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Design a 3D CAD Model of a Stealth Aircraft and Generate Mesh to Optimize Mesh Quality

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Abstract - *This research focuses on creating a 3D CAD model of a stealth aircraft, cleaning the CAD geometry, and generating the mesh using the pre-processing software Altair SimLab (2021) and HyperWorks (2019.1). Valid CAD geometry must be checked for errors, intersecting faces, and open edges before meshing and after meshing compared to the quality check reports from SimLab and Hypermesh for Aspect Ratio Check, Jacobian Ratio Check, Warpage Angle Check, Skewness, Quad Interior Angle Check, and Tria Interior Angle Check. The quality of the mesh plays a key role in the design analysis accuracy. As a result, we optimized the design to the point where elements passed with 99.5% accuracy in the model quality check report for Simlab and Hypermesh.*

***Key Words*:** Stealth Aircraft, Meshing, SimLab, HyperWorks, CAD geometry

1.INTRODUCTION

In the early stages of design analysis, where approximate results may suffice, you can specify a larger element size for a faster solution, but for a more accurate solution, a smaller element size may be required. There has been a lot of research activity on the subject of computational fluid dynamics for aerodynamic applications in recent years. In theory, advancements in the numerical solution of the Potential and Euler equations allow for inviscid flow simulation around complex aerodynamic forms. At this stage, substantial emphasis was placed on methods for producing meshes on which such calculations could be conducted.

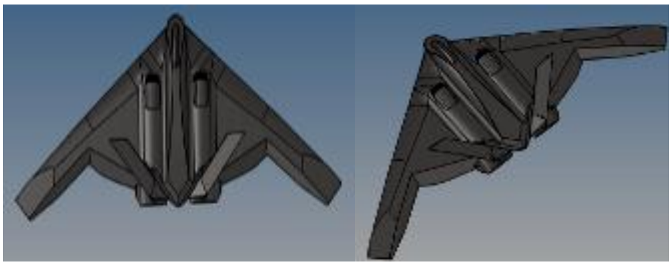
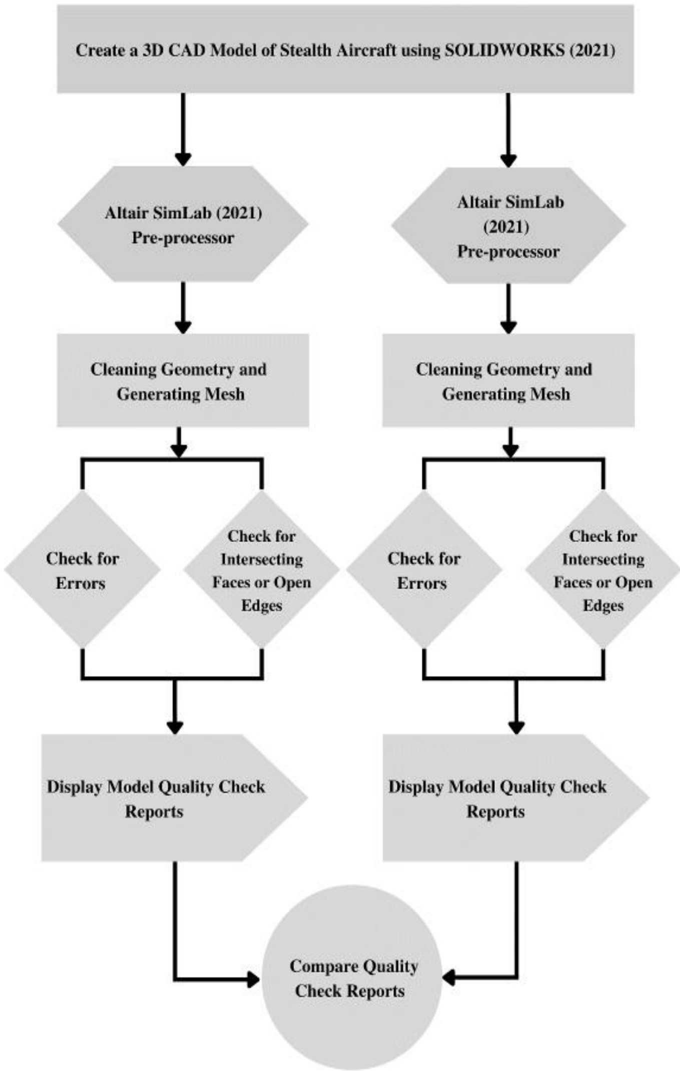


