Ford Additive Manufacturing Capstone Design Project

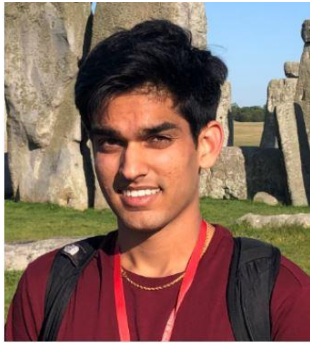
MAE 189 Capstone Design
University of California, Irvine
April 30, 2021

Our Team

Edward Pedro

Omid Souri

Elizabeth Suarez



Anil Verman

Advisor: Benjamin Dolan

Sponsor: Siddharthan Selvasekar

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Project Definition

Problem statement, overview of the project, our objectives, and research

Problem Statement

Conventional manufacturing methods, such as injection molding, can be expensive when it’s being used for low volume (< 20,000 units) production. Since tooling is not universal and must be altered to fabricate various parts, traditional manufacturing methods can lead to high upfront tooling costs. However, additive manufacturing, also called 3D printing, provides users a range of advantages that can help reduce costs.

Ford has asked us to redesign an automotive air duct by using multi-jet fusion 3D printing technology for low volume production. To utilize this technology properly, we must abide by the packing density rules and build requirements of the 3D printer that will be used. We will be following the Engineering design process to implement multiple designs that will minimize the unit cost and maintain similar performance to a traditionally manufactured automotive air duct.

Overview

Project

- Redesigning an HVAC duct from a Lincoln Navigator using Design for Additive Manufacturing principles
- Using HP Multi-jet 5200 printer
- Materials: PA-11, PA-12, PP, TPU

Objectives

- Provide 3 designs
  - 2 CAD versions of each design: as-printed and deployed
  - Maximize Nesting Efficiency
  - Minimizing Unit Cost
- Business cases for each design along with build nesting scenario
- CAE evaluation of pressure drop difference with new designs
- Engineering report detailing design development and test methodology

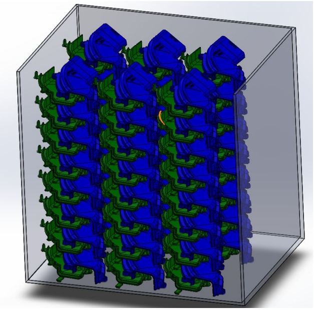
Primary & Secondary Research

Multi-jet Fusion Printer

- UCI: HP 4200 → PA-12
- Ford: HP 5200 → PA-12, PA-11, PP, TPU
- Specs:
  - Build Volume: 380 x 284 x 380mm
  - Min. wall thickness: 0.5mm
- Cost & production:
  - Material costs are associated with part volumes
- How it works
  - The printer first deposits a layer of material on the build platform. Fusing agent is applied on the layer of material where particles need to fuse as well as detailing agent. Lastly energy is applied so that the reactions between the agents and material can happen.
- 3D Nesting
  - Ability to pack many parts in build volume
  - Softwares: **Netfabb**, Materialise, 4D Additive

Existing Solutions

- Current Ford design
- Telescoping design
  - Consider clearance between each "tube" and locking mechanism
- Collapsible design
- Foldable design



More Information

- Estimated Ford Print Costs
  - PA 12: $750
  - PA 11: $1000
  - TPU: $1500
  - PP: $600 ← cheapest
- TPU and PP are hard to run in the printers
  - Can warp during printing due to heat and after part is printed during cool down
- PP has more constraints when printing
  - 25 mm distance from the build wall

