Delft University of Technology

Knowledge Based Engineering (AE4204)
Generative Turbine Rear Structures

October 15, 2025

1 Assignment description

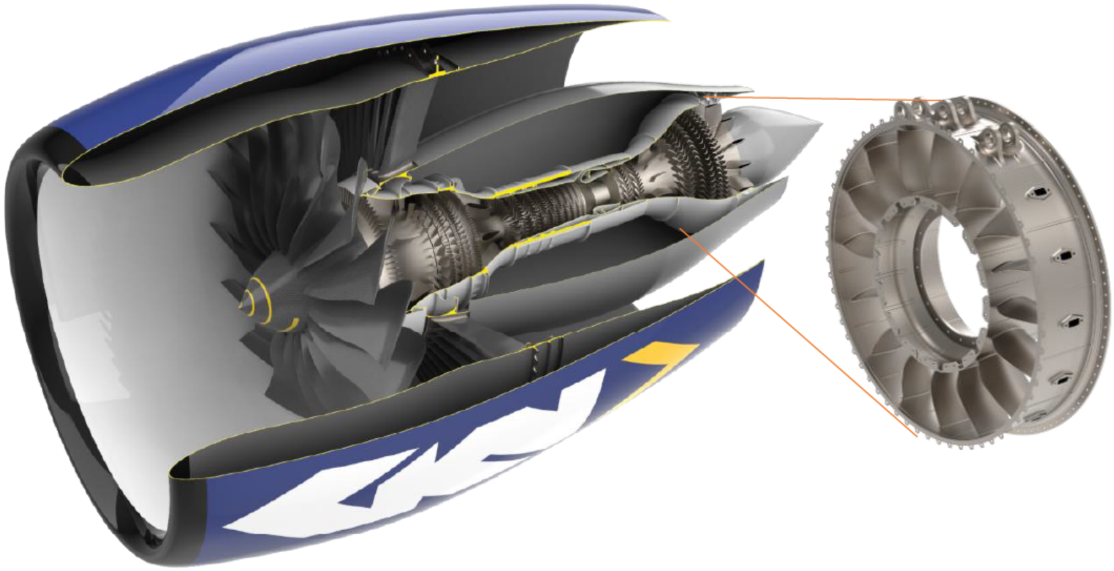


Figure 1: Use of a Turbine Rear Structure

1.1 Design case description

The KBE app was designed to generate a Turbine Rear Structure (TRS) from a simple input file containing various geometric parameters. While doing so, it makes intelligent geometric choices based on the knowledge acquired from the engineers at GKN Aerospace. Its also raises appropriate warnings if design rules are violated. This CAD file that is generated as an intermediate result can be exported as a STEP file to be read by NX software. furthermore, the TRS model can be meshed to be exported and run by ANSYS or an external FEM tool.

