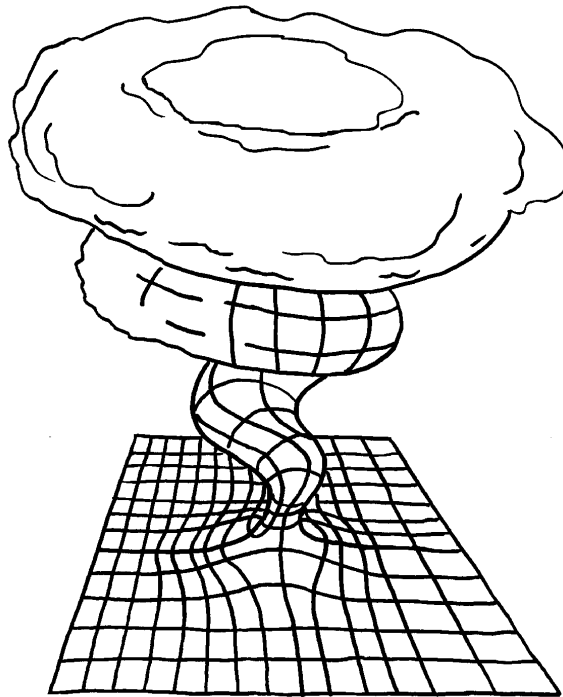


USER'S GUIDE

Reference manual

TORNADO 1.0

RELEASE 2.3 2001-01-31



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Background

This document is a part of the master thesis "A Vortex Lattice MATLAB Implementation for Linear Aerodynamic Wing Applications" by Tomas Melin written at the Aerodynamics department during 1999-2000. This is the user's guide for the Matlab program "Tornado", which is part of the thesis, and contains a description of the program.

Aim

It is the aim of this document to provide a user's guide and a reference manual for Tornado. The contents should give instructions on how to use and develop the program. Also, the inner structure of Tornado is explained and the course of program execution is shown.

Copyright information

This document as well as the program "Tornado" is distributed according to the GNU-Open license protocol.

Introduction to Tornado

The program.

Tornado is a 3D-vortex lattice program with flexible wake. It may be used for a variety of tasks that require the Tornado's output. These outputs are: 3D forces acting on each panel, aerodynamic coefficients in both body and wind axis. Stability derivatives with respect to angle of attack, angle of sideslip, angular rates and rudder deflections.

In order to be easily ported, Tornado is written in Matlab. The required Matlab version is 5.3. Tornado works on any Matlab-supporting platforms. It has been tested for win95, win98, NT4, Solaris and Mac OS.

Tornado is an open source program, according to GNU.

Methods.

Tornado is based on standard vortex lattice theory, stemming from potential flow theory. The wake coming off the trailing edge of every lifting surface is flexible and changes shape according to the flight condition. For example: a rolling aircraft will have a “cork-screw” shaped wake, which will influence the aerodynamic coefficients. The classical “horse-shoe” arrangement of other vortex-lattice programs has been replaced with a “vortex-sling” arrangement. It basically works in the same way as the “horse-shoe” procedure with the exception that the legs of the shoe are flexible and consist of seven (instead of three) vortices of equal strength. This is shown in figure 1.

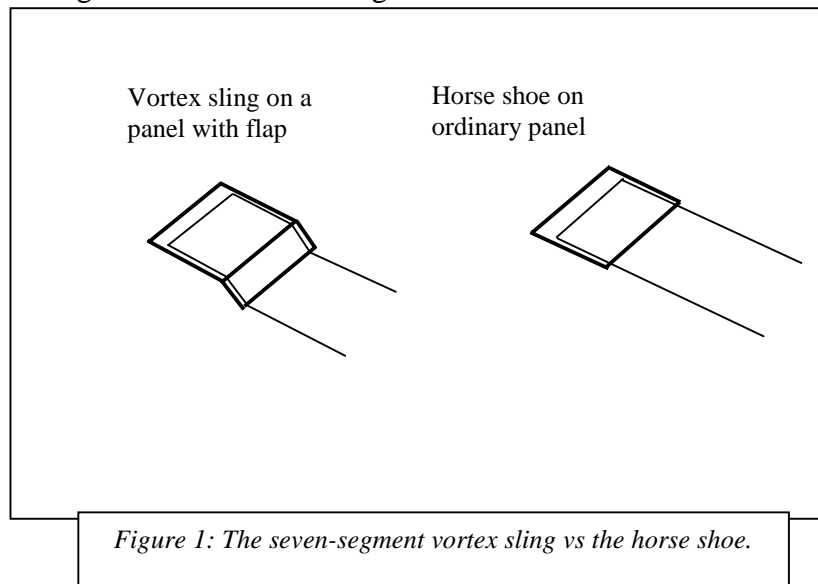


Figure 1: The seven-segment vortex sling vs the horse shoe.

The source of the basic theory for the vortex lattice method used in Tornado has been the book "Computational Fluid Dynamics" by Moran [1].

To calculate the first order derivatives, Tornado performs a central difference calculation using the pre-selected state and disturbing it by a small amount, usually 0.5 degrees.

With the distorting wake, non-linear effects will be visible in some designs, especially in those where main wing/stabiliser interactions are important.

Applications.

Tornado is meant to be used primarily in the conceptual design stage of aircraft construction or in training and education.

Tornado supports multi-wing designs with swept, tapered, cambered, twisted and cranked wings with or without dihedral. Any number of wings may be utilised as well as any number of control surfaces. Canards, flaps, ailerons, elevators and rudders may be employed. Winglets, fences and engine mounts may also be incorporated in the design.

Cautions.

One of the primary assumptions in the vortex lattice theory is the small angle of attack. Therefore, caution is advised when examining large angles as well as large rotational speeds.

No consideration is taken to fuselage effects or to any friction drag.

Compressibility effects are neglected, as are thickness effects of the lifting surfaces.

Quick-start

How-to

Start Tornado

Start Matlab, version 4.2 or later.

Connect to the directory containing Tornado.

Start Tornado by typing “Tornado”, and press enter.

Load a geometry

Select option <Aircraft geometry setup>

Select option <load geometry>

Load the example file X-00.mat by typing “X-00” and press enter.

Load a state

Select option <flight state setup>

Select option <load state>

Load the example file a5v10.mat by typing “a5v10” and press enter.

Calculate a solution

Select option <Processor access>

Select option <Simple solutions calculation>

View results

Select option <Post processor >

Select option <Solution plot, simple state>

User Interface

Menu system

Most functions in Tornado may be reached via text menus. The menu that becomes visible directly at start-up is the main menu. Other menus are the flight state menu, the solver menu and the result/plot menu. Navigate through the different menus enter the number of the row containing the desired command.

Tornado Main Menu (TMM)

This version of Tornado is text-based with a menu system. From the Tornado main menu all of the essential functions in Tornado may be reached, see fig. 2.

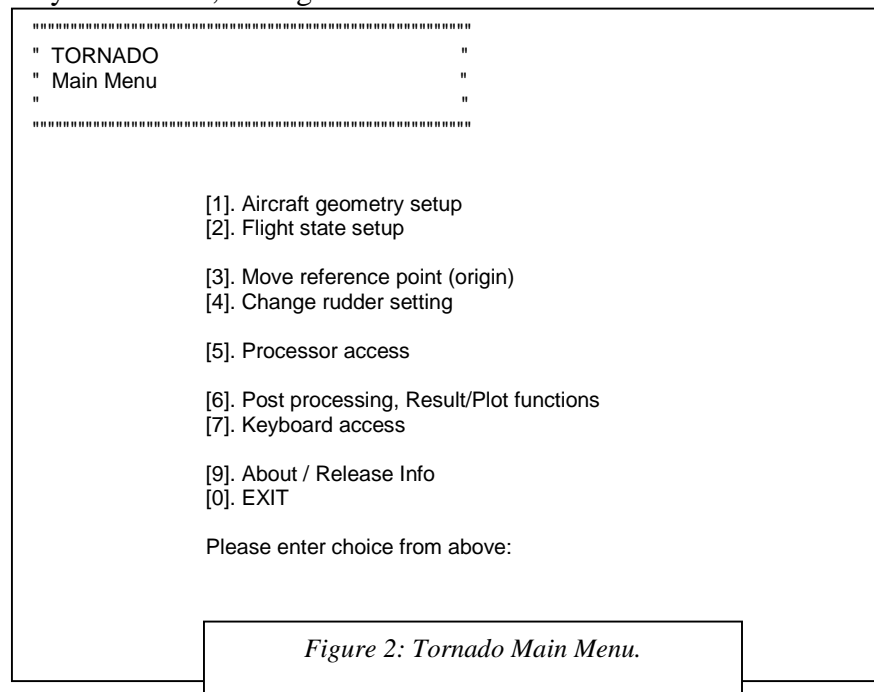


Figure 2: Tornado Main Menu.

Aircraft geometry setup menu.

From the Aircraft geometry setup menu, you may select to create a new geometry design, to load a geometry from file, to save a geometry to file or to edit a geometry currently in memory. The aircraft geometry setup is shown in figure 3

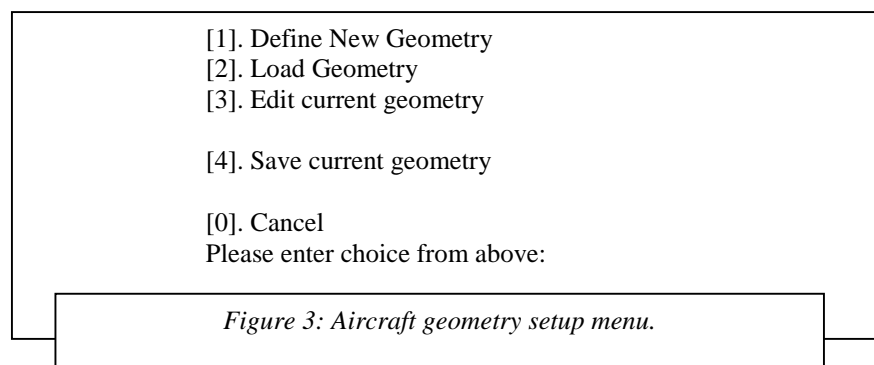


Figure 3: Aircraft geometry setup menu.

Flight state setup menu.

In the flight state setup menu, you may select to create a new state, to load a state from file or to save a state to file. The state is the flight condition with angle of attack, angle of sideslip rotational angular rates and true airspeed. The flight state menu is shown in figure 4.

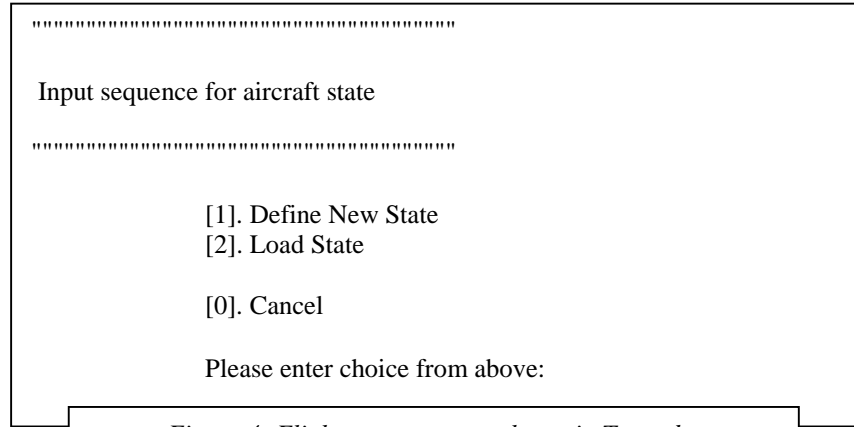


Figure 4: Flight state menu as shown in Tornado.