Figure 1 3D CAD model of stealth aircraft

2. METHODOLOGY



3. MESHING

Meshing is the process of transforming irregular shapes into more recognizable volumes called "elements". Meshing is one of the most crucial steps in performing an accurate simulation. A mesh is made up of elements that contain nodes or coordinate locations in space that can vary depending on the element type and which describe the geometry's shape. The size of the generated mesh (number of nodes and elements) depends on the geometry and dimensions of the model, element size, mesh tolerance, mesh control, and contract specifications. The amount of time available to commit to the mesh, and the amount of time available to invest in solving it all affect the mesh's quality.

3.1 Mesh Quality Check Parameters

3.1.1 Aspect Ratio Check

An aspect ratio is the ratio of width to height or length. It is the elemental deviation from having all sides of equal length. The best numerical accuracy comes from a mesh with uniform, perfect elements and edges that are all of the same length. It is quite challenging to generate a mesh of ideal components for general geometry. Some of the generated elements may have edges that are significantly longer than others due to narrow edges, curved geometries, thin features, and sharp corners. Results are less precise when an element's edges have large length discrepancies.

3.1.2 Jacobian Ratio Check

The Jacobian ratio calculates how far an element deviates from being perfectly shaped. To map a curved geometry, the Jacobian ratio of an element rises as the curvature of its edges increases.

3.1.3 Skewness

Proximity to an idealistic face or cell (i.e., equilaterally or equiangularity)

3.1.4 Warpage angle check

The warping angle, which is the angle between the normal of two (triangular) planes created by dividing the quad element along diagonals, is used to measure how far a quad element deviates from being in a single plane.

3.2 Structured Mesh

Meshes with a well-known pattern in which the cells are arranged are known as structured meshes. The cells are organized in a particular order, which results in a regular topology for such a mesh. Such meshes make it easy to locate neighboring cells and points due to their design and structure. Rectangular, elliptical, and spherical coordinate systems are combined to form structured meshes, which are then utilized to produce a regular grid. In CFD, structured meshes are frequently employed.

