TAU Transition module (V9.28)

User guide (V1.04)

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1. Introduction

Predicting and modelling the laminar-turbulent transition in Reynolds-averaged Navier-Stokes (RANS) solvers can be an important requirement for the computation of flows around general two- and three-dimensional geometries. Neglecting or using inaccurate transition locations can lead to significant errors of the predicted aerodynamic performance.

For automatic transition prediction, the Navier-Stokes solver TAU is equipped with a transition prediction module. The module uses an hybrid approach to calculate the relevant data for transition prediction, i.e., laminar boundary layer data are either extracted from the Navier-tokes solver TAU directly or calculated using the boundary layer method Coco for swept, tapered wings. The standard transition criterion used in the transition module is the so called e^N-method, which is based on the linear stability theory. For the efficient stability analysis of the laminar boundary layers and the calculation of the amplification rates for the integration of the N-factor the stability solver Lilo is used. The transition module forms a coupled program system, consisting of an interface and analysis module implemented directly into the TAU code and the two external programs Coco and Lilo, which are accessible via file I/O. Depending on the method to provide the laminar boundary layer data, the prediction method is applied along two different types of lines: a) inviscid streamlines derived form the boundary layer edge velocities for the application of boundary layer data from the Navier-Stokes solution. b) line-in-flight cuts for the application of the boundary layer code Coco. Data not depending on the flow solution (e.g. line-in-flight cuts) are processed before the Navier-Stokes solver iterations start. For every call of the transition module during the solution process of the solver, the inviscid streamlines are calculated using the boundary layer edge velocities projected onto the geometry's surface. The boundary layer profiles along the streamlines are then extracted and passed to the stability analysis. For the application of the boundary layer code, the pressure distribution is determined along line-in-flight cuts and is used as input for Coco. The resultant boundary layer profiles are used for the stability analysis.

2. Transition prediction method

2.1. Overview

The automatic transition prediciton capability in the Tau code consists of a coupled program system which includes the transition module attached directly to the Tau code, the boundary layer code Coco for swept, tapered wings and the linear stability equations solver Lilo.

The transition module allows to chose between different empirical and semi-empirical transition criteria including linear stability analysis for the prediction of new transition locations for 2D and 3D flows.

The transition criteria are applied along *transition prediction lines* (Sec. 2.3), which can be divided into three different types:

- *attachment lines*
- *streamlines along the boundary layer edge derived from the flow solution* (Fig. 1)
- *streamlines derived from line-in-flight cuts of the geometry* (Fig. 1)

The different transition criteria need laminar boundary layer data of different complexity (integral values, whole profiles) which can be calculated using two different methods (Sec. 2.4):

- *boundary layer data extracted directly from the Navier-Stokes solution*
- *boundary layer data calculated with a separate boundary layer code*

Depending on the special requirements of certain components, the following composition of the different methods is asssumed for 3D flows:

- *attachment lines and edge streamlines with boundary layer data from the Navier-Stokes solution*
- *line-in-flight cuts with boundary layer data from the boundary layer code*

In 2D flows the edge streamlines coincide with the line-in-flight cuts and no differentiation has to be made.

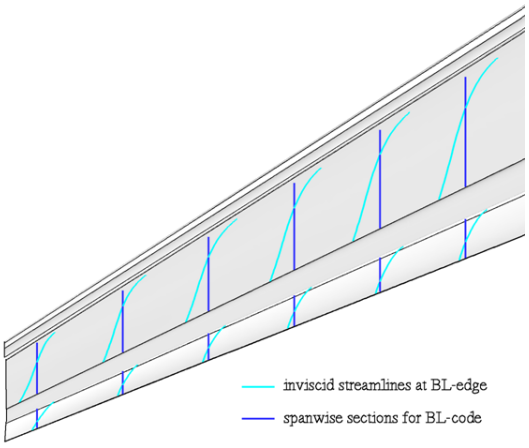

Figure 1: Edge streamlines and line-in-flight cuts on the lower surface of a 3D 3-element wing

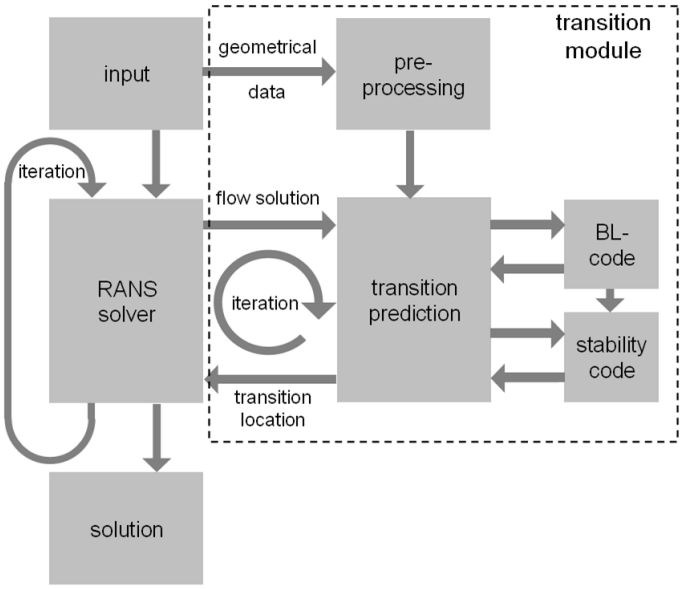

Figure 2: Coupling of TAU solver and transition module

2.2. General procedure

In a preprocessing step, right before the RANS solver iterations start, data not depending on the flow solution are processed (Fig. 2), i.e., calculation of wall-normal lines, line-in-flight cuts (Sec. 2.3] and geometrical sweep angles (Sec. 2.3). During the solution process of the solver, the iteration process is interrupted in certain intervals, and the transition prediction is executed. A new transition line is calculated and applied with under-relaxation to generate new laminar and turbulent regions in the RANS solver. This procedure is repeated, until the transition lines itself are converged (Fig. 2), i.e., the transition points on the transition detection lines stay constant in terms of grid points.

For each transition prediction step, the following general procedure is executed (Fig. 3): For all surface points of the geometry, the boundary layer profiles are assembled along wall-normal lines, integral boundary layer data are determined and the boundary layer edge velocity is projected onto the surface.

After the calculation of the 3D edge streamlines, the velocity profiles along the streamlines are extracted and passed to the stability analysis or are transferred to the transition module (Fig. 3, left branch)..

For the application of the boundary layer code, a series of line-in-flight cutting lines at different positions of the wing is determined once in the preprocessing stage of the transition prediction module. During runtime, these cutting lines are separated in an upper and lower surface part at the corresponding attachment line and the pressure distribution is extracted and passed along with the on-flow conditions and the local sweep angles to the boundary layer code. The velocity profiles along the cutting lines are then calculated in the boundary layer code and transferred either to the stability analysis or directly back to the transition module (Fig. 3, right branch).

Depending on the chosen transition criterion, an empirical transition criterion is applied to the calculated boundary layer data or the data from the stability solver is evaluated to give new transition locations.

2.3. Transition prediction lines

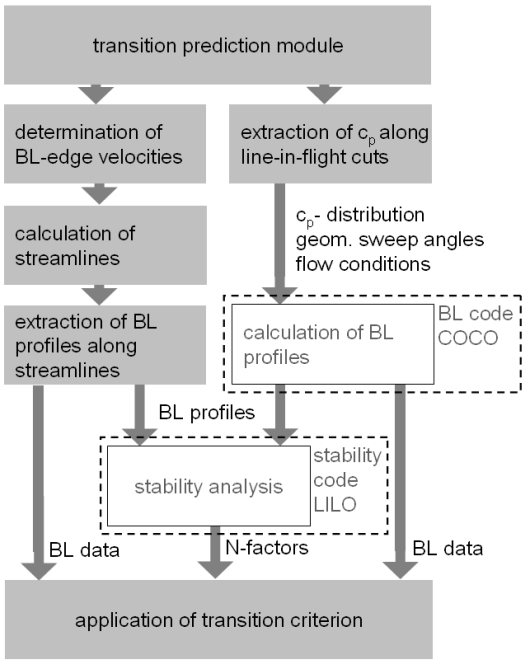

Figure 3: Different approaches to calculate the boundary layer data

Attachment lines The attachmentline is a particular streamline, which divides the flow into two parts. For general 3D wing flow, one part of the flow follows the upper surface of the geometry and another part follows the lower surface of the geometry. The attachment lines are calculated using the surface shear stress distribution. This can be done, since the flow of the attachment line is two-dimensional and the skin friction line coincides with the projection of the edge streamline onto the surface of the geometry. The calculation is based on a multistage Runge-Kutta scheme and is started at a user-defined initial point. The integration is executed *against* the streamwise direction along the attachment line and is stopped, if a stagnation point is reached, or a user-defined geometrical limit (limiting plane) is reached.

Edge streamlines The edge streamline is a quasi-streamline, which follows the direction of the flow at the boundary layer edge. However, the boundary layer edge is not defined by a single streamline. Referring to edge streamline in this context means the "local projections of the loci, where the streamlines cross the boundary layer edge". The integration of the edge streamlines is based on the same multistage Runge-Kutta scheme as for the attachment lines, but uses the boundary layer edge velocities, projected onto the surface, as input. The calculation of the edge streamlines is stopped, if a previously calculated attachment line, the trailing edge of a geometry part, or a user-defined geometrical limit (limiting plane) is reached. Starting point is again a user-defined initial point on the surface, but the integration is performed in both directions, *upstream and downstream.*

Line-in-flight cuts / Contourlines Line-inflight cuts are defined in the preprocessing stage of the transition prediction process. They are calculated by extracting the intersections of the surface of the geometry with user-defined cutting planes parallel to the on-flow direction. The line-in-flight cuts enclose the leading and trailing edges and the local geometrical sweep angles can be extracted from the grid.

During runtime, the pressure distribution along the line-in-flight cuts is interpolated from the Navier-Stokes solution and the lines are divided into upper and lower surface parts at the attachment line.

Since the cutting lines depend only on the shape of the contour of the geometry, they are in the context of the transition module also referred to as *contourline*.

2.4. Determination of boundary layer data

The basis of the application of transition criteria is the calculation of boundary layer data along the transition prediciton lines. There are two different ways to calculate boundary layer profiles included in the transition module:

- extract the boundary layer profiles directly from the Tau solution (Sec. 2.4.1)
- calculate the boundary layer profiles with the boundary layer code Coco (Sec. 2.4.2)

2.4.1. Boundary layer data from the Navier-Stokes solution

The basis of the determination of boundary layer data from the Navier-Stokes solution is the knowledge of the wall-normal lines corresponding to the surface grid points and the list of grid points associated with these lines. The length of the wall-normals is limited by a maximum distance or by a maximum number of grid points, both defined by the user and usually in accordance with the extension of the structured part of the hybrid Navier-Stokes grid.

Velocity profiles inside the boundary layer are directly accessible, if the surface point and the point associated with the end of the wall-normal line are placed in the same domain. In this case, only the knowledge of the point list for the wall-normal has to be known, and the velocities at each wall-normal point is interpolated from the Navier-Stokes solution.

If a boundary layer profile is cut by a domain boundary, the wall-normal lines are divided at the domain boundaries into separate wall-normal parts, where each part of the wall-normal lies in a different domain. The velocities for each wall-normal part are interpolated from the Navier-Stokes solution of the corresponding domain and are communicated to the domain containing the surface point associated with the examined wall-normal. After the velocity profiles are assembled, the boundary layer edge is detected and all relevant boundary layer data are calculated and stored together with the velocity vector of the boundary layer edge at the surface grid points.

2.4.2. Boundary layer data from the boundary layer code

It can be shown, that for general transition prediction, and especially for the prediction of cross flow type transition, a high normal-to-wall mesh density is required to resolve the boundary layer adequately. To overcome this constraint, a boundary layer method is in many cases an efficient alternative to a high resolution Navier-Stokes computation.

However, the boundary layer method attached to the transition module is a first-order boundary layer method for swept, tapered wings. It is limited to quasi-2D boundary layer flows, i.e. it is generally insufficient for the prediction of flows around complex geometries and low aspect-ratio wings or for the resolution of laminar separation bubbles.

During runtime, the line-in-flight cuts are separated in an upper and lower surface part at the point corresponding to the attachment line and the pressure distribution is extracted and passed along with the onflow conditions (Re, Ma, angle of attack α) and the local sweep angles to the boundary layer code. The geometrical sweep angles are automatically extracted from the underlying Tau grid.

From these input parameters, the boundary layer code computes the 3D boundary layer profiles which can be utilised in the following transition prediction process.

2.5. Application of transition criteria

2.5.1. Pre-prediction phase

In the transiton moduel it is possible to perform two different ways of transition prediction consecutevily. In the main prediction phase, the actual, "physical" transition criterion is applied (emperical criterion, e^N-method). In a so called pre-prediction phase, two different very simple transition criteria can be applied. These criteria are solely used to generate a flow solution with laminar zones prior to the application of the physical transtion criterion. Both available criteria are based on simple flow quanteties which are available with sufficient accuracy in the transient pahse of the RANS computation. Additionally, both criteria are able to prevent the flow from early (in terms auf RANS iterations) laminar separation and thus result in a stable converging solution process in the transient phase of the computation by guaranteeing a suitable extent of laminar flow to improve the convergence of the "physical" transition prediction after the pre-prediction phase. The first criterion is based on the pressure distribution. Transition is set during the pre-prediction phase at the first local pressure minimum downstream of the stagnation point. This ensures, that there is turbulent flow in adverse pressure gradient regions, leading to attached flow (in the laminar region). The second criterion uses laminar separation points as transition points with the constraint, that transition can only be moved upstream (compared to the old transition location). In doing so, the laminar extent of the flow is maximized and at the same time laminar separation is avoided.