Move reference point.

When selecting the menu choice <Move reference point> you will be transferred into the submenu for moving the reference point. N.B. The reference point in Tornado is always the system origin [0,0,0]. Thus moving the reference point will actually move the entire aircraft geometry together with the wake to accommodate the new position of origin. <The move reference point> menu is shown in figure 5. This change cannot be saved to file. For a permanent modification, use the edit geometry option in the geometry menu to move the wing apex and then save to file.

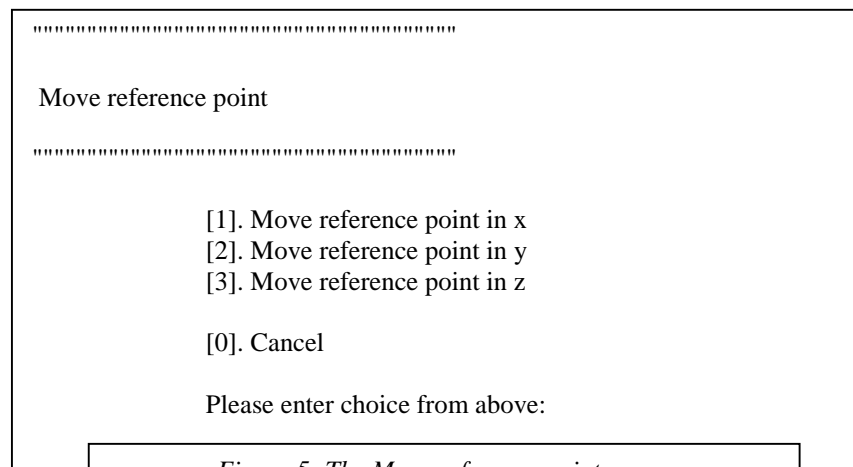
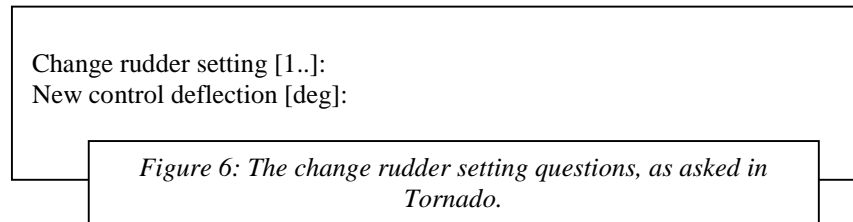


Figure 5: The Move reference point menu.

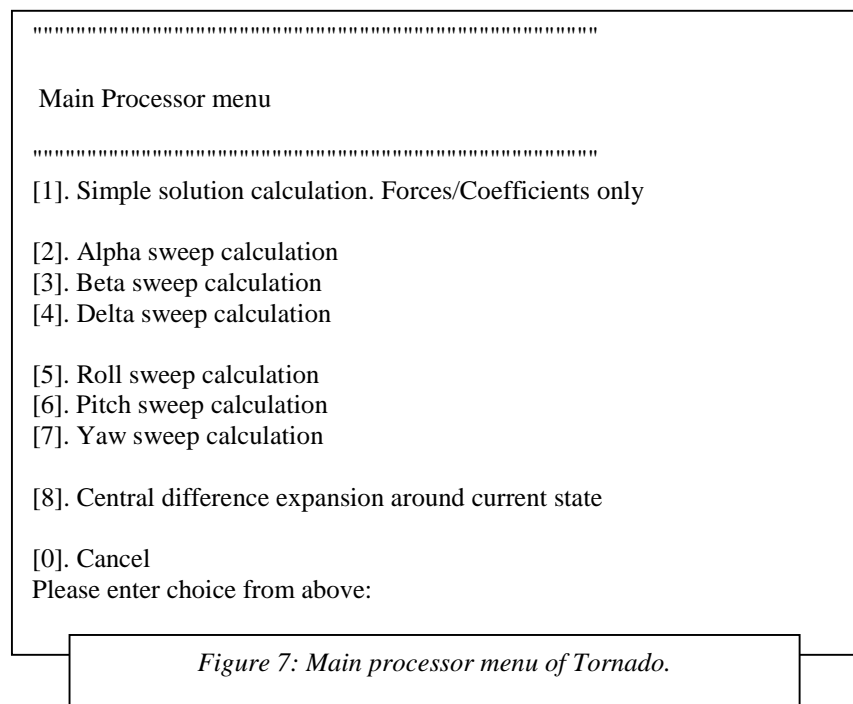
Change rudder setting.

The change rudder setting menu will allow change of deflection of flaps, ailerons, elevators and other trailing edge control surfaces. Keep in mind that all deflecting surfaces are called flaps in Tornado and that they are numbered in the order that they were created. The <Change rudder setting> menu option will not start a sub-menu, but rather just ask two questions as shown in figure 6



Processor access

This menu option will open the main solver submenu. From here you may choose different forms of solutions. See figure 7.



The simple solution calculation will give you the zeroth order coefficients (CL, CD and so on) for the entire design at the selected state. Results are saved in the output file /output/fmcoeff.mat, you can also access them from the post-processor menu.

The different sweep calculations will perform a series of simple calculations by varying the selected parameter (alpha, beta ...) and saving the coefficients as vectors in the output file.

(Example: output/Cx_alpha.mat). The parameter delta is the flap deflection. In this function you must also specify for which rudder to do the deflection sweep.

You can also get result plots from the post-processor menu.

The central difference calculation option will launch a central difference calculation in order to get the first order derivatives of the coefficients. Results are saved in the output/fmfcoeff.mat. As before you can review the results directly in the post-processor menu. Rudder derivatives are stored as a vector in the same order as their corresponding rudders.

Post-processing, Result/Plot functions

In the post-processor menu you can reach the solutions to each calculation done in the processor menu. However since results are saved to file after each calculation, a lock-variable will stop you from plotting old results from previous calculations. To be on the safe side you may want to delete all files in the /output/ directory when starting a new design.

The post-processor menu is shown in figure 8.

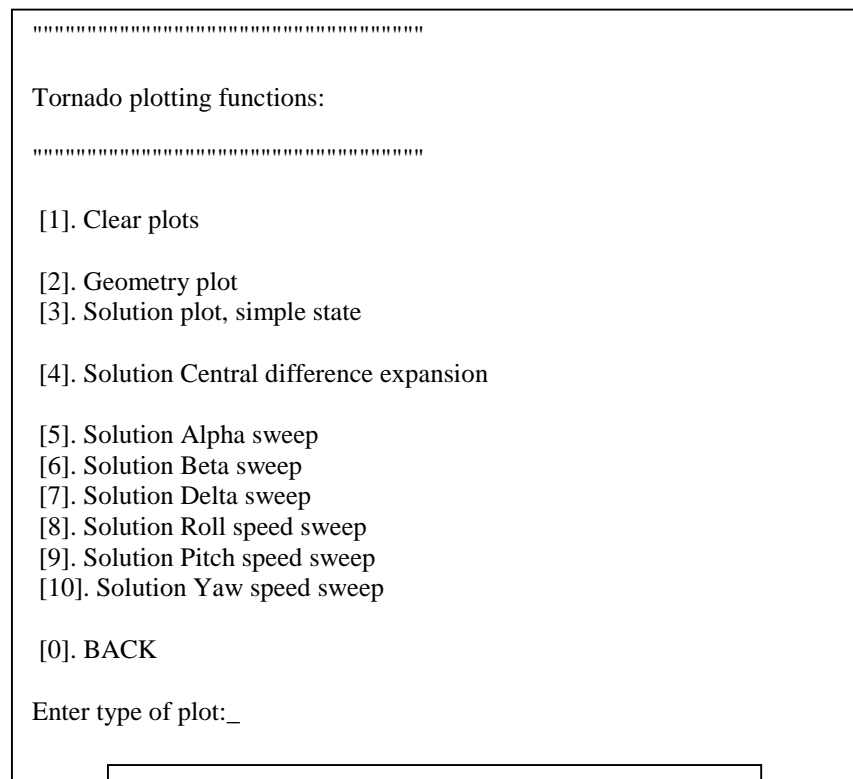


Figure 8: The post-processor menu of Tornado.

Keyboard access

Selecting the <keyboard access> option will give you a “>>” prompt in the workspace, this might come in handy if you want to

check some variables during execution. Return to the Tornado main menu by typing "return" and press enter.

About / Release Info

The about / release info menu option will, when selected, give you the release info with changes in design since the last update.

EXIT

Terminates Tornado, some variables will remain in memory, so be sure to clear these if running your own modules afterwards. If you have run the solver, the result variables will be available in the output directory and are called "*.mat" files.

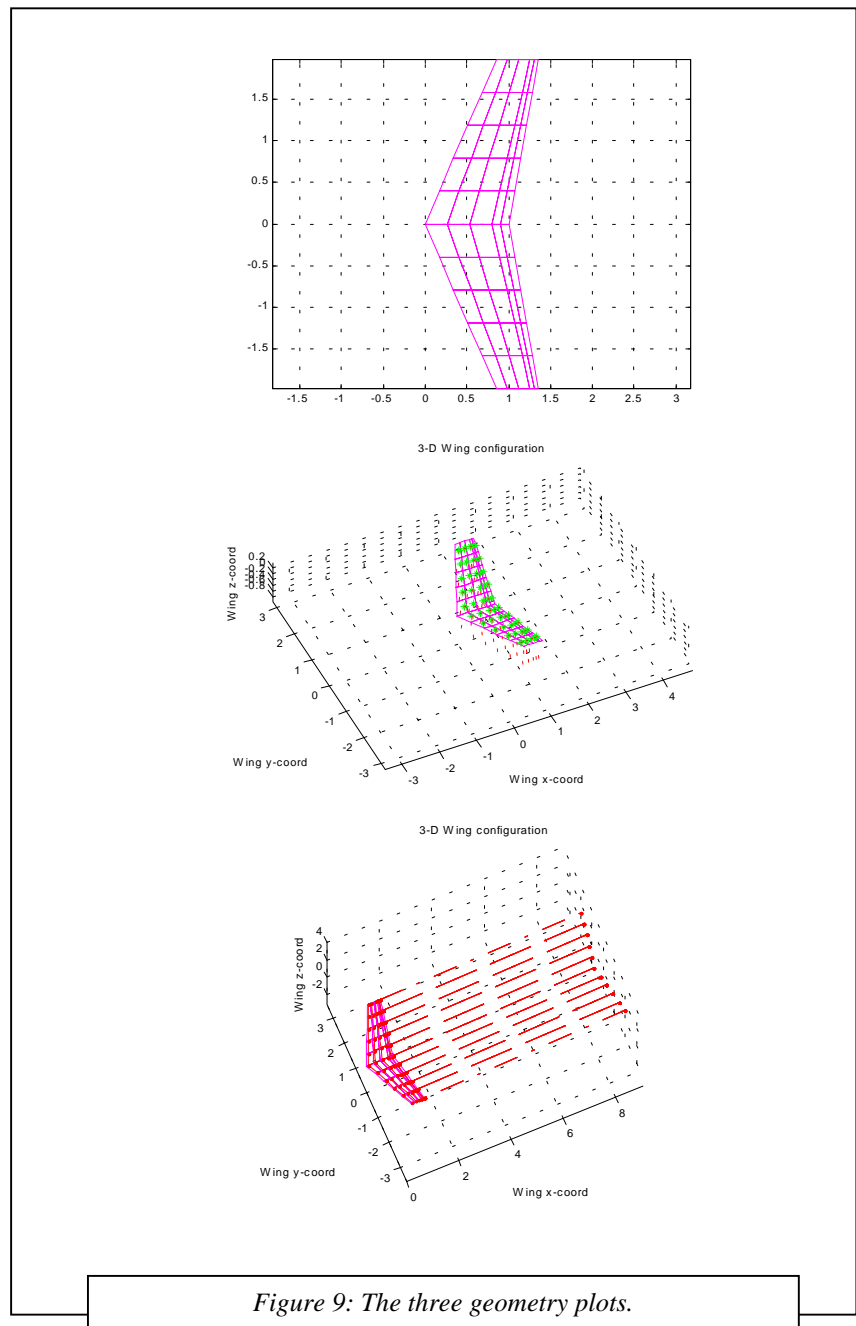
Plots

Geometry plots

When you select the option <draw geometry> in the postprocessor menu, Tornado will draw three plots. The first plot is a 2D-plot of the planform with layout of wings, partitions and panels. This figure is drawn in the XY- plane.