Elizabeth

Design Attributes

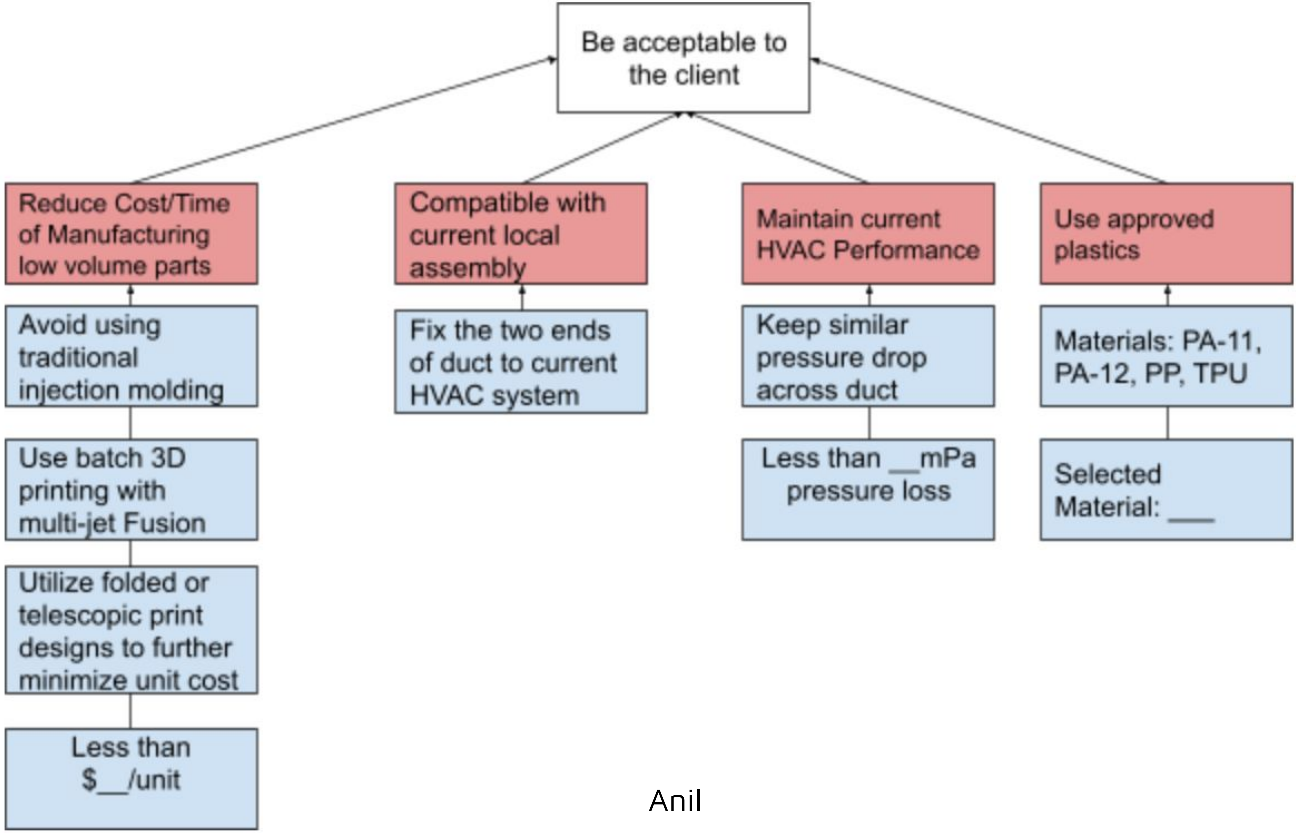
O-objective, C-constraint, F- function, M-means

Attributes	O	C	F	M
Must have similar pressure drop to current design		x		
Must not have interference in same local assembly as current design		x		
Should reduce the unit cost compared to current design for small volume parts	x			
Could be foldable, telescopic, or collapsible				x
Should be as durable as current design	x			
Should maximize nesting efficiency	x			
Must use one of the following material: PA-12, PA-11, PP, or TPU		x		
Must be compatible with multi-jet fusion printer technology		x		

Anil

Objectives–Requirements Tree

Red - Objective, Blue - Requirement



Anil

02

Conceptual Design

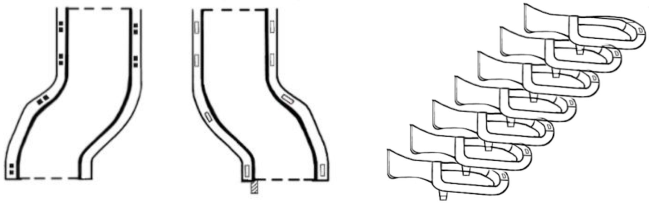
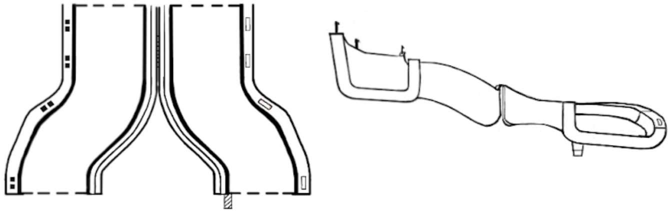
Design Requirement Table

Level of Importance: 1 (low) and 5 (high)