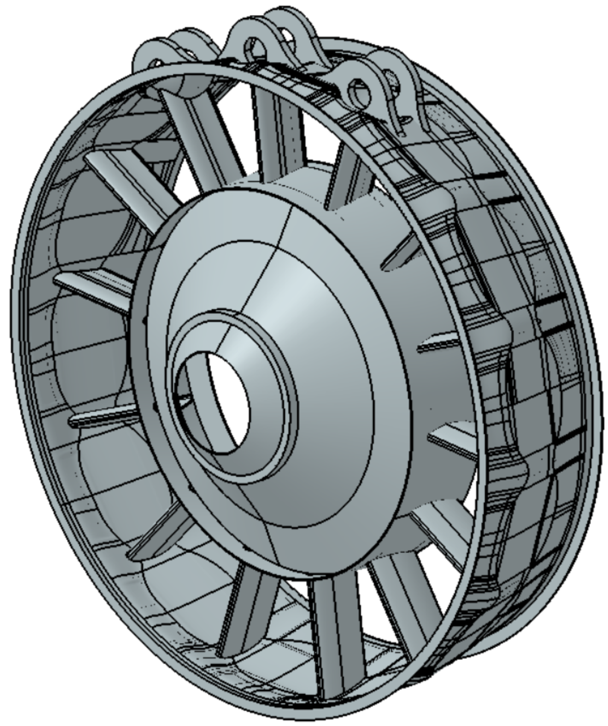


Figure 2: Reference CATIA model of TRS by GKN Aerospace

1.2 Suitability of KBE for TRS generation

Without the use of KBE, very limited design iterations can be completed within a given time frame resulting in an inefficient use of the company corporate knowledge. This may at times result in excessive simplifications and approximations entailing the risk of expensive re-work of re designing. The use of KBE is extensive for the automation of the detailed structural components. By implementing the acquired knowledge from the company, GKN would be able to generate various design configurations within minutes. This would otherwise take days or even weeks. Due to the automation of repetitive and non-creative design tasks, the company can save time which is crucial. By using the mesh created in the previous step, the strength analysis of the structure could be done easily using ANSYS or open-source FEM. This is however, outside the scope of the project.
All of these KBE features cant be explited in basic Python, Matlab or any CAD software.

1.3 Rule based parametric model

An aircraft engine like a turbofan is usually attached to the wings at two points, one at the front and the other at the rear. The TRS is used for the rear end and is made up of two, hollow concentric cylinder like shapes with vanes running radially in between. These vanes (also called struts) are used to allow the exhaust air to flow through while allowing structural integrity. The TRS is designed to withstand mechanical as well as thermal loads. The TRS can be assumed to be made up of the following components. Note that the origin of the TRS is on the axis and at the front flange location