The second plot shows the planform layout in 3D. The “Rotate3D” function is enabled so you can grab the figure and rotate it. This plot will also show the collocation points of the panels with the panel normals drawn as dashed lines.

The third plot shows the panel layout with the trailing vortices visible. All of these plots are shown in figure 9.



Simple solution plots

The <Solution plot, simple state> option in the post-processor menu will when selected yield plots 4 to 7. Plot number four displays the delta cp distribution across the aircraft. A colour bar indicates the values. An example is shown in figure 10

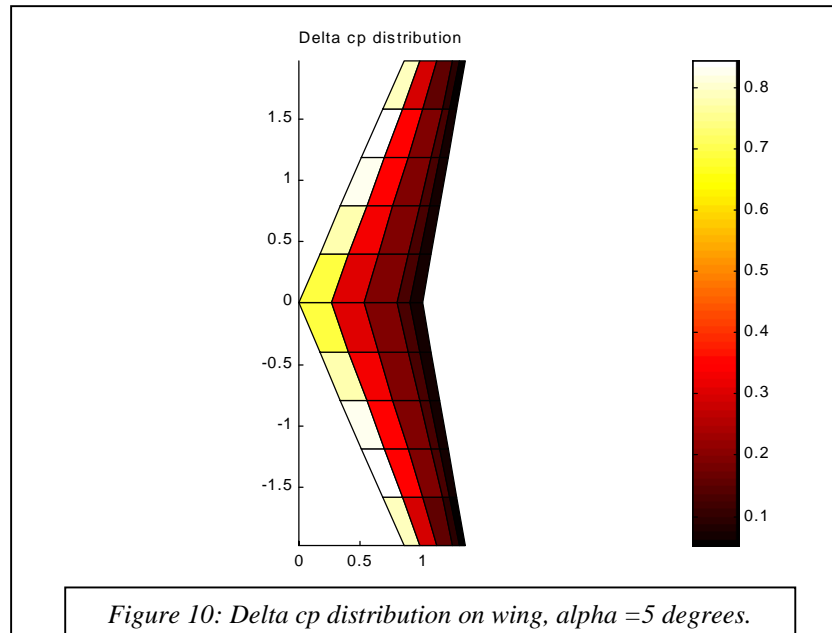
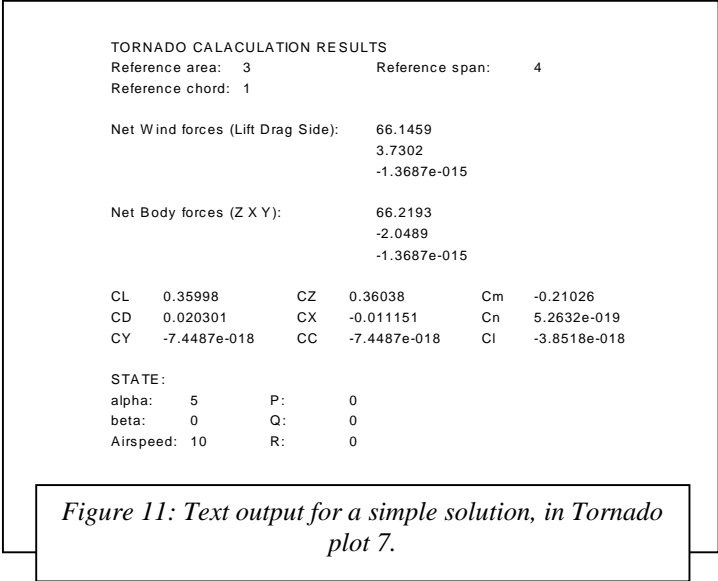


Figure 10: Delta cp distribution on wing, alpha =5 degrees.

Plot number five shows the panel force's Z-component displayed as an arrow on each panel. As the arrow starts in the xy-plane, this plot is the clearest for designs with moderate dihedral.

Plot number six shows the wing vorticity as an elevated surface above the planform. This plot will only be useful, or accurate, if you have a “convex hull” geometry. Otherwise all points within the design’s hull which are not part of the geometry (e.g. area between wing and stabilizer) will be displayed with an interpolated vorticity.

Plot number seven will present calculation results as hard numbers. These are loaded from the output file “fmcoeff.m”, where more data is available. An example of the plot is shown in figure 11.



Central difference solution plots.

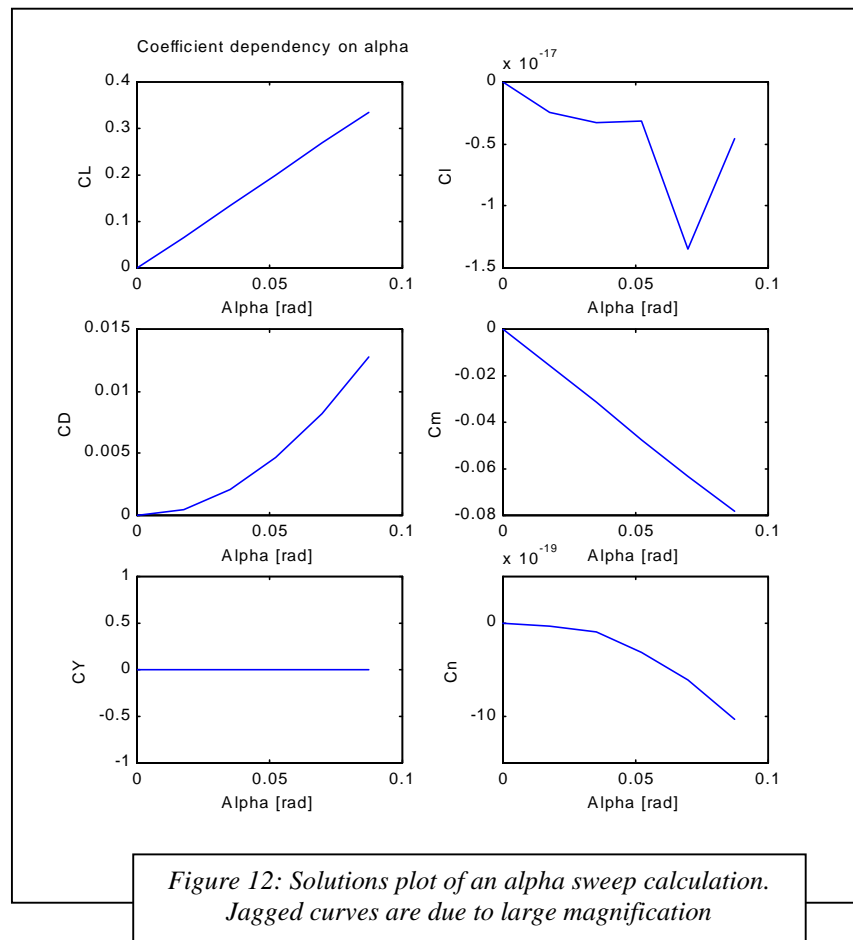
After a central difference expansion calculation is made, the results may be viewed in the post-processor. The results are presented in two figures containing text. The first one, plot number 8, shows the stability derivatives with respect to the different state variables. The second one, plot number 9, shows the rudder derivatives.

Sweep plots.

When a sweep calculation has been performed in the <processor access> menu results can be reviewed using the < Solution Alpha sweep>, or any other type of sweep that has been performed, from the post-processor.

All of the sweep plots will yield a figure with six subplots. Each of these subplots will show a coefficient as a function of the selected sweep parameter.

An example of a sweep plot is shown in figure 12.



Output files.

Tornado will produce a number of files containing the output from the different kinds of calculations. Regarding the contents of these files, please see the chapter on data structures.

The output files are located in the /output/ directory and they are:

ac.mat	A copy of the geometry used for the last solution
fmcoeff.mat	Results of a simple state calculation.
Fmfcoeff.mat	Results of a central difference expansion.
Cx_alpha.mat	Results of an alpha sweep.

The other sweep results follow the same pattern, and are called Cx_beta, Cx_P and so on.

Design features.

Co-ordinate system.

Tornado uses a Cartesian coordinate system with the X-axis along the aircraft body, increasing aft. The Y-axis is aligned positive out through the starboard wing when no dihedral is present. The Z-axis is right-hand perpendicular to the X- and Y-axis. I.e. positive “upwards”. When the dihedral is 90 degrees (as for a fin) the span is fully aligned in the Z-positive direction.

Main wing reference.

The first wing entered is considered to be the main wing. The root chord of the main wing defines the direction of the X-axis

Wings.

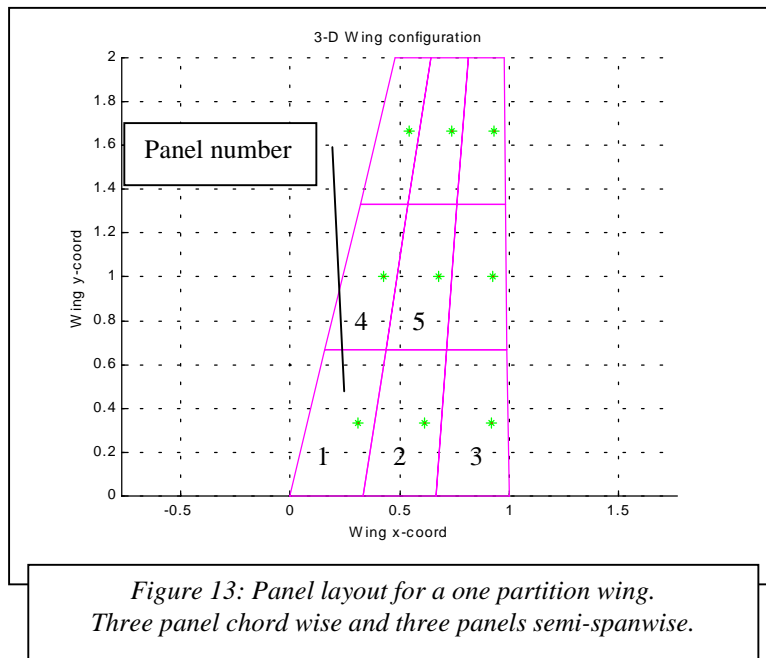
In TORNADO, every flat surface is considered as a wing, this means that there are no differences in input or calculation between main wing, stabiliser or fin. To create both the starboard and the port sides of the main wing, tick “wing is mirrored”. Do the same for the stabiliser. As for the fin, don’t use the symmetry setting but set the dihedral angle to 90 degrees. This procedure will give you one wing half with its span directed in the Z-direction.

