1.61528 | 0.85598 | 0 |
| 1.43252 | 106.0000 | 0.90588 | 1.62087 | 0.85053 | 0 |
| 1.43505 | 105.1429 | 0.90551 | 1.62545 | 0.84337 | 0 |
| 1.43761 | 104.2746 | 0.90469 | 1.63034 | 0.83490 | 0 |
| 1.44009 | 103.3840 | 0.90322 | 1.63316 | 0.82585 | 0 |
| 1.44247 | 102.4675 | 0.90185 | 1.63586 | 0.81555 | 0 |
| 1.44459 | 101.5065 | 0.90011 | 1.63826 | 0.80496 | 0 |
| 1.000 | 15 | 15 | | | |
| 1.43539 | 115.7299 | 0.87803 | 1.57656 | 0.80215 | 0 |
| 1.44387 | 115.6883 | 0.88304 | 1.60802 | 0.81713 | 0 |
| 1.45181 | 115.5891 | 0.88654 | 1.63469 | 0.82993 | 0 |
| 1.45940 | 115.4508 | 0.88883 | 1.65706 | 0.84009 | 0 |
| 1.46616 | 115.2204 | 0.89018 | 1.67554 | 0.84667 | 0 |
| 1.47171 | 114.8514 | 0.89112 | 1.68911 | 0.85079 | 0 |
| 1.47629 | 114.3673 | 0.89167 | 1.70006 | 0.85167 | 0 |
| 1.47982 | 113.7551 | 0.89222 | 1.70932 | 0.85005 | 0 |
| 1.48293 | 113.0816 | 0.89258 | 1.71656 | 0.84574 | 0 |
| 1.48548 | 112.3265 | 0.89267 | 1.72264 | 0.84045 | 0 |
| 1.48782 | 111.5306 | 0.89185 | 1.72744 | 0.83324 | 0 |
| 1.48961 | 110.6531 | 0.89038 | 1.73108 | 0.82509 | 0 |
| 1.49072 | 109.6735 | 0.88819 | 1.73342 | 0.81558 | 0 |
| 1.49133 | 108.6122 | 0.88549 | 1.73565 | 0.80529 | 0 |
| 1.49210 | 107.5510 | 0.88293 | 1.73655 | 0.79375 | 0 |
| 1.047 | 15 | 15 | | | |
| 1.45571 | 117.8247 | 0.85894 | 1.63142 | 0.77718 | 0 |
| 1.46419 | 117.8024 | 0.86104 | 1.66507 | 0.78922 | 0 |

| | | | | | |
|---------|----------|---------|---------|---------|---|
| 1.47254 | 117.7653 | 0.86278 | 1.69368 | 0.80055 | 0 |
| 1.48081 | 117.7205 | 0.86441 | 1.71618 | 0.81073 | 0 |
| 1.48894 | 117.6603 | 0.86617 | 1.73605 | 0.81889 | 0 |
| 1.49709 | 117.6001 | 0.86773 | 1.75238 | 0.82537 | 0 |
| 1.50494 | 117.5073 | 0.86919 | 1.76791 | 0.82937 | 0 |
| 1.51283 | 117.4165 | 0.87075 | 1.78089 | 0.83108 | 0 |
| 1.52068 | 117.3200 | 0.87258 | 1.79334 | 0.83029 | 0 |
| 1.52789 | 117.1494 | 0.87478 | 1.80505 | 0.82817 | 0 |
| 1.53447 | 116.9051 | 0.87643 | 1.81444 | 0.82446 | 0 |
| 1.53985 | 116.5185 | 0.87689 | 1.82189 | 0.81856 | 0 |
| 1.54461 | 116.0510 | 0.87579 | 1.82752 | 0.80946 | 0 |
| 1.54895 | 115.5241 | 0.87341 | 1.83320 | 0.79920 | 0 |
| 1.55203 | 114.8377 | 0.86956 | 1.83684 | 0.78705 | 0 |