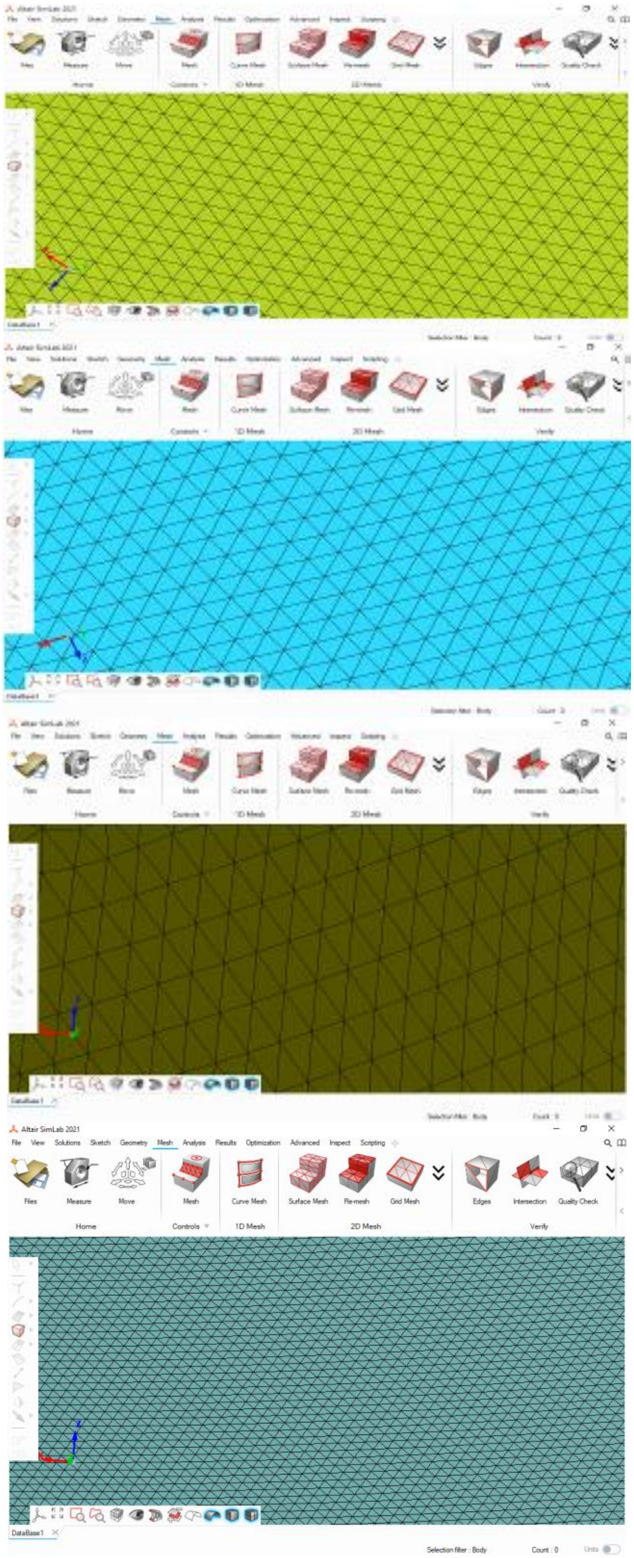


Figure 2 Structured Mesh

3.3 Unstructured Mesh

As the names suggest, unstructured meshes are more general and can randomly form any geometry shape. Unstructured meshes do not follow a consistent pattern because, unlike structured meshes, the connectivity pattern is not fixed. Unstructured meshes, however, offer greater flexibility. Unstructured meshes are generally used in complex mechanical engineering projects.

Unstructured mesh generation schemes have advanced almost independently of work on structured meshes This is primarily due to the fact that finite element methods have historically used unstructured meshes, but the nature of finite difference methods lends themselves to a structured regular mesh. Only recently have engineers in these domains begun to work more closely together as a result of increased understanding of the mesh creation issues that are prevalent in both of these fields.

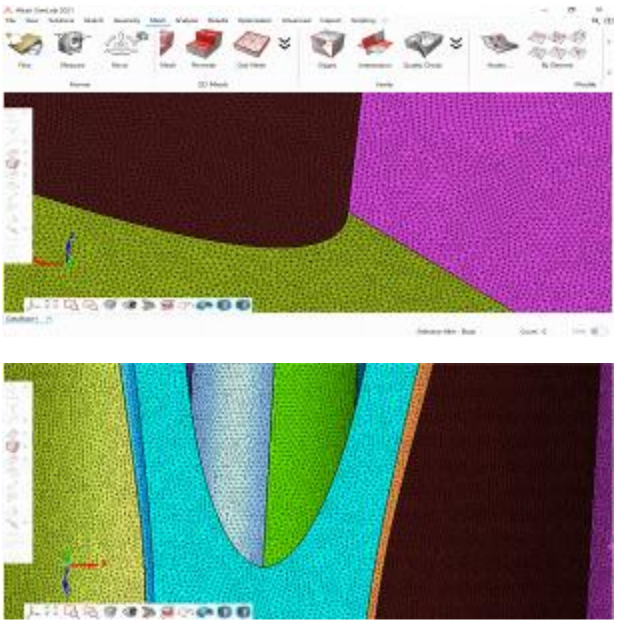


Figure 3 Unstructured Mesh

The primary distinction between unstructured and structured meshes is the type of data structure that best describes the meshes. A structured mesh of quadrilaterals or triangles is made up of a set of coordinates and connectivity that readily map into matrix elements. The nearby elements in the mesh point matrix are the neighboring points in the mesh in physical space. However, for an unstructured mesh, the points cannot be represented in this way and must be supplemented with additional information. The link between any two points must be explicitly defined in the connectivity matrix for each point.

The advantages of the structured method include flexibility in the creation of various flow algorithms, effective use of computer vector architecture, reduction of solver time and computer memory requirements, and a favorable setting for multigrid-based algorithm convergence. The relative drawbacks are the infrequent possibility of mesh point enrichment and the absence of complete freedom for exceedingly complicated geometrical regions.

The unstructured approach offers a natural environment for mesh and is adaptive for very complex geometrical designs. Some downsides include not being suitable for all classes of flow algorithms and multigrid implementation, as well as being rather wasteful in computer memory. It is important to keep in mind that the disadvantages of one strategy are actually its underlying benefits.

