IDENTIFYING THE MINIMUM MESHABLE REPRESENTATION IN TURBOMACHINERY GEOMETRIES

Thomas Shannon[1], Trevor T. Robinson[1], Cecil G. Armstrong[1], Declan C. Nolan[1],
Gordon Kalwak[2]

[1]*Queen's University Belfast, Belfast, United Kingdom. thomas.shannon@qub.ac.uk*

[2]*Rolls-Royce plc, Derby, United Kingdom. Gordon.Kalwak@rolls-royce.com*

ABSTRACT

This research note outlines ongoing work in automated geometry decomposition, as a first step in the process of hexahedral meshing complex geometries. Specifically, the focus is on the minimal meshable representation, a term used to describe the minimal amount of geometry, and associated attributes, from which a mesh can be generated for the entire component. The mesh on the identified subset can be duplicated and transformed to construct the global mesh based on the captured attributes. Herein, a minimal meshable representation is constructed by identifying cyclic symmetries in the global geometry. As the complexity of geometries increases, novel logic is required to accurately and robustly extract the minimal geometry subset. This note outlines the developments of ongoing research to achieve this goal. Initial experiments have demonstrated significant potential in this as an approach to automated hexahedral meshing and have provided confidence for investing further research effort in this field.

Keywords: geometry decomposition, minimal meshable representation, symmetry, hexahedral meshing

1. INTRODUCTION AND RELATED WORK

The challenge of automated hexahedral meshing remains a formidable task for geometries of industrial complexity. Multiple threads of research seek to address this challenge, such as the development of automated hexahedral meshing routines and the development of geometry decomposition strategies. Geometry decomposition strategies seek to decompose the global geometry into simpler sub-domains to which the hexahedral meshing routines can be robustly applied. The ultimate research goal is that these individual threads of research will unitedly achieve automated hexahedral meshing for geometries of arbitrary complexity.

This research note outlines ongoing research in the area of geometry decomposition. Two primary decomposition methods are explored. The first decomposition method seeks to identify and extract sub-domains of a model that are repeated multiple times in the global geometry, while also capturing as attributes of the sector the transformation matrices which can be used to construct the entire geometry from the sub-domains. The rationale is that a repeated sub-domain only needs to be meshed once, and transformation matrices can be used to copy the parent mesh to repeated regions. Lecallard [1] coined the term "minimal meshable representation" (MMR) to articulate the concept of extracting the minimum subset of geometry that must be meshed. After the repeated sub-domain is extracted it may be meshed directly or further decomposed. The second decomposition method uses geometric reasoners to identify and extract sub-domains of the global geometry (or the sub-domain extracted using MMR) that are suitable for known hexahedral meshing algorithms. Some examples of these sub-domains include thin-sheet regions, long slender regions, and general swept bodies. Automated hexahedral meshing can be applied to the identified sub-domains; however, there may be residual geometry that requires further decomposition manually.

Boussuge et al. [2] developed the initial concept of MMR. They recognized that high-level shape properties, such as symmetries, could be exploited to extract simplified sub-domains of a model. They aimed to extract axisymmetric and repeated cyclic sectors of quasi-axisymmetric CAD models. Previous work that exploited symmetries in application to meshing was limited to fully cyclic features [3], or utilized tetrahedral meshing strategies [4]. The approach outlined by Boussuge et al. was particularly suited for turbomachinery applications, where a common axis of symmetry could be manually identified in the model and used as an input to the process. This was exploited to identify all axisymmetric, pseudo-axisymmetric (an axisymmetric face with inner loops), and cyclic faces and edges in a B-Rep model. Sets of cyclic faces were then identified, based on adjacent connections between faces, to form cyclic features. An optimization loop ensured faces were connected with a maximal number of shared edges, with the objective of identifying cyclic features with the smallest angular span.

After classification and grouping, methods were then implemented to decompose the geometry. Firstly, axisymmetric regions of the model were extracted. Subsequently, cyclic features were extracted, with consideration given to cyclic features with inner voids and regions of the model that were non-axisymmetric.

Tierney et al. [5] highlighted the importance of considering the assembly configuration of models where there is a requirement to maintain mesh conformity at component interfaces. They presented an extension to axisymmetric and cyclic decomposition strategies where symmetry attributes were propagated to the imprinted interfaces between components. The imprinting information was used to update the decomposition strategy to ensure a conformal mesh at the interface was maintained.

The described strategies have demonstrated their potential in reducing the amount of geometry for which a mesh must be generated when meshing an entire component, offering significant savings in terms of time and computational cost. However, the current state of the art in creating the MMR has exhibited limitations as the complexity of the geometry to be decomposed has increased. The remainder of this research note will outline the challenges identified and developments proposed to address these challenges through on-going research. The scope of geometries remains restricted to turbomachinery type applications, where a global symmetry axis can be defined.

2. MMR STRATEGIES

The developed cyclic decomposition discussed previously can be robustly implemented when individual cyclic features can be clearly identified. This is demonstrated in Figure 1, where cyclic vanes are identified and extracted, with red representing the cyclic master and grey representing the blades that pattern it. The vanes shaded yellow are not part of this pattern as the geometry of the mounts at the top of the component are not part of the identified pattern. In this model, the dark green region is identified as axisymmetric, and so is not part of a pattern.