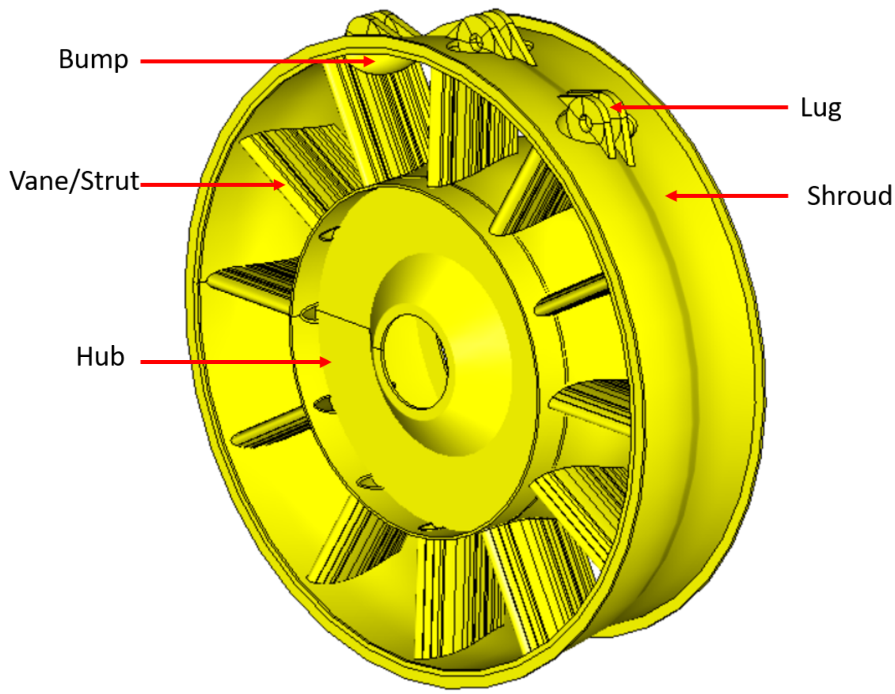


Figure 3: TRS parts and components generated by the KBE application

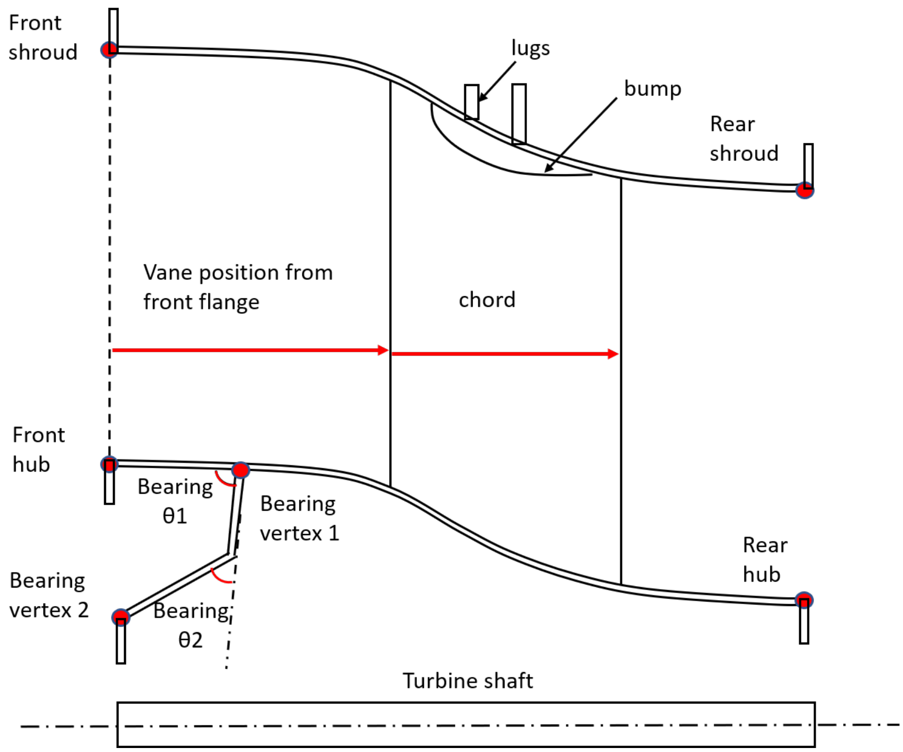


Figure 4: Cross section view of TRS

1. Shroud: The shroud is the outer casing of the TRS that encloses all the blades and the hub. It also serves the purpose of containing the blades within the TRS in case of structural breakdown of any of the low pressure turbine blades. The shroud can be categorised into round or polygonal based on the shape of the shroud as seen from the front of the engine. If the shape is polygonal, the number of sides is the same as the vane count. The position of the forward flange and the rear flange is defined using x (in axial direction) and y (in radial direction) coordinates which would be provided as input by the user. The shroud further has two more parts called the lug and the bump.

   (a) Lugs: These are the two connecting links that are used to attach the engine to the pylon of the wing. (The third one as seen in the above figure is usually for safety purposes and should not be considered as a