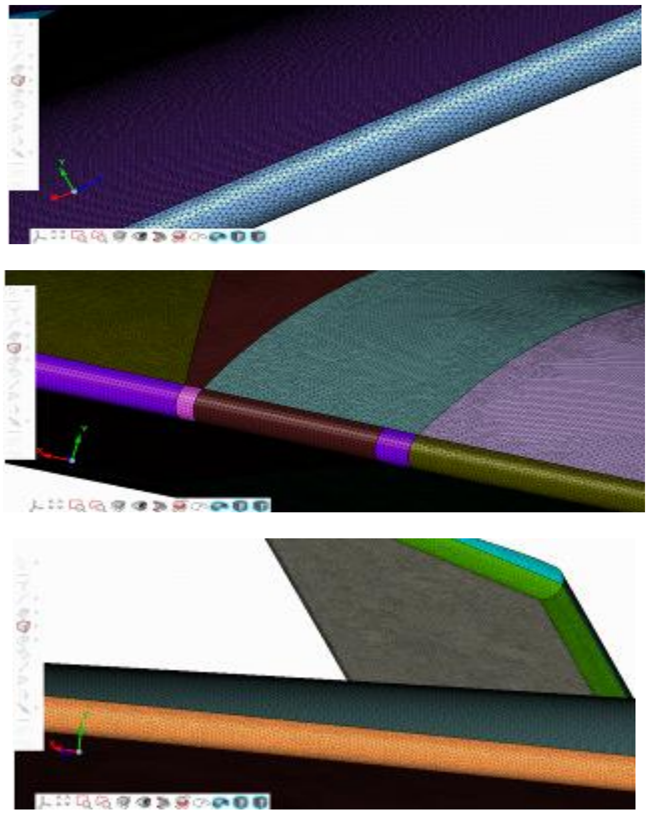


Figure 4 curved boundaries

The edges of an element may cross over one another in the vicinity of very sharp or curved borders, distorting the element and generating self-intersecting geometry. With a negative Jacobian ratio, distorted elements give inaccurate results. But in our model from figures (a), (b), (c) there are no edges crossing over, element distortion, and self-intersecting geometry.