2.5.2. Empirical criteria

The transition module provides a variety of emperical transition criteria (see also Sec.). The application of the emperical transition criteria is carried out along the transition prediction lines. Generally, the criteria are formulated to be applied along edge streamlines in 3D. However, all empirical transition criteria can be applied in 3D along line-in-flight cuts (e.g. together with the boundary layer method) as well. In doing so, the curvature of the actual inviscid streamline will be neglected. This is resulting in a shorter laminar length, which is used in the formulation of certain empirical transition criteria and may lead to different results compared to computations where the criterion is applied along an inviscid streamline.

Currently implemented are the following empirical transition criteria:

- transition at $c_{p,min}$
- transition at laminar separation
- Michel/Cebeci/Thwaites
- AHD (Arnal, Habiballah, Delcourt)
- C1 (Arnal)
- Mayle

Note: implementation of the emperical transition criteria is not fully validated!

2.5.3. e^N-method (envelope methods)

Additionally to the general emperical transition criteria (Sec. 2.5.2), a range of envelope methods is also available. The same considerations as for the emperical transition criteria (Sec. 2.5.2) for the application in 3D holds for the envelope methods as well.

Currently implemented are the following envelope methods:

- eN-Method with N-factors from envelope method of Wuerz

- eN-Method with N-factors from envelope method of Drela (1987)
- eN-Method with N-factors from envelope method of Drela (1991)

Note: implementation of the envelope methods is not fully validated!

2.5.4. e^N-method (linear stability theory)

If the linear stability therory in form of the e^N-method is used for transition prediction, a suitable integration path to calculate the N-factors from the amplification rates has to be applied. The velocity and direction of the energy transport of a wave is represented by the group velocity and thus, the group velocity can be taken as the amplification direction. The group velocity trajectory in turn can be approximated by an edge streamline, and this streamline can be used as the integration path.

For the calculation of the edge streamlines the velocity vector at the boundary layer edge is determined and projected onto the geometry for every surface grid point. The streamlines are then calculated on the surface of the geometry using a Runge-Kutta integration scheme.

The integration of the amplification rates is done in two different ways, depending on the approach to calculate the boundary layer data. If the boundary layer profiles are extracted directly from the Navier-Stokes solution, the integration is performed along the edge streamlines determined by the transition module. If the boundary layer code is used, the integration path is determined inside the stability code. I.e., from infinite swept wing considerations the edge streamline is determined from geometrical relations and the direction of the boundary layer edge velocity.

The stability analysis yields a series of N-factor curves, which are analyzed in the transition prediction module with appropriate N-factor criteria to give new transition locations for every streamline/-contourline. The limiting N-factors are applied using the 2N-factor strategy, treating the N-factors for Tollmien-Schlichting and cross flow instabilities independently. The interaction of Tollmien- Schlichting and cross flow waves cannot be evaluated by linear local stability theory and is instead modelled by applying a stability curve, where the critical N-factor of one instability form depends on the local N-factor of the other instability form.

3. Structure of the parameter file

For transition prediction two distinct sets of parameters are requiered: one set of parameters for transition prescription and one set for transition prediction.

The prescription prameters are generally used by the transition setting process in the Tau preprocessing but are also used by the transition module. On one hand, these parameters are used by the transition module, if transition is prescribed in the solver at the beginning of the calculation (in contrast to prescribing transition in the preprocessing). On the other hand, these parameters are needed to connect the transition prediction blocks, and hence the predicted transition lines, to the transition blocks for prescribing transition. The other set of parameters, the prediction parameters, is only used in the transition module for transition prediction and controlling of the calculation processes within the transition module.

The parameters of both sets have to be set in the parameter file in a very distinct form. The parameters used for transition prescription have to be written completely in block form (Fig. 4), whereas the parameters for transition prediction are written in a mixed form with block-parameters and non-block-parameters (Fig. 5).

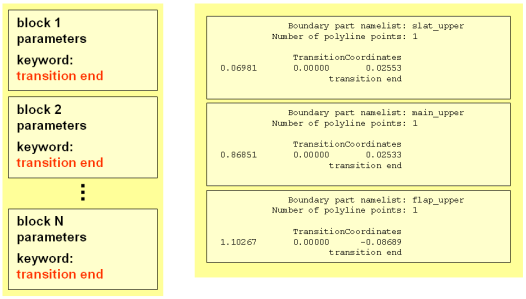

Figure 4: Structure (left) and example (right) of the parameters for transition prescription (used in the Tau preprocessing and in the transition module)

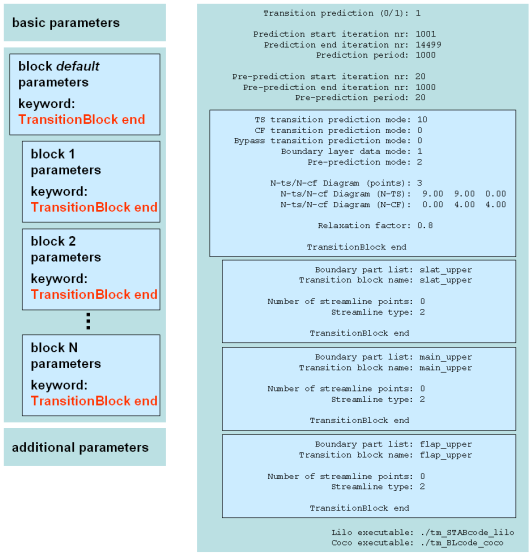

Figure 5: Structure (left) and example (right) of the parameters for transition prediction (used in the transition module)

3.1. Transition prescription

All parameters for transition prescription are written in a block-structure (Fig. 4). The transition data from each block are matched to one or several boundary parts for which the specified transition lines have to be applied. Each block of the prescription parameters is marked at the end with the keyword transition end. The prescription parameters are used to define the laminar regions and their extend. A description can be found in Sec. A.1.

3.2. Transition prediction

The parameters for transition prediction have to be written partly in block-structure (Fig. 5). Several parameters (here labeled as *Basic parameters*, Sec. 3.2.1 and *Additional parameters*, Sec. 3.2.3 can be used like normal Tau parameters and have not to be written in block-structure. These parameters control the main behaviour of the transition prediction (e.g. output options, etc.) and the external programs (Lilo and Coco).

The parameters controlling the actual transition prediction method (here labeled as *Block default parameters*, Sec.3.2.2 and *Block individual parameters*, Sec.3.2.2) have to be declared in block-structure. Data of this type are matched to the transition prescription blocks during runtime and thus to one or several boundary parts.

3.2.1. Basic parameters

The first set of basic parameters of the transition prediction controls the in- and output of the transition module (Sec. A.2.1).

The second set of basic parameters of the transition prediction is labeled as general parameters in the log-file and includes the main parameters to control the transition prediction process (Sec. A.2.2).

3.2.2. Block parameters

Parameters of this category are needed for the transition prediction itself. If only boundary layer data are to be assessed without prediction of transition no transition block has to be specified.

There are two types of blocks: one is the so called *default transition block*, the other is a so called *individual transition block*. Transition blocks (default and individual) have to be marked at the end with the keyword **TransitionBlock end** (Fig. 5).

The transition blocks contain the parameters that are essentially needed to create the new transition lines during transition prediction. Each transition block is assigned to certain boundary parts and will produce the transition lines applied to these boundary parts. Every transition block can be very individually configured, so that for different boundary parts very different ways of predicting transition are possible. The ways of predicting transition mainly differ in the applied transition criteria and in the type of transition prediction line (Sec. 2.3) they are applied to (line-in-flight cuts, streamlines, attachment lines).

For a simple way of setting up the transition blocks, the *default transition block* contains all the default parameters for the transition prediction and these parameters are automaticly transferred to the *individual transition blocks*, if they are not explicitly specified in the *individual transition blocks*. I.e., all parameters, that can be specified in the *default transition block* can also be specified in every *individual transition block* (Sec. 3.2.2 and Sec. A.2.3). Additionally, there are a few parameters, that are not shared by both block types and that have to be specified for every *individual transition block* (Sec. 3.2.2 and Sec. A.2.3). These additional parameters are used to distinguish the transition blocks from each other (e.g. for output putposes) and to connect each transition block (and the transition line associated with this block) to certain boundary parts.

For a description of the block parameters see Sec. 4.2.2, Sec. 4.2.3 and Sec. A.2.3.

Important:

- For transition prediction, a default transition block is required!
- For transition prediction, only one default transition block is allowed!
- The default transition block has to be placed **above** the individual transition blocks!
- All transition prediction blocks (this includes the default transition block) have to be marked at the end with the keyword **TransitionBlock end**!

Block default parameters To apply the transition prediction, a single default block is requiered above the individual blocks. In this block the default values that will be valid for all indivdual transition blocks are specified. These parameters define the method to determine the new transition lines. All of the parameters defined in the default transition block are automatically transferred to all individual transition blocks (Sec. A.2.3).

Block individual parameters The individual transition blocks contain informations for the calculation of transition prediction lines and parameters to connect the transition prediction lines to the corresponding boundary part (Sec. A.2.3). Additionally, an individual transition block can contain all the parameters that can be specified for the individual transition block. If specified, they alter the default setting for the corresponding individual transition blocks.

3.2.3. Additional parameters

The additional parameters summarize the parameters to control the external programs Coco and Lilo (Sec. A.2.4).

4. Setting up a calculation with transition prediction

4.1. Choice of prediction method

There is a significant number of combinations of the different techniques implemented in the transition module available to choose as the prediction method for a Tau calculation with transition prediction. Generally, The transition prediction method can be devided into four elements:

- The type of transition prediction lines (Sec. 2.3).
- The method to calculate the boundary layer data (Sec. 2.4).
- The chosen transition criterion (Sec. 2.5).
- The calling sequence of the transition module.

Some of the options of the transition module are limited by the geometry to be investigated and the available computational grid. There are three basic geometry dependant issues that mainly influence the setting up of a calculation with transition prediction:

- The dimensionality (2D, 2.5D, 3D).
- The topology of the geometry to be investigated (wing, fuselage, ...).
- The resolution of the grid around the geometry to be investigated.

There are certain limitations in the application of the different transition prediction lines for transition prediction (Sec. 2.3). The procedures are limited by their implementation or by their calculation method. E.g., for line-in-flight cuts together with boundary layer data from the boundary layer code, the application is limited to swept, tapered wings with high aspect ratio (limitation from the boundary layer code) lying in the Tau x-y plane (limitation from the implementation in the transition module). Table 1 gives an overview over the possible combinations.

Table 1: Application of transition prediction lines

	Navier-Stokes + streamlines	Navier-Stokes + line-in-flight cuts	BL code + line-in-flight cuts
2D	x	x	x
2.5D	-	x	x
laminar separation bubble	x	x	-
3D, wing in x-y plane	x	x	x
3D, low AR wing	x	(x)	(x)
3D, wing not in x-y plane	x	x	x
3D, fuselage	x	-	-
3D, nacelle	x	-	-
3D, arbitrary body	x	-	-

Another general issue to be considered when chosing a certain prediction method is the resolution of the grid, especially the resolution of the (laminar) boundary layer normal to the wall. Investigations on a 2.5D case showed the following requirements for the resolution of the boundary layer: for a sufficient resolution of the boundary layer profile for Tollmien-Schlichting type transition 32 - 64 points normal to the wall in the structured grid part are needed, for cross flow induced transition 128 points. When using a boundary layer method, these limitations are invalid as the compuational grid of the boundary layer code is independent of the normal to wall resolution of the Navier-Stokes grid. For typical grids for 2D flows (2,5D flows) the following distinction for the grid resolution can be made (known from experience):

- **coarse grid**: 32 points normal to wall, 128 points on the surface
- **medium grid**: 64 points normal to wall, 256 points on the surface
- **fine grid**: 128 points normal to wall, 512 points on the surface

These resolution can be approximately transferred to 3D calculations too. They have a direct influence on the accuracy of the predicted transition locations for the two main transition scenarios (TS and cross flow). A suggestion for the application of different techniques to calculate the boundary layer data is summarized in Table 2.

Table 2: Suggested application of different boundary layer calculation methods

	Navier-Stokes		BL code	
	TS	CF	TS	CF
coarse grid	(x)	-	x	x
medium grid	x	-	x	x
fine grid	x	x	x	x

Generally, it is of advantage to cover the whole boundary layer with the structured grid part when using hybrid grids. I.e., an a priori estimation of the expected boundary layer thickness is essential for the grid generation. For this, the evolution of the turbulent boundary layer on a flat plate can be used as an estimation of the boundary layer thickness:

$$\delta_t = 0.37x \left(\frac{U_\infty x}{\nu} \right)^{-\frac{1}{5}} \tag{1}$$

The required resolution of the boundary layer profile when using boundary layer data directly from the Navier-Stokes solution for transition prediction is generally independant of the chosen transition criterion. However, criteria depending only on integral boundary layer parameters (momentum thickness, shape factor) are less sensible to the normal-to-wall resolution of the gird compared to techniques that need boundary layer profiles as input (linear stability theory). Additionally, there are some simple criteria implemented in the transition module that are only based on data not directly extracted from the boundary layer (Tab. 3).

