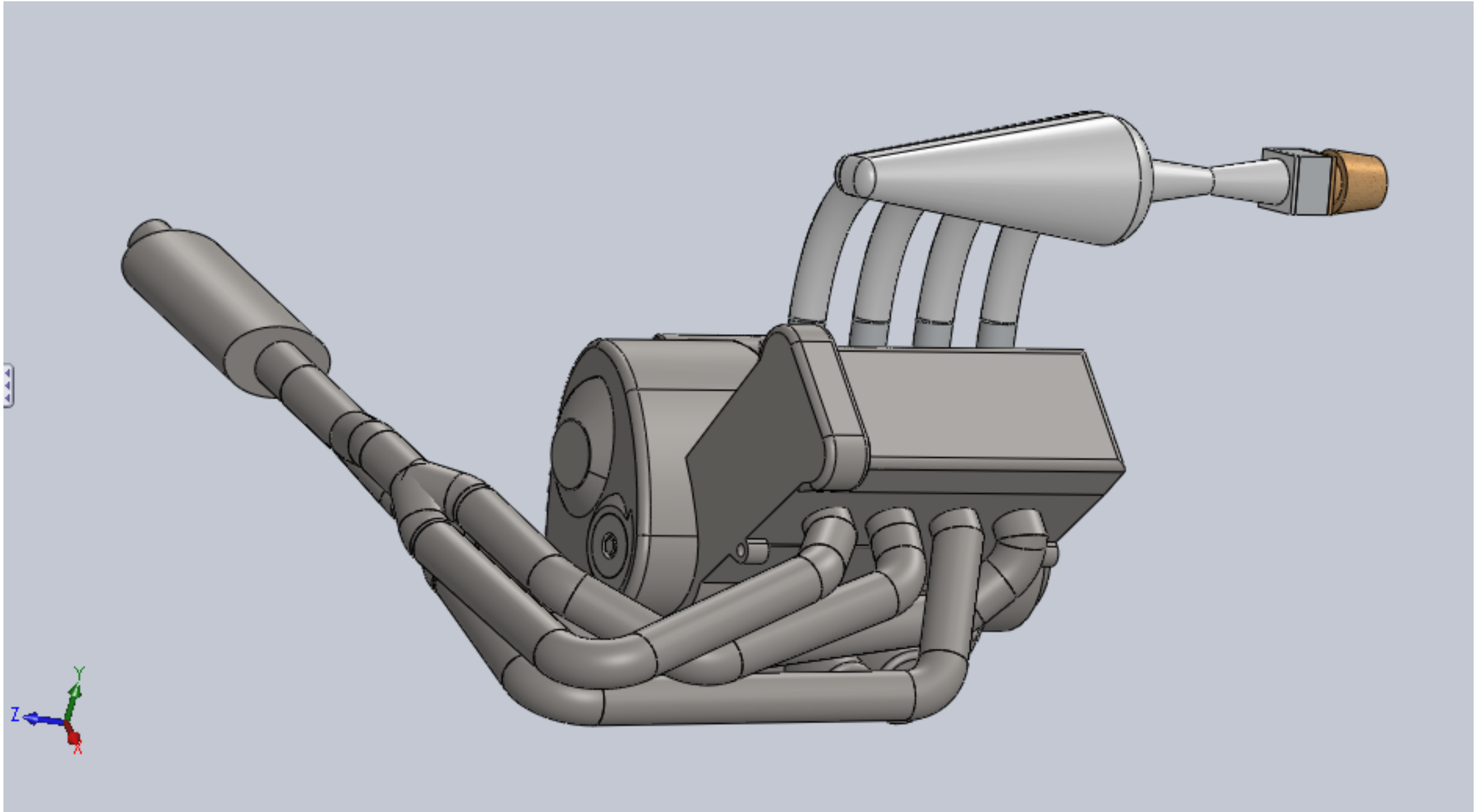
FSAE Power Plant Assembly

Team 26
Nimai Delgado, Kori Lutenbacher, Corey McCon, Michael Quarls, Suman Thakuri
Sponsor: TigerRacing
Faculty Advisor: Dr. Schoegl
Alumnus Advisor: Collin Kappe
November 28, 2012

Final Design Assembly



Project Objectives

- Select an engine and design an intake and exhaust system to optimize the power output
- Design, analyze, and test intake and exhaust prototypes
- Comply with FSAE standards
- Stay within budget of $7500
- Use these designs for 2014 FSAE car

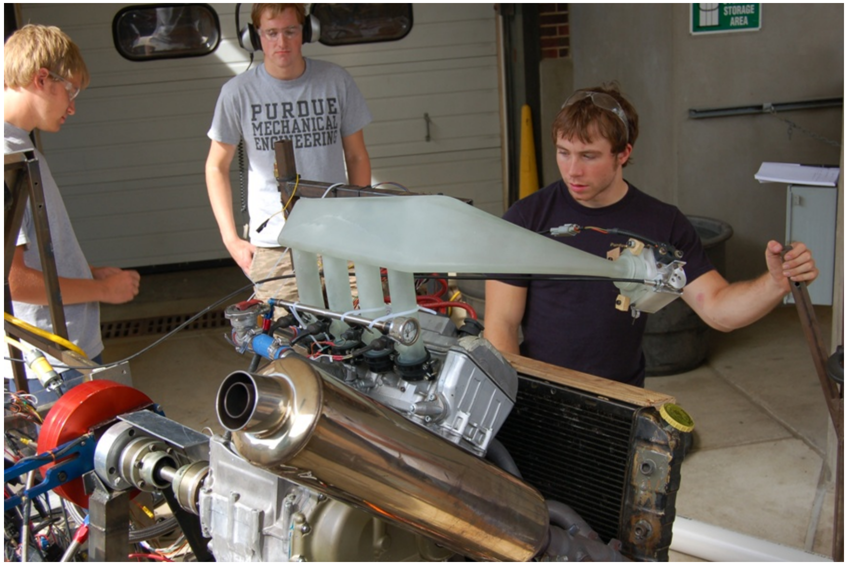
Background Information

- What is Formula SAE?
  - Design, manufacture, and test a Formula style car
  - Race the car in Michigan