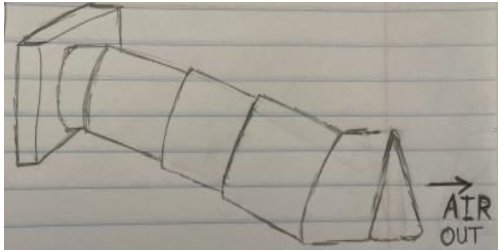
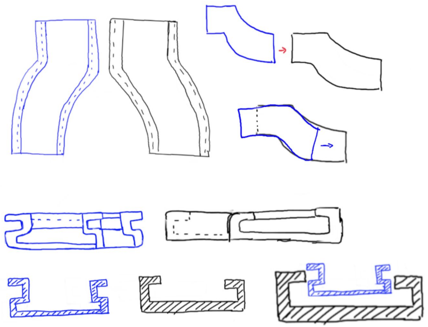
Metric No.	Requirement/Metric	Imp.	Units	Marginal Value	Ideal Value
1	Withstand estimated operating temperature range	1	℉	-40 - 150	-40 - 150
2	Within % pressure drop of current design	3	N/A	≤ 10%	0%
3	Maximize number of parts per batch (nesting efficiency)	4	N/A	>71	>100
4	Minimize unit cost compared to injection molding at low volume production (<20,000 units)	4	\$	<\$8.50	<\$8
5	Fits within local assembly with no interference	5	N/A	N/A	N/A

Omid

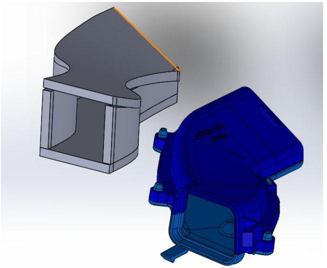
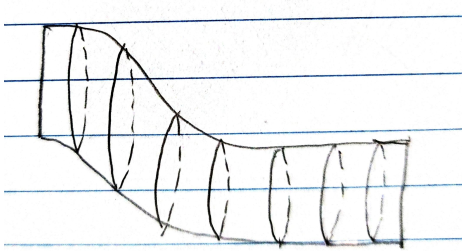
Concepts

Name & Picture	**Pros**	**Cons**
Snap Fits 	• PA 12 - Cheaper material • Can easily stack on top of each other • Labor after printing only involves placing 2 pieces together	• May still be bulky • Must ensure connections align properly
Book Style 	• Labor after printing only involves closing the duct • Easier to assemble than snap fits	• Due to geometry of the duct, closing it would move in an arc path • May not pack as much per printing batch due to the hinge connection

Concepts

Name & Picture	**Pros**	**Cons**
Telescoping 	● PA-12 - Cheaper material ● telescopic design is compact ● Low labor after printing	● Needs to be split in two pieces because triangular section needs to be attached after printed
Sliding lock 	● Same amount of steps needed after printing to current design ● Reduces dimensions by getting rid of extruding parts	● Needs to use flexible material TPU/PP ● Nesting would have to follow more constraints

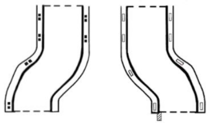
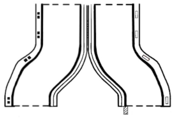
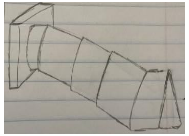
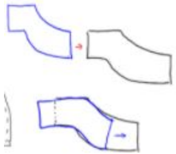
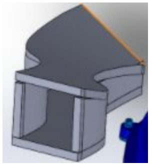
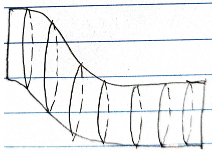
Concepts

Name & Picture	Pros	Cons
Separate Wall Ducts 	• Can be compactly nested because all pieces are mostly flat • PA-12 - Cheaper material	• Needs more assembly work after printing • finding a secure method to connect all walls
Semi-Rigid Duct 	• Flexible due to TPU which allows for more design freedom	• TPU is much more expensive(about twice as much as PA-12) • TPU harder to print with and can warp

Concept Selection Process

- Used Pugh Matrix to determine the designs that we will go forward with
- Justified scores based on information from pros and cons table

	Ford design (reference)	**Snap fits**	**Book style**	**Telescoping**	**Sliding lock**	**Separated wall ducts**	**Semi-Rigid**
Selection Criteria	***Relative Score***	Relative Score	Relative Score	Relative Score	Relative Score	Relative Score	Relative Score
Nesting Efficiency	***S***	1	-1	1	-1	1	-1
Material Feasiblity	***S***	1	1	1	-1	1	-1
Ease of Assembly Post-Print	***S***	0	1	1	0	-1	1
Durability	***S***	0	0	0	0	0	0
Smoothness of inner surfaces	***S***	0	0	-1	0	0	-1
Score	***0***	2	1	2	-2	1	-2

