Improving the Optimization Process of a Boeing 777 Thrust Reverser

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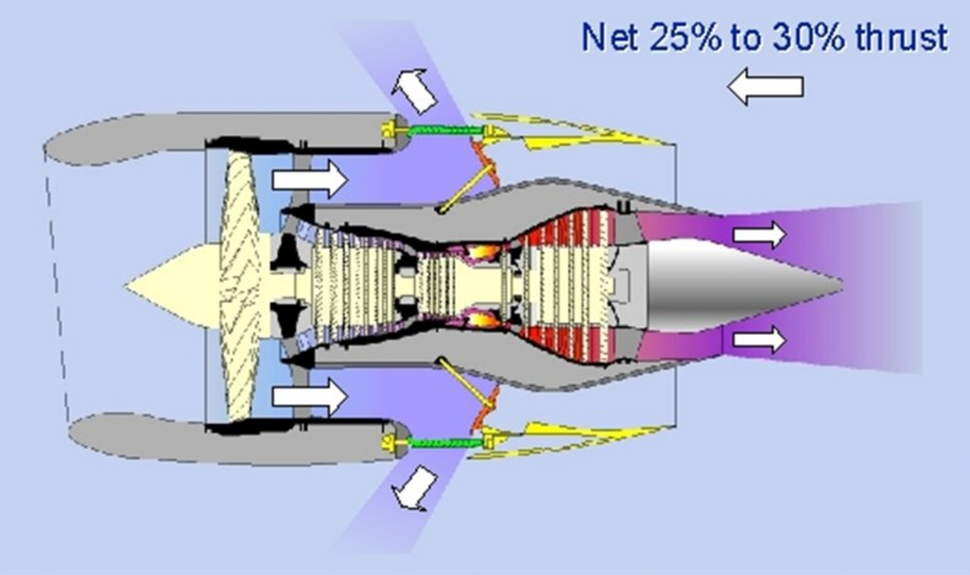
SCOPE Senior Capstone Program in Engineering

Franklin W. Olin College of Engineering

What is a Thrust Reverser?

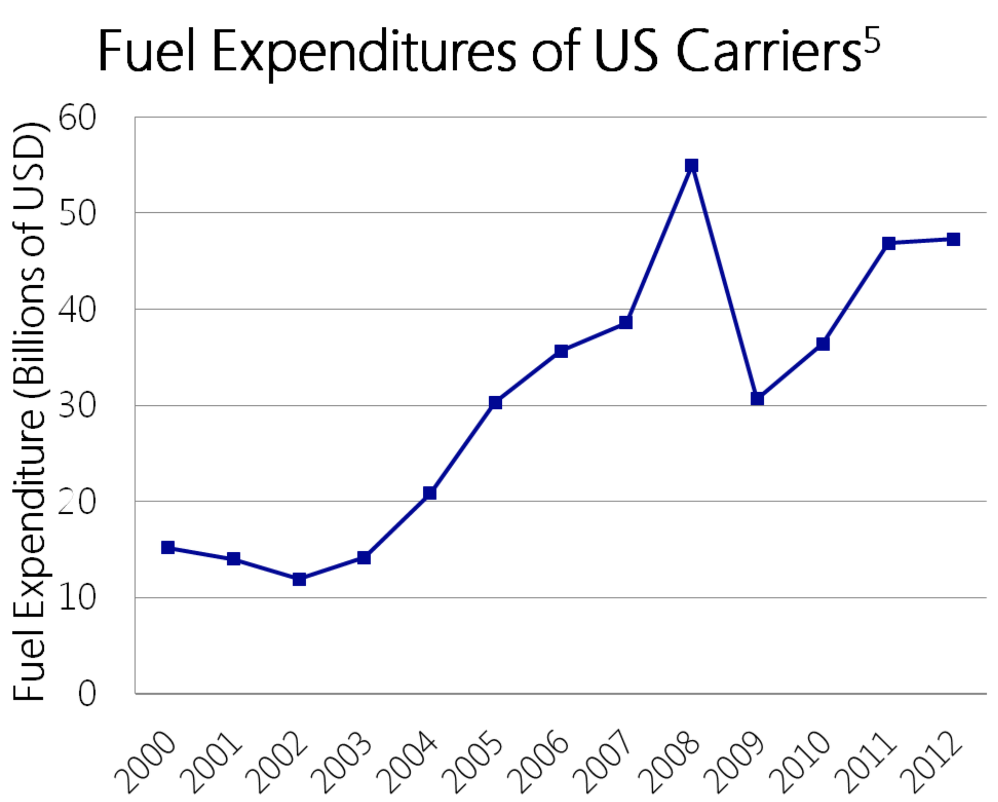
Thrust reversers are assemblies that take the exhaust from jet engines, which normally propels the aircraft in a forward direction, and reverses the flow in order to slow the forward momentum of the aircraft during landing. These devices are meant to be used in conjunction with the wheel braking assembly. Thrust reversers have an advantage when ground conditions are slippery. In icy or wet conditions, the wheels have a tendency to slip, resulting in added wear on the tires and braking assembly and longer braking distances. The braking power of thrust reversers is derived from the reversed air flow, thus runway conditions do not affect the efficiency of the thrust reverser's braking potential.[6]