part of structural integrity or strength analysis) They are attached to the shroud from the top with a circumferential gap in between. This gap is determined on the basis of spacing between the vane tips as it is desired for the lugs to be placed at locations where struts(vanes) are present. The shape of these lugs would be determined on the basis of the bolt diameter (which is also equal to the inner diameter of the hole in the lug). Using the value of the inner diameter as input from user, the outer diameter can be estimated using empirical relations. In addition, the lug thickness would also be an input from the user.

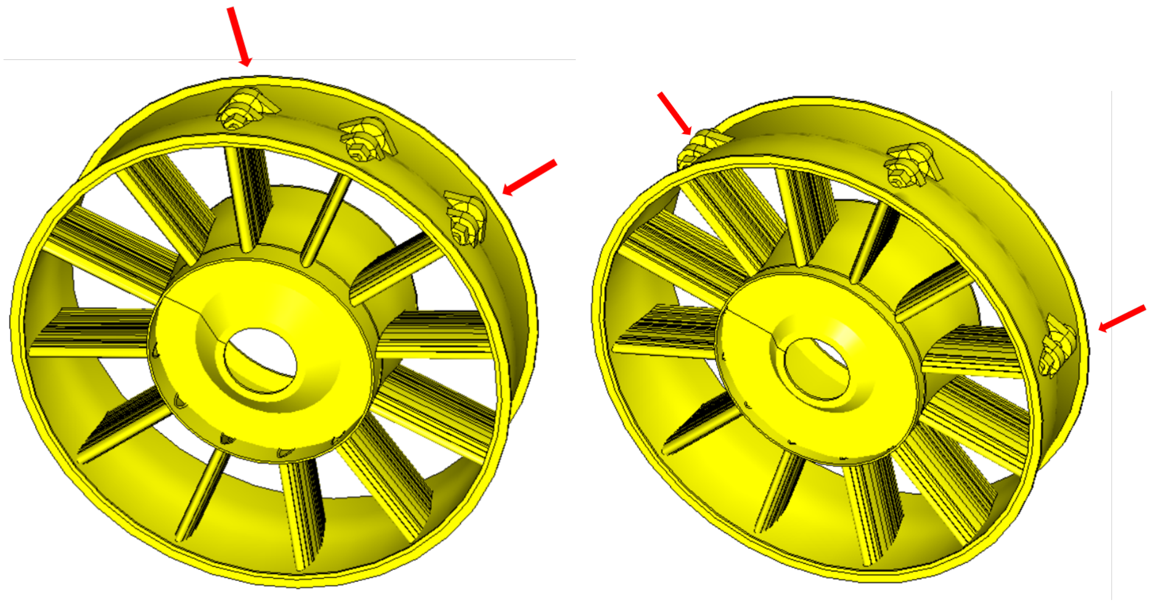
   (b) Bumps: The lug is attached to the pylon using bolts. These bolts run through the thickness of the shroud, thereby protruding into the exhaust duct between the shroud and the hub. The bump is used to provide an aerodynamic fairing for the same. The location of this fairing thus depends on the location of the lugs. The bump is generated using ellipsoid shape and with a specified thickness which is an input form the user.