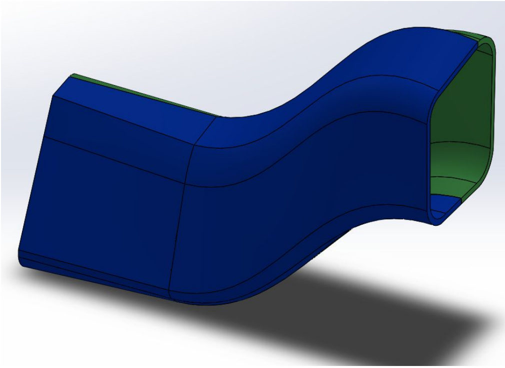
Omid

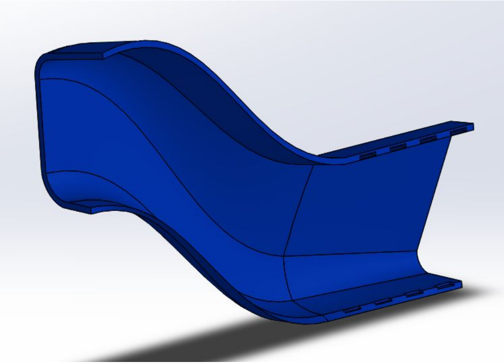
03

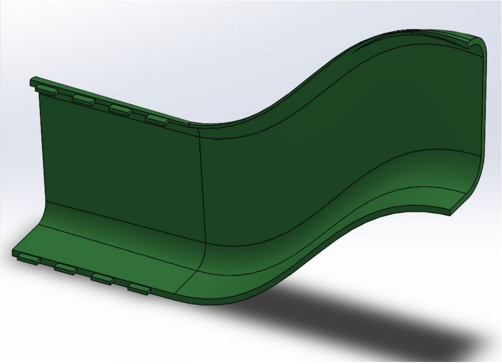
Preliminary Design

Preliminary CAD Models

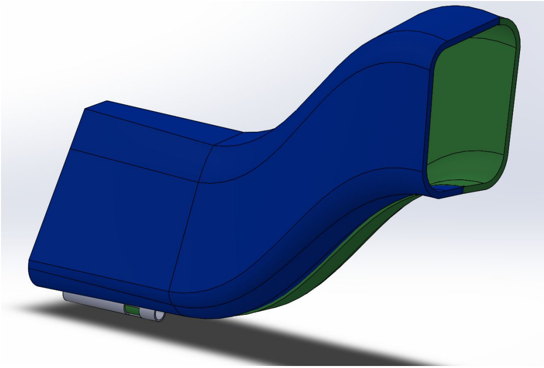
Snap Fits

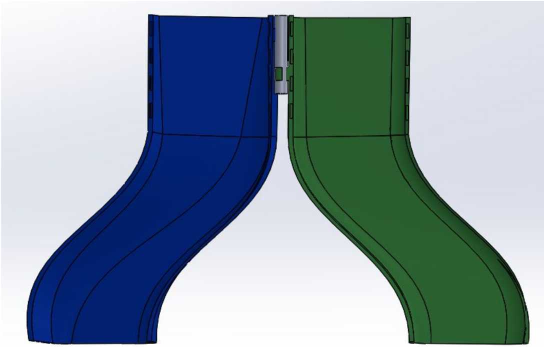






Book Style

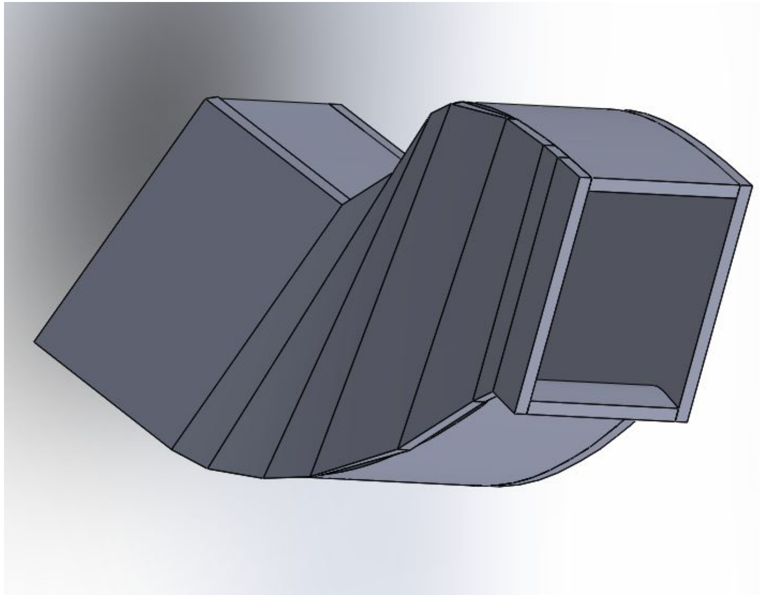


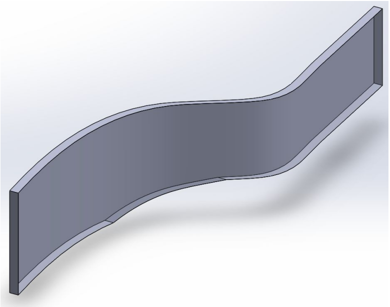


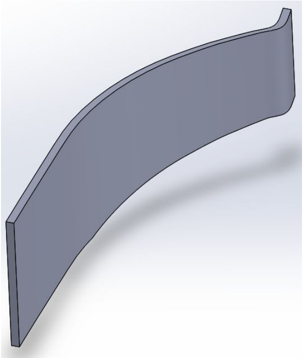
Edward

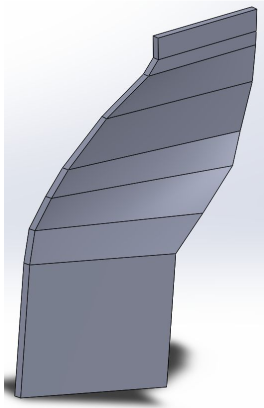
Preliminary CAD Models

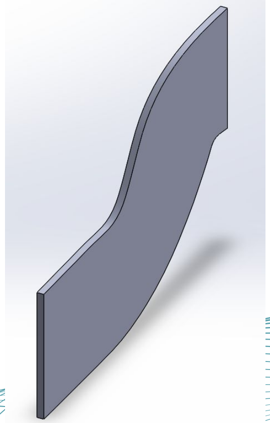
Separate Wall Ducts









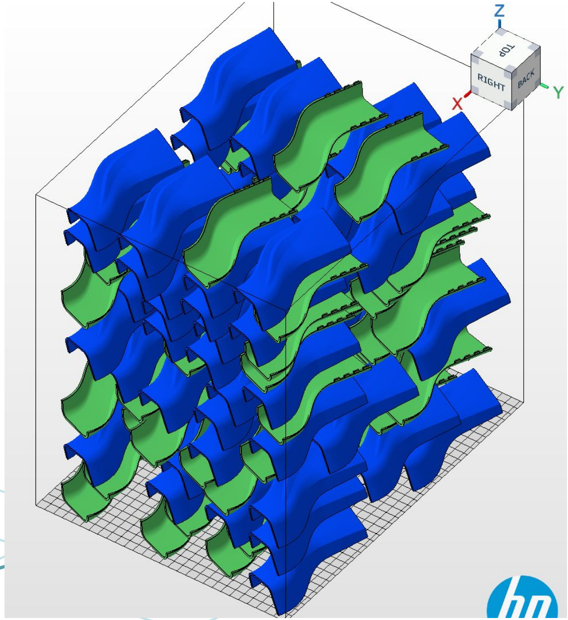


Edward

Nesting Scenarios