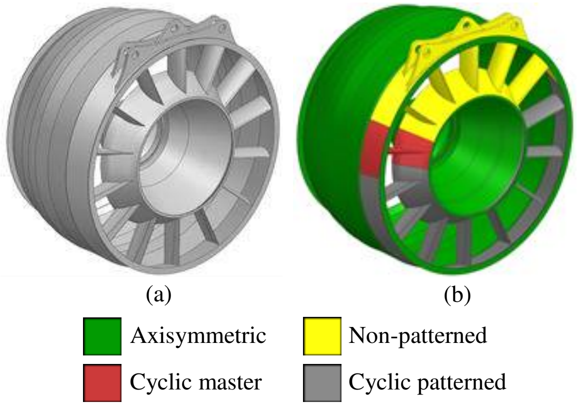

(a) (b)

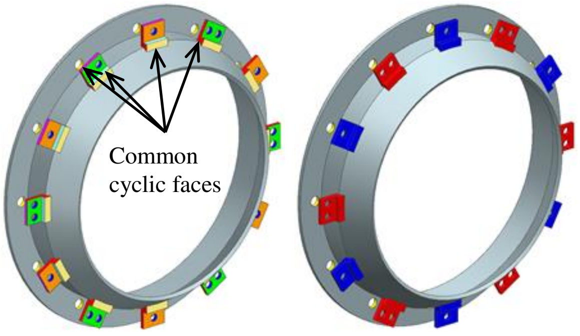
Figure 1. (a) original geometry (b) MMR decomposition

However, several geometric features can increase the complexity of the geometry, requiring enhanced reasoning for accurate decomposition. The challenges are outlined in the following subsections, with suggestions given for how these will be addressed in the current research.

2.1 Complexity in cyclic features

After cyclic faces and their angular position are identified within a model, cyclic features are identified by grouping adjacent cyclic faces.

As the level of fidelity required in analysis models increases, an increasing range of small features such as lugs and bolt holes are included in the analysis geometry. It is common for the same set of cyclic faces to be shared between multiple cyclic features, and at times, a cyclic feature may contain multiple instances of a particular cyclic face. This is depicted in Figure 2a, where a common cyclic lug face (e.g. highlighted red, magenta, cyan and yellow faces) is shared between different lug features, and one lug feature contains multiple instances of a hole feature (blue). Additional geometric reasoning was required to identify the cyclic features that accurately correspond with the lug features in the model (Figure 2b). This was achieved through allowing divergent cyclic features that may have been initiated with a cyclic face common to more than one feature. Further, checks on the transformation angle of adjacent cyclic faces being added to a cyclic feature ensures that the appropriate face is selected when there are multiple instances of a cyclic face set occurring in a cyclic feature.



(a) (b)

Figure 2. (a) matched cyclic faces (b) cyclic feature identification

While these developments facilitate additional complexity in the geometry model, there is further consideration required to address cyclic features with inner voids, where the geometry of the void is not consistent across instances of the cyclic feature. This is not identified in the current implementation, as the voids do not share an adjacent face connection with the outer faces of the cyclic feature.

2.2 Irregular cyclic repetition patterns

It is common for turbomachinery geometries to have repeated cyclic features that do not have a consistent cyclic repetition angle or pattern. For example, to accommodate systems within the engine, a pattern of bolt holes may have a single instance at a different cyclic angle (Figure 3). While the cyclic feature is common, the differing angle introduces challenges in identifying the appropriate cyclic sector to extract.

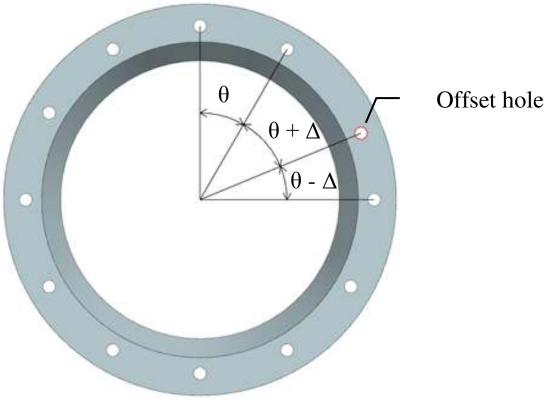


Figure 3. Inconsistent cyclic pattern

There are multiple ways in which this may be addressed, and user inputs may sometimes be required to guide the decomposition reasoner. At times, the deviation in geometry of the offset feature may be small and could be ignored in the analysis with limited impact on the accuracy of the analysis. A measure of the geometric deviation would determine if this assumption could be accepted. Alternatively, it is recognized that the same mesh topology would be suitable for the repeated cyclic sectors and the offset sector. A simple morphing of the cyclic sector mesh would provide a suitable mesh for the offset sector, and so it is only required to mesh one sector. Finally, if there is a significant difference in the geometry of the offset sector, this should be treated as a non-axisymmetric feature, and the sector should be left as a sub-region requiring its own meshing strategy.