2. Hub: The inner casing of the TRS is called the hub. The hub is responsible to provide a supporting structure for the thrust bearing of the engine and also serve as a base mounting for the vanes. Similar to the shroud, it is defined using the coordinates of the front flange and the rear flange location. In addition, it also needs two coordinates of the bearing support as input from the user. Two angles, namely θ_1 and θ_2 related to the bearing support structure are defined as seen in the figure below. These are also inputs from the user.

3. Vanes: These are blade like structures which are enclosed between the shroud and the hub. They are characterised by a specified airfoil and chord length, both of which are assumed to be constant throughout the span of each vane. Each vane will have the same outer profile as that of the others but can have different thicknesses defined in the inward direction. The vane count and the angle of incidence of the vanes with respect to the axial flow direction will also be taken as inputs from the user.

1.4 Internal Analysis capabilities

Often, it is the case that the design parameters that have been entered by the used may not be either geometrically sound, or feasible from an engineering point of view. These decisions are made by the internal analysis modules. In the design of the TRS, there are two such internal analysis capabilities namely, Blockage area evaluation and minimum lug distance criteria. Flow blockage is the reduction in the effective flow area due to excessive number of vanes or very high angle of incidence of an acceptable number of vanes. The KBE application smartly evaluates these blockage effects based on simple analytical approximations (as an in depth analysis would entail the use of CFD which is outside the domain of this project) and suggests the maximum possible number of vanes such that the blockage is within permissible limits. The radial angle between the vanes will also be recalculated to obtain uniform spacing between them.



(a) Lug positioning within acceptable limits

(b) Lugs transferred to adjacent vane tips as corrective measure

Figure 5: Internal analysis module for lug positioning

Another such capability is regarding the lug positioning. As said earlier, the lugs need to be positioned on the shroud's outer surface just above the first vane (the one at 12 'O' clock position) and the last vane (going in clockwise sense after first one) tips. If we go on increasing the number of vanes, after a point the angle between the two blades becomes very small. As a result, the distance between the two lugs also goes on reducing. This causes a problem for the linkage component that connects the wing and the TRS as it cannot be smaller than a specific length. In such situations, the lugs get transferred to the outward adjacent positions as a corrective measure.
These internal analysis modules are checked for every design configuration that is entered by the user.

1.5 Rule violation warnings and corrective measures

The warnings are displayed whenever the internal analysis capabilities discussed above violate their corresponding design criterion. These messages also elaborate on the corrective measures that have been taken to counter the problem.