Table 3: Implemented transition criteria

	2D	3D	TS	CF	input
AHD	x	x	x	-	integral values
C1	-	x	-	x	integral values
Michel/Cebeci/Thwaites	x	-	x	-	c_p
p_{min}	x	x	(x)	-	c_p
laminar sep.	x	x	(x)	-	skin friction
e^N (envelope methods)	x	x	x	-	integral values
e^N (lin. stab. theory)	x	x	x	x	profiles

For the transition prediction a suitable calling sequence has to be applied. An appropiate prescription of start and end iteration and iteration period between to consequtive calls of the transition prediction is highly dependent on the chosen boundary layer calculation method, and, more general, on the solution and convergence behaviour of the Navier-Stokes solver. It is important that the main input parameters (Tab. 3) for the applied transition criterion are well converged. For cases where the boundary layer is calculated by the boundary layer code, the relevant flow quantety (pressure distribution) converges

relatively fast. If the boundary layer data is extracted directly from the Navier-Stokes solution a careful revision of the convergence of the laminar boundary layer is recommended.

The shortcoming of this application is that there is actually no sensor for the convergence of the relevant part of the boundary layer velocity profiles. The consideration of the general velocity residual (or even density residual) of the Tau code does not necessarily lead to an adequate information of the solution quality inside the laminar boundary layer. Disturbances in the velocity field (e.g. at the trailing edge, small oscillations in the presence of a laminar separation bubble) may falsify the information on the local convergence of the velocity field. This is why recommendations on the calling sequence of the transition prediciton currently rely basicallly on previous experiences with the code and can only be considered as rough guidelines (Tab. 4). A careful revision of the convergence of the transition locations and the general convergence of the coupled computation (Navier-Stokes with transition prediction) is indispensable for the evaluation of the plausibility of the solution.

Table 4: Calling sequence (pre-pred: lam. sep; pred: e^N)

	Navier-Stokes, 2D	Navier-Stokes, 3D	Boundary layer code
pre-prediction start	20-100	20-100	20
pre-prediction end	999-4990	999-1999	999
pre-prediction period	20	20	20
prediction start	1000-5000	1000-2000	1000
prediction end	after 5-8 calls	after 5-8 calls	after 5-8 calls
prediction period	1000-5000	1000-2000	500

The general recommendation for the pre-prediction phase is to use the laminar separation criterion. With this criterion, the extent of the laminar region is maximized while guaranteeing attached (laminar) flow. From experience, it is suggested to check very frequently for laminar separation during the pre-prediction phase (Tab. 4). The suggested calling sequence for the main prediction phase is deduced from the application of the linear stability theory in form of the e^N-method. Since the laminar stability theory has the highest requirements on the solution quality, the recommendation in Table 4 can be transferred to all other implemented transition criteria.

4.2. Parameter choice

There exist approximately 20 parameters that are essential for transition prediction. These parameters are needed e.g. to generally define the transitition prediction method (Sec. 2, 4.1). They are listed and are briefly described in the following sections (Sec. 4.2.1 - 4.2.4). These "main" parameters can generally not be entirely coverd by well chosen default values and have to be customized for every calculation.

Another set of parameters may be used to individualize the settings for certain calculations further (Sec. 4.2.5). These parameters control mainly the output. However, there are parameters that can be used to regulate memory consumption and stability of the transition prediction.

The rest of the available parameters are expert parameters (Sec. 4.2.6). These should only be changed by users who have a certain experience with transition predicition. The expert parameters have well chosen default values that have proved to be accurate for a wide range of applications.

For example parameter files see Sections 7 and B, for additional descriptions of the parameters and a description of the complete set of parameters see Section A. The structure of the parameter file is very important and can be looked up in Sec. 3.

4.2.1. Basic parameters

Main switch First of all, there exists a switch to simply activate or deactivate transition prediction. With this parameter set to 0, no further activities for transition prediction will be performed.

- **Transition prediction (0/1)**: 1

Calling sequences The calling sequence for the pre-prediction can be specified with the following three parameters, recommendations for these values are given in Sec. 4.1 and Table 4. The pre-prediction criterion itself has to be specified in the transition blocks (Sec. 4.2.2).

- **Pre-prediction start iteration nr**: 20, see Tab. 4
- **Pre-prediction end iteration nr**: 999, (dependent on solution convergence), see Tab. 4
- **Pre-prediction period**: 20, see Tab. 4

For the calling sequence of the main transition prediction three parameters can be used, recommendations for these values are given in Sec. 4.1 and Table 4. The transition criterion of the main prediciton phase has to be specified in the transition blocks. The pre-prediction end iteration is automatically adjusted in the transition module, so that no overlapping of pre-prediction and main prediction phase will occur.

- **Prediction start iteration nr**: 1001, see Tab. 4
- **Prediction end iteration nr**: 9000, (case dependent), see Tab. 4
- **Prediction period**: 500, (BL code) / 1000-5000 (NS-solution) (parameter dependent on boundary layer calculation method and solution convergence), see Tab. 4

4.2.2. Default block parameters

For transition prediction, a default transition block is required (Sec. 3). In this block the default values that will be valid for all indivdual transition blocks, are specified. The parameters specified here control mainly the transition criterion and the determination of new transition lines. All of the parameters defined in the default transition block are automatically transferred to all individual transition blocks, but may be overwritten for certain individual transiton blocks, if the corresponding parameter is seperately defined in an individual transition block.

Transition criterion For the conventional application of the transition module the specification of criteria for the two main transition scenarios (Tollmien-Schlichting, cross flow) is sufficient. However, there are different criteria for e.g. attachment line transition or bypass transition implemented (Sec. A.2.3). These criteria are currently not completely verified and validated and thus should only be used by expert users.

The default (and most tested and validated) criteria in the transition module for Tollmien-Schlichting (TS) and cross flow (CF) transition is the e^N method with N-factors from linear stability theory. For the pre-prediction phase (Sec. 2.5.1), the check for laminar separation is recommended.

Another important issue for transition prediciton is the choice of the calculation method for the laminar boundary layer. If the velocity profiles should be extracted from the Navier-Stokes solution or if they should be calculated within a separate boundary layer code depends mainly on the geometry to be investigated inculding the computational grid and the flow phenomena that have to be resolved (Sec. 4.1).

- **TS transition prediction mode**: 10, for a list of available criteria see Sec. A.2.3
- **CF transition prediction mode**: 10, (only 2.5D, 3D), for a list of available criteria see Sec. A.2.3

- **Pre-prediction mode**: 2, for a list of available modes see Sec. A.2.3
- **Boundary layer data mode**: 1, see also Sec. A.2.3
  - 0: use boundary layer profiles from Navier-Stokes solution for TS and CF criterion
  - 1: use boundary layer profiles from boundary layer code for TS and CF criterion
  - 2: expert option
  - 3: expert option

For two of the main transition criteria there are additional input values needed. If using the e^N method, the critical N-factors have to be specified. This is typically done by prescribing the instability region with the help of a N_{TS}/N_{CF}-diagram. If no interaction of the two modes has to be modelled, the N_{TS}/N_{CF}-diagram gives a rectangular box with the values for $N_{TS,crit}$ and $N_{CF,crit}$ as maximum values.

According to Mack [2], for wind tunnel data the critical N-factor for streamwise instabilities can be related to the free stream turbulence level by the following relationship:

$$N_{TS,crit} = -8.43 - 2.4 \cdot ln(Tu) \tag{2}$$

This expression is valid for turbulence levels $Tu \geq 10^{-3}$. A typical value for a low disturbance subsonic wind tunnel is $Tu = 10^{-3}$ [2], for which the critical N-factor will be $N_{TS,crit} = 8.15$.

If the AHD or the Mayle criteria are used, the turbulence intensity has to be prescribed to accurately predict transtion. The value has to be specified in %.

- **N-ts/N-cf Diagram (points)**: n
- **N-ts/N-cf Diagram (N-TS)**: $N_{TS,crit,1}$ $N_{TS,crit,2}$ ... $N_{TS,crit,n}$
- **N-ts/N-cf Diagram (N-CF)**: $N_{CF,crit,1}$ $N_{CF,crit,2}$ ... $N_{CF,crit,n}$
- **Turbulence intensity for transition criteria**: 0.1 (for AHD or Mayle)

Special 3D parameter Another parameter is essential for the correct setting of the new transition locations on 3D geometries. For 3D computations, the transition lines predicted with the transition module are polylines with nodes on the transition prediction lines. I.e., the transition lines generally are not extended beyond the edges of the corresponding boundary part. For an accurate prescription of the transition, the transition lines should be extended beyond the edges of the boundary part. An offset can be defined, giving a length of which is used to extrapolate a transition line at its two endings.

- **Offset for polylines extrapolation**: grid dependent, only 3D

4.2.3. Individual block parameters

For transition prediction at least one individual transition block (Sec. 3) is required. The individual transition block can contain all the parameters that can be specified for the default transition block (Sec. A.2.3). These parameters, if specified, can be used to alter the default settings for certain individual transition blocks.

There is a number of additional parameters only applicable to the individual transition blocks (Sec. A.2.3). These parameters contain the information for the transition prediction line calculation (Sec. 2.3) and parameters to connect the transition prediction lines (resp. the predicted transition locations) to the corresponding boundary part. If no connection between an individual transition block and a boundary part is available, the transition criterion can be applied to the corresponding transition prediction lines without setting the determined transition line for the Navier-Stokes calculation.

Generally, an individual transition block is used to create a data set (during transition prediction) that will superseed the information given in an transition prescription block (Sec. 3.1), if a unique connection between individual transition block and transition prescription block can be made.

Each individual transition block should be given a unique name:

- **Transition block name**: name

This name is mainly used for output to files and the log-file to relate the different transition prediction lines to the different transition blocks.

Two parameters are used to connect the predicted transition lines to certain boundary parts for the setting of new laminar regions during runtime. The connection between transition line and boundary part is done with the help of the transition prescription blocks.

The data of a transition prescription block is matched to the boundary parts by matching the names given in the parameter Boundary part namelist (Sec. A.1) and the names of the boundary parts. It is generally possible to define one transition prescription block which is valid for more than one boundary part.

The data of a transition *prediction* block is in turn matched to a transition *prescription* block by matching the names given in the parameter Boundary part list (Sec. A.2.3) and the names given in the parameter Boundary part namelist. It is possible to define different transition prescription blocks with the same names in parameter Boundary part namelist. If this is the case, a unique connection between a transition prediction block and a transition prescription block is not possible by the parameter Boundary part list only. Here, a matching of another parameter (Exclude surface normal/angle, available in both block types, prediciton and prescription) is performed to connect the blocks.

- **Boundary part list**: namelist
- **Exclude surface normal/angle**: only needed, if block is not unambiguously connected to prescription block by names in Boundary part list.

An important parameter to setup a transition prediciton calculation is the type of the transition prediction line (Sec. 2.3, Sec. 4.1, Tab. 1).

- **Streamline type**: n, 1 for edge streamline, 2 for line-in-flight cut, 3 for attachment line

For a 2D airfoil calculation the contourline type (type 2) should be preferred. With this type no additional information for the starting points of the calculation of the transition prediciton line has to be given. Instead, the geometry is automatically scanned for leading edge points, and these points are then used as starting points for the transition prediciton line calculation.

For 3D flows, the choice of the type of transition prediciton lines is dependent on geometry and grid topology (Sec. 4.1, Tab. 1). However, there are certain general procedures that should be followed for the application of the different transition prediciton lines.

- Streamline type 1 (edge streamline) can be used for general 3D geometries. Edge streamlines should only be calculated in regions where a clear definition of the boundary layer edge is possible and where the assumptions of boundary layer theory are valid. The calculation of (correct) streamlines or the extraction of accurate boundary layer data can fail in concave corners (wing body intersection), for highly seperated flows or for internal flows.

  The edge streamline approach does not support the application of the boundary layer method for calculating boundary layer profiles.

  Generally, edge streamlines should end for 3D flows in an previously calculated attachmnet line. For this, attachment lines have to be specified in an additional inidividual transition block. (It is not necessary to compute attachment lines for fuselages.)

- Streamline type 2 (line-in-flight cut) can only be used for wings/airfoils with spanwise extension in the y-direction of the Tau grid (i.e., the cutting line lies in the x-z-plane) and only for geometries, that allow a segmentation of the line-in-flight cut in an upper and a lower part.

  The y-coordinates of the line-in-flight cuts have to be placed in a way, that no sharp edges/corners (or other geometry parts, connected to the corresponding surface to be cut) are cut, exept for the trailing edges of a wing. This restriction is based on the calculation procedure of the line-in-flight cuts: the calculation of the line-in-flight cuts is stopped where a sharp edge is detected. At this position, the trailing edge sweep angle is extracted and the corresponding grid coordintes of this position are used to determine the local chord length. If the ending point is not the trailing edge of a wing, erroneous results are likely.

  Line-in-flight cuts have to be assigned (in the transition module) to a certain boundary part for a correct execution of the transition prediction process. I.e., all line-in-flight cuts of one transition block have to cuts the boundary part they are assigned to.

  For line-in-flight cuts no attachment lines have to be calculated.

- Streamline type 3 (attachment line) is generally used to generate ending lines for streamline type 1. However, these lines may be needed for the application of attchamnet line transition criteria.

  The calcualtion of the attachment lines is automatically performed prior to the calculation of the edge streamlines in the transition module, i.e. no special order in the parameter file is required. Since the calculation is based on the skin friction vectors, the placing of the starting point for the attchament line has to ensure that no seperated flow areas will be crossed by the attachment line. Additionally, it has to be considered, that the attachment line calculation is carried out only in one direction: against the flow.