This diagram[7] shows a cross sectional view of a jet engine when the thrust reversers are deployed. Upon activation, the blocker doors impede the air outside of the combustion area, and redirect this airflow in the opposite direction of the thrust. The net effect of the thrust reverser is between 25% to 30% of the total thrust of the engine. When used properly, the thrust reverser can reduce the wear on the braking system resulting in significantly lower maintenance costs over the lifetime of the aircraft.

Although the thrust reverser aids in decelerating the plane, the thrust reverser assembly is unused during takeoff and flight; thus it is important that the entire mechanism is optimized for weight in order to reduce the added fuel cost due to its added weight to the aircraft.

Why Optimize?



The objective of airplane component optimization is to minimize mass while maintaining structural integrity, rather than optimizing for minimum material costs or for the greatest ease of assembly. This is because material and assembly costs are one-time costs that contribute to the initial cost of a plane, but the fuel costs are on-going. A plane with a lower mass requires less fuel to fly, and therefore saves its operator money on every single flight it makes, even if it is initially more expensive to produce.

Optimizing airplane components for mass while ensuring the part will still be strong enough to stand up to the heavy loads experienced during flight requires the use of powerful computational optimization software. This software must have the capabilities of modeling a part's behavior when various changes are made to the geometric design that would affect the part's final mass. Although this specialized software is very powerful, it can be complicated and difficult to use.

After exploring the optimization process, the Boeing-Olin SCOPE team identified areas of opportunities within the method, and decided to focus on the learning process. To that end, a series of Boeing-specific tutorials were created to

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Special thanks to Ronnie Wilson for being an excellent liaison.

Sources:

[1]http://manufacturingscience.asmedigitalcollection.asme.org/article.aspx?articleid=1433639

[2]http://www.sv.vt.edu/classes/MSE2094_NoteBook/97ClassProj/num/widas/history.html

[3]http://www.nenastran.com/NewtoFEA/

[4]http://altairenlighten.com/2011/12/sizing/

Sources:

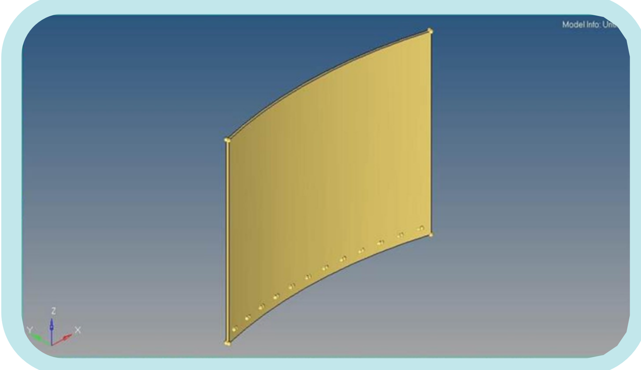
[5]http://www.transtats.bts.gov/fuel.asp