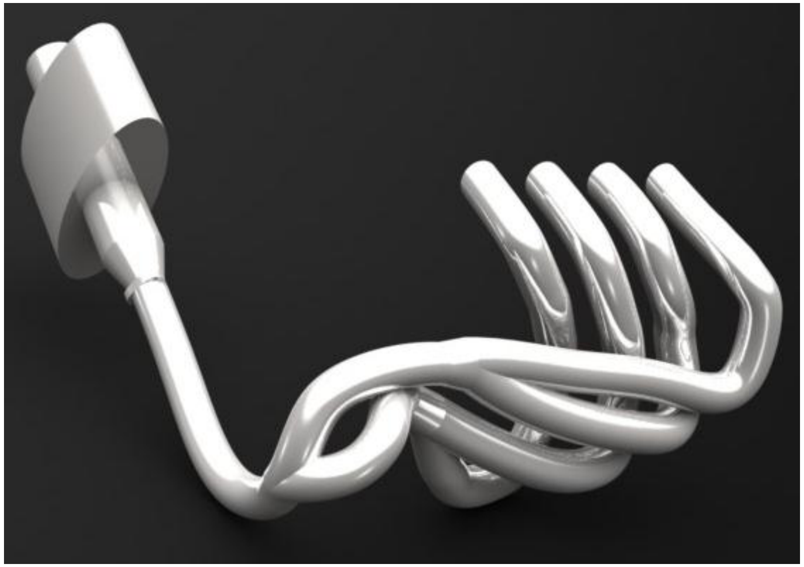
Formula SAE Competition

- Dynamic Events
  - Skid Pad (5%)
  - Acceleration (7.5%)
  - Autocross (15%)
  - Endurance (40%)
- Static Events
  - Engineering Design (15%)
  - Cost Analysis (10%)
  - Presentation (7.5%)

Existing Technologies



Realize, Inc. 3D Printed Intake



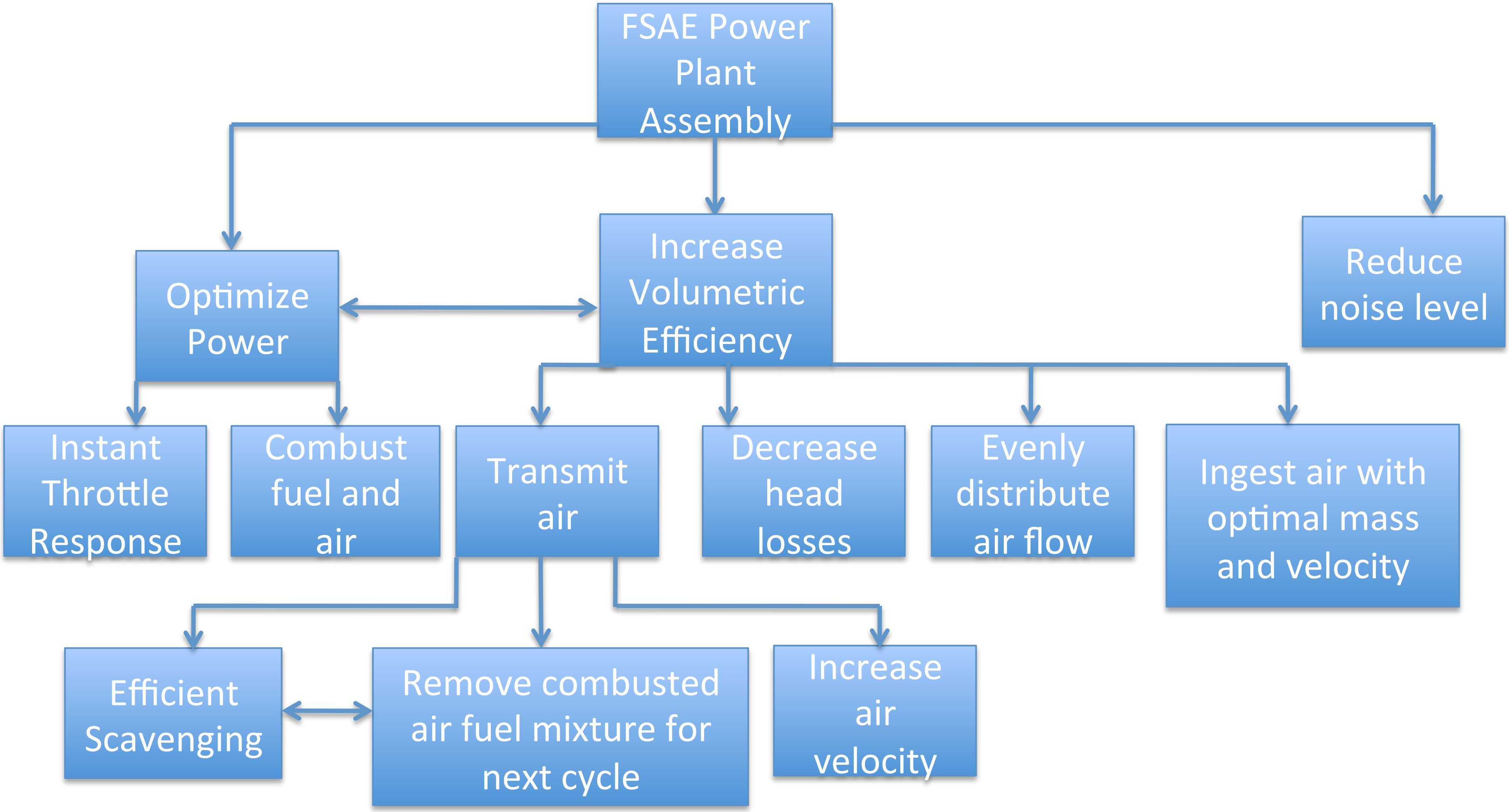
Former FSAE teams concepts

Customers

- Primary
  - Tiger Racing Club
  - Competition Judges
- Secondary
  - Faculty
  - Competing teams
  - Manufacturers and Vendors