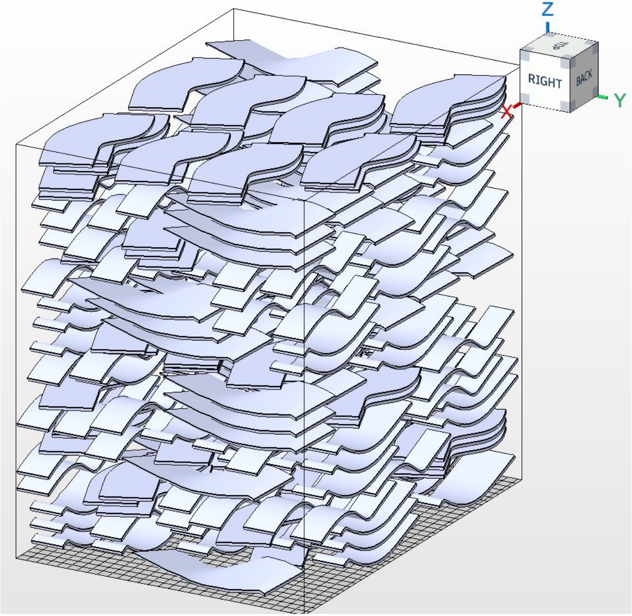
Snap Fits

- Part interval: 5mm
- Packed Height 378.3mm
- Total Parts: 108
- # of sets: 54



Separate Walls

- Part interval: 5mm
- Packed Height 366.9 mm
- Total Parts: 228
- # of sets: 57



Edward

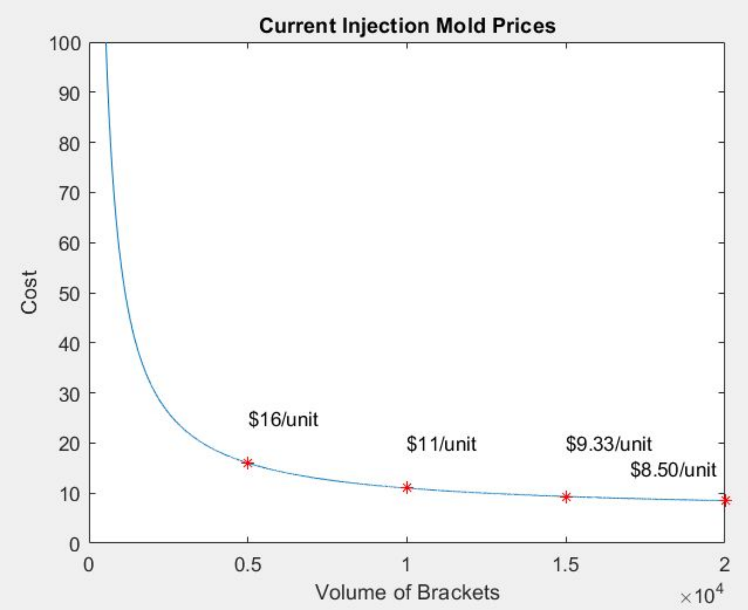
Current Business Model

Conventional Cost Estimates for a 2 piece duct

- $50,000 in investment costs (tooling, etc.)
- $6 in part cost (material, cycle cost)

Price per unit equation

f(x) = price per unit = (50,000 + 6*x)/x



Injection Mold Business Case

Current Business Models for the Designs:

Snapfits:

- PA-12: $13.89/unit

Separated Walls:

- PA-12: $13.16/unit

Edward

SWOT Analysis

Using AM methods for low volume production

Strengths	Weaknesses
• Multi-jet printing technology allows for more recyclability • No large initial investment cost needed for mold	• Inconsistent part quality • Must adhere to constraints set by the printer which limits nesting efficiency
Opportunities	**Threats**
• Nesting • Folding/collapsing designs • Lower unit cost for low volume items compared to traditional manufacturing	• Only viable at low volume production • 3D Printer malfunction • PP material harder to work with than PA-12 and has more limitations

