Exploring New Designs of Tie Rods to Reduce Cost in Manufacturing Boeing Aircraft

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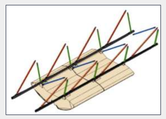
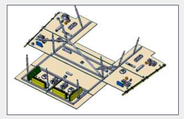
Introduction

Background: Tie rods are a two-pin system that provides support throughout the aircraft structure. This design enables applications with both tension and compression loads. As a basic but very versatile component, tie rods can be used in a variety of applications - from structuring large interior parts like a stowage bins to supporting flight control systems inside the cockpit (both shown below).



Center Stowage Bin Overhead Supports

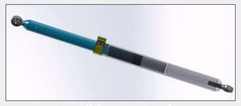


Center Lowered Ceiling Support

Objectives: Our team aims to explore different design and manufacturing options for tie rods. These options will be evaluated for efficiency based on:

- **Manufacturing**: The new designs should utilize optimal production times and be feasible to produce for current Boeing manufacturers.
- **Cost**: Designs should be cost-effective to produce in terms of material, labor, and other production costs.
- **Engineering function**: The new design should have appropriate weight ratio and strength to carry loads in both tension and compression.
- **Ease of use**: The new design should be easy to install, adjust and maintain by Boeing employees.

Current Design



Possible New Design

Cost-Benefit Analysis

Raw Material Cost

- Swaged Volume 12.71 in^3 (currently being used at The Boeing Company)
- Clamp Adjust Volume 16.28 in^3
- Camber Bolt Volume 16.65 in^3

Aluminum 6061 with a T6 heat treatment was chosen by the Mechanical Engineers stress analysis of the designs.

Materials	Al 7075	**Al 6061**	Al 5052	Al 3003	Al 2024
Price per Ton	$ 3,200.00	**$ 2,400.00**	$ 2,400.00	$ 2,000.00	$ 1,800.00
Price per lb	$ 1.60	**$ 1.20**	$ 1.20	$ 1.00	$ 0.90
Density (lb/in^3)	0.101	**0.098**	0.097	0.099	0.1
Swaged Weight (lb)	1.284	**1.245**	1.233	1.258	1.271
Clamp Adjust Weight (lb)	1.644	**1.595**	1.579	1.611	1.628
Camber Bolt weight (lb)	1.682	**1.632**	1.615	1.648	1.665
Swaged Cost per Rod	$ 2.05	**$ 1.49**	$ 1.48	$ 1.26	$ 1.14
Clamp Adjust Cost per Rod	$ 2.63	**$ 1.91**	$ 1.89	$ 1.61	$ 1.46
Camber Bolt Cost per Rod	$ 2.69	**$ 1.96**	$ 1.94	$ 1.65	$ 1.50

Short list of Assumptions

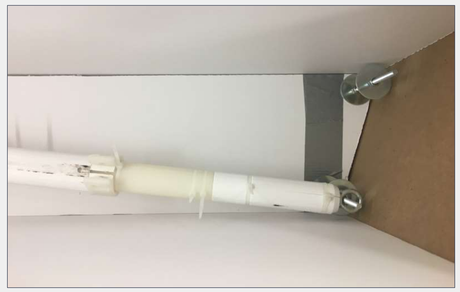
****This is a very incomplete list, only some of the most impactful assumptions****

1) We have 4 CNC machines
2) All rod ends machining costs are the same, regardless of end type
3) The following are the only costs impacted by volume ---
   Lifespan of CNC lathes — Raw Material
   Dipping layer cost — Labor

Human Factors Analysis

To simulate the space envelope required for the tie rods, we constructed a cardboard mockup.