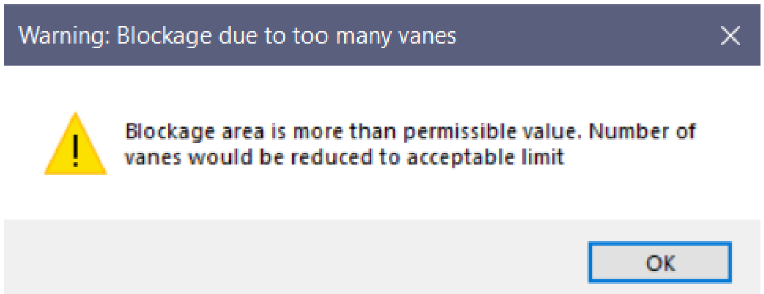


Figure 6: Blockage warning

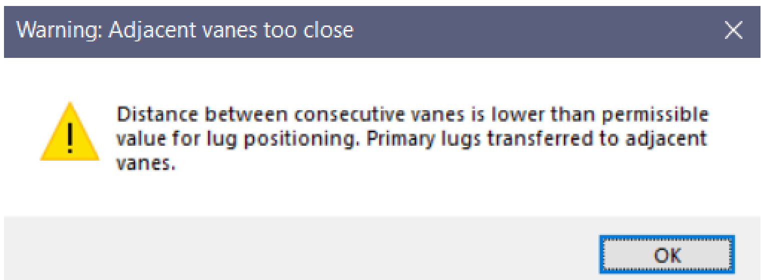


Figure 7: Lug positioning warning

1.6 External analysis capabilities

The TRS model that is generated can be meshed and exported to run in one of the external analysis tool like ANSYS or FEM solvers. The external module that is used for meshing is provided by Salome. The user can specify the mesh size of the unstructured tetrahedral mesh which is most suitable for such complex geometries. Post processing of the results to obtain deformations etc. is not within the scope of the project.

1.7 External input handling capabilities

The KBE application reads all the required input data from a JSON file. These values work as initial design parameters for the TRS to be generated and can further be manipulated dynamically in the ParaPy GUI.

sdfs

1.7.1 Output data reporting capabilities

The CAD file of the generated TRS model can be exported as a STEP file output to be read by software like CATIA, NX etc. Along with this, the meshed file can also be exported if desired as an output by the user.

2 Output file

This section displays the detailed TRS model that has been generated in the ParaPy GUI.

Figure 8: Component 1: Shroud

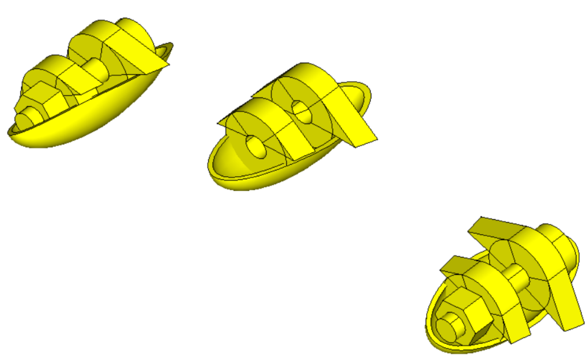


Figure 9: Parts of component 1: Lugs, bumps and bolts

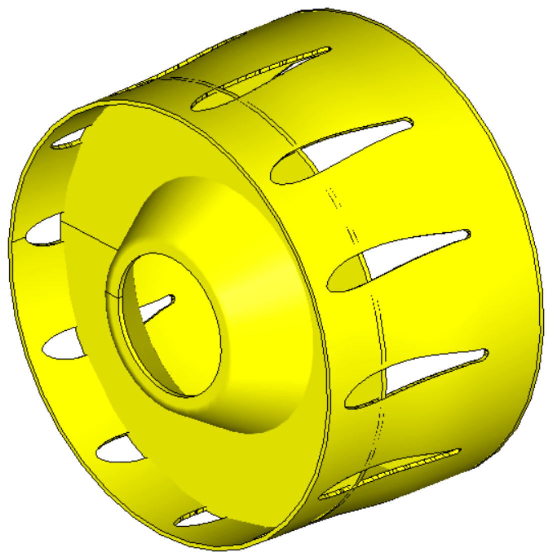


Figure 10: Component 2: Hub

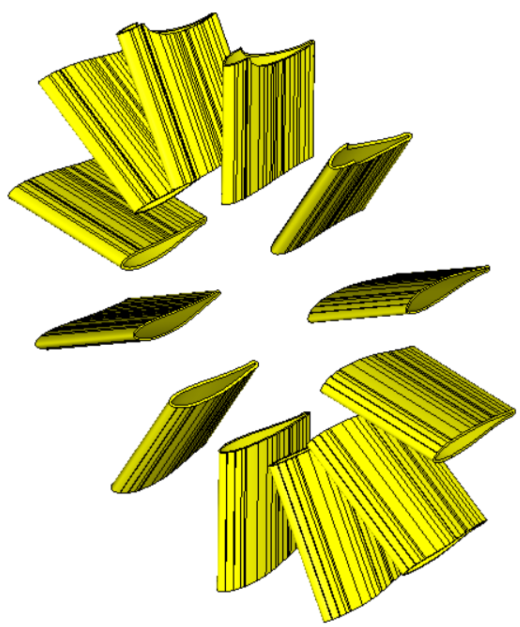


Figure 11: Component 3: Vanes

Combining all of these results in the TRS assembly

Figure 12: Assembly: TRS

The TRS file generated above is then meshed and exported to be open and run in ANSYS or any open source FEM solver.

