Turbomachinery Setup Guide for Star-CCM+

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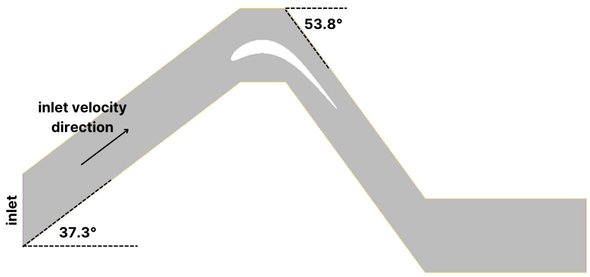
1 Introduction

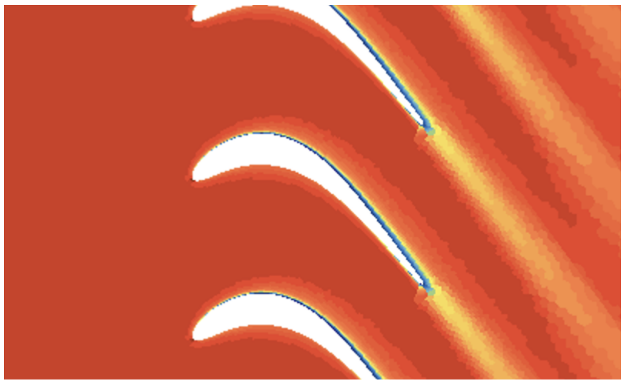
This guide provides pathway to setting up two-dimensional turbomachinery simulations in Star-CCM+. Geometry and simulation data were taken from paper *Direct Numerical Simulations of the SPLEEN cascade: a study of the impact of compressibility on transition and separation in a low-pressure turbine passage* [1].

2 Example Problem Definition

The problem is given by domain in Figure 1a, which enables simulation of accurate flow around the blade. Note that the angle information was written on the domain to make it easier to set up as similar simulation for other cases. Simulating one blade is sufficient to obtain a good understanding of turbomachinery simulations, since periodic boundary conditions will be applied to bottom and top surfaces - see Figure 1b for post-processed total pressure field visulisation.



(a) Example domain.



(b) Total pressure visualisation.

The following table summarises values used in the tutorial and are taken from [1].

Table 1: Boundary conditions for the example simulation.

Mach Number	$M_{\mathrm{s,out}}$	0.7
Inlet Total Pressure	$p_{0,\mathrm{in}}$	10779.39 Pa
Outlet Static Pressure	p_{out}	7771.16 Pa
Inlet Total Temperature	$T_{0,\mathrm{in}}$	300 K
Inlet Flow Angle	α	37.3°
Outlet Flow Angle	α	53.8°

3 Boundary Conditions

3.1 Inlet

Inlet type is set as *Stagnation Inlet*, because this is well-suited for compressible internal flows [2]. It enables setting total pressure and total temperature upstream of the simulation domain. *Supersonic Static Pressure* option may rise some confusion, but it is actually quite simple. For subsonic inflow, then this value is ignored, and for supersonic flow it is calculated based on the isentropic relationship:

$$\frac{p}{p_t} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-\frac{\gamma}{\gamma-1}} \tag{1}$$

where p is the supersonic static pressure, p_t is total/stagnation pressure, γ is the ratio of specific heats (for air this is 1.4) and M is Mach number [3]. Since in this case, the highest Mach number value is $M = 0.96$, it is expected that the flow will be not supersonic and that value is ignored. The rest of the entries are set as default, which includes *Turbulence Intensity* and *Turbulent Viscosity Ratio.*

Table 2: *Physics Values* for the inlet.

Property	**Example Value**
Flow Direction	Domain-dependant*
Supersonic Static Pressure	Irrelevant for Subsonic
Total Pressure	10779.39 Pa
Total Temperature	300K
Turbulence Intensity	Default
Turbulence Viscosity Ratio	Default

* Default direction is `[1.0,0.0]`, which is along the x-axis. If the flow is inclined, then *Field Function* can be specified for the angle of incidence. Then the expression for *Flow Direction* is `[cos(angle_in), sin(angle_in),0.0]` assuming that `angle_in` is given in radians.

3.2 Outlet

Pressure Outlet option was chosen for the outflow condition, because it enables specification of outlet static pressure. There are multiple other properties that need to be carefully. Firstly, let us discuss the *Physics Conditions* that ought to be specified for this boundary type to be able to simulate turbomachinery. The paper that is used in this tutorial [1] explicitly specifies the outlet static pressure, which is why pressure at the outlet has to be kept constant. This is possible by setting *Backflow Pressure* is static, where "pressure is maintained at the specified pressure" [2]. The other values in *Backflow Specification* are set as default.

Table 3: *Physics Condition* choices for *Pressure Outlet* boundary type.