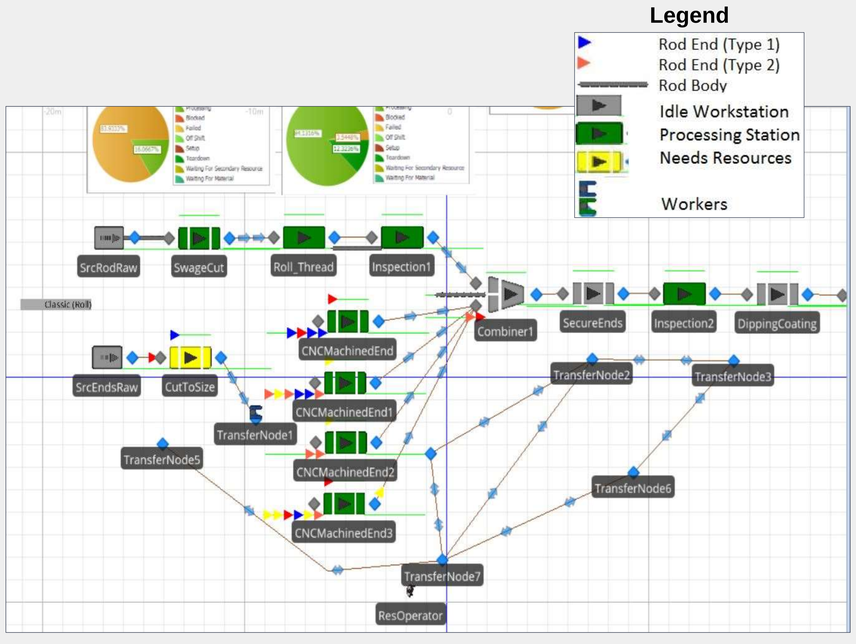
- A mockup can be used to test if the rod functions well from an ergonomic perspective.
- Installation and adjustment times have importance throughout the entire life of the rod, and there is value in knowing which rod design has the most ease of use.



A 3D-printed tie rod hooked up in a mockup space envelope

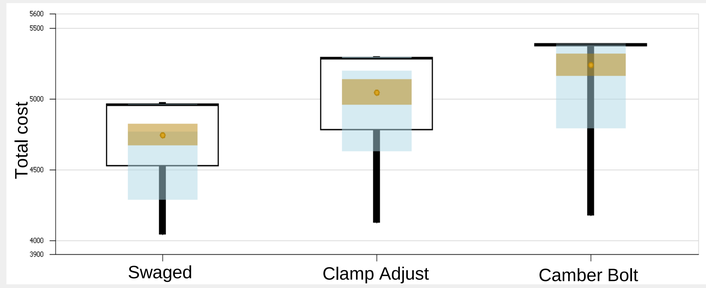
Simulation Model and Analysis

- Using SIMIO, we can model every individual manufacturing operation, and create a simulated manufacturing environment.
- The simulation is also capable of handling data for complex manufacturing schedules, and we can use the model to track resource consumption and cost.



What-if Scenario Results

Using our SIMIO model, we ran an experiment to determine which rod will cost the least to manufacture in large quantities. Below are the results for overall cost to manufacture 500 rods for each of the three designs.



Index of Performance

Legend
= 3 points
= 2 points
= 1 point

Criteria	Weights	Swaged	Camber Bolt	Clamp Adjust
Raw Material Cost (dollars)	15%	1.49	1.95	1.89
Machining Cost (dollars/unit)	15%	4.56	6.40	5.28
Weight (lb)	25%	1.25	1.61	1.58
Processing Time (minutes)	5%	56	115	93
Adjustability (inches)	40%	0.2	3.0	3.0
Stress Effectiveness	-	4149 lbs	43.5 ksi	83.5 ksi
Weighted Score		**2.2**	**1.8**	**2.4**

The Clamp Adjust design returned the highest weighted score

Based on the weighting criteria we established for this project, the "Clamp Adjust" model has the most promise as a low-cost design alternative for Boeing of all the options we considered.

Recommendations

We found that making design improvements is feasible and not overly expensive to manufacture. We recommend that Boeing evaluates the possibility of introducing a new rod with design elements influenced by our rods. However, Boeing and it's suppliers will have to determine which changes will best impact their operations, especially from a human-factors standpoint.

- Aluminium 6061 T-6
- Explore more flexible CNC machines with more automation
- Recycle unused material
- Manufacture one part and one tie rod type at a time

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