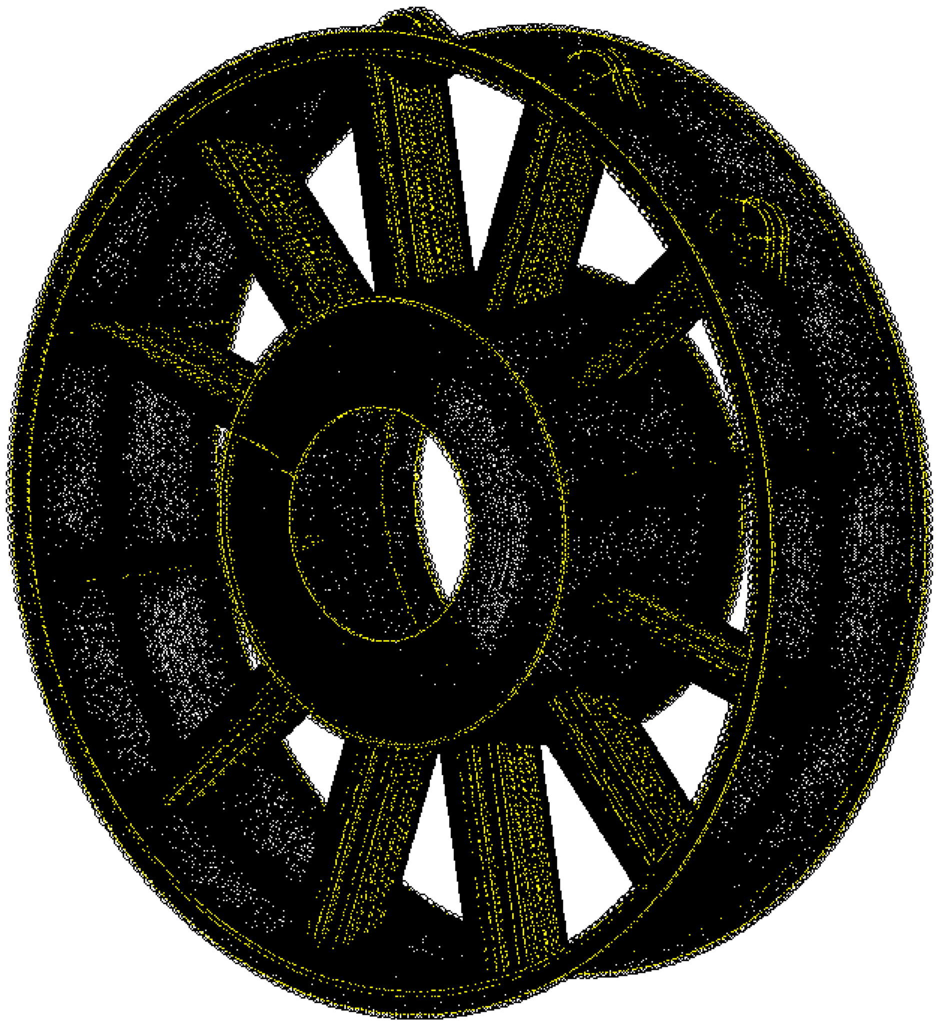


Figure 13: Assembly: TRS

Figure 14: Assembly: TRS

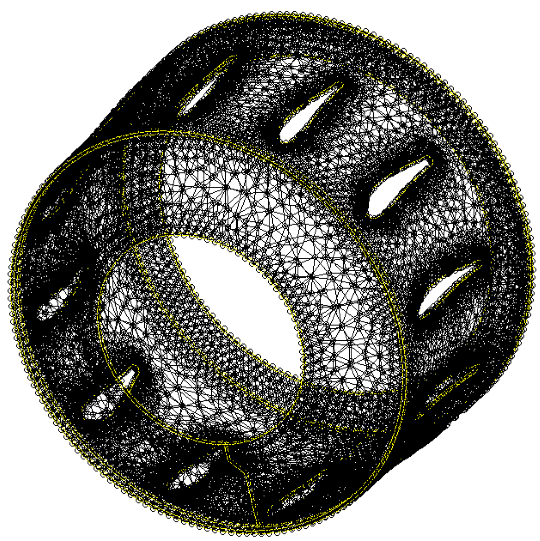


Figure 15: Assembly: TRS

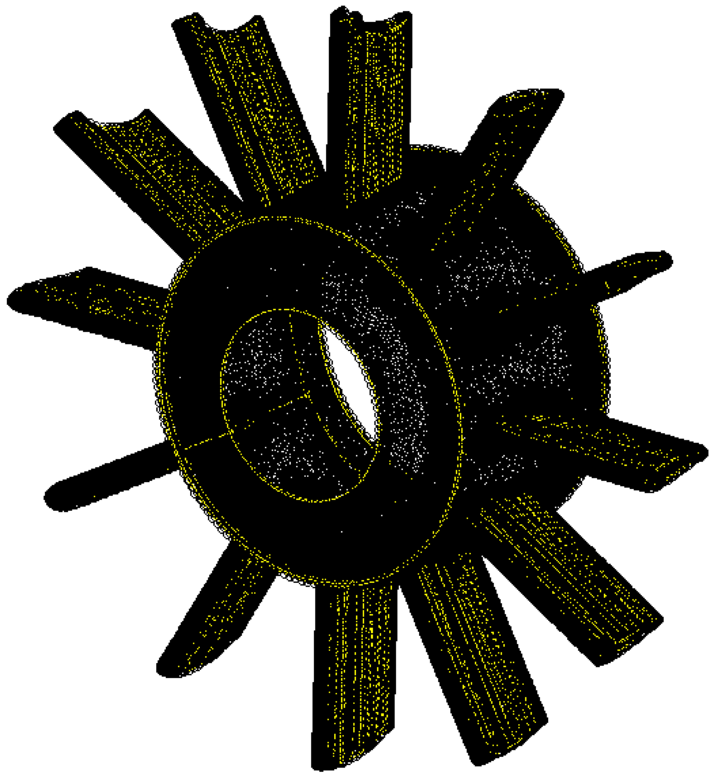


Figure 16: Assembly: TRS

3 CATIA model

The TRS file generated in KBE application is exported as a .stp file and opened in CATIA V5 as an established CAD modeller.