Constraints

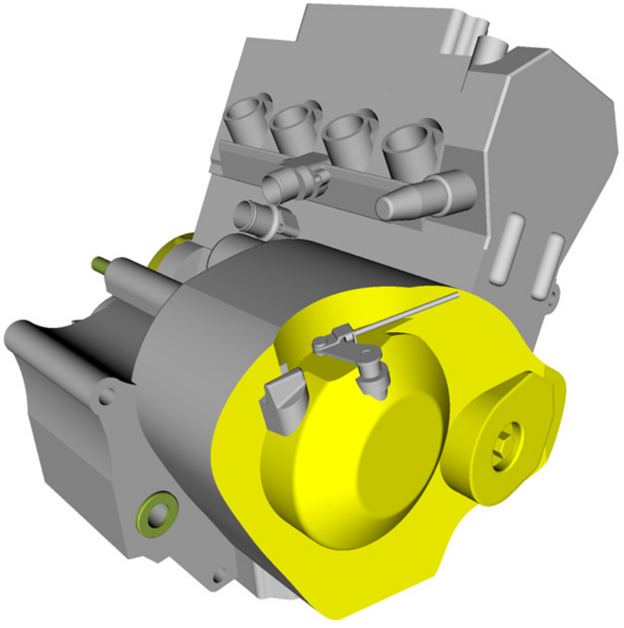
- Tiger Racing
  - Reliability
  - Cost
  - Performance
- Competition
  - Engine displacement volume <610cc, 4-stroke
  - Exhaust noise level <110db
  - 20mm restrictor on intake
  - Single throttle body
- Other
  - Time
  - Faculty requirements