SimLab Results

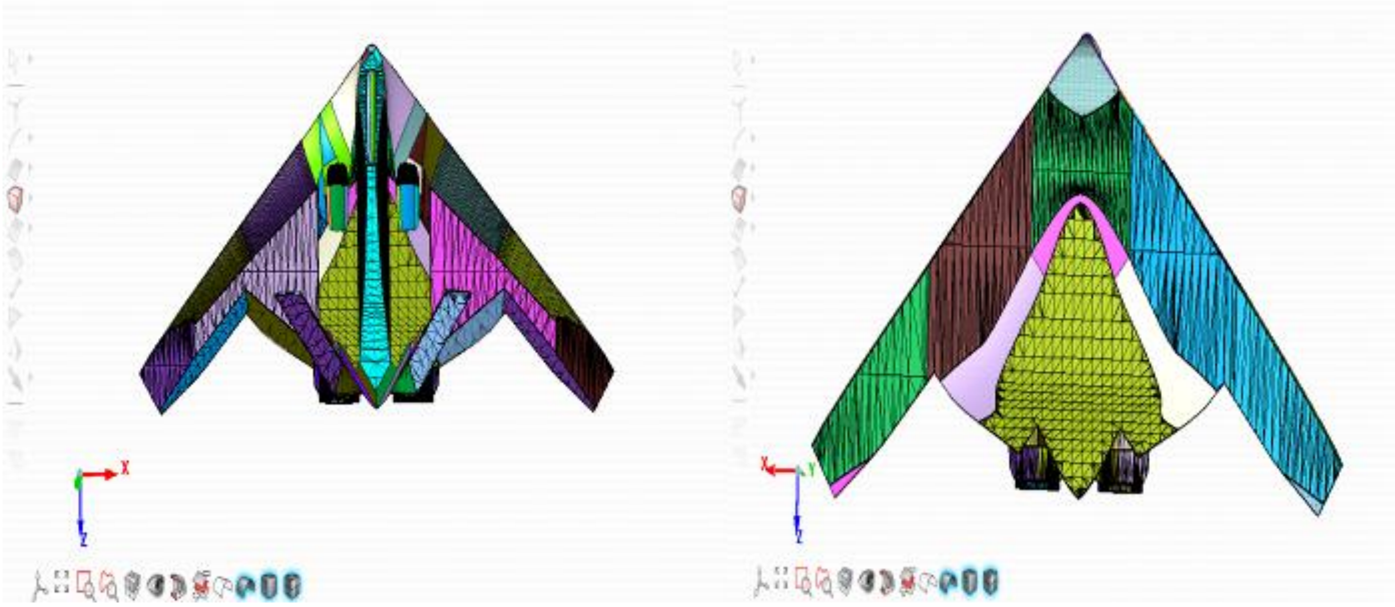


Figure 5 Before meshing

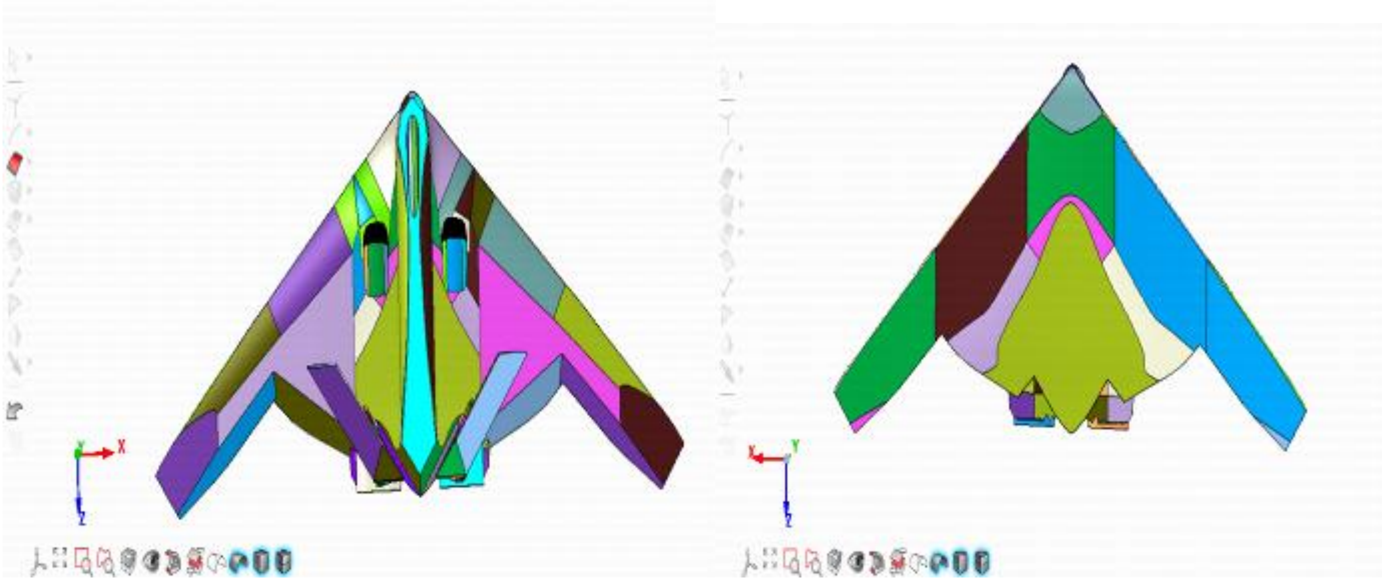


Figure 6 After meshing

Utilizing the three given nodal points, TRI3 enables the software to produce a linear plane to interpolate deformation from. Because a linear plane of deformation produces a constant strain and, as a result, stresses an entire element, there is a problem with the correctness of the solution. But in reality, stress is always changing and structured, thus it is quite misleading to say that something is under permanent pressure. Because of this, outcomes produced by TRI3 elements frequently have an excessive amount of stiffness and undervalue stress. A second-order or quadratic variation of TRI3 is TRI6. Being a second-order has one significant benefit. No longer is software restricted to a linear plane of deformation. The software may apply a linear plot of stress and strain by using a polynomial plot for deformation, increasing accuracy over TRI3. If the analysis is straightforward enough and sufficient TRI3 elements are used, the software can produce findings relatively quickly. However, TRI6 will demand significantly more computational resources and time due to the fact that there are twice as many nodes.