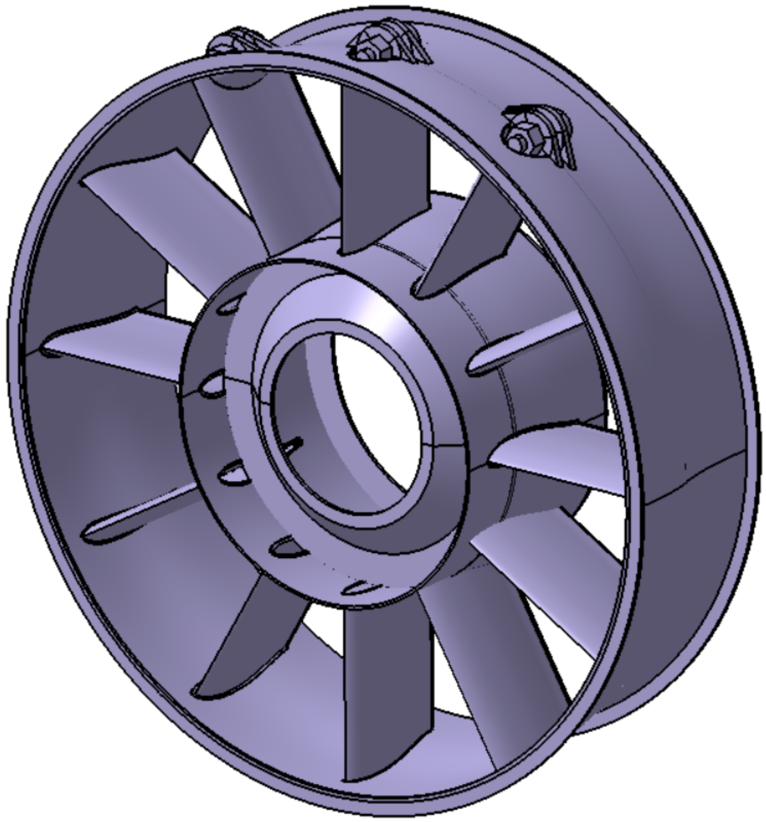


Figure 17: Assembly of Exported STEP file opened in CATIA V5

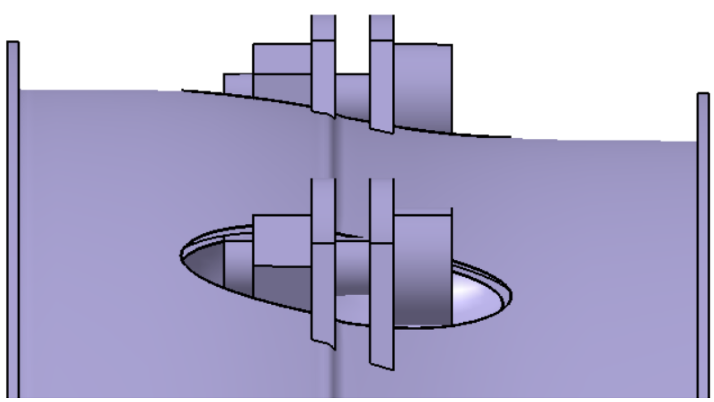


Figure 18: Lug-bolt-shroud interface

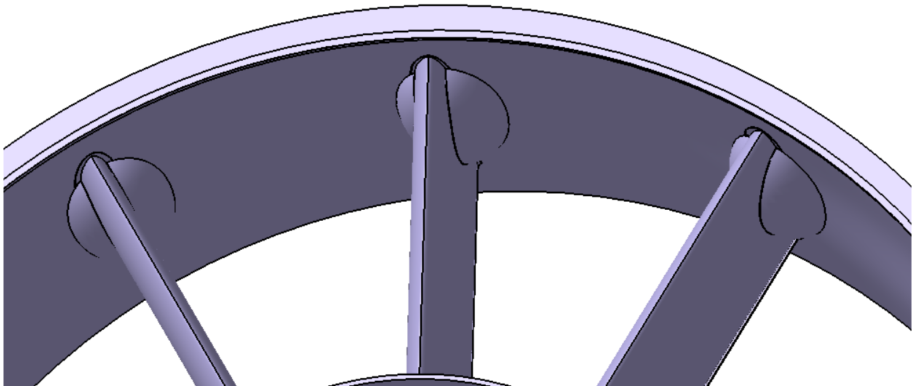


Figure 19: Bump

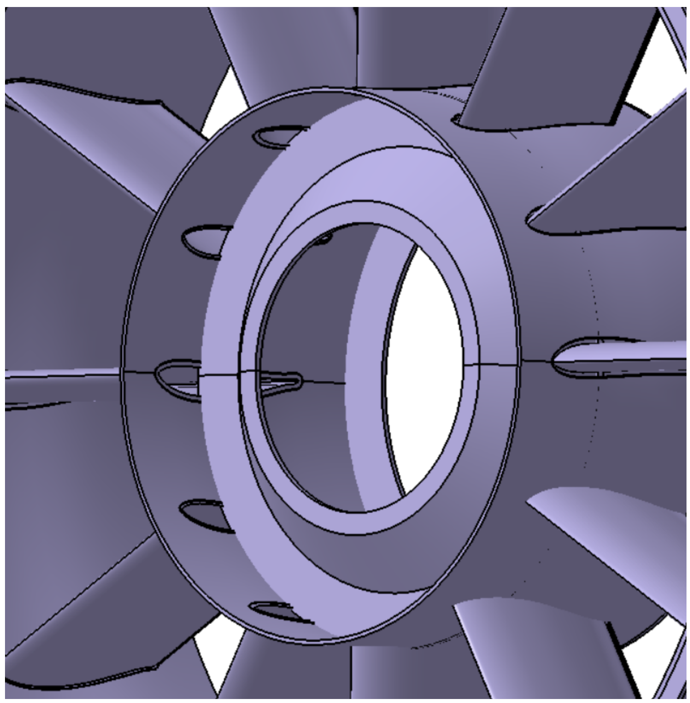


Figure 20: Details of Hub section