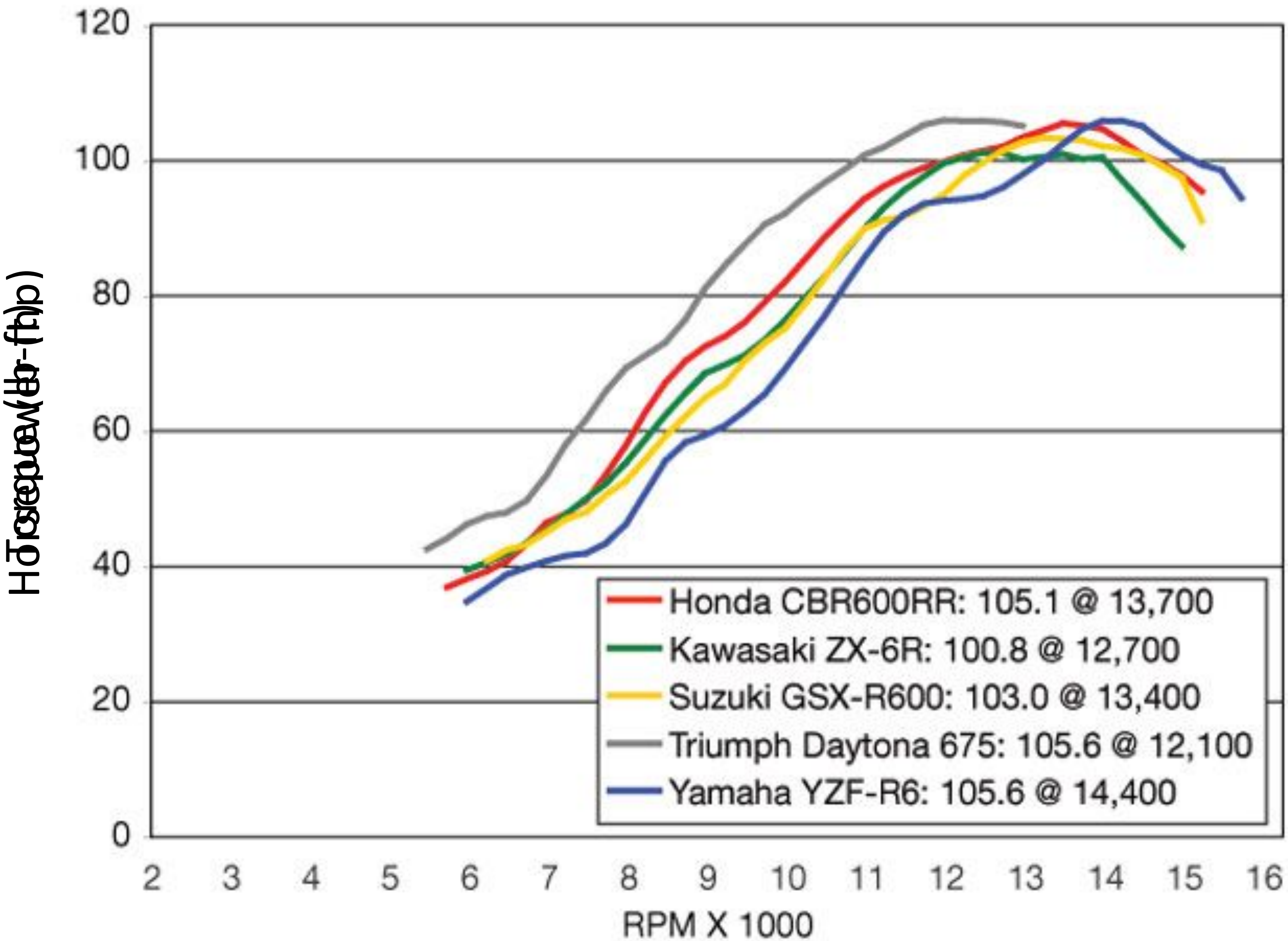


Functional Decomposition

Engine Selection: Honda CBR 600RR

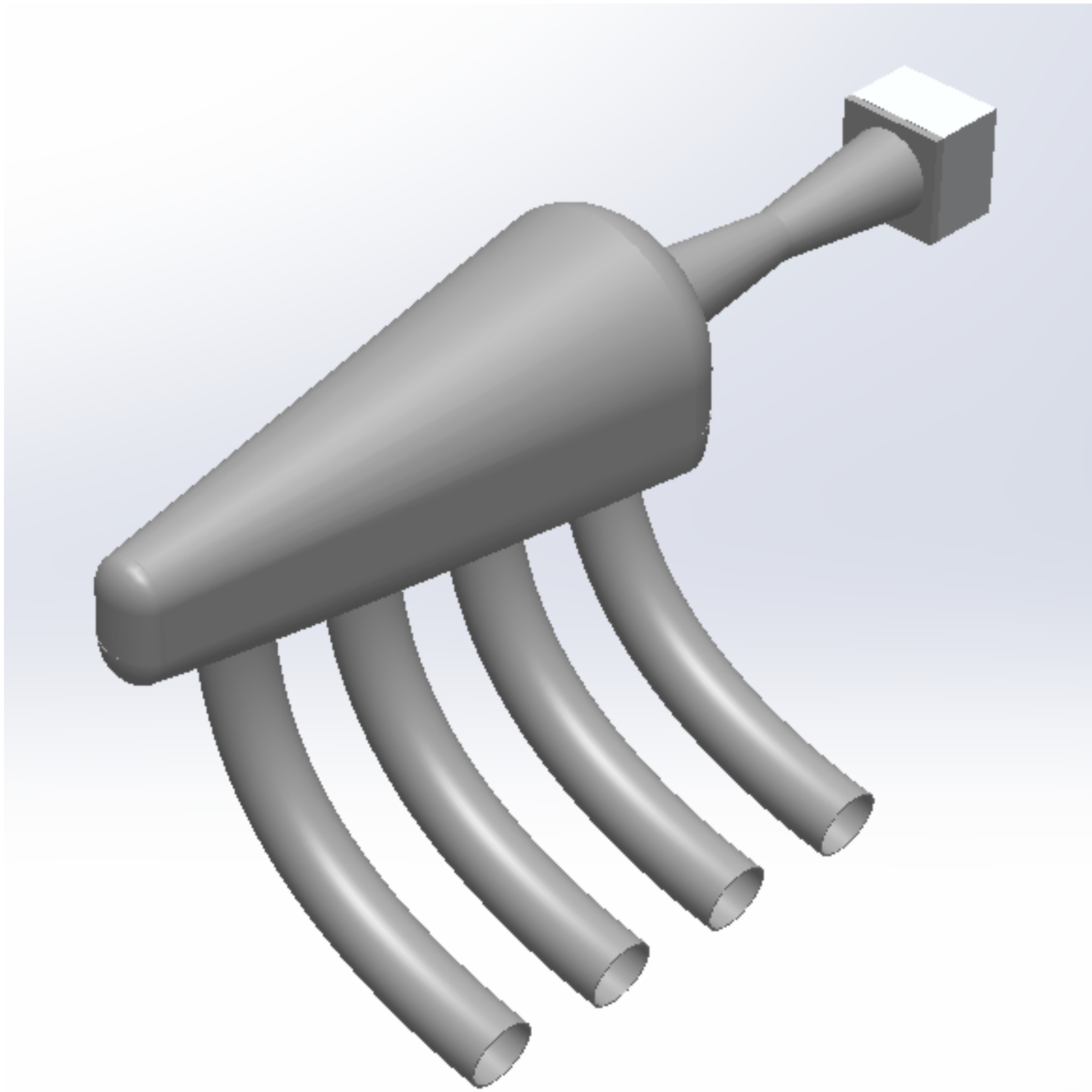
- Higher peak torque and horsepower
- Less valve overlapping period (26˚)
- Larger intake valve diameter
- Availability