  A trajectory calculated from the skin friction distribution will automatically end in the attchment line, whereever the starting point is. However, the starting point should be placed as near as possible to the expected (and actual) attachment line. The basic rules for the attachment line calculation are:

  – One single starting point at the pressure side of the geometry (as near as possible to the actual attchment line).
  – No edge streamline starting point beyond the attachment line starting point (in direction of the main extension of the attchment line).
  – For the typical application, a limiting plane for the ending of the attachment line should be defined.

The start coordinates for the transition prediciton lines have to be specified by prescribing the number n of coordinates to be read and n coordinate sets (x, y, z). The coordinates should be extracted from the geometry and should lie as near as possible to the corresponding surface to avoid uncertainties in the projection of the coordinates onto the surface.

- **Number of streamline points**: `n`
- **StreamlineCoordinates/StreamlineCoordinates**

4.2.4. Additional parameters

The parameters to control the external programs are numerous and are explained in Sec. A.2.4. Generally, the default values of these parameters are valid and adequate for the standard application with the transition prediction module, so that only the paths to the executable have to be specified in the parameter file:

- **Coco executable**: ./coco
- **Lilo executable**: ./lilo

4.2.5. Advanced parameters

Additional prediction options

- **Max. number of points on wallnormal**:
- **Relaxation factor for transition**: value

Output options

- **Transition prediction output directory prefix**: name
- **Transition history file name prefix**: name
- **Transition history output values**: $name_1\_name_2\_...name_n$
- **Prediction info output level**:
- **Transition history output in pre-mode (0/1)**:
- **Keep files from pre-mode (0/1)**:
- **Write streamline data to file (0/1)**:
- **Write boundary layer profiles to file (0/1)**:
- **Write additional contourline data to file (0/1)**:
- **Keep N-factor files (0/1)**:
- **Keep Coco log files (0/1)**:
- **Keep Coco run files (0/1)**:
- **Keep Coco profiles files (0/1)**:
- **Keep Coco auxiliary files (0/1)**:
- **Keep Lilo log files (0/1)**:
- **Keep Lilo run files (0/1)**:
- **Keep Lilo auxiliary files (0/1)**:

4.2.6. Expert parameters

The broad variety of the so called expert parameters (mainly all parameters not described in Sec. 4.2.1 - 4.2.5) is in general not necessary to be modified by the user. The default values of these parameters have been carefully chosen and have proved to be adequate for a wide range of 2D and 3D applications. However, certain circumstances may make it inevitable to adopt the functionality of the transition module to new tasks with these parameters (list of all parameters: Sec. A.2).

4.3. Automatic restart

Performing a restart of a calculation with transition prediction (or with modified transition lines compared to those from the preprocessing) is not a completely trivial issue. The main shortcoming is the fact, that the transition location is set in the grid (instead of the solution file). Since the information of the grid is only saved in the prepreocessing, information of new transition locations e.g. from transition prediction is only known during runtime of the Tau code. To do a restart with modified transition locations, the following two parameters have to be set:

- **Update transition blocks in para file (0/1)**: 1
- **Set transition at solver start (0/1)**: 1

The first parameter makes sure that the last used transition locations will be updated in the parameter file. The now updated parameter file can then be used for a restart. With the second parameter, the updated transition locations will be prescribed at the beginning of a new Tau calculation.

For an example parameter file with restart option see Sec. B.1.3.

5. Predicted transition locations

For each transition prediction line (2.3) one ore more (e.g. for Tollmien-Schlichting- and cross flow instabilities) transition criteria are applied. However, the transition point predicted by the apllied criteria may not be the transition point actually applied to the RANS solution process. Different scenarios that will influence the final transition location for a single transiton prediction step are described in the following.

5.1. New transition locations

The general procedure to determine a new transition location for a certain transition prediction line is as follows:

- apply the chosen transition criteria
- apply under-relaxation to the transition location
- check for maximum allowed distance for transition location movement

5.1.1. Transition locations from transition criteria

If more than one transition criterion is applied to a certain transition prediction line, all criteria are evaluated. From the set of possible transition locations, the location lying furthest upstream is chosen to give

$$x_{tr} = min(x_{tr,c1}, x_{tr,c2}, ..., x_{tr,cn}) \tag{3}$$

If none of the applied transition criteria gives a new transition location, transition is set to the laminar separation point from the RANS solution (if a separation exists):

$$x_{tr} = x_{sep,RANS} \tag{4}$$

Alternatively, if the boundary layer code has been executed for the investigated transition prediction line, the laminar separation point from the boundary layer code is applied:

$$x_{tr} = x_{sep,BLcode} \tag{5}$$

If neither of this criteria (applied transition criterion, laminar separation from RANS solution or boundary layer code) gives a new transition location, a new transition point is constructed by moving the old transition location a destinct distance downstream:

$$x_{tr} = x_{tr,old} + \Delta x \tag{6}$$

The distance Δx is specified by the user with the parameter Maximum delta for transition, which also gives the maximum permitted distance the transition location can be altered (5.1.3). Δx is specified as arc length along the transition prediction line.

5.1.2. Under-relaxation of the transition location

After a (prelimenary) transition location has been determined according to the rules in Sec. 5.1.1, this location is applied using under-relaxtion:

$$x_{tr} = x_{tr,old} + f_{relax}(x_{tr} - x_{tr,old}) \tag{7}$$

The relaxation factor can be adjusted with the parameter Relaxation factor for transition.

5.1.3. Limitation of the transition location movement

The maximum distance a transition location will be moved can be limited in order to avoid to large steps in the transient phase of the transition prediction:

$$x_{tr} = min(x_{tr,old} + \Delta x, x_{tr}) \tag{8}$$

The maximum distance, measured in arc length along the transition predicition line, can be prescribed with the parameter Maximum delta for transition.

5.2. Determination of transition lines

If for all transition prediction lines a transition point has been determined according to Sections 5.1.1 - 5.1.3 (equations 3 - 8), the transition locations are applied in different ways, depending on the dimensionality of the problem.

5.2.1. 2D transition

In 2D flows, the new transition location will be applied using a plane. All surface points upstream of this plane will be flagged laminar. The plane is simply defined as follows:

x_{tr} 0 0
x_{tr} 0 1
x_{tr} 1 0

(Note: the location x_{tr} is moved upstream, so that x_{tr} lies in the middle of to surface grid points.)

5.2.2. 3D transition

For 3D flows, the transition points on the different transition prediction lines belonging to a certain surface boundary part are connected, giving a single polygon line. At the edges of this transition line, a simple extrapolation is performed, to ensure that the transition line reaches beyond the edge of the boundary part. The extend of the extrapolation can be adjusted with the parameter Offset for polylines extrapolation.

6. Limitations of the method

In the following, known limitations of the method are summarized. Most of these limitations are not definite and there may exists workarounds to treat cases which exhibit these limitations. For known workarounds, please contact the developers.

6.1. Sharp leading edges

Generally, the transition prediction lines (edge streamlines, attachment line, line-in-flight cuts, 2.3) are calculated with a marching method. I.e., the calculation of the lines starts at a single point (coordinate) and is continued from this point, until a specified limit is reached. Generally, sharp edges are such a limit. They are automatically determined by the transition module with the help of the parameter Lim. angle to detect sharp edges (deg). However, only sharp trailing edges are considered (parameter Flow direction for sharp edges).

Nevertheless, it can not generally be assumed, that there exists a good reproduction of the velocity profiles from the Navier-Stokes solution near/around a sharp leading edge, so that the calculation of the edge streamlines may fail here. Moreover, no detailed testing of the transition module with flows around sharp leading edges has been accomplished, so that there exists currently a lack of experence for cases with sharp leading edges.

6.2. Round trailing edges

As described in Sec. 6.1 and 2.3, the calculation of the transition prediction lines stops at sharp trailing edges. If no sharp trailing edge is existant, the edge streamline calculation may be stopped by using *limiting planes* (A.2.3). Currently, the approach of *limiting planes* does not exists for the calculation of line-in-flight cuts. Here, the calculation may be stopped irregularly, with a warning message printed to the TAU error log. The current workaround for this is to adjust the angle by which sharp edges are detected (Lim. angle to detect sharp edges (deg)). If reduced, this parameter will eventually identify a round edge as a sharo edge due to the finite discretisation of the surface. This workaround works best with rather coarse resolved round trailing edges.

6.3. Super- and hypersonic flows

The external programs Coco (boundary layer code) and Lilo (stability code) have been developed with special focus on subsonic and transsonic cases. Additionally, for the analysis with Lilo, the propagation direction for Tollmien-Schlichting waves does not generally correspond to the direction of the group velocity for higher Mach numbers. Here, wave angles $\neq 0$, i.e. wave number $\beta \neq 0$, might be considered as well. This could generally be adjusted with the parameter Second wave number [BETA], but no experiences have yet been gathered with this approach.

6.4. Internal flows

The assumption of constant pressure normal to the wall inside the boundary layer might be violated for internal flows and thus may lead to erronous results for the boundary layer data from the Navier-Stokes solution (due to inaccuracies in the boundary layer edge detection based on c_p).

6.5. Moving walls/Rotor in hover

Cases with onflow conditions not prescribed in the farfield (i.e., e.g., moving walls, rotor in hover, etc.) are not supported yet.

6.6. Deformation

Cases with deformation are currently not supported by the transition module.

7. Examples

7.1. 2D airfoil

Deliberately left blank.

7.2. 2D multi-element airfoil

Deliberately left blank.

7.3. 2.5D infinite swept wing

Deliberately left blank.

7.4. 3D multi-element configuration

Deliberately left blank.

7.5. 3D geometry

Deliberately left blank.

8. References

[1] Schlichting H, Gersten K: Boundary layer theory, eighth ed., 2000. Berlin Heidelberg New York: Springer; 2001.

[2] Arnal D: Boundary layer transition: prediction based on linear theory. AGARD-R-793; 1994.

A. Description of parameters

A.1. Transition prescription

- **Boundary part namelist:** (none); The transition data are matched to the boundary parts by matching the names given in this parameter and the names of the boundary parts. Therefore it is possible to define one transition block which is valid for more than one boundary part.

- **Transition flow direction:** 1 0 0; This parameter defines the projection of each polygon line to the surface. Per default it points along the X-axis.
  If the scalar product of the vector between a surface point and its nearest visible polygon-line coordinate and of the flow direction vector is positive the surface point is considered to be on the laminar side. If the scalar product is negative or zero the point is assumed to be on the turbulent side. Thus, the polygon-line is projected inside a plane normal to the flow direction (which is for the default a plane of constant x). This holds also if the nearest point of the nearest polyline segment is not in the interior of the segment but if it is either the start point or the end point of the segment. Thus, if a polygon-line ends over the half of the surface, the transition line would have a constant x value (in case of the default flow direction) for the rest of the surface.

- **Exclude surface normal/angle:** 0 0 0 0; This parameter can be used to select certain sections of a boundary part for which a polyline is not applicable. For example, when defining different transition-lines for the lower and the upper wing surface, this option is needed if both surfaces are contained in the same boundary part.
  The 'Exclude surface normal/angle' is an array containing 4 floats. The first three define a vector, the 4th defines an angle (in degree). If these values are set to: 1.0, 0, 0, 60 all surface points with a normal which has an angle lower to 60 degrees to the vector (1, 0 , 0) will not be marked by the polygon-line to which this parameter is assigned.

- **Laminar height:** 0; For each field point the distance is calculated to the nearest viscous wall boundary point, and when this boundary point is laminar the wall distance is multiplied by -1 to define a laminar region. When for a transition viscous wall this parameter is set, only the field points which are nearest to the laminar points on *this* transition viscous wall *and* have a wall distance less than this value are set as being laminar. This parameter has to be specified in grid units.

- **Number of polyline points:** 0; The number of points in the polyline or 0 if a plane is defined in this transition block. This number has to match the number of coordinates (x, y, z components) which follows in the input.

- **Number of plane points:** 0; This number has to be 0 (in case that a polyline is defined) or 3, which is the number of points to define a plane. The input for plane point coordinates equals the input of polygon line coordinates.

- **TransitionCoordinates / transition end** Keywords to define the beginning and the end of the set of coordinates to describe a polyline or a plane. Additionally, transition end is also the keyword to mark the end of the transition prescription block.
  TransitionCoordinates
  x_0 y_0 z_0
  x_1 y_1 z_1
  x_n y_n z_n
  transition end

A.2. Transition prediction

A.2.1. Basic parameters. Set 1

- **Transition prediction description file:** (thisfile); Name, including path, of the file containing the parameters for the transition prediction.
- **Prediction info output level:** 3; Sets the level of information written by the transition module during transition prediction to stdout. If set to 0, no output is written to stdout.
- **Prediction debug output level:** 0; Sets the level of special information for debugging written by the transition module during transition prediction to stdout. This option includes also additional file output for debugging (e.g. sharp edges). This parameter is only available if the code is compiled with the development option.
- **Transition prediction output directory prefix:** 'Tranpred'; Prefix for the directories of the file output of the transition prediction. At each transition prediction step the files created will be saved in a directory named prefix.iteration.dir, e.g. 'Tranpred.01000.dir'.
- **Transition history file name prefix:** 'transition_history'; Prefix for the file containing the history of specific values determined during transition prediction. The file created will have the name prefix.dat. The output values can be specified using the parameter Transition history output values. Note: this file will not be moved to a transition prediction output directory.
- **Transition history output values:** 'set'; Character string containing the names of the output variables joined with an underline (e.g. set_sep_pmin). Valid names are:
  - set: The transition points applied to the code.
  - new: The transition points coming from the applied prediciton method.
  - sep: Separation point from Tau.
  - reatt: Re-attachment point from Tau.
  - pmin: Local pressure minimum.
  - cfmin: Local skin friction minimum from Tau.