Partitions.

Every lifting surface such as wing, fin and so on is composed of a number of partitions. The simplest wing contains only one partition while a more complex one may have five or more. In each partition the wing design features are constant. Examples are sweep and taper ratio. Exceptions are twist and camber which have to be defined with inner and outer values for the first partition of a wing. Succeeding partitions take on the outer feature of the previous element as their inner feature to assure continuity along the wing's span. Thereby, elements are numbered outwards.

Panels.

The panels are the small four-corned elements that build up each partition. No special input is needed to define their shape, as this is auto generated once the number of panels in the chord-wise and span-wise directions have been entered. In the current version of Tornado the panels are evenly distributed on the partitions. For reference, panels are numbered from the leading edge backwards in row by row outwards. See figure 13



Wing features.

Each wing has special features, which define the shape of the wing. During the geometry setup these are the inputs needed for each partition:

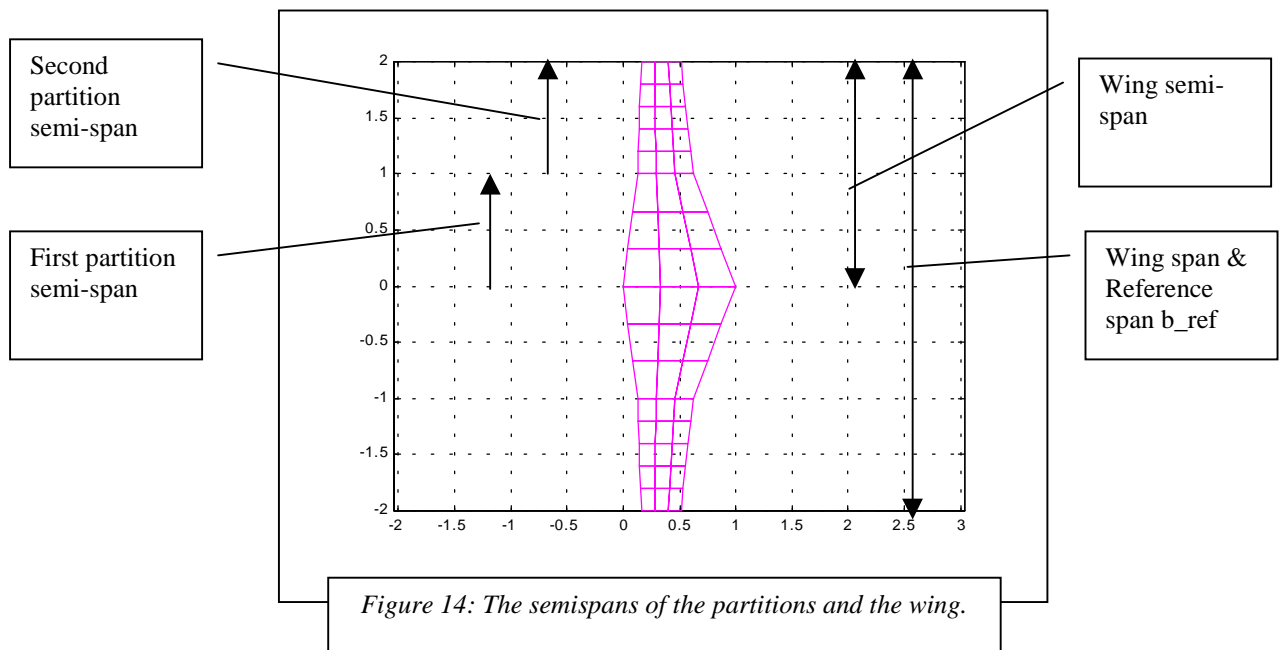
- Apex coordinates.
- Span.
- Taper.
- Sweep.
- Camber.
- Dihedral.
- Twist.
- Symmetry.
- Root chord. (One per wing.)
- Flaps.
- Flap symmetry. (If flap is present.)
- Flap chord in parts of root chord. (If flap is present.)
- Number of panels in chord (X) direction.
- Number of panels in span (Y) direction.
- Number of panels on the flap (If flap is present.)

Apex coordinates.

For each wing the apex coordinates have to be specified. The apex is located at the first partition root chord leading edge. It is important to know that all moments are calculated around the system origin (0,0,0) so that the main wing apex is placed accordingly (most often in [-0.25,0,0] if the root chord is 1).

Span.

The span you are required to enter is the semispan of the partition in question, i.e. the distance from the innermost to the outermost part of the partition. The sum of the semispans of the partitions is the semispan of the entire wing. See figure 14 for details.



Taper.

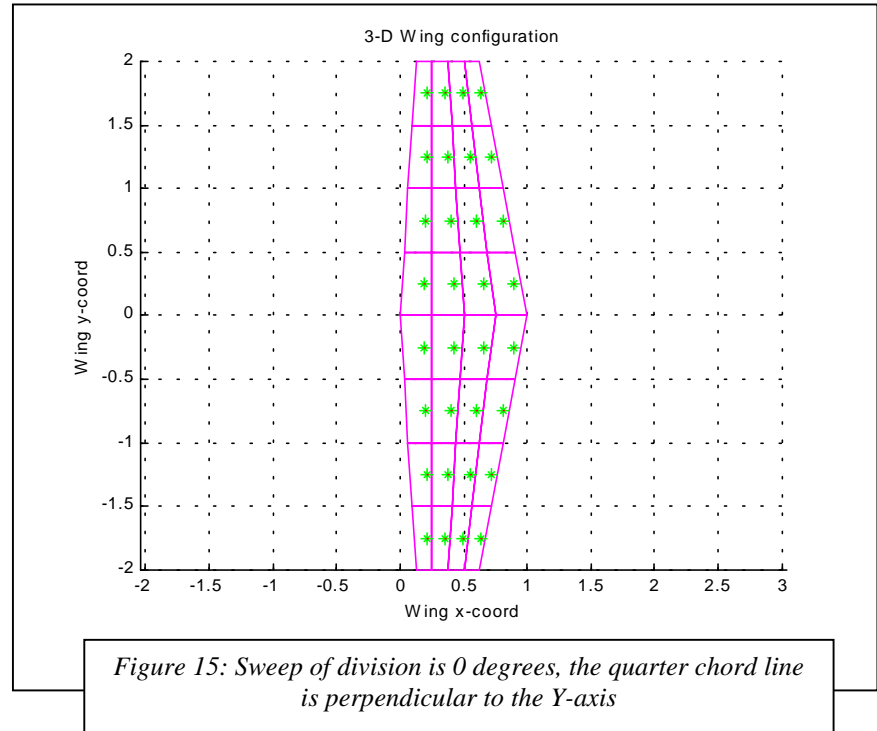
The taper or taper ratio, is defined for each partition as follows:

$$T = \frac{c_{outer}}{c_{inner}} \quad (1)$$

where c is the local chord of the partitions. Figure 13 above has a taper ratio of 0.5, which is visible in the picture.

Sweep.

The sweep of the partition is defined for the quarter chord line (see figure 15) The sweep is the angle between the quarter chord line and the Y-axis.



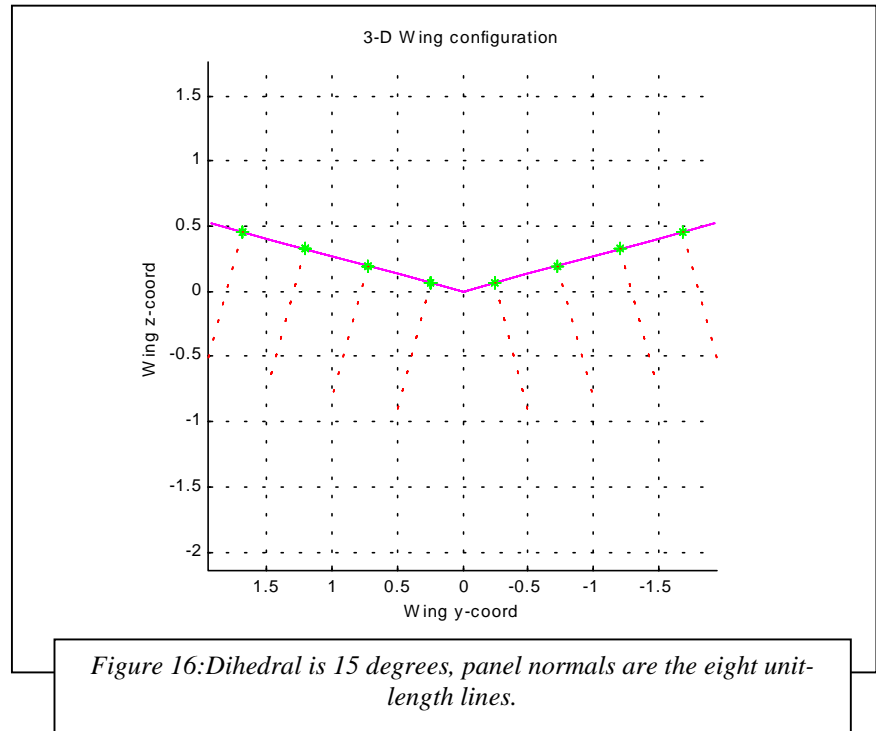
Camber.

The camber lines currently available are taken from the NACA-XXXX series. For the first partition of a wing, both inner and outer camber must be specified. For subsequent partitions only the outer camber is needed.

Note for advanced users: The slope is calculated in the function "slope.m". To use other airfoils, this is the function to edit.

Dihedral.

The dihedral is the angle between the XY-plane and the quarter chord line (see figure 16). Currently only one dihedral angle per wing is possible. For multiple dihedral wings, please use more than one wing and set the outer wing apex to fit with the inner wing tip.



Twist.

The partition twist is defined as the angle between the tip chord of the partition and the root chord of the main wing (The first wing entered). For every additional wing, the root twist has to be entered as well as the tip twist.

Symmetry.

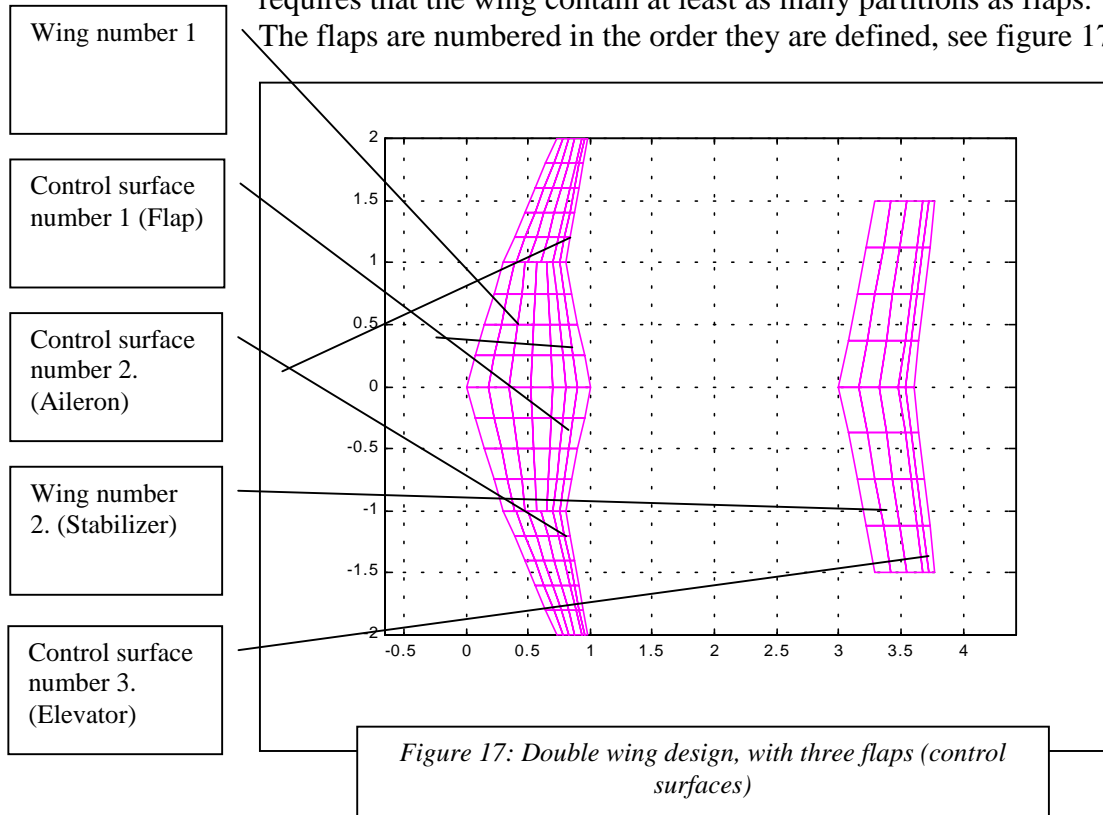
The symmetry option is a Boolean operator, which when set as "true" mirrors the wing in the XZ plane. When editing geometry, true =1, false =0. Usually symmetry should be set for main wing and stabiliser, but not for the fin.