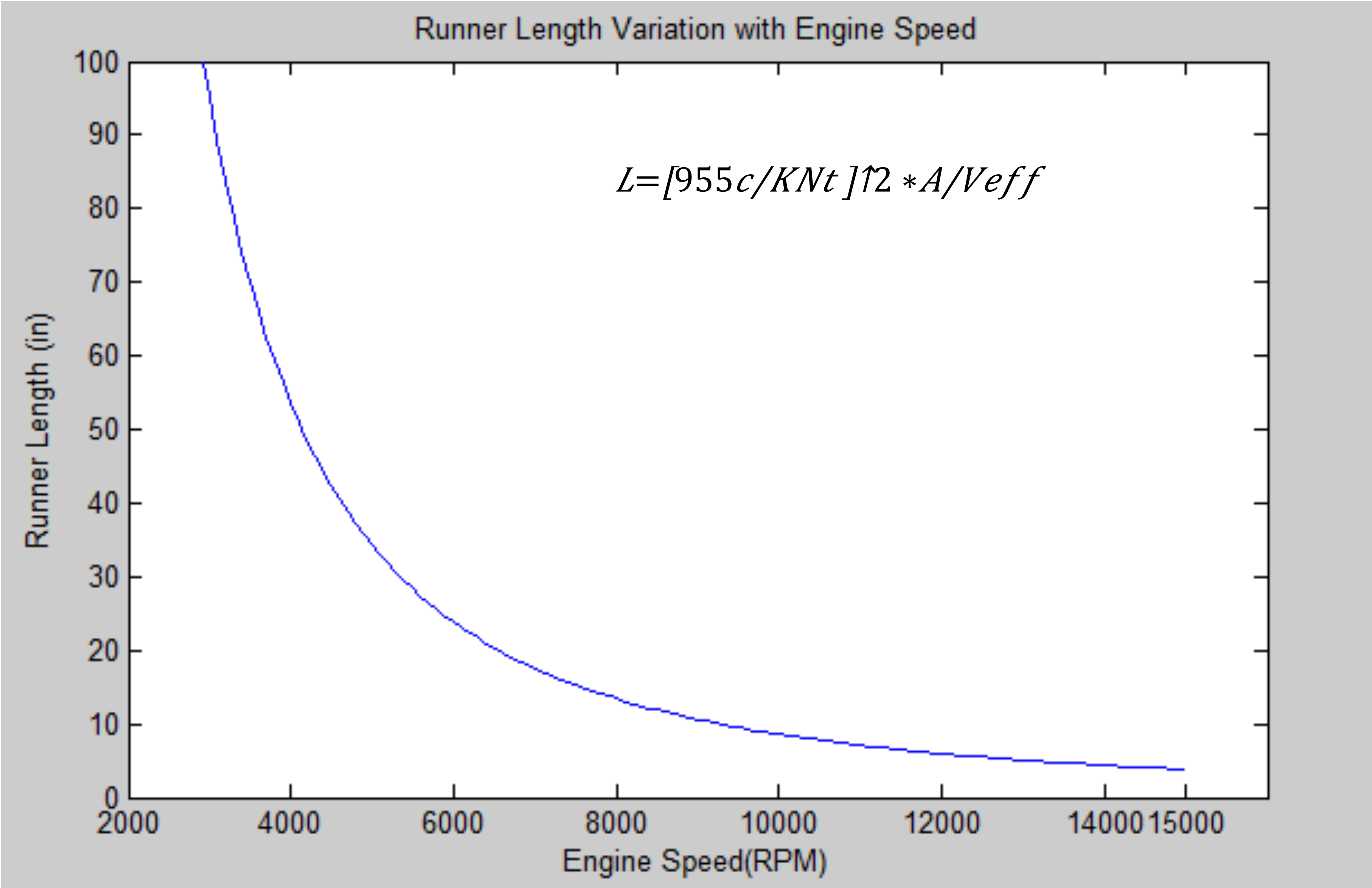
Honda CBR600RR: 105.1 @ 13,700
Kawasaki ZX-6R: 100.8 @ 12,700
Suzuki GSX-R600: 103.0 @ 13,400
Triumph Daytona 675: 105.6 @ 12,100
Yamaha YZF-R6: 105.6 @ 14,400
RPM X 1000

Final Intake Concept

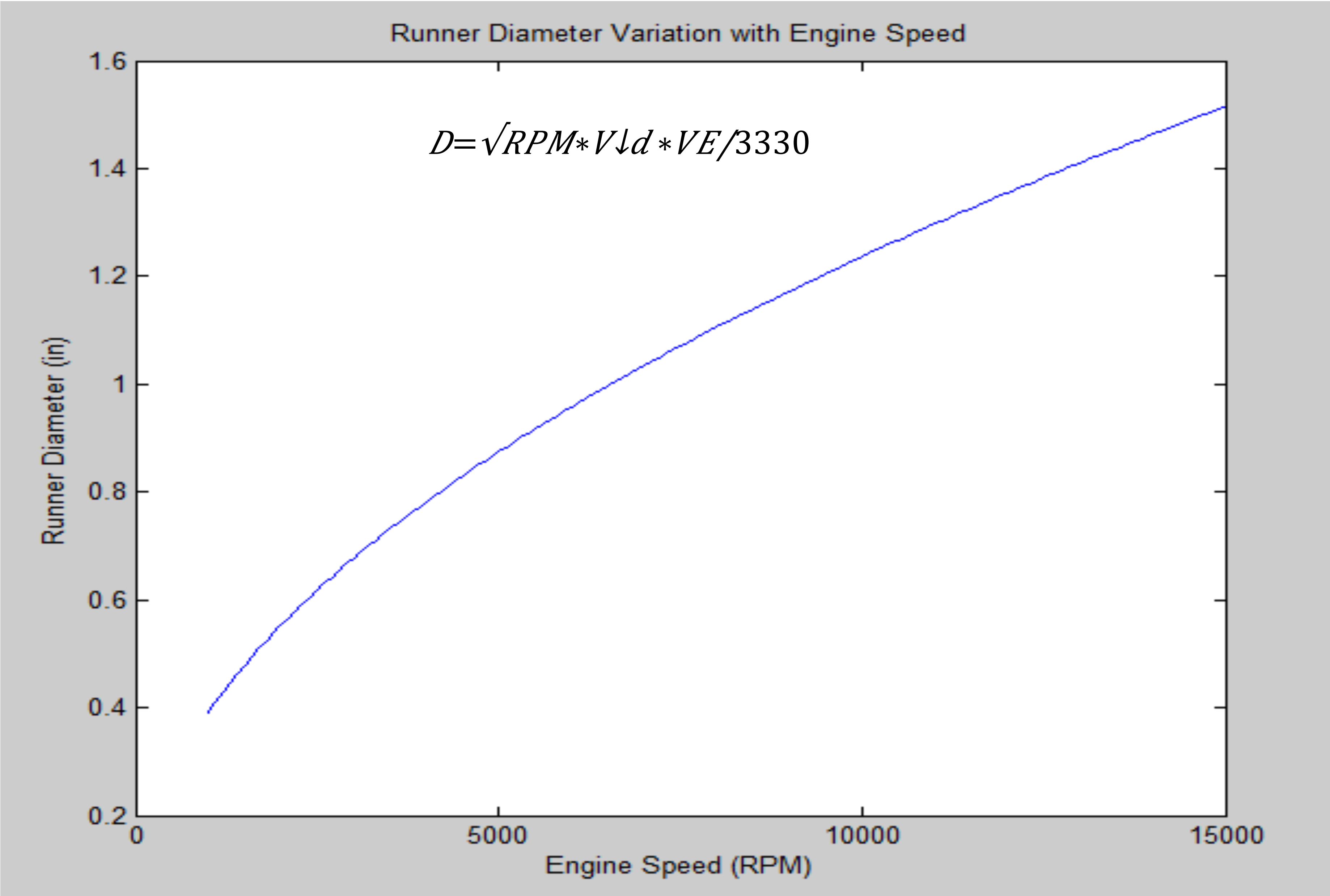


Intake Objectives

- Distribute air to each cylinder evenly
- Maximize air flow through each cylinder
- Minimize pressure losses throughout intake manifold