Hypermesh results

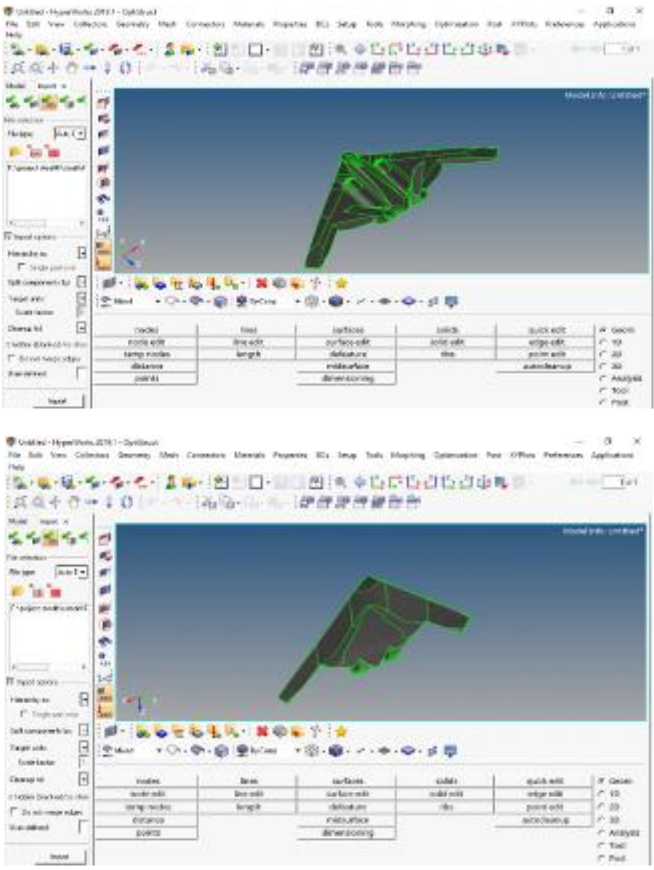


Figure 7 Imported CAD Model into HyperWork

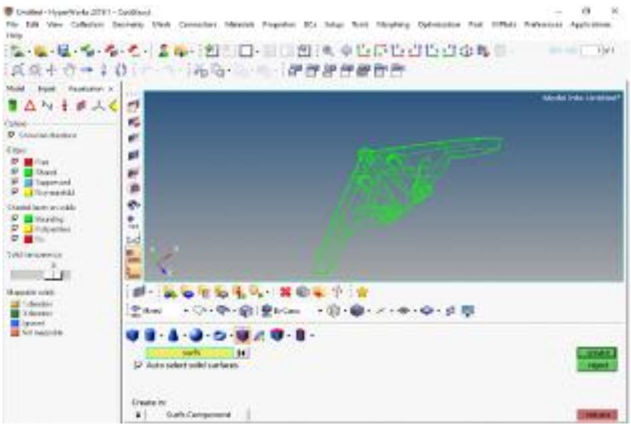
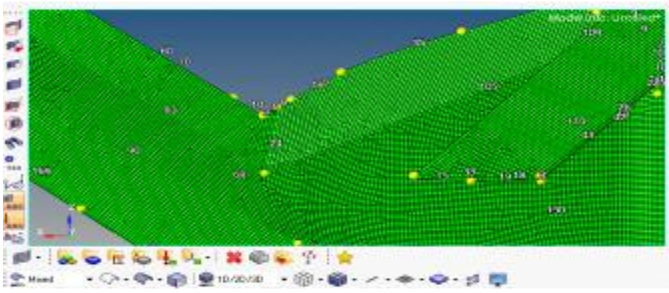


Figure 8 Model view to mix

Valid CAD geometry must be checked for errors, intersecting faces, and open edges. Set the view to mix to check for geometry errors, and then confirm there are no free or nonmanifold edges in the visualization panel (the red colour indicates free edges, while the yellow colour indicates nonmanifold edges). external flow CFD simulation, it is essential that the mesh completely encloses the volume, i.e., there are no free edges in geometry.



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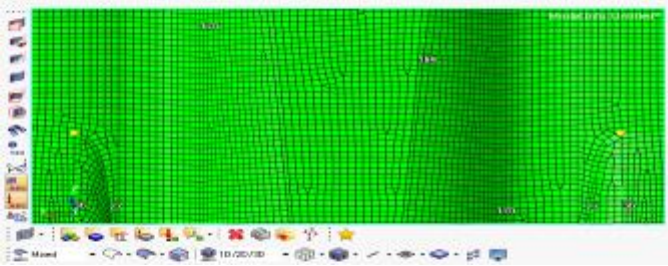