Property		**Value**
Backflow Specification	Direction	Extrapolated
	Pressure	Static
	Scalars	Default
Pressure Outlet Option		None
Turbulence Method		Default

Pressure Outlet boundary type does not allow for explicit Mach number specification - instead *Static Temperature* is set, which can be recalculated using the isentropic relations:

$$\frac{T}{T_t} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-1} \tag{2}$$

T_t is total/stagnation temperature and T is static temperature. Stagnation pressure can be assumed constant for this simulation, since adiabatic boundary conditions (BCs) are enforces on the boundary of the blade. For the example Mach number of $M = 0.7$, static temperature was calculated to be $T = 273.22K$. The rest of the values are taken from the paper [1].

Table 4: *Physics Values* for the outlet.

Property	**Example Value**
Pressure	7771.16 Pa
Static Temperature	273.22 K
Turbulence Intensity	Default
Turbulent Viscosity Ratio	Default

3.3 Periodic Boundaries

Periodic Boundary condition is set on the top and bottom boundaries of the domain by creating an *Interface*. Once the interface between the boundaries is established, as depicted in Figure 1, the *Topology* has to be ste to *Periodic*.

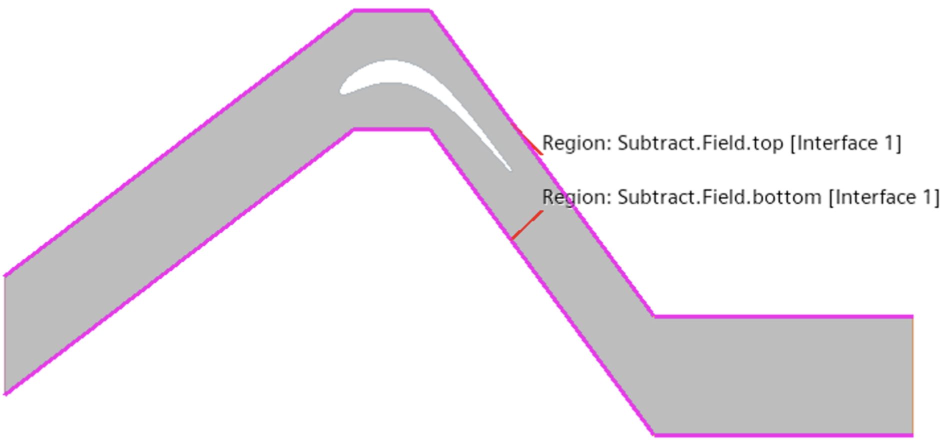


Figure 1: Interface between boundaries for the periodic BCs.

4 Initial Conditions

Inlet data is used to initialise *Pressure* and *Static Temperature*. Default values are used for other properties, for examples those defining turbulence. Should you need to change fluid type or its properties, you may do that by going to *Continua - Physics 1 - Models - Gas* and specifying correct values.

Table 5: Solver choices.

Property	**Model**
Material	Gas
Flow	Coupled Flow
Equation of State	Ideal Gas
Energy	Coupled Energy
Time	Steady
Viscous Regime	Turbulent
Turbulence	Reynolds-Averaged Navier-Stokes
Reynolds-Averaged Turbulence	Spalart-Allmaras Turbulence
Spalart-Allmaras Wall Treatment	All y+ Wall Treatment

5 Solver Choice

Turbomachinery flows are chaotic and characterised by unsteadiness, separation and potential local turbulence. The following *Physics Models* were chosen to simulate the flow accurately. The approach was followed from [2], namely *Tutorials - Compressible Flow - Subsonic Flow: NACA-Type Intake - Setting Up the Physics Models*.

6 Useful Information

If you're looking for definition of a property within Star-CCM+, highlight the property of interest and press *Shift+F1*. Star-CCM+ will launch the User Guide on the relevant page.
Relevant and potentially useful websites:

1. `https://volupe.com/simcenter-star-ccm/turbomachinery-workflow-in-simcenter-star-ccm/`
2. `https://docs.sw.siemens.com/documentation/external/PL20200805113346338/en-US/userManual/userguide/html/index.html#page/STARCCMP`
3. `https://www.cfd-online.com/Wiki/Turbulence_intensity`

References

[1] Maxime Borbouse, Nathan Deneffe, Mars Thys, Margaux Boxho, Michel Rasquin, Gustavo Lopes, and Sergio Lavagnoli. Direct Numerical Simulations of the SPLEEN cascade: a study of the impact of compressibility on transition and separation in a low-pressure turbine passage. In *16th European Turbomachinery Conference (ETC16)*, Hannover, Germany, March 2025. Presented March 24-28, 2025. Available at `https://orbi.uliege.be/handle/2268/330117`.

[2] Siemens Digital Industries Software. *Simcenter STAR-CCM+ User Guide (Online Documentation)*. Siemens Digital Industries Software, 2020. Version identified by internal ID PL20200805113346338.

[3] Siemens Digital Industries Software. *How do I prescribe the supersonic static pressure*. Siemens Community, 2023.