Additionally, cyclic features can follow an irregular repetition pattern that can be simplified by identifying higher-level groups or sets of features. This is depicted in Figure 4, where a single cyclic feature does not have a consistent cyclic sector that can be extracted due to the irregular cyclic repetition. However, the cyclic features can be grouped into sets for which a regularly repeating cyclic sector can be identified. While this development has been achieved for the case shown, a more general implementation is required for identifying more complex sets of features.

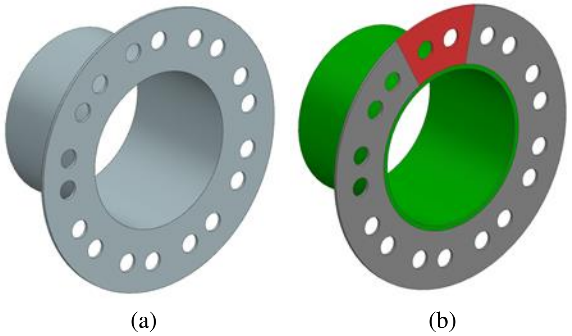

(a) (b)

Figure 4. (a) irregular cyclic holes (b) identified high-level feature set

2.3 Interacting cyclic features

When each pseudo-axisymmetric has a single cyclic feature connected, the cyclic sector can be identified and extracted with relative ease. However, in more complex geometries, there may be multiple cyclic features connected to a pseudo-axisymmetric face. This presents challenges when identifying the cyclic sector to be extracted. This challenge is compounded when the cyclic features have angular, axial, or radial overlaps. Similar to the previous sub-section, this may be addressed by identifying and extracting higher-level sets of features that have a consistent cyclic repetition. An example of this is depicted in Figure 5, where two cyclic sets are identified containing multiple instances of several independent cyclic features.

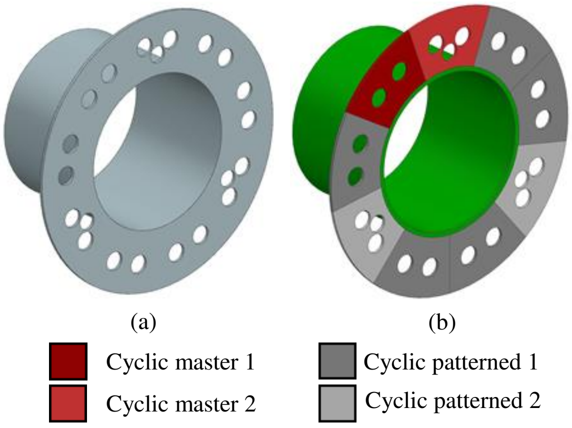

(a) (b)

Figure 5. (a) interacting cyclic faces (b) multiple high-level cyclic sets

There is further scope for isolating more complex sets of cyclic features, and also where an axisymmetric face could be used to partition the global geometry into individual sub-domains containing subsets of all the cyclic features. This will alleviate the challenge with identifying high-level cyclic sets; however, an additional challenge is introduced with ensuring mesh conformity between the isolated sub-domains. This is of a similar nature to the challenge addressed by Tierney et al. [5].

2.4 Cognizance of meshing requirements

As the aim of the MMR decomposition is to identify a reduced subset of the original geometry to be meshed, it is vital that decomposition decisions are made that facilitate and respect meshing requirements. For example, the original implementation of MMR extracts features with a planar cutting face when there is sufficient space between the cyclic features to facilitate this. However, based on the cyclic feature geometry at the connection with the pseudo-axisymmetric face, non-planar cuts that complement the desired mesh flow may be more appropriate. Furthermore, analysis requirements may also drive the mesh requirements in the vicinity of particular features, such as radial growth of a mesh around a hole feature, or mesh refinement around a feature of interest. Decomposition decisions should be made that respect these analysis requirements.

A final consideration is the choice of the location of the cuts used to extract a cyclic feature where there are multiple viable options for extracting a cyclic sector. The topology and geometry of the extracted sub-domain could provide guidance for the appropriate choice. For example, this may be based on a decision that minimizes the number of singularities required in the sub-domain mesh. Additionally, when there is insufficient space between cyclic features to insert a decomposition cut, a cyclic feature may be split. The choice of the optimal cyclic feature to split and the location of the split is a subject of consideration.

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3. DISCUSSION AND CONCLUSIONS

The original implementation of the MMR has demonstrated that it is possible to significantly reduce the amount of geometry that must be meshed in order to mesh a complete component. Currently, the significant limitation of the concept is the inability to create a good quality decomposition when the level of complexity of geometries increases. The ongoing developments, as outlined in the previous section, seek to address this challenge while also introducing novel functionality by remaining cognizant of meshing requirements throughout the decomposition process.

Recent developments, such as the creating of sets of cyclic features, show promise in increasing the complexity of the geometries that can be decomposed. While the concepts have been tested on several test cases, the generality of these developments is the subject of ongoing research.

Ultimately, the aim of this research is to reduce the pre-processing overhead in hexahedral meshing complex geometries. Rapid decomposition and meshing strategies will facilitate more extensive use of subsequent analysis tools in the design and development of commercial products.