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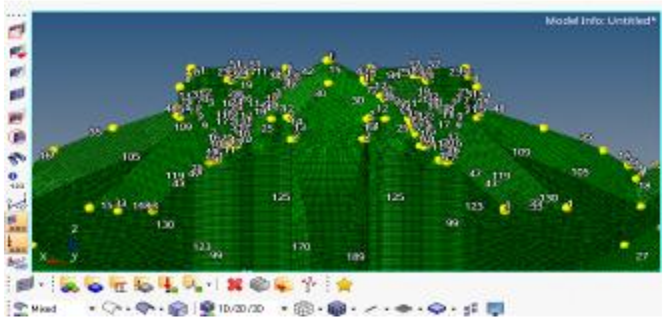

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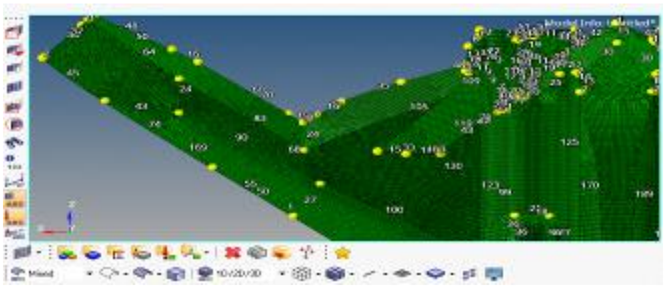

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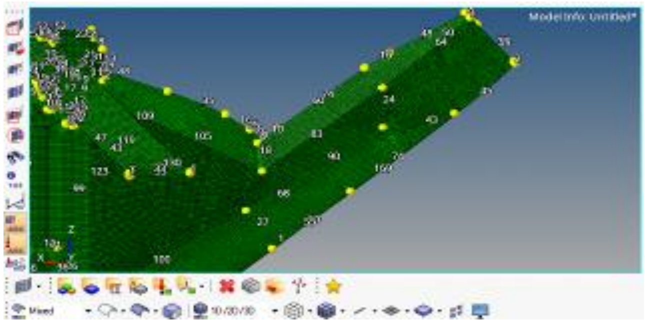

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Quality Check Report					
Model Name	stealthr1 3d prototype_sltr_paratr1_SM.gda				
Element Type	Tri				
Element Quality	**Min Value**	**Max Value**	**Condition**	**Limit Value**	**% Failure**
Aspect Ratio	1.000	9.996	≥	10.000	0.000
Edge Length	0.101	11.158	<	0.000	0.000
			≥	100.000	0.000
Interior Angle	5.023	157.797	<	10.000	0.018
			>	160.000	0.000
Stretch	0.144	1.000	<	0.100	0.000
Skew	0.007	80.095	>	75.000	0.014
Area	0.009	5.531	<	0.000	0.000
Mid-Node Offset : Ratio			>	0.500	0.000
Mid-Node Offset : Distance			>	0.500	0.000
Jacobian-Ratio	1.000	1.000	<	0.100	0.000
Area Skew	0.021	1.000	<	0.010	0.000
Area Skew : Fluent	0.000	0.979	>	0.950	0.001
Height	0.042	1.695	<	0.500	0.365
Surface Grading	1.000	12.789	>	2.000	1.313
Stable time increment-Radioss			<	0.005	0.000

Figure 9 SimLab Quality check report for TRI3

Quality Check Report					
Model Name	stealthr1 3d prototype_sltr_paratr1_SM.gda				
Element Type	Tri				
Element Quality	**Min Value**	**Max Value**	**Condition**	**Limit Value**	**% Failure**
Aspect Ratio	1.000	9.996	≥	10.000	0.000
Edge Length	0.101	11.158	<	0.000	0.000
			≥	100.000	0.000
Interior Angle	5.023	157.797	<	10.000	0.018
			>	160.000	0.000
Stretch	0.144	1.000	<	0.100	0.000
Skew	0.007	80.095	>	75.000	0.014
Area	0.009	5.559	<	0.000	0.000
Mid-Node Offset : Ratio	0.000	1.201	>	0.500	0.001
Mid-Node Offset : Distance	0.000	1.684	>	0.500	0.261
Jacobian-Ratio	0.046	1.000	<	0.100	0.000
Area Skew	0.021	1.000	<	0.010	0.000
Area Skew : Fluent	0.000	0.979	>	0.950	0.001
Height	0.042	1.695	<	0.500	0.365
Surface Grading	1.000	12.789	>	2.000	1.313
Stable time increment-Radioss			<	0.005	0.000