Root chord. (One per wing.)

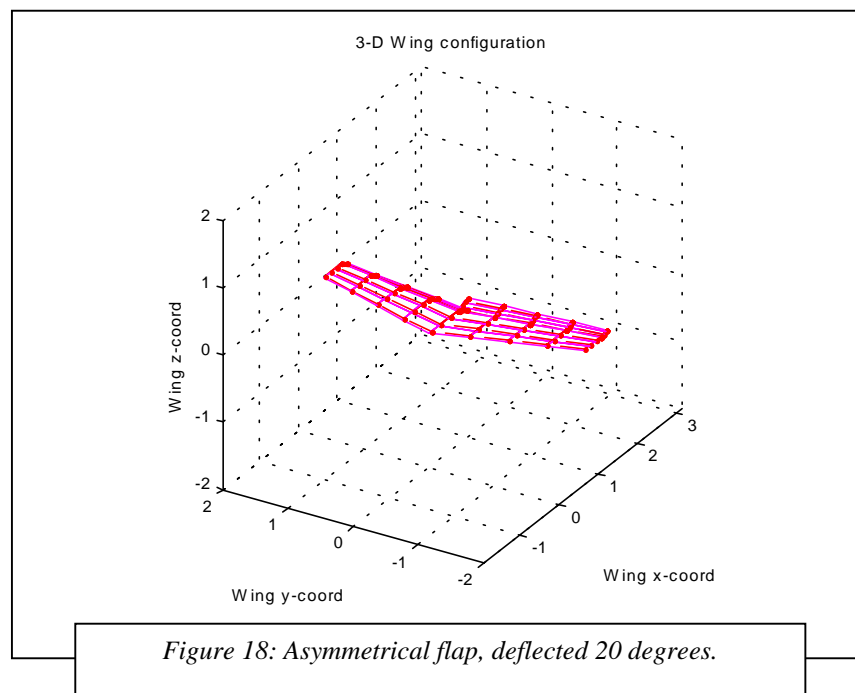
The root chord has to be entered for each wing. For a multiple partition wing, every additional partition after the first will have their root chords defined by the first partition root chord and taper-ratio (see section on taper). This is done automatically.

Flaps.

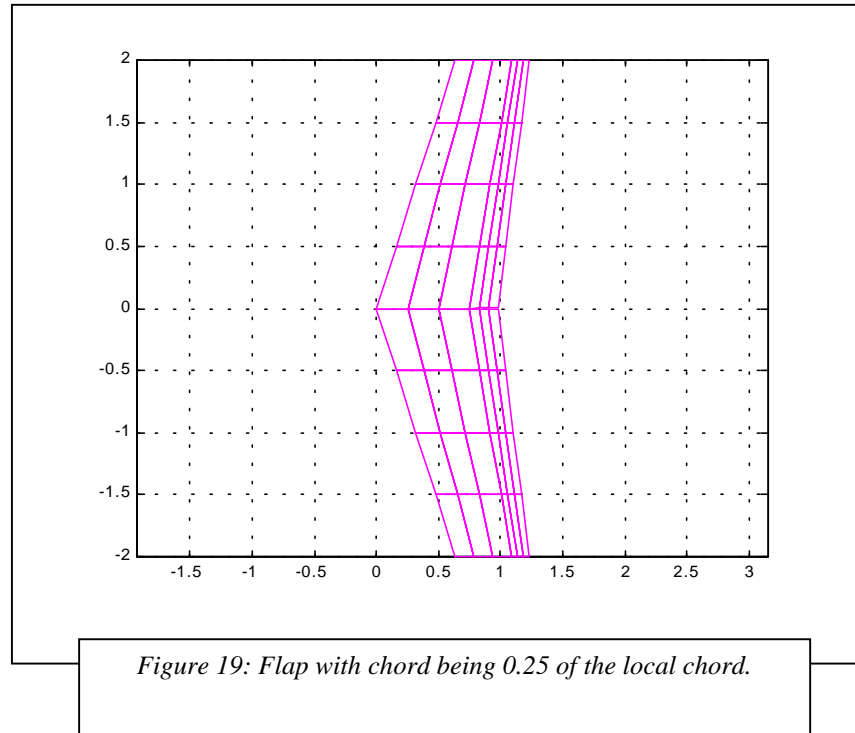
The flap option is a Boolean operator, when this is enabled the whole trailing edge of the partition is assumed to be a control surface. It is possible to have more than one flap per wing, but this requires that the wing contain at least as many partitions as flaps. The flaps are numbered in the order they are defined, see figure 17.



Flap symmetry. (If flap is present, and wing symmetry is set). If symmetry for the wing is enabled, you will be asked if the flap should be deflected symmetrically, i.e. both starboard and port flap down at the same time. The flap symmetry is a Boolean operator and should be true for flaps and elevators, but false for ailerons. See figure 18.



Flap chord fraction of local wing chord. (If flap is present.)
To define the flap chord, you should enter which fraction of the local wing chord is allocated to the flap. Valid inputs are in the range [0 to 1]. See figure 19



Number of panels in chord (X) direction.

The number of panels in the chord direction will only have to be specified for the first partition of a wing. Every subsequent partition will have the same number of panels.

Note to advanced users: It is possible to change this value for subsequent partitions of a wing. To do so, use the <Edit> function in the geometry menu. Select the wing and partition to change and select <change nx>.

Number of panels in span (Y) direction.

For each partition, the number of panels in the span direction must be specified.

Number of panels on the flap (If flap is present.)

If a flap is present, the number of panels in the chord direction of the flap must be specified.

Reference units.

There are three reference units used in Tornado. They are automatically calculated during the geometry setup. If you want to use any other value you must edit the file config.m, in which instructions for this are included.

Name:	Dimension:
S_ref.	[L ²]
c_mac	[L]
b_ref	[L]

S_ref

Reference area, is by default the sum of areas of all panels on the first wing. The first defined wing considered to be the main wing of the design.

c_mac

Mean aerodynamic chord, is by default the area-weighted average mean aerodynamic chord of each partition on the main wing.

b_ref

The sum of partition semi-spans of the main wing, and twice this value if the wing is mirrored in the XZ-plane.

The state model

State model features

Angle of attack

The angle of attack is defined as the angle of the oncoming air-stream and the main wing root chord in the XZ-plane.

By convention it is denoted “alpha”.

Angle of sideslip

The angle of sideslip is defined as the angle of the oncoming air-stream and the main wing root chord in the XY-plane.

By convention it is denoted “beta”.

Roll angular rate

The roll angular rate is the angular velocity around the X-axis. It is denoted as “P” and should be entered in rad/s

Pitch angular rate

The pitch angular rate is the angular velocity around the Y-axis. It is denoted as “Q” and should be entered in rad/s

Yaw angular rate

The yaw angular rate is the angular velocity around the Z-axis. It is denoted as “R” and should be entered in rad/s

Air speed

The air speed is needed to calculate forces and moments. It is denoted “AS” and should be entered in meters/second.

Tornado functions.

Geometry setup.

Creating a model.

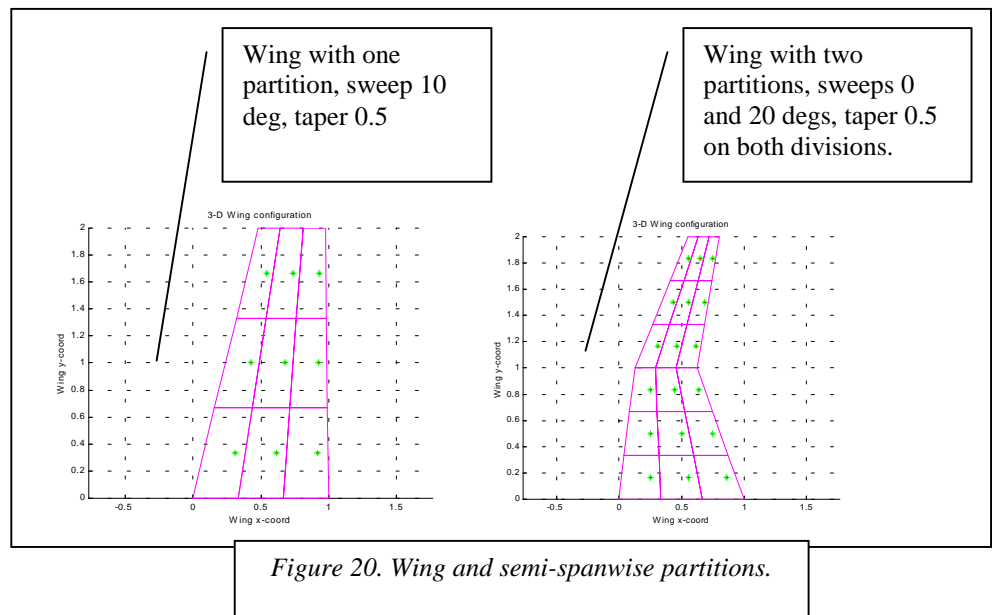
The creation of a new aircraft model is initiated by selecting <create new geometry> in the geometry menu. This will initiate a sequence of questions regarding the geometry of the new aircraft. First the number of wings in the new design should be entered. Wing in this context means every coherent surface producing lift, e.g. main wing, stabiliser or vertical fin. For a GA-aircraft these three would constitute the 3 wings to enter.

For each wing, the input of necessary wing features will be requested. This will be done in a nested loop, one partition after another, running down each wing. Please see the wing features chapter for reference to these inputs.

For each wing, the number of semispanwise partitions should be entered. The semispanwise partition is a subdivision of the entire wing. Basically, more than one partition should always be used if the wing is cranked, or wing properties (taper, sweep etc.) are changed along the wing's span.

A sketch of the wing and the wing partition is supplied as figure 20

Important: partitions are numbered running outboard.



When the number of partitions for the current wing has been supplied the sequence with input of wing features for the first partition is started.

When all partitions for the current wing have been defined, the input sequence turns to the next wing where the procedure is repeated.