[6]http://www.airliners.nl/Schiphol/united.htm\

[7]http://forum.flyawaysimulation.com/forum/topic/21745/how-exactly-does-reverse-thrust-work/

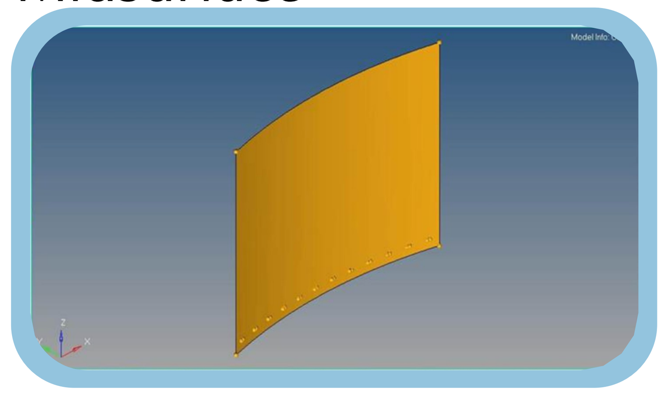
The Optimization Process

3D Geometry



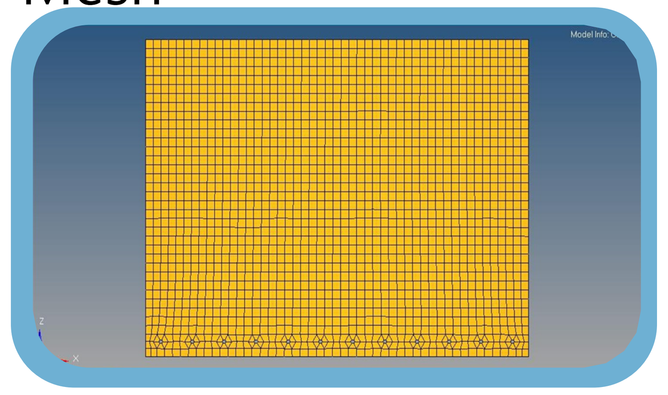
The 3D geometry is an exact representation of the designed part that has either been designed for the system or is currently being used in the system.

Midsurface



The geometry of a 3D thin-walled structure is represented with a collection of midsurfaces during the optimization process. The creation of a midsurface is a geometric simplification that assigns material thickness to a 2D model representation. This process reduces the computational complexity and run time for the engineering analyses[1].

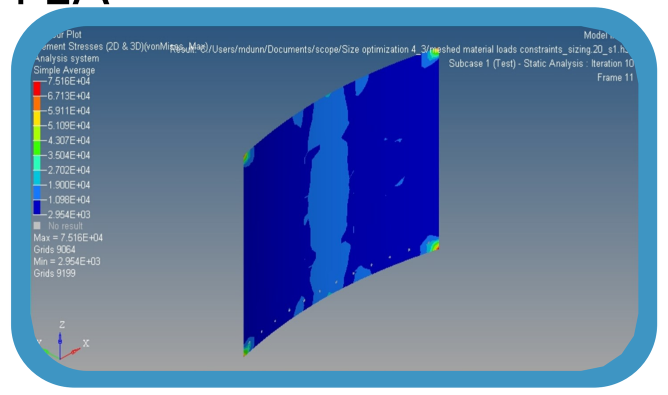
Mesh



A mesh is a complex network of nodes that contains information about the material and structural properties of the geometry. This node system helps define how a geometry will function under loads and constraints, and thus a mesh is used in conjunction with an FEA solver to calculate stresses, strains and displacements[2].