Figure 10 SimLab Quality check report for TRI6

Hypermesh Quality check report

Model Quality Aspect Ratio Check - Results

Check Status	PASS
Check Name	Aspect Ratio Check
Check Category	Model Accuracy
Check Description	This task performs aspect ratio check on elements
Check Criteria	
Target Values:	Min = 1 ; Max = 5
Expected Percentage:	99
Check Results	
No. of Elements Checked:	183324
No. of Elements Passed:	182606
No. of Elements Failed:	718
Actual Pass Percentage:	99.61
Detailed Results	
Worst elements, value : element id:	Min 5.001 : 6221 ; Max 3587.728 : 72894

Figure 11 Model Quality Aspect Ratio Check

Model Quality Warpage Angle Check - Results

Check Status	PASS
Check Name	Warpage Angle Check
Check Category	Model Accuracy
Check Description	This task performs warpage angle check on elements
Check Criteria	
Target Values:	Min = 0 ; Max = 12
Expected Percentage:	99
Check Results	
No. of Elements Checked:	183324
No. of Elements Passed:	183008
No. of Elements Failed:	316
Actual Pass Percentage:	99.83
Detailed Results	
Worst elements, value : element id:	Min 12.002 : 34154 ; Max 180.000 : 179941

Figure 12 Model Quality Warpage Angle Check

Model Quality Jacobian Ratio Check - Results

Check Status	PASS
Check Name	Jacobian Ratio Check
Check Category	Model Accuracy
Check Description	This task performs jacobian ratio check on elements
Check Criteria	
Target Values:	Min = 0.5 ; Max = 1
Expected Percentage:	99
Check Results	
No. of Elements Checked:	183324
No. of Elements Passed:	182895
No. of Elements Failed:	429
Actual Pass Percentage:	99.77
Detailed Results	
Worst elements, value : element id:	Min -0.431 : 179941 ; Max 0.500 : 177307

Figure 13 Model Quality Jacobian Ratio Check

Model Quality Trias/Shell Ratio Check - Results

Check Status	PASS
Check Name	Trias/Shell Ratio Check
Check Category	Model Accuracy
Check Description	This task checks the trias ratio
Check Criteria	
Target Values:	Min = 0 ; Max = 5
Check Results	
No. of Elements Checked:	183324
No. of tria elements:	5911
Actual Percentage:	3.22

Model Quality Quad Interior Angle Check - Results

Check Status	PASS
Check Name	Quad Interior Angle Check
Check Category	Model Accuracy
Check Description	This task checks quad elements for the interior angle
Check Criteria	
Target Values:	Min = 35 ; Max = 140
Expected Percentage:	99
Check Results	
No. of Elements Checked:	183324
No. of Elements Passed:	183088
No. of Elements Failed:	236
Actual Pass Percentage:	99.87
Detailed Results	
Worst elements, value : element id:	Min 1.706 : 137343 ; Max 215.541 : 34105

Model Quality Tria Interior Angle Check - Results

Check Status	PASS
Check Name	Tria Interior Angle Check
Check Category	Model Accuracy
Check Description	This task checks tria elements for the interior angle
Check Criteria	
Target Values:	Min = 12 ; Max = 120
Expected Percentage:	99
Check Results	
No. of Elements Checked:	183324
No. of Elements Passed:	183199
No. of Elements Failed:	125
Actual Pass Percentage:	99.93
Detailed Results	
Worst elements, value : element id:	Min 0.014 : 72894 ; Max 179.343 : 177077

Figure 14 Model Quality Quad Interior Angle Check **Figure 15** Model Quality Tria Interior Angle Check **Figure 16** Model Quality Trias/Shell Ratio Check

3. CONCLUSIONS

In numerical simulations, the results are as good as the mesh quality. This is why it is important to ensure that the mesh quality is improved to produce more accurate results. From model quality check results in Hypermesh, 1,83,324 total elements were checked. There are 718 failed elements and 1,82,606 passed elements with 99.61% accuracy from aspect ratio checks; 316 failed elements and 1,83,008 passed elements with 99.83% accuracy from Warpage angle checks; 236 failed elements and 1,83,088 passed elements with 99.87% accuracy from Jacobian ratio checks;125 failed elements and 1,83,199 passed elements with 99.93% accuracy from Tria interior angle checks.

For the SimLab quality check, there is 0% failure in aspect ratio, edge length, stretch, Jacobian ratio, and area skew. Interior angle failure was 0.18%, skew failure was 0.14%, mid node offset: the ratio was 0.01%, mid node offset: distance was 0.261%, height was 0.365%, and surface grading was 1.313%.

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