  All parameters can also be applied in dimensionless form when using contourlines for the prediciton of transition by adding /c to the keyword (e.g. set/c_sep/c_pmin/c).
  There is a distinction between the parameter set and new: set will show the transition location actually applied to the code, after using relaxation etc. to the transition location from the prediction method. new will show the transition location predicted by the chosen prediciton method (e.g. e^N-method) before relaxation etc. is applied to the transition locations.
- **Write streamline data to file (0/1):** 1; Write boundary layer data of each streamline to a file in tecplot-format (streamlines.dat). If specified, this file can be found in the transition prediction output directory of the corresponding transition prediciton step. For each streamline a separate tecplot zone will be written. The file contains the following parameters:
  - x, y, z: The streamline coordinates.
  - uedge: The boundary layer edge velocity, calculated from the surface pressure distribution.
  - uedge_mod: The boundary layer edge velocity, taken at the position, where the boundary layer edge is actually found in the transition module.
  - id: The number of points normal to the wall lying inside the boundary layer.
  - d: The boundary layer thickness δ.

- dss: The boundary layer displacement thickness of the streamwise velocity profile δ_s^*.
- dsc: The boundary layer displacement thickness of the cross flow velocity profile δ_c^*.
- ths: The boundary layer momentum thickness of the streamwise velocity profile θ_s.
- thc: The boundary layer momentum thickness of the cross flow velocity profile θ_c.
- hs: The shape factor of the streamwise velocity profile $H_s = \delta_s^*/\theta_s$.
- hc: The shape factor of the cross flow velocity profile $H_c = \delta_c^*/\theta_c$.
- b: The angle β between the direction of the skin friction line and the flow direction at the edge of the boundary layer.
- p: The pressure along the streamline.
- cp: The pressure coefficient c_p along the streamline.
- s: The arc length of the streamline.
- Reth: The local Reynolds number based on boundary layer edge quanteties and the momentum thickness of the streamwise velocity profile: $Re_{\theta_s} = u_e\theta_s/\nu_e$.
- dps: Deliberately left blank.
- dpc: Deliberately left blank.
- dvs: Deliberately left blank.
- dvc: Deliberately left blank.

All lengths have the dimension of the grid, i.e. they are in grid units. All other values are dimensional (if applicable).

If there are streamlines of the type contourline present, an additional file in tecplot-format will be written with data for the complete line-in-flight cuts (contourlines.dat). This file can be found in the transition prediction output directory of the corresponding transition prediciton step. For each contourline four separate tecplot zones will be written: One zone containing the contourline, two zones containing a single point respectively marking the pressure minima, one zone marking the stagnation point. The file contains the following parameters:

- x, y, z: The streamline coordinates (in grid units).
- p: The pressure along the contourline.
- cp: The pressure coefficient c_p along the contourline.

- **Write boundary layer profiles to file (0/1):** 0; Write boundary layer profiles of each streamline to files (BL_profiles.nr.dat). If specified, these files can be found in the transition prediction output directory of the corresponding transition prediciton step. The files contain the following parameters:
  - yd1: Non-dimensional wall distance y/δ_s^*. For laminar flow $\delta/\delta_s^* \approx 3$ [1].
  - u: Streamwise velocity component (non-dimensional).
  - v: Cross flow velocity component (non-dimensional).
  - du: First derivative of streamwise velocity component (non-dimensional).
  - dv: First derivative of cross flow velocity component (non-dimensional).
  - ddu: Second derivative of streamwise velocity component (non-dimensional).
  - ddv: Second derivative of cross flow velocity component (non-dimensional).
  - t: Temperature (non-dimensional).
  - dt: First derivative of temperature (non-dimensional).

  - dt: Second derivative of temperature (non-dimensional).
  - y: Distance normal to the wall (dimensional).
  - ue: Boundary layer edge velocity (dimensional).
  - uu: Norm of the velocity (non-dimensional).
  - duu: First derivative of the norm of the velocity (non-dimensional).
  - vort: Vorticity (non-dimensional).
  - Rev: Strain rate Reynolds number: $Re_v = y^2 S/\nu_e$.

- **Write additional contourline data to file (0/1):** 0; If there are streamlines of the type contourline specified, additional data in tecplot-format (contourlines.trans.dat) can be written with this option. This file can be found in the transition prediction output directory of the corresponding transition prediciton step. The file contains the following parameters:

  - eta: The dimensionless spanwise coordinate of the line-in-flight cut (if parameter Halfspan reference length is specified).
  - y: The dimensional spanwise coordinate of the line-in-flight cut.
  - Relocal: The local Reynolds number based on the chord length of the line-in-flight cut.
  - Retheta: The attachment line Reynolds number Re_θ, if calculated by prepcp.
  - phieff: The effective sweep angle, if calculated by prepcp.
  - phile: The leading edge sweep angle, extracted from the Tau grid.
  - phile: The trailing edge sweep angle, extracted from the Tau grid.
  - x/c_tran_set: The non dimensional transition point applied to the code.
  - x/c_tran_new: The non dimensional transition point coming from the applied prediciton method.
  - x/c_sep_tau: The non dimensional separation point from Tau.
  - x/c_sep_coco: The non dimensional separation point from Coco.
  - x/c_att_tau: The non dimensional reattachment point from Tau.
  - x/c_pmin: The non dimensional point of the pressure minimum.
  - x/c_pmin: The non dimensional point of the local skin friction minimum.

- **Transition history output in pre-mode (0/1):** 0; Switch, to decide if the transition history file will be updated during the pre-prediciton phase. For 3D calculations, specifying to update the history file in the pre-prediction mode may result in a large and unclear history file.

- **Keep files from pre-mode (0/1):** 0; Switch, to decide if the output files from the pre-prediciton phase will be saved.

A.2.2. Basic parameters. Set 2

- **Prediction start iteration nr:** 1000; The start iteration number for the transition prediction. The first transition prediction step is performed, if the Tau inner iteration corresponds to the prediction start iteration.

- **Prediction end iteration nr:** 10500; The end iteration number for the transition prediction. A transition prediction step is performed, if the Tau inner iteration is lower than the prediction end iteration and the inner iteration matches the prediciton period.

- **Prediction period:** 500; The length of the intervall in terms of inner Tau iterations between two consecutive transition prediciton steps.

- **Pre-prediction start iteration nr:** 20; The start iteration number for the transition pre-prediction. The first transition pre-prediction step is performed, if the Tau inner iteration corresponds to the prediction start iteration.
- **Pre-prediction end iteration nr:** 1000; The end iteration number for the transition pre-prediction. A transition prediction step is performed, if the Tau inner iteration is lower than the pre-prediction end iteration and the inner iteration matches the pre-prediciton period.
- **Pre-prediction period:** 20; The length of the intervall in terms of inner Tau iterations between two consecutive transition pre-prediciton steps.
- **Relate period to start iteration (0/1):** 1;
- **Max. number of points on wallnormal:** 128; Maximum number of points normal to the considered for the determination of the boundary layer profiles. This parameter should correspond to the number of points normal to the wall of the structured grid part. A lower value will result in less memory consumption during the calculation.
- **Min. number of points on wallnormal:** 32; Currently not used.
- **Max. distance for wallnormals:** 1e+20; Maximum distance in grid units of the wall normals. This parameter should exceed the extension of the the structured grid part normal to the wall. This parameter does not affect the memory consumption during the calculation.
- **Lim. angle to detect sharp edges (deg):** 30; This angle (in degrees) is used to detect sharp edges of the surface grid. If the angle between the normals of two neighbor wall points is larger than the limiting angle, the corresponding wall point is assumed to lie on a sharp edge. Generally, sharp edges are used to stop the streamline integration and the contourline detection.
- **BL edge criterion:** 3; Criterion to detect the boundary layer edge:
  - 0: 95% criterion (specify with Velocity factor for BL edge)
  - 1: Chose best of 80%-100% criterion or apply local maximum.
  - 2: Vorticity criterion (specify with Vorticity factor for BL edge)
  - 3: Same as mode 1 with advanced search for local maximum.
- **Velocity factor for BL edge:** 0.95; For the searchg of the boundary layer edge, the theoretical boundary layer edge velocity is calculated from the surface pressure. The boundary layer edge is then detected if 0.xy, i.e. xy% of this value is reached.
- **Vorticity factor for BL edge:** 0.001; The boundary layer edge is detected when the ratio between the local vorticity and the maximum vorticity inside the boundary layer is below this value.
- **Trailing edge calculation mode:** 0; New (0)and old (1) version for the calculation of the trailing edge sweep angle.
- **Keep N-factor files (0/1):** 1; Switch, to decide if the output files from e^N-method will be saved.
- **Window size for pmin/pmax search:** 5; Half size (in numbers of streamline points) of the window for the search of pressure minimum and pressure maximum of a streamline. The pressure maximum and pressure minimum is locally defined, e.g. the pressure minimum used in the transition prediction is the first minimum downstream of the stagnation point. To neglect small oscillations in the pressure distribution, a local pressure minimum is a global pressure minimum within the defined window.

- **Maximum delta cp for pmin/pmax search:** 0.5; Size of the allowed maximum jump in the pressure distribution for the detection of a local pressure minimum or maximum.
- **Runge Kutta steps for streamline integration:** 10; The number of Runge Kutta steps that are performed at least within one surface element during the streamline integration. For the determination of the step size of the Runge Kutta integration the shortest edge of the corresponding surface element is used together with the traget parameter for the number of Runge Kutta steps.
- **Use grid point as start coordinate (0/1):** 0; Generally, the start coordinates for the streamline and contourline calculation are projected onto the surface of the geometry. This projected point does not necessarily correspond to a surface grid point. In some cases, it may be favorable to have the coordinates of the nearest grid point as start coordinates.

A.2.3. Block parameters

Block default parameters

- **TS transition prediction mode:** 10; Criterion for the prediciton of Tollmien-Schlichting transition.

mode	method	available
0	none	release
1	cp,min	release
2	laminar separation	release
6	eN-Method with N-factors from envelope method of Wuerz	development
7	eN-Method with N-factors from envelope method of Drela (1987)	development
8	eN-Method with N-factors from envelope method of Drela (1991)	development
9	eN-Method with N-factors from Database method (Stock, Degenhart)	development
10	eN-Method with N-factors from linear stability solver Lilo	release
11	Michel/Cebeci/Thwaites	development
12	AHD (Arnal, Habiballah, Delcourt)	development

- **CF transition prediction mode:** 10; Criterion for the prediciton of cross flow transition.

mode	method	available
0	none	release
1	C1 (Arnal)	development
9	eN-Method with N-factors from Database method (Casalis, Arnal)	development
10	eN-Method with N-factors from linear stability solver Lilo	release

- **Bypass transition prediction mode:** 0; Criterion for the prediciton of bypass transition.

mode	method	available
0	none	release
1	Mayle	development
2	H12 bypass detection	development
3	Braslow/von Doenhoff	development
4	Braslow/von Doenhoff + H12 bypass detection	development

- **LSB transition prediction mode:** 0; Criterion for the prediciton of transition in laminar separation bubbles.

mode	method	available
0	none	release

- **Attachment line transition prediction mode:** 0; Criterion for the prediction of attachment line transition.

mode	method	available
0	none	release
1	Pfenninger/Poll (Re,Theta from Tau AL)	development
2	Pfenninger/Poll (Re,Theta from first point of streamline	development
3	Pfenninger/Poll (Re,Theta from Prepcp)	development

- **Boundary layer data mode:** 0; Selection of the source (Navier-Stokes solution from Tau or boundary layer code solution from Coco) for the boundary layer data for transition prediction.

mode	method	level
0	use Tau BL-data for transition prediction	normal
1	use Coco BL-data for transition prediction	normal
2	use Coco for CF, use Tau for TS	expert
3	use Coco for TS, use Tau for CF	expert

- **Pre-prediction mode:** 2; The pre-prediction mode (Sec. 2.5.1) is a procedure which is applied before the actual prediction process in order to stabilize the computation:
  - Set transition at laminar separation points to stabilize the computation in the transient phase
  - Set transition at cp,min e.g. when started as fully turbulent calculation

mode	method	available
0	none	release
1	transition at cp_{min} + offset (offset = "Pre-Maximum delta for transition")	release
2	laminar separation from Tau	release
3	laminar separation from Coco	no

- **Critical N-factor TS:** 12; Critical N-factor for Tollmien-Schlichting instabilities. The default value corresponds to free flight conditions. (See also N-ts/N-cf Diagram)
- **Critical N-factor CF:** 9; Critical N-factor for cross flow instabilities. The default value corresponds to free flight conditions. (See also N-ts/N-cf Diagram)
- **N-ts/N-cf Diagram (points):** 3; Number of points to specify a polygonal line which approximates the stability boundary.
  - $n = 0$: not active
  - $n \geq 3$: active (minimum: 3)

  This parameter specifies the number of coordinate pairs which have to be given with the input parameters N-ts/N-cf Diagram (N-TS) and N-ts/N-cf Diagram (N-CF). If this parameter is not set, a rectangular stability boundary is used by applying the two parameters Critical N-factor TS and Critical N-factor CF.