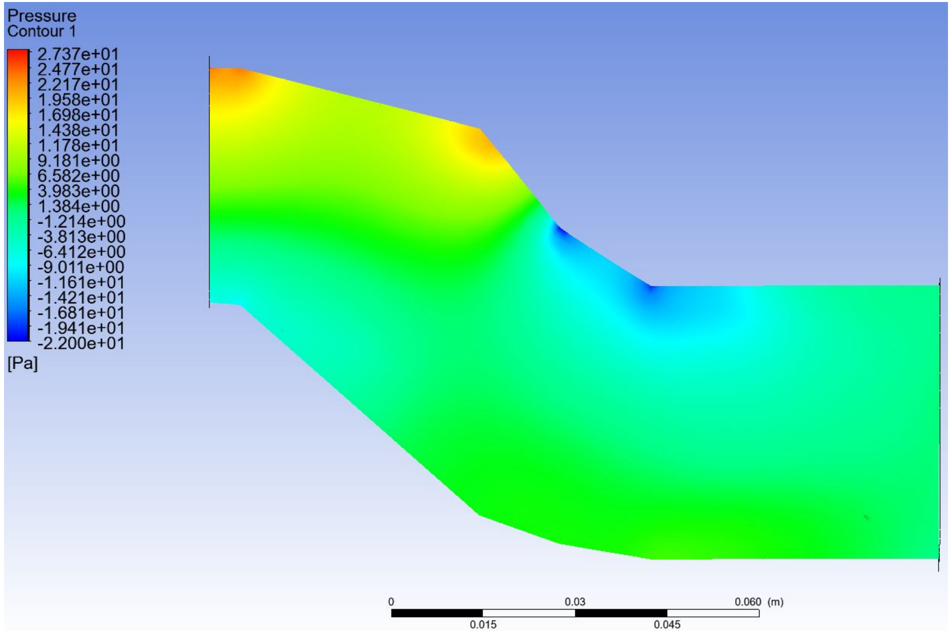
SWOT Analysis

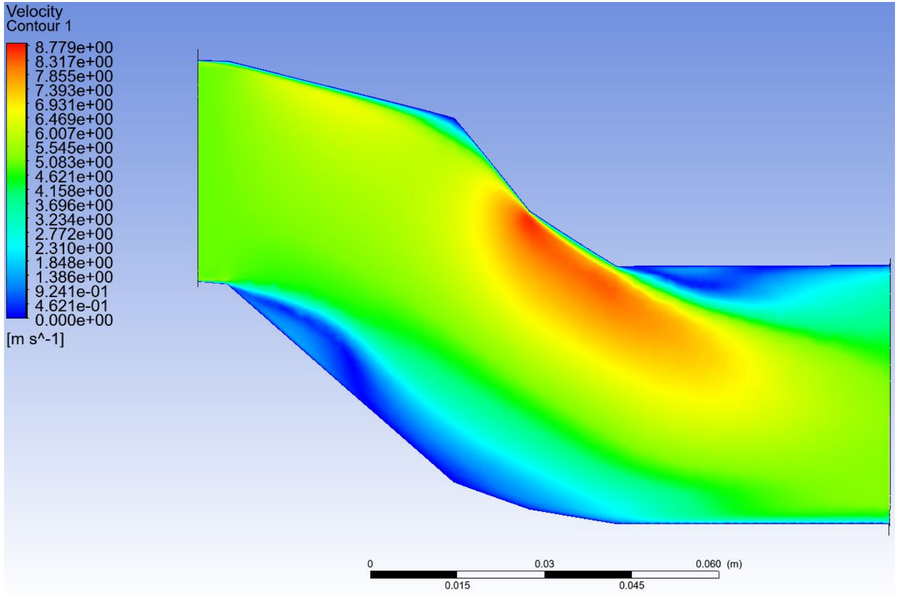
Book Style Duct

Strengths	Weaknesses
● PA 12 - easier material to work with ● Can easily stack on top of each other ● Assembly after printing only involves closing two pieces together	● Can't pack as much per printing batch due to the hinge connection
Opportunities	**Threats**
● Multi-jet printing capable of printing live-hinges ● Seek guidance from experienced advisors at Ford and UCI	● 3D printer malfunction could lead to faulty hinge

Edward

ANSYS Simulation





Assumptions: v=5m/s @ inlet; P = 0 @ outlet
Standard Air

Pressure drop found: **27.37 Pa**

Anil

Hand Calculations

$$\text{Minor loss equation: } h_{minor} = \varepsilon(\frac{v^2}{2g})$$

$$\text{Major loss equation: } h_{major} = \lambda LD(\frac{v^2}{2g})$$

where ε is minor loss coefficient, λ is friction factor, L is length of straight pipe, D is diameter of pipe, and g is the gravitational constant

Since the duct is only about 125 mm in length, major loss is negligible. However, since there are two 45 degree turns in the duct, minor loss will be significant.

From a minor loss coefficient table, it is found that the minor loss coefficient for a 45 degree bend is equal to 0.2. From the ANSYS flow simulation, the flow speed near the 45 degree bends is about 10 m/s.

Therefore, the total loss is equal to:

$$h_{total} = \Sigma h_{minor} = \varepsilon_{bend1}(\frac{v^2}{2g}) + \varepsilon_{bend2}(\frac{v^2}{2g}) = 0.2(\frac{10^2}{2g}) + 0.2(\frac{10^2}{2g})$$

$$h_{total} \approx 2\ m$$

Hand Calculations (cont.)