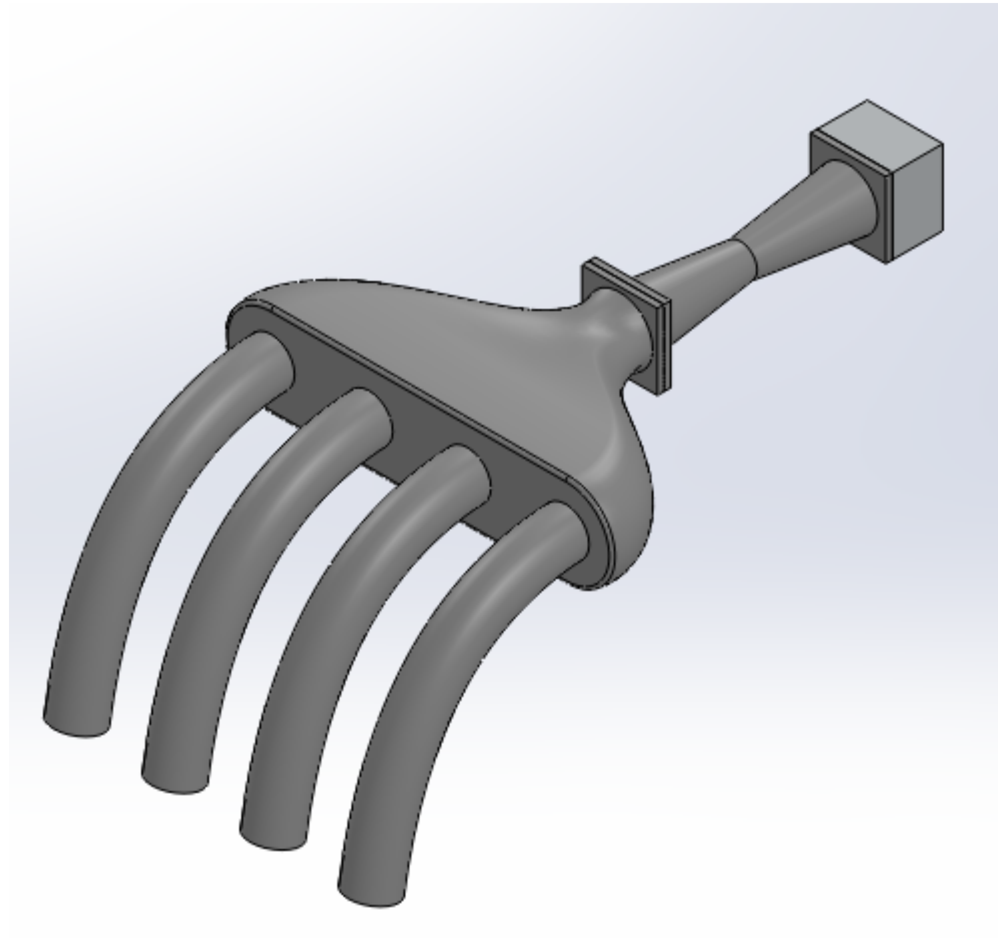
- Optimum runner length for 9500 RPM = 9.5 in.
  - Helmholtz resonator equation



- Optimum runner diameter = 1.2 in.
  - David Vizard's rule for intake runner diameters [5]