A typical input sequence for a one-wing one-partition design is shown in figure 21. The resulting geometry is shown in figure 22

```

*****
* Data regarding wing number: 1
*****
Number of semispanwise divisions: 1
*****
Data regarding division1
Is wing mirrored in xz [1 0]: 1

Apex x-coord: 0
Apex y-coord: 0
Apex z-coord: 0
Root chord: 1
Base chord airfoil nr: 0
Wing dihedral [deg]: 0
Number of vortices chordwise: 3
Number of vortices semispanwise: 4
Span of division: 2
Taper ratio: .5
Outboard airfoil nr: 0
1/4 Chord line Sweep [deg]: 20
Outboard 1/4 Chord twist [deg]: 0
Is division flapped [1 0]:1
Flap chord in parts of root chord (0..1): 0.2
Number of chordwise vorticies on flap: 2
Does control deflect symetrically [1 0]:1

```

Figure 21. Typical input sequence for a wing partition.

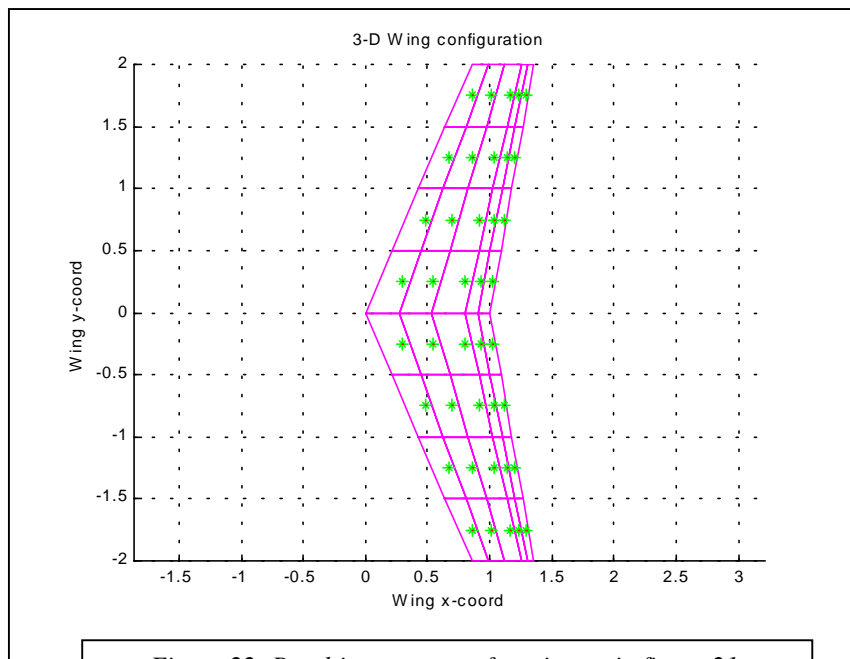


Figure 22: Resulting geometry from inputs in figure 21.

Saving a model.

To save a geometry design, select option <Save current geometry> in the GSM. A list of files of previously saved designs will be displayed as you are prompted for a file name for your new design. All aircraft designs are saved in the subdirectory /aircraft

Restoring a saved model.

To load a previously saved model, select <Load Geometry> in the GSM. A list of files of the contents of the aircraft/ directory will be displayed as you are prompted for the filename of the file to load.

Editing a model.

To edit a model, choose the option “Edit current geometry”. This will work only if a geometry is loaded in the memory.

In the geometry editor menu you may choose to add or remove wings or partitions or to edit the features of one or more partitions.

State setup.

Creating a model.

The state model is less complex than the geometric model. The state model consists of six variables: Alpha, beta, roll-, pitch- and yaw-angular rates as well as airspeed.

To create a new state model you must have a defined geometry onto which the state model should be applied.

Select the <state setup> option in the main menu, continue with the new state option. Enter the state model parameters as you are prompted for them.

Saving a model.

In the state menu, select <Save State>. The state model will be saved as a “*.mat” file in the data/ directory.

Restoring a saved model.

In the state menu, select load state. A list of previously defined state models is shown.

Change control surface setting.

Specifying control surface.

Control surfaces are numbered running outboard beginning with the first wing (normally main wing). For a GA design the first control surface would be the flaps, the second the ailerons, the third either rudder or elevator depending on if the fin was defined before the stabiliser or not.

Deflection.

Input control surface deflection is in degrees. All hinge lines are located at the leading edge of the rudder. Hinge lines run outboard and the deflection is defined right-hand positive for the starboard wing. The port side deflection is also defined in the same way if

rudder deflection symmetry is not selected, and the opposite if rudder deflection symmetry is selected (i.e. both flaps deflect downwards).

Program execution chart.

Figure 23 shows the execution chart of Tornado.

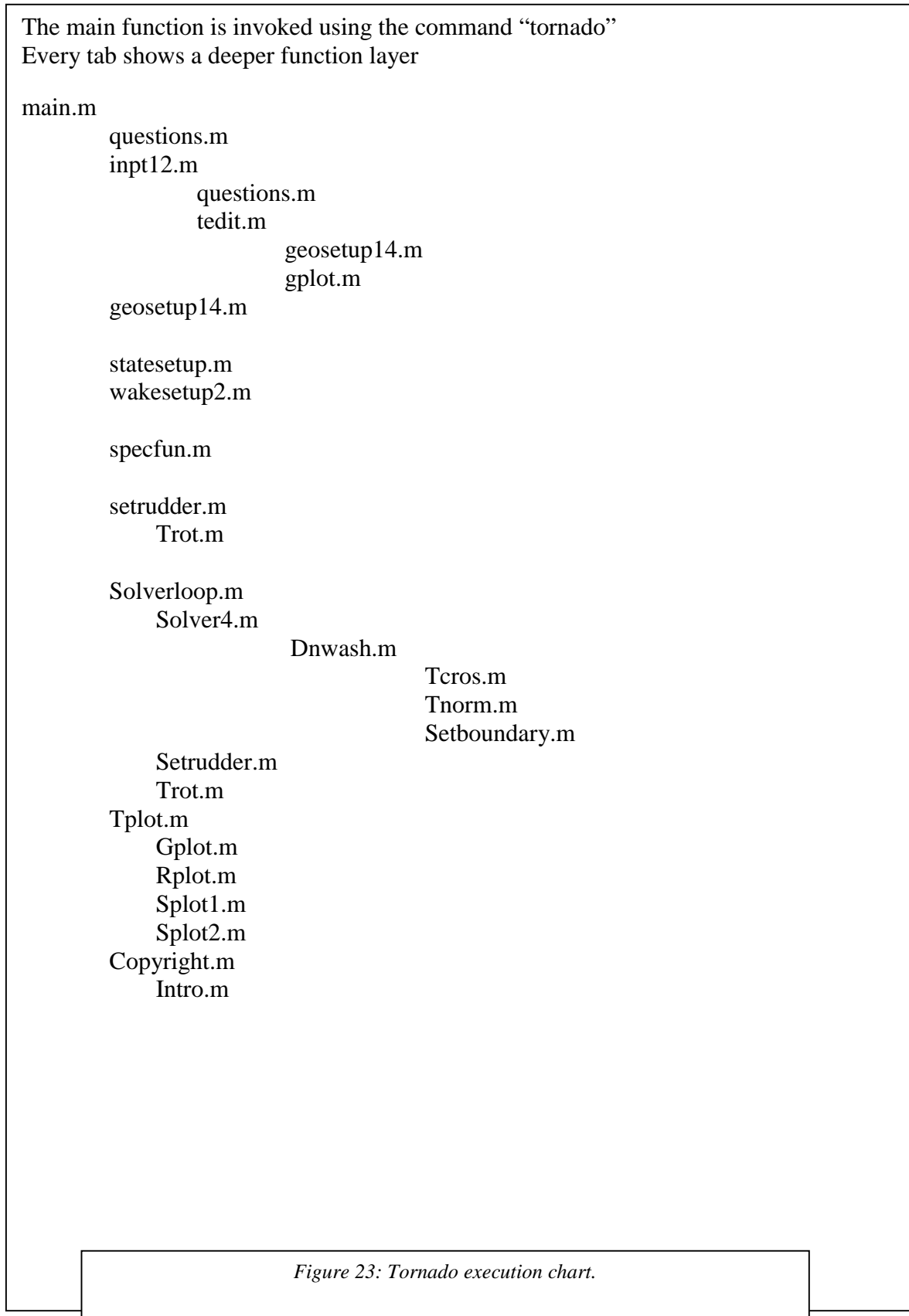


Figure 23: Tornado execution chart.

Data structures

Files

Input files.

Input files to Tornado are the geometry files, containing the aircraft design, and the state files, containing the description of the flight state.

None of these are needed to run Tornado the first time, but exist so that you may save and retrieve complex designs from disc.

The variables of the input files are listed below.

When using the standalone function <diffbatch.m> you are required to specify the files needed in the computation.

Diffbatch.m performs the central difference calculation in batch mode.

Output files.

A number of output files are produced by the different calculations possible in Tornado's main processor. They are all saved in the /output/ directory

They are:

fmcoeff.m	from simple solution.
fmfcoeff.m	from central difference.
Cx_alpha.m	from alpha sweep calculation.
Cx_beta.m	from beta sweep calculation.
Cx_P.m	from roll angular rate sweep calculation.
Cx_Q.m	from pitch angular rate sweep calculation.
Cx_R.m	from yaw angular rate calculation.

<Fmcoeff.m> contains the variables

Scalars

L	Lift
D	Induced drag
C	Side force
CL	Lift coefficient
CD	Induced drag coefficient
CC	Side force coefficient
CX	X-force
CY	Y-force
CZ	Z-force
CI	Roll moment coefficient

Cm Pitch moment coefficient
 Cn Yaw moment coefficient

Vectors

F Body force vector
 M Body moment vector

Matrices

FORCE Panel force vector (Force on each panel)
 MOMENTS Panel moment vector (Moments on origin caused by panel forces)

Cp Panel coefficient of pressure matrix

<fmfcoeff.m> contains the variables from the central difference calculation.

CC_P	CD_b	CX_R	CZ_P	Cl_b	Cn_R
CC_Q	CD_d	CX_a	CZ_Q	Cl_d	Cn_a
CC_R	CL_P	CX_b	CZ_R	Cm_P	Cn_b
CC_a	CL_Q	CX_d	CZ_a	Cm_Q	Cn_d
CC_b	CL_R	CY_P	CZ_b	Cm_R	
CC_d	CL_a	CY_Q	CZ_d	Cm_a	
CD_P	CL_b	CY_R	Cl_P	Cm_b	
CD_Q	CL_d	CY_a	Cl_Q	Cm_d	
CD_R	CX_P	CY_b	Cl_R	Cn_P	
CD_a	CX_Q	CY_d	Cl_a	Cn_Q	

The first letter, C, stands for coefficient.

The second letter stands for the coefficient involved (see <fmcoeff.m>)

The third letter stands for the derivative in question:

- a for alpha.
- b for beta.
- d for delta (rudder vector)
- P for roll speed.
- Q for pitch speed.
- R for yaw speed.

<Cx_alpha.m> Contains vectors describing a coefficient at different values of alpha, alpha itself is stored in the vector "affa".

Vectors:

CL_f_a	CL as function of alpha
CD_f_a	CD as function of alpha
CC_f_a	CC as function of alpha

Cl_f_a	Cl as function of alpha
Cm_f_a	Cm as function of alpha
Cn_f_a	Cn as function of alpha

CX_f_a	CX as function of alpha
CY_f_a	CY as function of alpha
CZ_f_a	CZ as function of alpha

Affa	The vector containing the different values of alpha.
------	--

The other output files <Cx_(parameter)> contains the coefficients, as a function of the parameter used in its name, just like Cx_alpha.