We convert total head loss to pressure loss using the following equation:

$$P_{loss} = \rho g h_{total}$$

where ρ is the density of standard air $(1.2\ kg/m^3)$, *and g is the gravitational constant.*

Finally, we get:

$$P_{loss} = \rho g h_{total} = (1.2\ kg/m^3)(9.8\ m/s^2)(2m) \approx \mathbf{24\ Pa}$$

Percent error of hand derived pressure loss versus ANSYS derived pressure loss:

$$\%\ error = \frac{27.37\ Pa - 24\ Pa}{27.37\ Pa} * 100\% = 12.3\%$$

Therefore, we can conclude that the pressure loss across the original Ford duct around 25 Pa, and we can say with higher certainty that the pressure loss is less than 50 Pa.

04

Moving Forward

Gantt Chart

TASK TITLE	TASK OWNER	PCT OF TASK COMPLETE	PHASE ONE					PHASE TWO														
			WEEK 2					WEEK 3					WEEK 4					WEEK 5				
			M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Team Organization	Everyone	100%																				
Initial Primary & Secondary Research	Everyone	100%																				
Problem Statement	Omid	100%																				
Design Attributes Table	Anil	100%																				
Work Breakdown Structure	Edward	100%																				
Milestones & Deliverables	Elizabeth	100%																				
Wk 2 Team Status Report	Everyone	100%																				
Ch. 2 Conceptual Design																						
Primary & Secondary Research	Everyone	100%																				
List of major components in design	Everyone	100%																				
Functional Analysis	Everyone	100%																				
Generate multiple design concepts (5-8)	Everyone	100%																				
Wk 3 Team Status Report	Everyone	100%																				
Ch. 2 Preliminary Design																						
Finalize generating concepts	Everyone	100%																				
Choose 3-4 design concepts	Everyone	100%																				
Learning Ansys	Anil	100%																				
Begin business cases for each design	Edward	100%																				
Wk 4 Team Status Report	Everyone	100%																				
Project Website	Everyone	100%																				
Ch. 2 Preliminary Design																						
Continue business cases																						
Description of fabrication method(s)																						
Initial CAD Model (2 for each)																						
Create nesting scenarios																						
Midterm Presentation	Everyone																					
Midterm Report	Everyone																					

Legend	
Planned	
In Progress	
Complete	
Behind Schedule	

Elizabeth

Gantt Chart

			PHASE THREE										PHASE FOUR									
			WEEK 6					WEEK 7					WEEK 8					WEEK 9				
TASK TITLE	TASK OWNER	PCT OF TASK COMPLETE	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Ch. 3 Detailed Design																						
Detailed Engineering Analysis and Component Testing																						
Finalize CAD Models																						
CAE evaluation of pressure drop																						
Detailed Bill of Materials (BOM)																						
Engineering Drawings																						
Wk 6 Team Status Report																						
Ch. 3 Detailed Design																						
Prototype Plan																						
Prototype Risk Assessment																						
Update BOM																						
Design Verification																						
Wk 7 Team Status Report																						
Ch. 4 Prototype Performance																						
Protoype Verification - Submit CAD																						
Description of Final Designs																						
Finalize BOM																						
Safety and Risk Assessment																						
Week 8 Team Status Report																						
Ch. 4 Prototype Performance																						
Redesign & Submit Parts																						
Test components																						
Design Verification																						
Finalize designs and document																						
Week 9 Team Status Report																						

Elizabeth

What We Need To Do

- Snap fits & Book style
  - Need to improve snap fits connections
  - Include clips to connect with local assembly
- Separate walls
  - Include clips to connect with local assembly
  - Improve design by including hinges and one snap fit
- Telescoping
  - Include adapters at the ends to fit local assembly
  - Discuss with advisor/sponsor about design
- Verify the design fits with local assembly
- Optimize design for lower pressure drop
- Increase nesting efficiency
  - Manual and automatic packing

Timeline

CAD
Week 6

Update models: improve snap fits connections, include clips, include hinges & snap fits

Testing
Week 6

Verify the design fits with the local assembly, optimize design for lower pressure drop, increase nesting efficiency

Initial Prototype
Week 7

Only need to print certain design features instead of the whole part (snap fits, hinges)

Redesign
Week 8

Note feedback for initial prototype from Advisor, modify CAD to improve design, safety and risk assessment

Final Prototype
Week 9

Submit full parts to print at UCI to advisor

Elizabeth

Questions and Concerns

- Prototyping budget?
- Any other engineering and economic analysis to take into consideration?
- Making the Design more airtight

Thank you!

Contact

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