Surge Line

| <i>Speed</i> | <i>Pressr. 1</i> | <i>Mass Flow</i> | <i>Eff. 1</i> | <i>Pressr. 2</i> | <i>Eff. 2</i> |
|--------------|------------------|------------------|---------------|------------------|---------------|
| 0.545 | 1.101753 | 46.06936 | 0.8853689 | 1.127205 | 0.6936671 |
| 0.635 | 1.151206 | 60.52664 | 0.9092988 | 1.192923 | 0.7874990 |
| 0.727 | 1.217009 | 72.02947 | 0.9143502 | 1.285211 | 0.8148959 |
| 0.864 | 1.346170 | 88.07531 | 0.9099077 | 1.474872 | 0.8045735 |
| 0.955 | 1.442848 | 102.2961 | 0.9015372 | 1.636291 | 0.8136464 |
| 1.000 | 1.492100 | 107.5510 | 0.8829300 | 1.736550 | 0.7937500 |
| 1.047 | 1.551284 | 115.0039 | 0.8704857 | 1.835965 | 0.7899715 |

10.2.6 Example File with Surge Line Input

In a file with **measured** data the surge line is given through the number of the surge point within a data group for constant speed.

Note: the explanations (text in blue/italic) are not part of an actual file!

Map Type *Map Title*

1 Fan Rotor J.Propulsion 1992 Page 200

of Speed Lines *Keyword (relativized or non-relativized)*

9 Non-Relativized Map

Speed *# of Points* *# of the Surge Point**

0.60000 9 3

Press Ratio *Mass Flow* *Efficiency*

1.23860 0.47970 0.82800

1.22870 0.51110 0.85500

1.24650 0.43660 0.80000 *<-Surge Point*

1.21780 0.53620 0.87500

1.20890 0.56330 0.89200

1.19400 0.58420 0.90450

1.18020 0.61620 0.91380

1.15148 0.63970 0.91500

1.12970 0.64890 0.91450

Next Speed Line...

**use 0 when the surge point is not included*

Look also at the complete file examples with measured **compressor** and **fan** data.

In a file with **smooth** data the surge line information is at the end of the file:

Surge Line

| <i>Speed</i> | <i>Press Ratio</i> | <i>Mass Flow</i> | <i>Efficiency</i> |
|--------------|--------------------|------------------|-------------------|
| 0,60 | 1,246477 | 0,4365782 | 0,7989637 |
| 0,70 | 1,343149 | 0,5287515 | 0,7920929 |
| 0,80 | 1,468887 | 0,6552594 | 0,8201060 |
| 0,85 | 1,543116 | 0,7298065 | 0,8405574 |
| 0,90 | 1,634555 | 0,7958678 | 0,8524758 |
| 0,95 | 1,743676 | 0,8646593 | 0,8637053 |
| 1,00 | 1,861099 | 0,9357553 | 0,8728305 |
| 1,05 | 1,989583 | 1,0008320 | 0,8708260 |
| 1,10 | 2,073170 | 1,0354850 | 0,8320776 |

10.2.7 Example File with Cycle Data

The sequence of the data lines in a file with cycle data is of no importance. The comment is optional. Points without a comment will be marked with numbers in the graphics.

Note: the explanations (text in blue/italic) are not part of an actual file!

File Type *File Title*
20 Fan Operating Line Data Points

of (not empty) lines with data to follow
7

| <i>Press Ratio</i> | <i>Mass Flow</i> | <i>Efficiency</i> | <i>Speed</i> | <i>Comment</i> |
|--------------------|------------------|-------------------|--------------|----------------|
| 1.24 | 0.631 | 0.890 | 0.640 | Idle SLS |
| 1.31 | 0.711 | 0.900 | 0.725 | |
| 1.42 | 0.792 | 0.902 | 0.805 | |
| 1.57 | 0.885 | 0.910 | 0.890 | Cruise |
| 1.65 | 0.972 | 0.925 | 0.940 | |
| 1.68 | 0.999 | 0.885 | 1.005 | |
| 1.75 | 1.025 | 0.840 | 1.045 | Max Climb |

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