A rectangular stability boundary is the simplest (but not always the best) approximation of the stability boundary. Stability limits of non-rectangulat form do consider the interaction of the two modes.

Note: If both, the two parameters Critical N-factor TS and Critical N-factor CF and the parameter N-ts/N-cf Diagram (points), are set in the input file and a set of coordinate pairs is specified, the N-ts/N-cf stability-diagram is applied, not the two parameters Critical N-factor TS and Critical N-factor CF.

- **N-ts/N-cf Diagram (N-TS):** -; N_{TS} values of the coordinate pairs specifying the points of the polygonal line which approximates the stability boundary. The number of values to be given here is specified by N-ts/N-cf Diagram (points).

- **N-ts/N-cf Diagram (N-CF):** -; N_{CF} values of the coordinate pairs specifying the points of the polygonal line which approximates the stability boundary. The number of values to be given here is specified by N-ts/N-cf Diagram (points).

- **Minimum N-factor for extrapolation (TS):** 0.001; The N_{TS} envelope will only be extrapolated if $N_{TS} > N_{limit,TS}$.

- **Minimum N-factor for extrapolation (CF):** 0.001; The N_{CF} envelope will only be extrapolated if $N_{CF} > N_{limit,CF}$.

- **N-factor extrapolation mode:** 3; N-factor envelope extrapolation mode.

  The extrapolation is important for calculations with linear stability theory (Lilo) and boundary layer data from the Navier-Stokes solution to get converged transition locations. Generally, there will be an upstream influence of the turbulence at the currently set transition point. This effect can influence the developped velocity profiles to become "partly turbulent" upstream of the transition point. I.e., the shape of an laminar boundary layer profiles becomes more and more similar to an turbulent boundary layer profile upstream of the transition point. This can lead to the effect that for boundary layer profiles in the laminar region shortly before transition no amplifications will be calculated by the stability solver and the critical N-factor will not be reached.

mode	method
0	no extrapolation
1	extrapolation at global maximum slope of envelope
2	extrapolation at maximum slope in the vicinity of $c_{f,min}$
3	extrapolation at maximum slope in the vicinity of $c_{f,min}$. The extend of this region can be altered by Cf-min offset for extrapolation mode 3
11	same as mode 1 (forced extrapolation, see remark)
12	same as mode 2 (forced extrapolation, see remark)
13	same as mode 3 (forced extrapolation, see remark)

  Important: When using the boundary layer method for the calculation of boundary layer profiles, extrapolation is switched off automatically for modes 1-3. To force extrapolation in this case use mode 11-13.

- **Cf-min offset for extrapolation mode 3:** 10; Size (in streamline points) of the region upstream of the $c_{f,min}$ location to be considered for the extrapolation of the N-factor curves for N-factor extrapolation mode:3.

- **Turbulence intensity for transition criteria:** 0.1; Specifies the turbulence intensity (in %) for transition criteria which are based on this value (Mayle, AHD).

- **Re,theta for attachment line transition:** 100; $Re_{\theta,crit}$ for the Pfenninger/Poll attachment line transition criterion (Attachment line transition prediction mode). Note: $Re_\theta = 0.404 \cdot \overline{Re}$.

scenario	$Re_{\theta,crit}$	$\overline{Re}_{crit}$
Tollmien-Schlichting instabilities	≈ 267	≈ 662
Goertler-Haemmerlin instabilities	≈ 235	≈ 582
attachment line contamination (bypass)	≈ 100	≈ 250

- **Skip streamline in case of ALT (0/1):** 1; Skip streamlines for further treatment with other transition criteria if attachmentline transition has been detected.

- **Points skipped near stagnation point:** 5; Number of points on the transition prediciton line in the neighborhood of the stagnation point which are excluded for the application of empirical transition criteria based on integral boundary layer parameters.

- **Relaxation factor for transition:** 0.8; Under-relaxation factor for iteration of the transition locations (see transition prediction parameter Maximum delta for transition).

- **Maximum delta for transition:** 1e+20; Maximum distance the transition location is allowed to move between two consecutive calls of the transition prediction. **Important**: If the maximum distance is lower than the local surface cell size the transition location can not be moved!.

  A new transition point is determined as follows (2D): $x_{tr} = x_{tr,old} + MIN(\delta_{max}, (x_{tr,new} - x_{tr,old}) * relax)$, where $relax$ is the under-relaxation factor (Relaxation factor for transition). If no transition is found: $xtr = x_{sep}$, where x_{sep} is the laminar separation point from the laminar boundary-layer code Coco (if available), or the laminar separation point from Tau. For more details on the determination of the new transition location see Sec. 2.5.

- **Pre-relaxation factor for transition:** 1.0; Same as Relaxation factor for transition, but for pre-prediction mode.

- **Pre-maximum delta for transition:** 1e+20; Same as Maximum delta for transition, but for pre-prediction mode.

- **Offset for pmin criterion:** 0.0; Distance in grid units of the downstream offset for then new transition location when using the $c_{p,min}$ transition criterion. $x_{tr} = x_{c_{p,min}} + x_{offset}$.

- **Offset for polylines extrapolation:** 1.5; The distance in grid units the transition lines are extrapolated in 3D before applied to the Navier-Stokes calculation. Generally, transition lines should be extended beyond the edges of the corresponding boundary part.

- **Half span reference length:** 0; Reference length for calculating non-dimensional η values for the spanwise position of contourlines. Only needed for output purposes. Only active for values > 0.

- **Reference flow direction:** 1 0 0; This direction is needed for the automatic determination of the geometrical sweep angles and for the generation of cutting planes for the contourline calculation from surface normal vectors.

- **Streamline coordinates type set:** xyz; Character string containing the names of components of the streamline start coordinates block. The variables are joined with an underline (e.g. *xyz_lesweep_fixed*). Valid names are:

  - xyz: start coordinates of the streamlines/contourlines (three floats are expected).
  - nxyz: normal vector to define the cutting plane for contourlines (three floats are expected).

  - lesweep: leading edge sweep angle (one single float is expected).
  - tesweep: trailing edge sweep angle (one single float is expected).
  - efsweep: effective sweep angle (see also **Effective sweep angle**, one single float is expected).
  - aesweep: aerodynamic sweep angle (see also **Aerodynamic sweep angle**, one single float is expected).
  - plane: character string to identify the cutting plane for contourline calculation (character string expected):
    * xy: cutting plane is the x-y-plane
    * xz: cutting plane is the x-z-plane
    * yz: cutting plane is the y-z-plane
    * wn: cutting plane is built from **Reference flow direction** and local wall normal vector.
  - fixed: character string to identify the treatment of the given coordinates (character string expected):
    * s: streamline coordinates are used as fixed transition point (no streamline/contourline calculation)
    * f: free transition (streamline/contourline calculation + transition prediction)
    * m: streamline coordinates are used as fixed transition point if this point lies in a laminar region (no streamline/contourline calculation)
    * t: transition is tripped at streamline start coordinates (streamline/contourline calculation + transition prediction)

Example for *xyz_lesweep_fixed*

```
StreamlineCoordinates
0.00 1.00 0.00 30.3 t
0.00 1.50 0.00 30.3 f
0.00 2.00 0.00 30.3 f
1.00 2.50 0.00 00.0 s
StreamlineCoordinates end
```

- **Set leading edge sweep angles:** 0; Switch to deactivate automatic calculation of leading edge sweep angles. Sweep angles have then to be prescribed by the user, either in the streamline coordinates block (see **Streamline coordinates type set**) or with the parameter **Leading edge sweep angle**.
- **Leading edge sweep angle:** 0.0; Prescription of the leading edge sweep angle if **Set leading edge sweep angles** is set to 1.
- **Set trailing edge sweep angles:** 0; Switch to deactivate automatic calculation of trailing edge sweep angles. Sweep angles have then to be prescribed by the user, either in the streamline coordinates block (see **Streamline coordinates type set**) or with the parameter **Trailing edge sweep angle**.
- **Trailing edge sweep angle:** 0.0; Prescription of the trailing edge sweep angle if **Set trailing edge sweep angles** is set to 1.
- **Set effective sweep angles:** 0; Switch to activate the setting of the effective sweep angle. The effective sweep angle is then used by Prepcp to modify the pressure distribution. If Prepcp is not used, this parameter has no effect. The effective sweep angles have to be prescribed either in the streamline coordinates block (see **Streamline coordinates type set**) or with the parameter **Effective sweep angle**.

- **Effective sweep angle:** 0.0; Prescription of the effective sweep angle if **Set effective sweep angles** is set to 1.
- **Set aerodynamic sweep angles:** 0; Switch to activate the setting of the aerodynamic sweep angle. The aerodynamic sweep angle is then used by to modify the local Reynolds number and the local chord length for Coco or Prepcp input. The aerodynamic sweep angle corresponds generally to the yaw angle β. The aerodynamic sweep angles have to be prescribed either in the streamline coordinates block (see **Streamline coordinates type set**) or with the parameter **Aerodynamic sweep angle**.
- **Aerodynamic sweep angle:** 0.0; Prescription of the aerodynamic sweep angle if **Set aerodynamic sweep angles** is set to 1.
- **TransitionBlock end** -; Keyword (case sensitive) to mark the end of a transition prediciton block (default block or individual block).

Block individual parameters

- **Transition block name:** (none); The name of the individual transition block. This name will be used essentially for output purposes.
- **Boundary part list:** (none); Identifier of the boundary marker for which transition prediction is performed. The transition prediction block is matched to the transition prescription block by matching the names given in this parameter and the parameter Boundary part namelist of the transition prescription block (Sec. A.1). If there is more than one transition prescription block with the same Boundary part namelist, the parameters Assigned transition block or Exclude surface normal/angle in the transition prediction block have to be used to create a unique matching between one transition prediction block and exactly one transition prescription block.
- **Assigned transition block:** -1; Number of the transition prescription block (Sec. A.1) to which the individual transition prediction block will be assigned. The numbering of the transition prescription blocks is top down, beginning with 0. This parameter can be used to uniquely assign an indivdual transition block to a transition prescription block.
- **Transition flow direction:** 1 0 0; same as in the transition prescription block (Sec. A.1). If a different value is set, the value of the transition block will be overwritten during transition prediction. If this value is *not* set, the value from the corresponding transition prescription block will be used.
- **Exclude surface normal/angle:** 0 0 0 0; same as in the transition prescription block (Sec. A.1). If a different value is set, the value of the transition block will be overwritten during transition prediction. If this value is *not* set, the value from the corresponding transition prescription block will be used.

  This parameter can be used to uniquely assign an indivdual transition to a transition prescription block. If there is more than one transition prescription block with the same Boundary part namelist, the transition prediction block is matched to the transition prescription block by matching the names in Boundary part namelist and the values of **Exclude surface normal/angle** of the block.
- **Laminar height:** 0; same as in the transition prescription block (Sec. A.1). If a different value is set, the value of the transition block will be overwritten during transition prediction. If this value is *not* set, the value from the corresponding transition prescription block will be used.
- **Streamline type:** 2; Type of the transition prediction lines of the individual transition block (Sec. 2.3).

type	description
1	Inviscid (edge) streamline, integrated from the boundary layer edge velocity. The streamline integration is carried out into two directions, upstream and downstream. It starts at a prescribed point on the surface and ends either when it reaches an attachment line, when a sharp edge is reached or a user defined limiting plane is reached.
2	Contour line parallel to oncoming flow ('line-in-flight' cut), only in x-z plane. Geometry has to be of wing-type, i.e. the surface can be divided into an upper and a lower surface part at an stagnation point. This is the standard type that should be used for 2D flows over airfoils.
3	Attachment line (is always computed from downstream to upstream). This type *is not* associated with Boundary part list, thus: Boundary part list: (none)

- **Number of streamline points:** 0; The number of start coordinates for the calculation of the transition prediciton lines (streamlines, line-in-flight cuts, attachment lines). This number has to match the number of coordinates bordered by the keywords StreamlineCoordinates and StreamlineCoordinates end.

- **StreamlineCoordinates / StreamlineCoordinates end** x, y, z; Keywords to mark the set of start coordinates used for the calculation of the transition prediction lines in the form:

  StreamlineCoordinates
  x_1 y_1 z_1
  x_2 y_2 z_2
  x_n y_n z_n
  StreamlineCoordinates end

  Commented lines are allowed between the keywords, the number of coordinates read is checked with the number specified with the parameter Number of streamline points for consistency. The keywords are case sensitive.

- **Use contourlines of block:** (none); The contour lines always contain the data for the upper and lower sides of a wing section, even if only on one side transition is considered in the computation. If transition is to be computed on both sides, it is *not* necessary to compute the contour lines twice because all needed information is already available. If two individual transition blocks share the same line-in-flight cuts the start coordinates have only to be specified in one block. The connection to these line-in-flight cuts is done with the parameter Use contourlines of block, where the value is a string containing the name of the individual transition block (Transition block name) where the line-in-flight cuts are initially specified.

- **Number of limiting planes:** 0; A number of planes can be defined using this parameter in order to force the streamline computation to stop if the streamline runs into one of the hereby defined planes. This feature can be important at the wing-body junction together with Streamline type 3 in order to avoid an attachment line calculation in regions where it is not needed and where problems with the integration might occur.