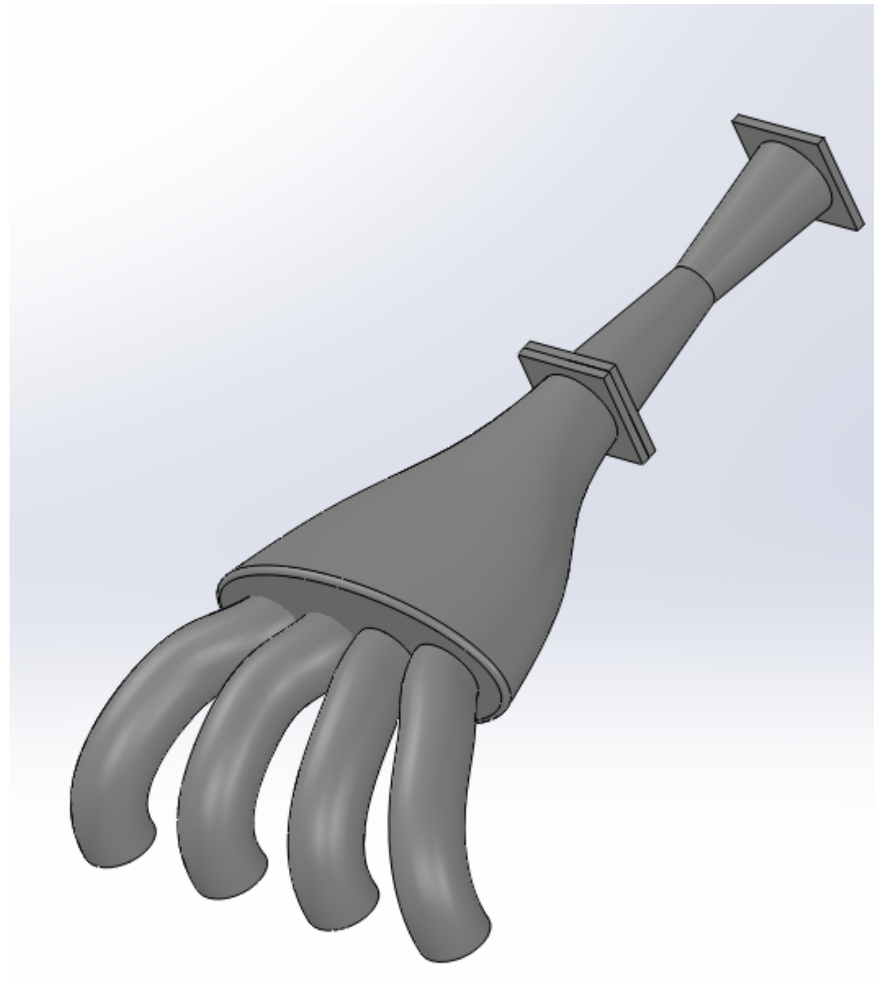
Concept 1

- Pros
  - Max air flow
  - Minimum pressure drop through plenum
- Cons
  - Uneven air distribution in cylinders