Variables.

Global.

The global variables in Tornado are:

b_ref	Scalar, reference span.
C_mac	Scalar, reference chord.
COLLOC	Matrix (3xnumber of panels) containing the xyz coordinates for all collocation points
gamma	Vector (number of panels) containing the vorticity of every vortex sling.
lock	Vector, lock-variable for different calculations/plots
N	Matrix (3xnumber of panels) containing the normals of every panel.
S_ref	Scalar of reference area.
VORTEX	Matrix (number of panelsx8x3) containing the xyz coordinates for all points on the vortex sling (normally 8 or 6).

Main.

The variables in Tornado's main function are:

alpha	Scalar, angle of attack.
AS	Scalar, airspeed.
b	Matrix (number of wings x number of partitions) showing span of each partitions.
betha	Scalar, angle of sideslip.
c	Vector (number of wings), root chord of each wing.

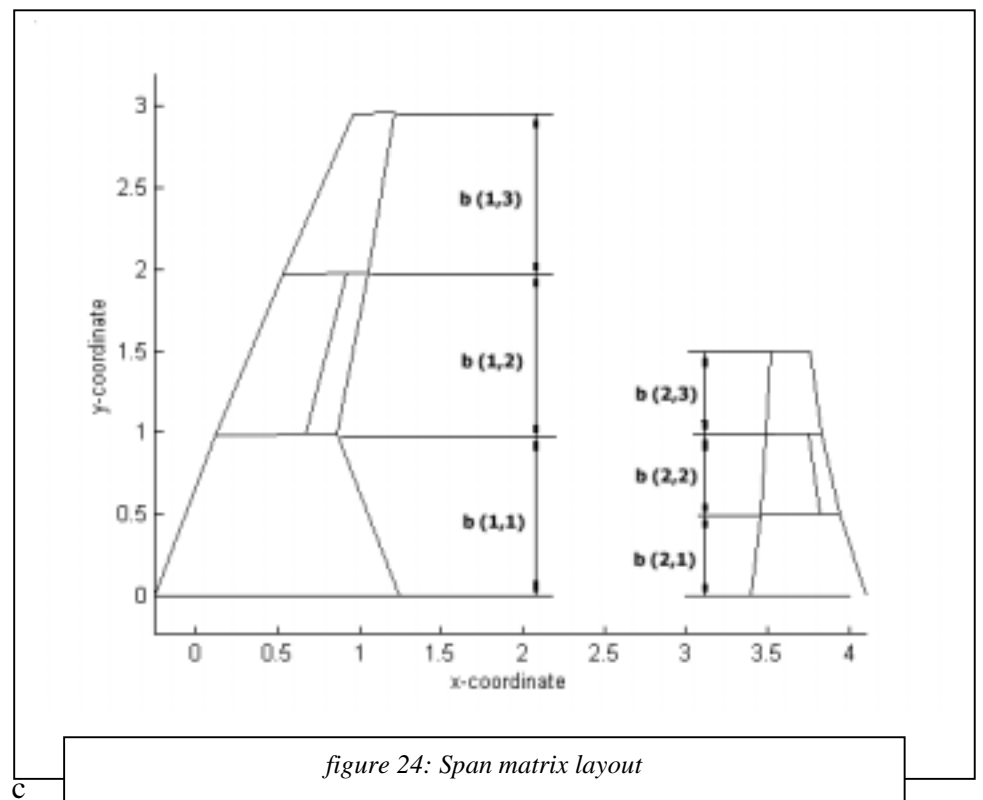
call	Scalar, status variable.
dihed	Matrix (number of wings x number of partitions) showing dihedral of each partitions.
fc	Matrix (number of wings x number of partitions) showing flap chord in parts of partitions chord.
flapped	Matrix (number of wings x number of partitions) showing if partition is flapped.
fnx	Matrix (number of wings x number of partitions) showing number of panels chordwise on each flap.
foil	Matrix (number of wings x number of partitions x 2) showing inner and outer airfoil of each partition, inner first
fsym	Matrix (number of wings x number of partitions) showing if flaps deflect symmetrically
Loop	Scalar, status variable.
nelem	Vector (number of wings), number of partitions per wing.
nx	Matrix (number of wings x number of partitions) showing number of panels chordwise.
ny	Matrix (number of wings x number of partitions) showing number of panels spanwise.
nwing	Scalar, number of wings
P	Scalar, roll angular rate.
Q	Scalar, pitch angular rate
R	Scalar, yaw angular rate.
stat	Scalar, status variable
startx	Vector (number of wings) showing apex x-coordinate of each wing.
starty	Vector (number of wings) showing apex y-coordinate of each wing.
startz	Vector (number of wings) showing apex z-coordinate of each wing.

SW	Matrix (number of wings x number of partitions) showing sweep of each partition.
symmetric	Vector (number of wings) showing symmetric state (1 or 0) of each wing.
T	Matrix (number of wings x number of partitions) showing taper of each partition.
TW	Matrix (number of wings x number of partitions x 2) showing inner and outer twist of each partitions, inner first.
void	Scalar, status variable.
XYZ	Matrix (number of panels x 5 x 3) showing xyz coordinates for every corner of each panel.

Input variables

All of these are variables in Toprnados main function. Some are needed to create a geometry and these are saved in the geometry input files in the "aircraft" directory. They are:

b Matrix (number of wings x number of partitions) showing span of each partitions. Figure 24 shows the layout of the b matrix, which is representative for all geometry matrices.



	Vector (number of wings), root chord of each wing.
dihed	Matrix (number of wings x number of partitions) showing dihedral of each partition. In the current release (1.10) of Tornado, the dihedral must be constant along the entire wing.
fc	Matrix (number of wings x number of partitions) showing flap chord in part of the local partition chord.
flapped	Matrix (number of wings x number of partitions) showing if partition is flapped. Boolean (1 or 0).
fnx	Matrix (number of wings x number of partitions) showing number of panels chord-wise on each flap.
foil	Matrix (number of wings x number of partitions x 2) showing inner and outer airfoil of each partition, inner first. Tornado release 1.10 supports flat and NACA-four digits chamber lines.
fsym	Matrix (number of wings x number of partitions) showing if flaps deflect symmetrically, Boolean.
nelem	Vector (number of wings), number of partitions per wing.
nx	Matrix (number of wings x number of partitions) showing number of panels chordwise.
ny	Matrix (number of wings x number of partitions) showing number of panels spanwise.
nwing	Scalar, number of wings
startx	Vector (number of wings) showing apex x-coordinate of each wing.
starty	Vector (number of wings) showing apex y-coordinate of each wing.
startz	Vector (number of wings) showing apex z-coordinate of each wing.
SW	Matrix (number of wings x number of partitions) showing sweep of each partition. In radians.

symmetric	Vector (number of wings) showing symmetry state Boolean (1 or 0) of each wing.
T	Matrix (number of wings x number of partitions) showing taper of each partition.
TW	Matrix (number of wings x number of partitions x 2) showing inner and outer twist of each partition, inner first.

Flight condition variables

These are the variables needed in a state file:

alpha	Scalar, angle of attack.
AS	Scalar, airspeed.
betha	Scalar, angle of sideslip.
P	Scalar, roll angular rate.
Q	Scalar, pitch angular rate
R	Scalar, yaw angular rate.

Function files.

config	Configuration function for different variables, i.e using other than standard S_ref.
cutline	Not used. For debugging only.
diffbatch	A batch program taking the filename of an aircraft geometry file and a state file as input. Producing a central difference expansion.
dnwash15:	Function calculating the aerodynamic influence of every vortex sling on every panel.
drawhinge:	Calculates the forward corners of a flap and draws a line in between, the hinge line.
geometry17:	Calculates the corner points, vortex points, normals and collocation points of each panel.
geosetup14:	Calculates the geometry of the wings and partitions, calls geometry to do the panels.

gplot Plots the geometry of the design, figures 1- 3

inpt12 Input function to get all geometry variables.

Intro Displays release info and startup-screen.

lemmabatch: Experimental function, not used in Tornado but please examine further.

main: Current main function of Tornado.

normals4: Calculates the normals of each panel.

questions: Most user interface questions are collected here.

rplot: Plots various results from a simple state solution.

setboundary3: Calculates the boundary conditions for each panel.

setrudder3: Function that rotates flap coordinates around the hinge.

setup12: Not used.

slope: Calculates the angle of normal rotation due to camber.

solver4: Calculates forces and moments of a design.

solverloop: Loops over solver4 to provide different kinds of solutions.

specfun: Moves the geometry around in the xyz-space.

splot: Not used.

splot1: Plots results of a central difference expansion.

splot2 Plots results of sweep calculations.

statesetup: Sets up the flight state.

tarea: Calculates the area of each panel.

tcros: Cross-product calculation.

tedit: Edit geometry function.

terror: Function to produce error messages.

tmesh Creates the panel cornerpoints.

tnorm Calculates length of a 3-d vector.

tplot Menu function that calls the different plotting functions.

trot3 Rotates one vector around another, used in drawing.

wakeplot Plots the wake in a geometry plot, not currently used, debugging function.

wakesetup2 Calculates the shape of the wake.

```

sample>matlab

                < M A T L A B >
      Copyright 1984-1999 The MathWorks, Inc.
        Version 5.3.0.10183 (R11)
           Jan 21 1999

To get started, type one of these: helpwin, helpdesk, or demo. For
product information, type tour or visit www.mathworks.com.

>>

>>Tornado
- program start -
*****
*
*
*      Welcome to Tornado 1.0
*
*      by: Tomas Melin
*      Copyright 1999-2000
*****
*
*
* Release 1.10 Beta 2000-10-02
* Fixes since last revision
*      divisions change name to partitions for better
*      clarity.
*
* Bug in setrudder fixed for multiple wing AC
*

(...)

.....
"  TORNADO          "
"  Main Menu       "
"                  "
.....

[1]. Aircraft geometry setup
[2]. Flight state setup

[3]. Move reference point (origin)
[4]. Change rudder setting

[5]. Processor access

[6]. Post processing, Result/Plot functions
[7]. Keyboard access

[9]. About / Release Info
[0]. EXIT

Please enter choice from above: 1

```

Figure 25: Sample screen output

Sample Run.

Figure 25 shows the screen output from a sample run of Tornado. The planform comes from Bertin and Smith [2].

Starting up.

In a standard program execution, Matlab (5.3) should be started in the normal way.

Start Matlab in the directory where the Tornado files reside

Start Tornado by typing "Tornado" then press enter.

First, some release and copyright information will be shown before the Tornado main menu is displayed.

The main menu

The main menu shows the available options in Tornado. Select 1 to get to the geometry setup menu.

```

.....

[1]. Define New Geometry
[2]. Load Geometry
[3]. Edit current geometry

[4]. Save current geometry

[0]. Cancel
Please enter choice from above:1

Number of Wings: 1
*****
*
* Data regarding wing number: 1
*
*****

Number of semispanwise partitions: 1
*****
* Data regarding partition 1
*

Is wing mirrored in xz [1 0]: 1

NOTE!
Moment calculation will be done around the
system origin. Place main wing apex accordingly.

Apex x-coord: 0
Apex y-coord: 0
Apex z-coord: 0

Root chord: 2
Base chord airfoil nr: 0
Wing dihedral [deg]: 0
Number of vortices chordwise: 1
Number of vortices semispanwise: 4

Span of partition: 5

Taper ratio: 1

Outboard airfoil nr: 0
1/4 Chord line Sweep [deg]: 45

Outboard 1/4 Chord twist [deg]: 0
Is partition flapped [1 0]:1
Flap chord in parts of root chord (0..1): 0.2
Number of chordwise vortices on flap: 1

Does control deflect symmetrically [1 0]:1

```

Figure 25 (continued): Sample output

The Geometry menu

In the geometry menu, select the option Define new geometry.