- **LimitingPlane / LimitingPlane end** x, y, z; Keywords to mark the set of points defining the limiting plane in the form:

  LimitingPlane
  x_{11} y_{11} z_{11}

x_{12} y_{12} z_{12}
x_{13} y_{13} z_{13}
LimitingPlane end
LimitingPlane
x_{21} y_{21} z_{21}
x_{22} y_{22} z_{22}
x_{23} y_{23} z_{23}
LimitingPlane end
LimitingPlane
x_{n1} y_{n1} z_{n1}
x_{n2} y_{n2} z_{n2}
x_{n3} y_{n3} z_{n3}
LimitingPlane end

The number of limiting plane blocks is specified by the parameter Number of limiting planes. The planes are always defined by three points. The keywords are case sensitive.

- **TransitionBlock end** -; Keyword (case sensitive) to mark the end of a transition prediciton block (default block or individual block).

A.2.4. Additional parameters

Coco parameters

- **Coco executable:** ./coco; Path to the Coco executable.
- **Prepcp executable:** ./prepcp; Path to the Prepcp executable.
- **Use Prepcp (0/1/2):** 0; 0: Prepcp is not used — 1: Prepcp is only used to determine effective sweep angle and Re,theta,al — 2: Prepcp is used to modify cp-distribution.
- **Prepcp factor for number of stations:** 1.0; Factor to modify number of streamline stations in Prepcp.
- **Prepcp number of stations:** -1; Fixed number of stations to be used in Prepcp. If set to -1, the number of stations is f_{prepcp}*n_c, where f_{prepcp} is set by the parameter **Prepcp factor for number of stations** and n_c is the number of points of the line-in-flight cut.
- **Prepcp max. x/c on upper surface: Prepcp max. x/c on upper surface** 1.0; Maximum local coordinate on upper surface of line-in-flight cut up to which Prepcp will be executed.
- **Prepcp max. x/c on lower surface: Prepcp max. x/c on lower surface** 1.0; Maximum local coordinate on lower surface of line-in-flight cut up to which Prepcp will be executed.
- **Keep Coco log files (0/1):** 1; Save the log files from Coco.
- **Keep Coco run files (0/1):** 0; Save all files needed to run Coco manually.
- **Keep Coco profiles files (0/1):** 0; Save files containing the Coco velocity profiles in Tecplot format.
- **Keep Coco auxiliary files (0/1):** 1; Save files containing some additional output from Coco.
- **Keep Prepcp files (0/1):** 1; Save all Prepcp files.

- **Smooth cp for Coco input (0/1):** 1; Switch for the activation of a simple pressure smoothing. If activated, increase in pressure between stagnation point and pressure minimum is simply cut off. (It is assumed, that only a pressure decrease exists from stagnation to pressure minimum. A (small) increase in pressure may lead to early separation in the boundary layer code Coco.)
- **Modify cp for Coco input:** 1; Switch for the activation of simple pressure modification for the input of the boundary layer code Coco to account for the (effective) sweep angle (**Use phi,le/phi,geo (0/1) to modify cp**). The theoretical stagnation pressure is calculated and the value from the Tau solution is altered to fit to this value.
  - 0: no pressure modification,
  - 1: pressure is modified relative to the position between stagnation point and last point (**Use cp,min/max (0/1) as reference for modified cp**). The shift in pressure is maximum at stagnation point and decreases to 0 at last point (and beyond),
  - 2: constant shift in pressure distribution.
- **Use phi,le/phi,geo (0/1) to modify cp:** 0; Switch to chose which sweep angle is used for the calculation of the theoretical value of the stagnation pressure to modify the pressure distribution (**Modify cp for Coco input**).
  - 0: leading edge sweep angle extracted from Tau grid is used,
  - 1: the so called geometrical sweep angle is used.
- **Use cp,min/max (0/1) as reference for modified cp:** 0; Switch to chose if the pressure distribution will be modified between
  - 0: stagnation point and pressure minimum,
  - 1: stagnation point and last point of streamline,

  when using non-constant pressure shift (**Modify cp for Coco input**). A relaxation factor can be applied (**Relaxation factor for modified cp**).
- **Relaxation factor for modified cp:** 0.5; Relaxation factor for last point of pressure modification (see **Modify cp for Coco input** and **Use cp,min/max (0/1) as reference for modified cp**)

Lilo parameters

- **Lilo executable:** ./lilo; Path to the Lilo executable.
- **Keep Lilo log files (0/1):** 1; Save the log files from Lilo.
- **Keep Lilo run files (0/1):** 0; Save all files needed to run Lilo manually.
- **Keep Lilo auxiliary files (0/1):** 1; Save files containing some additional output from Lilo.
- **Use Coco script for task11 (0/1):** 1; Instead of performing task 10 of Lilo the database method in Coco is used to produce initial data for task 11 of Lilo.
- **Use Coco script for task21 (0/1):** 1; Instead of performing task 30 of Lilo the database method in Coco is used to produce initial data for task 21 of Lilo.
- **Use separation point for task10 (0/1):** 0; Switch, to decide if task 10 of Lilo will be executed inside separation (1) or not (0).

- **Use indifference point for task10 (0/1):** 1; Switch, to decide if indifference point from Drela/Wuerz will be used for determining initial station for task 10 of Lilo.
- **Use logarithmic distribution for TS waves (0/1):** 1; Switch, to decide if a logarithmic distribution for the frequencies will be used when executing task 11 of Lilo.
- **Use logarithmic distribution for CF waves (0/1):** 1; Switch, to decide if a logarithmic distribution for the frequencies will be used when executing task 21 of Lilo.
- **Number of points for global step (TS) [NPGLOB]:** 40; Lilo input parameter NPGLOB: number of grid points for the global step.
- **Number of points for local step (TS) [NPLOC]:** 100; Lilo input parameter NPLOC: number of grid points for the local step.
- **Number of points for global step (CF) [NPGLOB]:** 40; Lilo input parameter NPGLOB: number of grid points for the global step.
- **Number of points for local step (CF) [NPLOC]:** 100; Lilo input parameter NPLOC: number of grid points for the local step.
- **Number of frequencies/wavelengths [NWAV]:** 40; Lilo input parameter NWAV: number of waves to be considered.
- **Analysis incompr./compressible (0/1) [ICOMP]:** 0; Lilo input parameter ICOMP: A compressible medium is assumed, unless ICOMP = 0. In this case, an incompressible medium is simulated by setting Ma to a value of one thousandth.
- **First wave number [ALPHA]:** 0.3; Lilo input parameter ALPHA: first wave number α.
- **Second wave number [BETA]:** 0.0; Lilo input parameter BETA: first wave number β.
- **Relaxation factor for init station for task10:** 0.5; Relaxation factor for the initial station for task 10 of Lilo.
- **Relaxation factor for last station for task10:** 0.5; Relaxation factor for the last station for task 10 of Lilo.
- **Relaxation factor for init station for task30:** 0.0; Relaxation factor for the initial station for task 30 of Lilo.
- **Relaxation factor for last station for task30:** 0.0; Relaxation factor for the last station for task 30 of Lilo.
- **Frequency of instability wave in Hz (CF) [FRQ]:** 500.0; Lilo input parameter FRQ: frequency of the instability wave in Hertz.
- **Number of loops for task 30:** 1; Number of consecutive executions of task 30 of Lilo. Task 30 will be executed until an amplified mode is found, the frequency reaches 0 Hz, or the loop number is exceeded. Initial frequency is set by **Frequency of instability wave in Hz (CF) [FRQ]**, the delta is set by **Delta frequency for task 30 loop**.
- **Delta frequency for task 30 loop:** 150.0; Specifying the delta by which the frequency of the instability wave is reduced when executing task 30 in a loop (**Number of loops for task 30**).

B. Parameter file examples

B.1. 2D airfoil

B.1.1. Boundary mapping

```
block 0:-----------------------------------------------
                                                  Name: upper_surface
                                               Markers: 1
                                                  Type: viscous wall
                                               Subtype: transition
                                             block end

block 1:-----------------------------------------------
                                                  Name: lower_surface
                                               Markers: 2
                                                  Type: viscous wall
                                               Subtype: transition
                                             block end

block 2:-----------------------------------------------
                                                  Name: farfield
                                               Markers: 4
                                                  Type: farfield
                                  Angle alpha (degree): 2.03
                                             block end

block 3:-----------------------------------------------
                                                  Name: Symmetry
                                               Markers: 5
                                                  Type: symmetry plane
                                             block end

block 4:-----------------------------------------------
                                                  Name: Symmetry
                                               Markers: 6
                                                  Type: symmetry plane
                                             block end
```

B.1.2. Transition prescription

```
block 0:-----------------------------------------------
                                 Boundary part namelist: upper_surface
                                 Number of plane points: 3

                                  TransitionCoordinates
                     1.00000       0.00000       0.00000
                     1.00000       1.00000       0.00000
                     1.00000       0.00000       1.00000
                                          transition end


```

```
block 1:-----------------------------------------------
                                Boundary part namelist: lower_surface
                                Number of plane points: 3

                                 TransitionCoordinates
                    1.00000       0.00000       0.00000
                    1.00000       1.00000       0.00000
                    1.00000       0.00000       1.00000
                                         transition end
```

B.1.3. Transition prediction

```
Transition restart parameters:-------------------------

                   Set transition at solver start (0/1): 1
                  Update transition blocks in para file: 1

Transition basic parameters:---------------------------

                             Transition prediction (0/1): 1

                           Prediction start iteration nr: 1001
                             Prediction end iteration nr: 9000
                                       Prediction period: 1000

                        Pre-prediction start iteration nr: 20
                          Pre-prediction end iteration nr: 999
                                    Pre-prediction period: 20

Transition block defaults:-----------------------------

                           TS transition prediction mode: 12
                                Boundary layer data mode: 0

                                     Pre-prediction mode: 2

            Turbulence intensity for transition criteria: 0.1

                                     TransitionBlock end

Transition block 0:------------------------------------

                                     Boundary part list: upper_surface
                                  Transition block name: upper_surface

                               Number of streamline points: 0
                                 Number of limiting planes: 0
                                           Streamline type: 2

                                     TransitionBlock end
```

```
Transition block 1:-----------------------------------

                                    Boundary part list: lower_surface
                                 Transition block name: lower_surface

                              Number of streamline points: 0
                                Number of limiting planes: 0
                                          Streamline type: 2

                                       TransitionBlock end
```

B.2. 2D multi-element airfoil

B.2.1. Boundary mapping

```
block 0:-----------------------------------------------
                                                 Name: farfield
                                              Markers: 1
                                                 Type: farfield
                                   Angle alpha (degree): 21.40
                                             block end

block 1:-----------------------------------------------
                                                 Name: slat_upper
                                              Markers: 2
                                                 Type: viscous wall
                                              Subtype: transition
                                             block end

block 2:-----------------------------------------------
                                                 Name: slat_lower
                                              Markers: 3
                                                 Type: viscous wall
                                              Subtype: laminar
                                             block end

block 3:-----------------------------------------------
                                                 Name: slat_rear
                                              Markers: 4
                                                 Type: viscous wall
                                              Subtype: turbulent
                                             block end

block 4:-----------------------------------------------
                                                 Name: main_upper
                                              Markers: 5
                                                 Type: viscous wall
                                              Subtype: transition
                                             block end

block 5:-----------------------------------------------
```

```
                                                    Name: main_lower
                                                 Markers: 6
                                                    Type: viscous wall
                                                 Subtype: laminar
                                               block end

block 6:-----------------------------------------------
                                                    Name: main_rear
                                                 Markers: 7
                                                    Type: viscous wall
                                                 Subtype: turbulent
                                               block end

block 7:-----------------------------------------------
                                                    Name: flap_upper
                                                 Markers: 8
                                                    Type: viscous wall
                                                 Subtype: transition
                                               block end

block 8:-----------------------------------------------
                                                    Name: flap_lower
                                                 Markers: 9
                                                    Type: viscous wall
                                                 Subtype: laminar
                                               block end

block 9:-----------------------------------------------
                                                    Name: flap_rear
                                                 Markers: 10
                                                    Type: viscous wall
                                                 Subtype: turbulent
                                               block end

block 10:----------------------------------------------
                                                    Name: side1
                                                 Markers: 11
                                                    Type: symmetry plane
                                               block end

block 11:----------------------------------------------
                                                    Name: side2
                                                 Markers: 12
                                                    Type: symmetry plane
                                               block end
```

B.2.2. Transition prescription

```
block 0:-----------------------------------------------
                                 Boundary part namelist: slat_upper
                                         Laminar height: 0.02
```

```
                              Number of polyline points: 1

                                 TransitionCoordinates
                     0.06981       0.00000       0.02553
                                       transition end

block 1:-----------------------------------------------
                                 Boundary part namelist: main_upper
                                       Laminar height: 0.0035
                              Number of polyline points: 1

                                 TransitionCoordinates
                     0.86851       0.00000       0.02533
                                       transition end

block 2:-----------------------------------------------
                                 Boundary part namelist: flap_upper
                                       Laminar height: 0.003
                              Number of polyline points: 1

                                 TransitionCoordinates
                     1.10267       0.00000      -0.08689
                                       transition end
```