Nodes are assigned to particular regions of a geometry and the compactness of the nodes depends on expected stress levels of a particular area. For example, a geometry with a hole will have higher stresses around the edges of the hole, and thus nodes are placed with a higher density around the hole. Other areas that should generally have a higher node density include suspected fracture points, fillets, corners, constrained areas, and complex detail. In comparison, for areas of a geometry with very little of no expected stresses, the node density will be much lower.

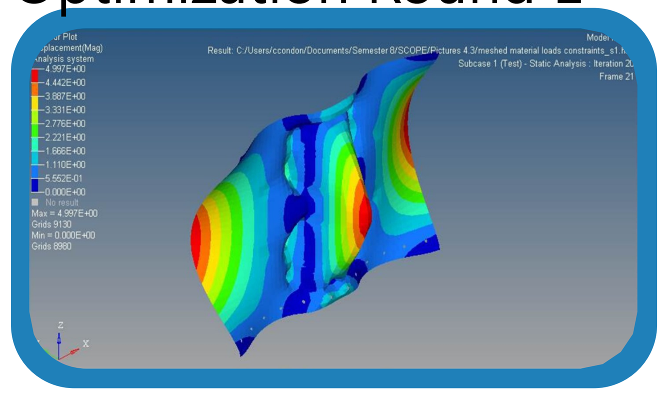
FEA



Finite Element Analysis (FEA) works in conjunction with a mesh to break a complex problem down into a finite number of simpler problems. FEA approximates a continuous geometry by breaking it down into smaller and simpler "elements." The boundaries of each element are defined by nodes which loads and constraints are applied too. The finer the mesh the more precise the FEA will be, but there is a tradeoff between precision and computational power needed to solve the problem.

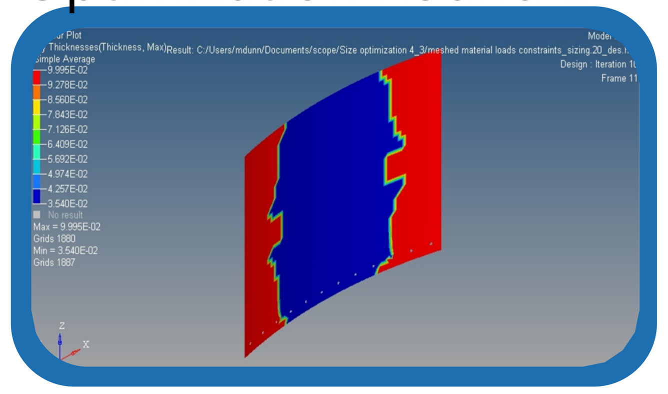
The final results of an FEA generally show a distribution of either stresses, strains, or displacements that can be used in the future optimization steps. These results can be imported into an optimization solver to aid in improving things such as mass, thickness, ply orientation and so on[3].

Optimization Round 1



During the first round of optimization ideal outcomes are defined for the solver to try and calculate. An example of this is setting a minimum and maximum thickness allowable and having the program try to find a value within that range. When designing airplanes optimization solvers are almost always run to minimize mass because overtime cost is measured in how much fuel is necessary to move the plane, and fuel costs are directly proportional to weight. For this optimization, displacement is constrained and mass is minimized.

Optimization Round 2



The second round of optimization also defines ideal parameters, such as minimizing thickness and mass and also generally has manufacturing constraints. An example of a manufacturing constraint is making sure a hole size stays the same, no material is removed, because a certain type of screw has to hold the part to the system. Another example might be to make sure the outer edge of a part maintains the same shape because it must fit with another part.

This second iteration of optimization takes into account the first optimization and the FEA that was previously run. In a way this is a more refined optimization in comparison with the first iteration. For this particular optimization composite strain and composite failure were constrained and the objective of the optimization was to minimize mass[4].

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