In this sample case, we want to look at a simple wing.
 We start by defining the number of wings: one
 <- Number of wings selected.

<- A loop regarding input for the first (and in this case only) wing starts here.

<- Since it's a simple wing we only need one partition, selected here.

<- A loop outwards on the first wing starts here. In this case we only have one partition. hence it isn't really a loop.

The wing should be mirrored in the xz plane, i.e. we want a port and a starboard wing.

Here you define the apex point of the wing, the origin works fine. More advanced users might want to put the apex x coordinate in -0.25 for a wing with a root chord of 1. Doing this would make all moments to be calculated around the c/4 point.

Root chord 2, international units (meters)
 Flat plate gives airfoil 0.
 Dihedral set to zero.
 Number of vortices equals number of panels.
 Chordwise = x , spanwise= y (if no dihedral is present)
 Span of partition =5 gives tip-to-tip span of 10 as wing is symmetric in xz
 A taper of 1 means that the tip chord also is 2 meters.
 Wing should be flat at the tip as well.
 Sweep the wing c/4 line 45 degrees from the y-axis
 No tip twist.
 Trailing edge flap selected.
 Selecting a flap chord of 20% of the local chord.
 One chord-wise panel on the flap.
 And the flaps should deflect symmetrically on both port and starboard side, as they would if they were real "flaps" and not "ailerons".

(Main menu as above)

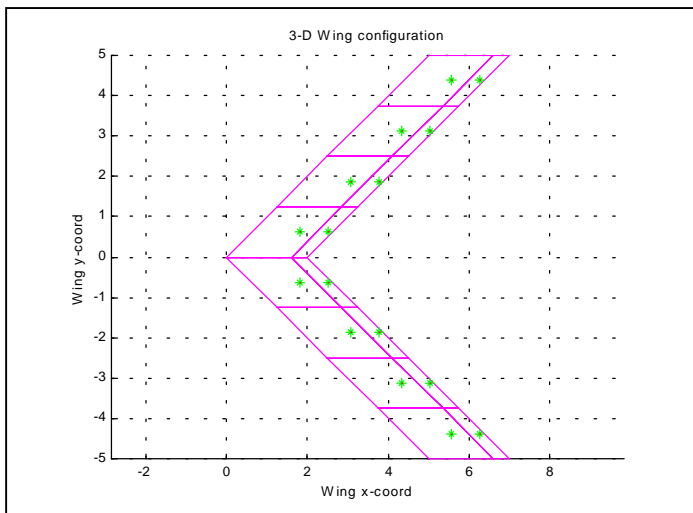
.....

Tornado plotting functions:

.....

- [1]. Clear plots
- [2]. Geometry plot
- [3]. Solution plot, simple state
- [4]. Solution Central difference expansion
- [5]. Solution Alpha sweep
- [6]. Solution Beta sweep
- [7]. Solution Delta sweep
- [8]. Solution Roll speed sweep
- [9]. Solution Pitch speed sweep
- [10]. Solution yaw speed sweep
- [0]. BACK

Enter type of plot:2



.....

Input sequence for aircraft state

.....

- [1]. Define New State
- [2]. Load State
- [0]. Cancel

Please enter choice from above:1

Figure 25 (continued): Sample output

After this input sequence, we return to the Main menu.

To be sure that the geometry looks the way we want it, we should plot it. This is done via the post-processor menu, option 6.

Select option 6 in the Main menu:

Post-processor.

Selecting plot option number 2 will plot the geometry stored in memory.

The plot to the left shows the aircraft geometry as plotted from the postprocessor, plot geometry option.

When the plotting functions have finished drawing the figures, we should be back in the main menu.

Since the geometry looked as we wanted, we can continue to the calculations.

Flight state setup

Before completing any calculations we must select a flight condition, or flight state as it is called in Tornado. Go to the flight state setup menu in Tornado by selection option number 2 in the main menu.

In the flight state setup menu, select option number 1 to define a new state:

Alpha [deg]: 5
Beta [deg]: 0
Roll angular velocity [deg/s]: 0
Pitch angular velocity [deg/s]: 0
Yaw angular velocity [deg/s]: 0
True airspeed [m/s]: 10

-
[1]. Save data, then go
[2]. Just go.

Please enter choice from above 2

(Main menu as before.)

.....
Main Processor menu

-
[1]. Simple solution calculation. Forces/Coefficients only

[2]. Alpha sweep calculation
[3]. Beta sweep calculation
[4]. Delta sweep calculation

[5]. Roll sweep calculation
[6]. Pitch sweep calculation
[7]. Yaw sweep calculation

[8]. Central difference expansion around current state

[0]. Cancel
Enter choice from above please: 1

Solution started, please wait.

Solution available in output/fmcoeff.mat

Six inputs are needed to define the flight condition. Enter the numbers in degrees or degrees per second. Tornado uses radians internally and your input number will be converted automatically.

When you have defined the state, you'll be asked if you want to save these settings for future use or not.

We choose the just go option.

Now we are back in the main menu and can start performing some calculations. Select option 5 for processor access.

The processor

The processor menu shows the different options regarding calculation types.

We'll start off by doing a simple solution to obtain the aerodynamic coefficients for the geometry and flight state we have selected.

<-This row shows that the solver has started.

<-This row signals that the calculation is completed, and where the results are saved.

This transfers us back to the main menu and from the post-processor menu we can now review the results as plots.

Figure 25 (continued): Sample output

Tornado plotting functions:

- [1]. Clear plots
- [2]. Geometry plot
- [3]. Solution plot, simple state
- [4]. Solution Central difference expansion
- [5]. Solution Alpha sweep
- [6]. Solution Beta sweep
- [7]. Solution Delta sweep
- [8]. Solution Roll speed sweep
- [9]. Solution Pitch speed sweep
- [10]. Solution Yaw speed sweep
- [0]. BACK

Enter type of plot: 3

```

TORNADO CALCULATION RESULTS
Reference area: 20      Reference span: 10
Reference chord: 1

Net Wind forces (Lift Drag Side):  366.7046
                                   5.9897
                                   9.4369e-016

Net Body forces (Z X Y):           365.8312
                                   -25.9935
                                   9.4369e-016

CL  0.29935      CZ  0.29864      Cm  -0.88124
CD  0.0048896   CX  -0.021219   Cn  9.9693e-019
CY  7.7036e-019 CC  7.7036e-019  Ci  2.0301e-018

STATE:
alpha:  5      P:  0
beta:    0      Q:  0
Airspeed: 10   R:  0
    
```

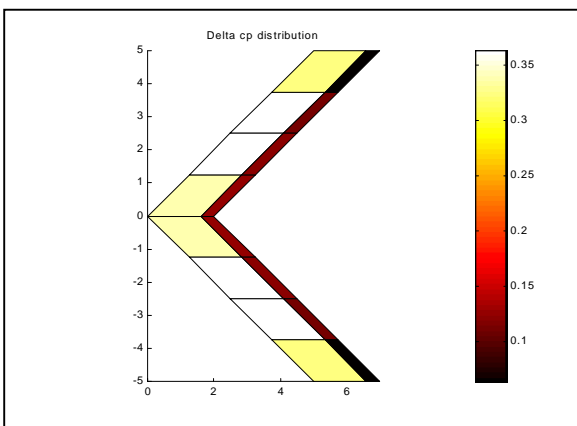


Figure 25 (continued): Sample output

Selecting option 3 in the post-processor menu yields a couple of plots, one being forces in Newton in both wind and body axis.

Coefficients of forces and moments are also represented. A glance at the pitching moment reveals a large nose down moment. This is because the reference point is located in the origin, where we put the apex. A better location of the apex should be somewhere at $x=-1$ or -2 .

Having a look at CL, which equals 0.29935 for an alpha of five degrees, one could easily calculate the lift slope CL_a . Knowing that the CL at $\alpha=0$ also should be zero (flat plate wing), the lift slope should be:

$$\frac{CL}{5 \cdot \frac{\pi}{180}} = 3.430 \text{ [1/rad]}$$

There is a difference in the lift slope calculated here and the lift slope calculated in Bertin & Smith [2] (3.443), but then again there is a slight difference in geometry (the flap)

A pressure difference coefficient plot is also displayed, which reveals the panel layout could be better. The large gradient in pressure from wing to flap indicates that a larger number of panels should be used chord wise to get better (more accurate) results.

References:

- [1] Moran.J, Computational Fluid Dynamics, Wiley & Sons, 1984.
- [2] Bertin.J & Smith,M, Aerodynamics for engineers, 3rd Ed.,Prentice Hall, 1998

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Tornado, a Vortex lattice program for conceptual aircraft design.

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The Royal Institute of Technology (KTH), hereby disclaims all copyright interest in the program Tornado (a vortex lattice program) written by Tomas Melin.

20 Dec 2000

Arthur Rizzi, Prof.

Tornado Reference Card (Detachable)

```

*****
"  TORNADO                               "
"  Main Menu                             "
*****

[1]. Aircraft geometry setup
[2]. Flight state setup

[3]. Move reference point (origin)
[4]. Change rudder setting

[5]. Processor access

[6]. Post processing, Result/Plot functions
[7]. Keyboard access

[9]. About / Release Info
[0]. EXIT

Please enter choice from above:

```

```

[1.]          Geometry menu.

[1]. Define New Geometry
[2]. Load Geometry
[3]. Edit current geometry

[4]. Save current geometry

[0]. Cancel

Please enter choice from above:

```

```

[5.]
*****

Main Processor menu
*****

[1]. Simple solution calculation. Forces/Coefficients only

[2]. Alpha sweep calculation
[3]. Beta sweep calculation
[4]. Delta sweep calculation

[5]. Roll sweep calculation
[6]. Pitch sweep calculation
[7]. Yaw sweep calculation

[8]. Central difference expansion around current state

[0]. Cancel
Enter choice from above please

```

```

[6.]
*****

Tornado plotting functions:
*****

[1]. Clear plots

[2]. Geometry plot
[3]. Solution plot, simple state

[4]. Solution Central difference expansion

[5]. Solution Alpha sweep
[6]. Solution Beta sweep
[7]. Solution Delta sweep
[8]. Solution Roll speed sweep
[9]. Solution Pitch speed sweep
[10]. Solution yaw speed sweep

[0]. BACK

Enter type of plot:

```

Shown to the left are the four most important menus of Tornado. They are:

Main Menu:

From here you may reach all pre- and post-processing functions available in Tornado.

Geometry Menu:

From here you can choose to create a new geometry, to edit a current geometry, to load one from file or to save a geometry to file.

Main Processor Menu:

From here you may start the computations that Tornado does.

The simple calculation should be the primary option when trying out a new design.

Tornado Plotting Functions Menu:

From here the results from previously done calculations may be accessed as plots.

Program Execution:

The normal way of performing computations with Tornado is to:

- 1) Define geometry, either load one or create a new one.
- 2) Define a flight condition, either by loading one or creating a new one. This is done in the "Flight state setup menu"
- 3) Perform a simple calculation in the processor menu.
- 4) Review the results in the postprocessor menu, using the "Geometry plot" option as well as the "Solution plot, simple state"
- 5) Iterate, change geometry or state, and perform some sweep calculations