B.2.3. Transition prediction

```
Transition basic parameters:---------------------------
                            Transition prediction (0/1): 1

                           Prediction info output level: 1

          Transition prediction output directory prefix: Tranpred
                    Transition history file name prefix: transition_history

                       Transition history output values: set_pmin_sep_cfmin

                    Write streamline data to file (0/1): 1
              Write boundary layer profiles to file (0/1): 1

                           Prediction start iteration nr: 1001
                             Prediction end iteration nr: 5000
                                      Prediction period: 500

                         Pre-prediction start iteration nr: 20
                           Pre-prediction end iteration nr: 1000
                                    Pre-prediction period: 20

Transition block defaults:-----------------------------

                           TS transition prediction mode: 10
                                Boundary layer data mode: 1
```

```
133
134                                  Pre-prediction mode: 2
135
136                                 Critical N-factor TS: 9
137                                 Critical N-factor CF: 4
138
139                       Relaxation factor for transition: 0.8
140
141                                  TransitionBlock end
142
143 Transition block 0:-----------------------------------
144
145                                    Boundary part list: slat_upper
146                                 Transition block name: slat_upper
147
148                              Number of streamline points: 0
149                                Number of limiting planes: 0
150                                           Streamline type: 2
151                             Maximum delta for transition: 0.05
152
153                                  TransitionBlock end
154
155 Transition block 1:-----------------------------------
156
157                                    Boundary part list: main_upper
158                                 Transition block name: main_upper
159
160                              Number of streamline points: 0
161                                Number of limiting planes: 0
162                                           Streamline type: 2
163                             Maximum delta for transition: 0.6
164
165                                  TransitionBlock end
166
167 Transition block 1:-----------------------------------
168
169                                    Boundary part list: flap_upper
170                                 Transition block name: flap_upper
171
172                              Number of streamline points: 0
173                                Number of limiting planes: 0
174                                           Streamline type: 2
175                             Maximum delta for transition: 0.6
176
177                                  TransitionBlock end
178
179 Transition additional parameters:----------------------
180
181                                       Coco executable: ./coco
182                                       Lilo executable: ./lilo
```

B.3. 2.5D infinite swept wing

B.3.1. Boundary mapping

Rectangular grid

```
block 0:-----------------------------------------------
                                                 Name: farfield
                                              Markers: 1
                                                 Type: farfield
                                    Angle alpha (degree): 2.206
                                     Angle beta (degree): 25.00
                                               block end

block 1:-----------------------------------------------
                                                 Name: upper_surface
                                              Markers: 2
                                                 Type: viscous wall
                                              Subtype: transition
                                            block end

block 2:-----------------------------------------------
                                                 Name: lower_surface
                                              Markers: 3
                                                 Type: viscous wall
                                              Subtype: transition
                                            block end

block 3:-----------------------------------------------
                                                 Name: side
                                              Markers: 4, 5
                                                 Type: periodic plane
                               Periodic translation vector: 0.0  1.0  0.0
                                    Periodic epsilon value: 1e-6
```

Trapezoidal grid

```
block 0:-----------------------------------------------
                                                 Name: farfield
                                              Markers: 1
                                                 Type: farfield
                                    Angle alpha (degree): 2.0
                                               block end

block 1:-----------------------------------------------
                                                 Name: upper_surface
                                              Markers: 2
                                                 Type: viscous wall
                                              Subtype: transition
                                            block end

block 2:-----------------------------------------------
```

```
                                                  Name: lower_surface
                                               Markers: 3
                                                  Type: viscous wall
                                               Subtype: transition
                                             block end

block 3:-----------------------------------------------
                                                  Name: side
                                               Markers: 4, 5
                                                  Type: periodic plane
                                 Periodic translation vector: 0.422618261  0.906307787  0.0
                                      Periodic epsilon value: 1e-6
```

B.3.2. Transition prescription

Rectangular grid

```
block 0:-----------------------------------------------
                                 Boundary part namelist: upper_surface
                                 Number of plane points: 3

                                  TransitionCoordinates
                     0.50000       0.00000       0.00000
                     0.50000       1.00000       0.00000
                     0.50000       0.00000       1.00000
                                          transition end

block 1:-----------------------------------------------
                                 Boundary part namelist: lower_surface
                                 Number of plane points: 3

                                  TransitionCoordinates
                     0.50000       0.00000       0.00000
                     0.50000       1.00000       0.00000
                     0.50000       0.00000       1.00000
                                          transition end
```

Trapezoidal grid

```
block 0:-----------------------------------------------
                                 Boundary part namelist: upper_surface
                                 Number of plane points: 3

                                  TransitionCoordinates
                     0.50000       0.00000       0.00000
                     0.96630       1.00000       0.00000
                     0.50000       0.00000       1.00000
                                          transition end

block 1:-----------------------------------------------
                                 Boundary part namelist: lower_surface
                                 Number of plane points: 3
```

```
92
93                                TransitionCoordinates
94                  0.50000       0.00000       0.00000
95                  0.96630       1.00000       0.00000
96                  0.50000       0.00000       1.00000
97                                       transition end
```

B.3.3. Transition prediction

```
98  Transition basic parameters:---------------------------
99                             Transition prediction (0/1): 1
100
101                          Prediction start iteration nr: 1001
102                            Prediction end iteration nr: 5000
103                                      Prediction period: 500
104
105                       Pre-prediction start iteration nr: 20
106                         Pre-prediction end iteration nr: 1000
107                                   Pre-prediction period: 20
108
109 Transition block defaults:-----------------------------
110
111                          TS transition prediction mode: 10
112                          CF transition prediction mode: 10
113                               Boundary layer data mode: 1
114
115                                    Pre-prediction mode: 2
116
117                                  Critical N-factor TS: 9
118                                  Critical N-factor CF: 4
119
120                                   TransitionBlock end
121
122 Transition block 0:-----------------------------------
123
124                                     Boundary part list: upper_surface
125                                  Transition block name: upper_surface
126
127                             Number of streamline points: 0
128                               Number of limiting planes: 0
129                                         Streamline type: 2
130
131                                   TransitionBlock end
132
133 Transition block 1:-----------------------------------
134
135                                     Boundary part list: lower_surface
136                                  Transition block name: lower_surface
137
138                             Number of streamline points: 0
139                               Number of limiting planes: 0
```

```
                                        Streamline type: 2

                                    TransitionBlock end

Transition additional parameters:----------------------

                                        Coco executable: ./coco
                                        Lilo executable: ./lilo
```

B.4. 3D multi-element configuration

B.4.1. Boundary mapping

```
block 0:-----------------------------------------------
                                              Name: Farfield
                                           Markers: 1
                                              Type: farfield
                                 Angle alpha (degree): 20.0
                                          block end

block 1:-----------------------------------------------
                                              Name: Symmetry
                                           Markers: 2, 3
                                              Type: symmetry plane
                                          block end

block 2:-----------------------------------------------
                                              Name: Body
                                           Markers: 4
                                              Type: viscous wall
                                           Subtype: turbulent
                                          block end

block 3:-----------------------------------------------
                                              Name: FlapInboard
                                           Markers: 5
                                              Type: viscous wall
                                           Subtype: transition
                                          block end

block 4:-----------------------------------------------
                                              Name: FlapOutboard
                                           Markers: 6
                                              Type: viscous wall
                                           Subtype: transition
                                          block end

block 5:-----------------------------------------------
                                              Name: Slat
                                           Markers: 7
                                              Type: viscous wall
```

```
                                              Subtype: transition
                                            block end

block 6:-----------------------------------------------
                                                 Name: Wing
                                              Markers: 8
                                                 Type: viscous wall
                                              Subtype: transition
                                            block end
```

B.4.2. Transition prescription

```
block 0:-----------------------------------------------
                               Boundary part namelist: FlapInboard
                            Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025
                            Number of polyline points: 2

                                TransitionCoordinates
                    0.26036       0.87800       0.02572
                    0.25668       1.15800       0.07480
                                       transition end

block 1:-----------------------------------------------
                               Boundary part namelist: FlapInboard
                            Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 -1 90
                                       Laminar height: 0.025
                            Number of polyline points: 2

                                TransitionCoordinates
                    0.33692       0.85645       0.08693
                    0.33415       1.17016       0.14539
                                       transition end

block 2:-----------------------------------------------
                               Boundary part namelist: FlapOutboard
                            Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025
                            Number of polyline points: 2

                                TransitionCoordinates
                    0.51126      -0.02200      -0.07749
                    0.25657       0.69800      -0.00497
                                       transition end

block 3:-----------------------------------------------
                               Boundary part namelist: FlapOutboard
                            Transition flow direction: 1 0 0
```

```
                          Exclude surface normal/angle: 0 0 -1 90
                                       Laminar height: 0.025
                             Number of polyline points: 2

                                 TransitionCoordinates
                    0.57288      -0.04483      -0.03990
                    0.33535       0.70520       0.05583
                                       transition end

block 4:-----------------------------------------------
                                Boundary part namelist: Slat
                             Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025
                             Number of polyline points: 2

                                 TransitionCoordinates
                     0.43259      -0.31200      -0.09705
                    -0.30700       1.16800       0.03461
                                       transition end

block 5:-----------------------------------------------
                                Boundary part namelist: Slat
                             Transition flow direction: 0 0 -1
                          Exclude surface normal/angle: 0 0 -1 90
                                       Laminar height: 0.025
                             Number of polyline points: 2

                                 TransitionCoordinates
                     0.44013      -0.32015      -0.08559
                    -0.31800       1.17489       0.10441
                                       transition end

block 6:-----------------------------------------------
                                Boundary part namelist: Wing
                             Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025
                             Number of polyline points: 2

                                 TransitionCoordinates
                     0.44392      -0.29200      -0.10033
                    -0.27558       1.13800       0.04286
                                       transition end

block 7:-----------------------------------------------
                                Boundary part namelist: Wing
                             Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 -1 90
                                       Laminar height: 0.025
```

```
                            Number of polyline points: 2

                                TransitionCoordinates
                    0.56786      -0.30200      -0.10297
                    0.04653       1.16800       0.08801
                                          transition end
```

B.4.3. Transition prediction

```
Transition basic parameters:---------------------------
                           Transition prediction (0/1): 1

                         Prediction start iteration nr: 1001
                           Prediction end iteration nr: 10000
                                     Prediction period: 500

                   Max. number of points on wallnormal: 36

Transition block defaults:-----------------------------

                         TS transition prediction mode: 10
                         CF transition prediction mode: 10
                              Boundary layer data mode: 1

                            N-ts/N-cf Diagram (points): 3
                              N-ts/N-cf Diagram (N-TS): 11.50 11.50  0.00
                              N-ts/N-cf Diagram (N-CF):  0.00  8.50  8.50

                    Offset for polylines extrapolation: 1.5

                                   TransitionBlock end

Transition block 0:------------------------------------

                                      Boundary part list: FlapInboard
                                   Transition block name: FlapInboard

                              Transition flow direction: 1 0 0
                            Exclude surface normal/angle: 0 0 1 90
                                         Laminar height: 0.025

                             Number of streamline points: 2
                                        Streamline type: 2

                                StreamlineCoordinates
                     0.25837       0.92800       0.03390
                     0.25367       1.09800       0.06273
                            StreamlineCoordinates end

                                   TransitionBlock end
```

```
Transition block 1:-----------------------------------

                                  Boundary part list: FlapOutboard
                               Transition block name: FlapOutboard

                             Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025

                           Number of streamline points: 4
                                       Streamline type: 2

                                  StreamlineCoordinates
                       0.51126     -0.02200     -0.07749
                       0.41070      0.26800     -0.04814
                       0.33253      0.47800     -0.02794
                       0.25657      0.69800     -0.00497
                              StreamlineCoordinates end

                                    TransitionBlock end

Transition block 2:-----------------------------------

                                  Boundary part list: Slat
                               Transition block name: SlatUpper

                             Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025

                           Number of streamline points: 6
                                       Streamline type: 2

                                  StreamlineCoordinates
                       0.43259     -0.31200     -0.09705
                       0.27280     -0.01200     -0.06290
                       0.11602      0.28800     -0.03088
                      -0.03871      0.58800     -0.00219
                      -0.20529      0.90800      0.02932
                      -0.33211      1.13800      0.05982
                              StreamlineCoordinates end

                                    TransitionBlock end

Transition block 3:-----------------------------------

                                  Boundary part list: Wing
                               Transition block name: WingUpper

                             Transition flow direction: 1 0 0
```

```
                          Exclude surface normal/angle: 0 0 1 90
                                       Laminar height: 0.025

                           Number of streamline points: 14
                                       Streamline type: 2

                                  StreamlineCoordinates
                       0.44392     -0.29200     -0.10033
                       0.42383     -0.25200     -0.09732
                       0.40106     -0.17200     -0.10340
                       0.36254     -0.09200     -0.09698
                       0.34262     -0.05200     -0.09363
                       0.32851     -0.02200     -0.09123
                       0.27005      0.09800     -0.08091
                       0.21163      0.21800     -0.07060
                       0.12600      0.33800     -0.03956
                       0.06542      0.45800     -0.02779
                       0.00485      0.57800     -0.01595
                      -0.06077      0.70800     -0.00312
                      -0.07075      0.72800     -0.00124
                      -0.27558      1.13800      0.04286
                               StreamlineCoordinates end

                                    TransitionBlock end

Transition block 4:-----------------------------------

                                     Boundary part list: Wing
                                  Transition block name: WingLower

                               Transition flow direction: 1 0 0
                          Exclude surface normal/angle: 0 0 -1 90
                                       Laminar height: 0.025

                                       Streamline type: 2
                               Use contourlines of block: WingUpper

                                    TransitionBlock end

Transition additional parameters:----------------------

                                       Coco executable: ./coco
                                       Lilo executable: ./lilo
```

B.5. 3D geometry

B.5.1. Boundary mapping

Deliberately left blank.

B.5.2. Transition prescription

Deliberately left blank.

B.5.3. Transition prediction

Deliberately left blank.

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