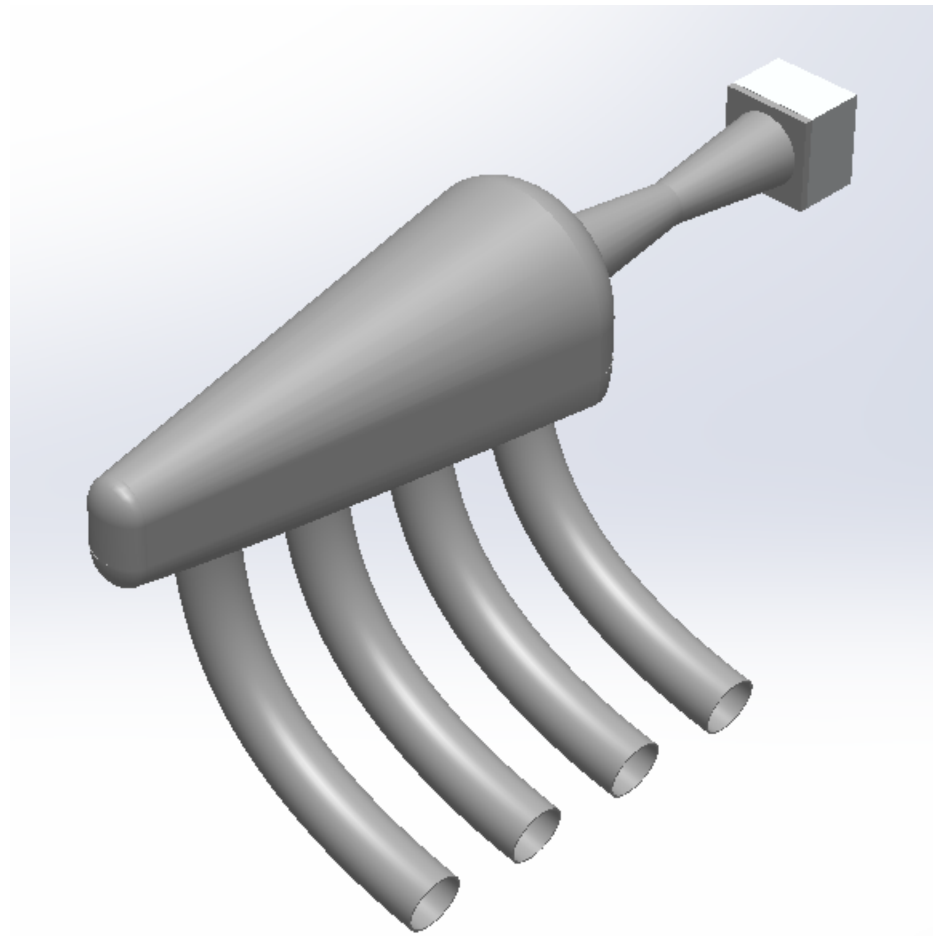
Concept 2

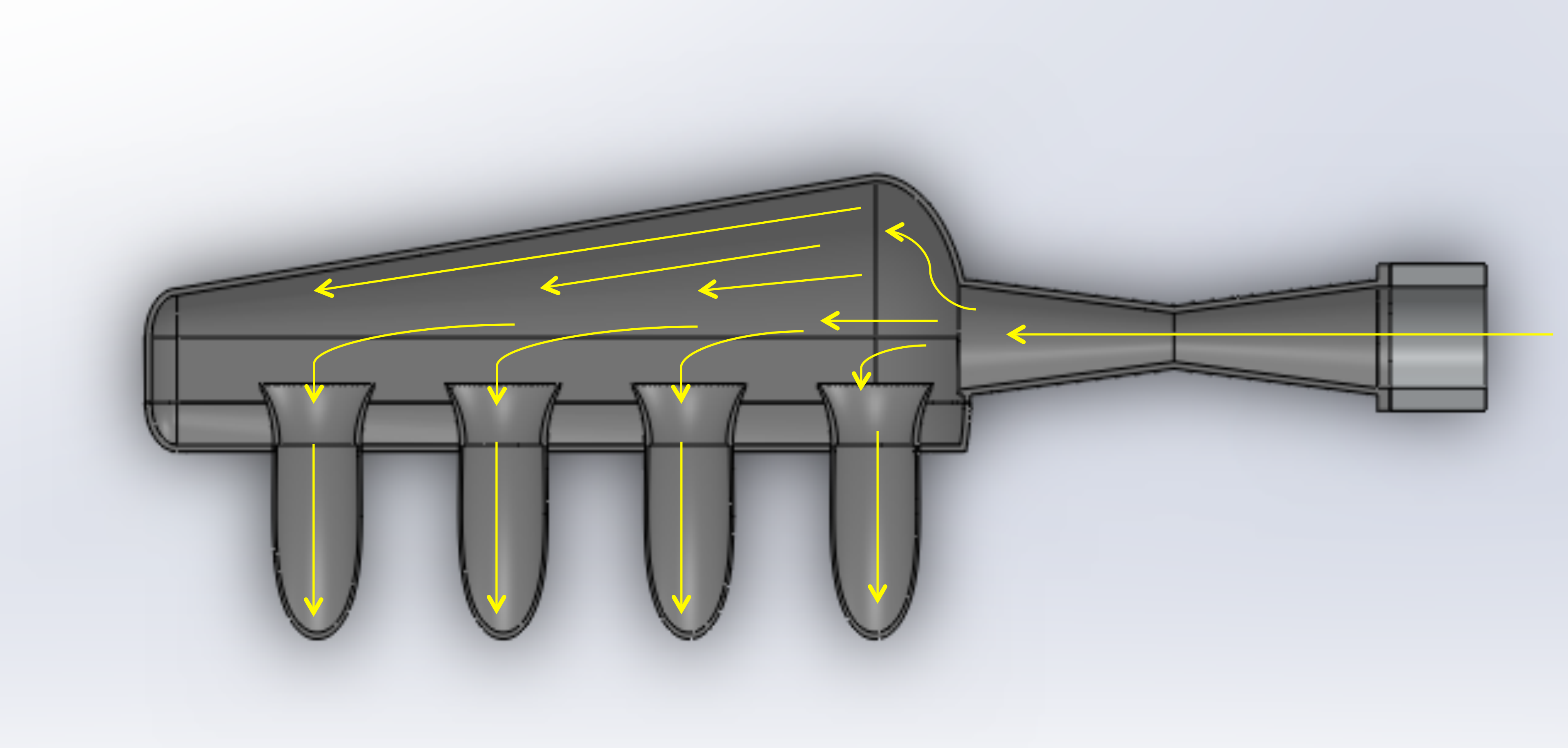
- Pro
  - Minimize pressure drop though plenum
- Con
  - Uneven air distribution in cylinder



Concept 3

- Pro
  - Even pressure distribution in cylinders
- Con
  - Larger plenum volume

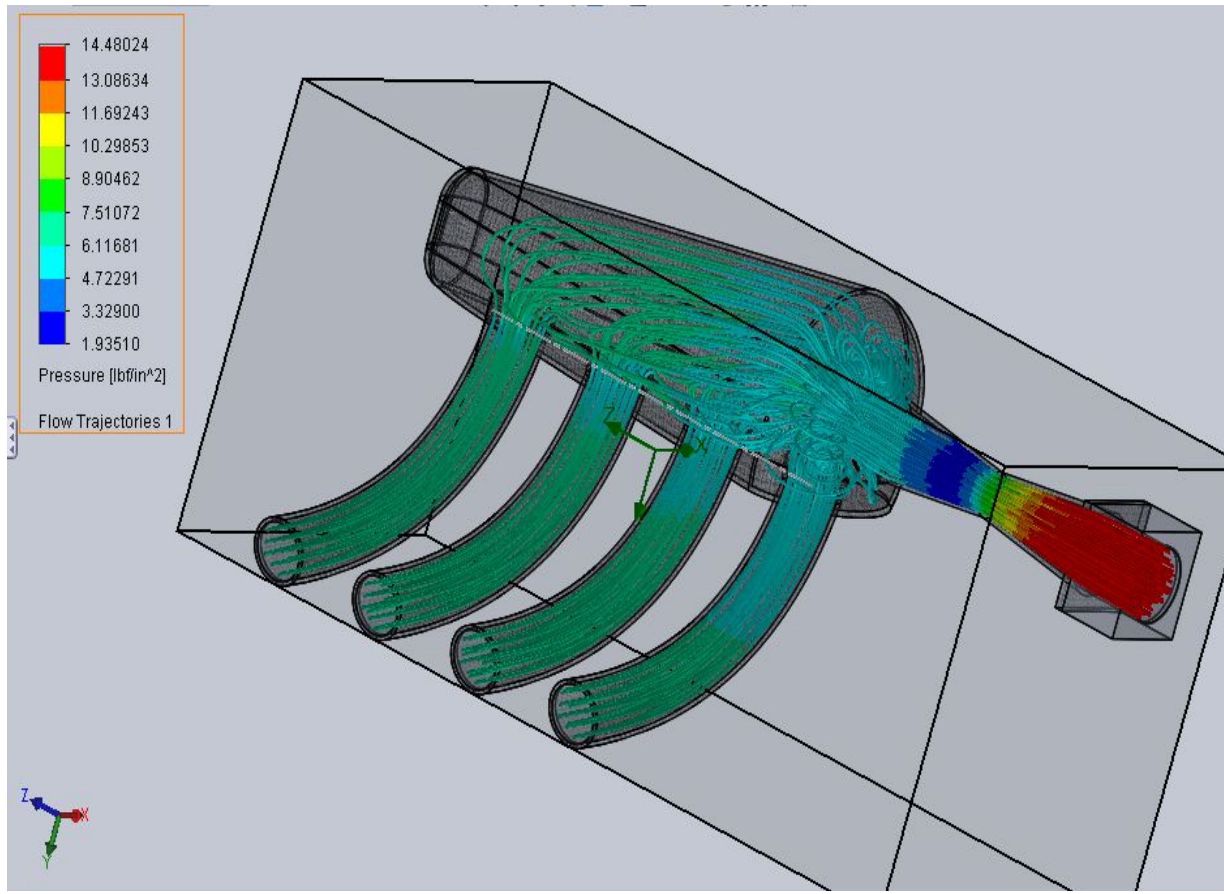


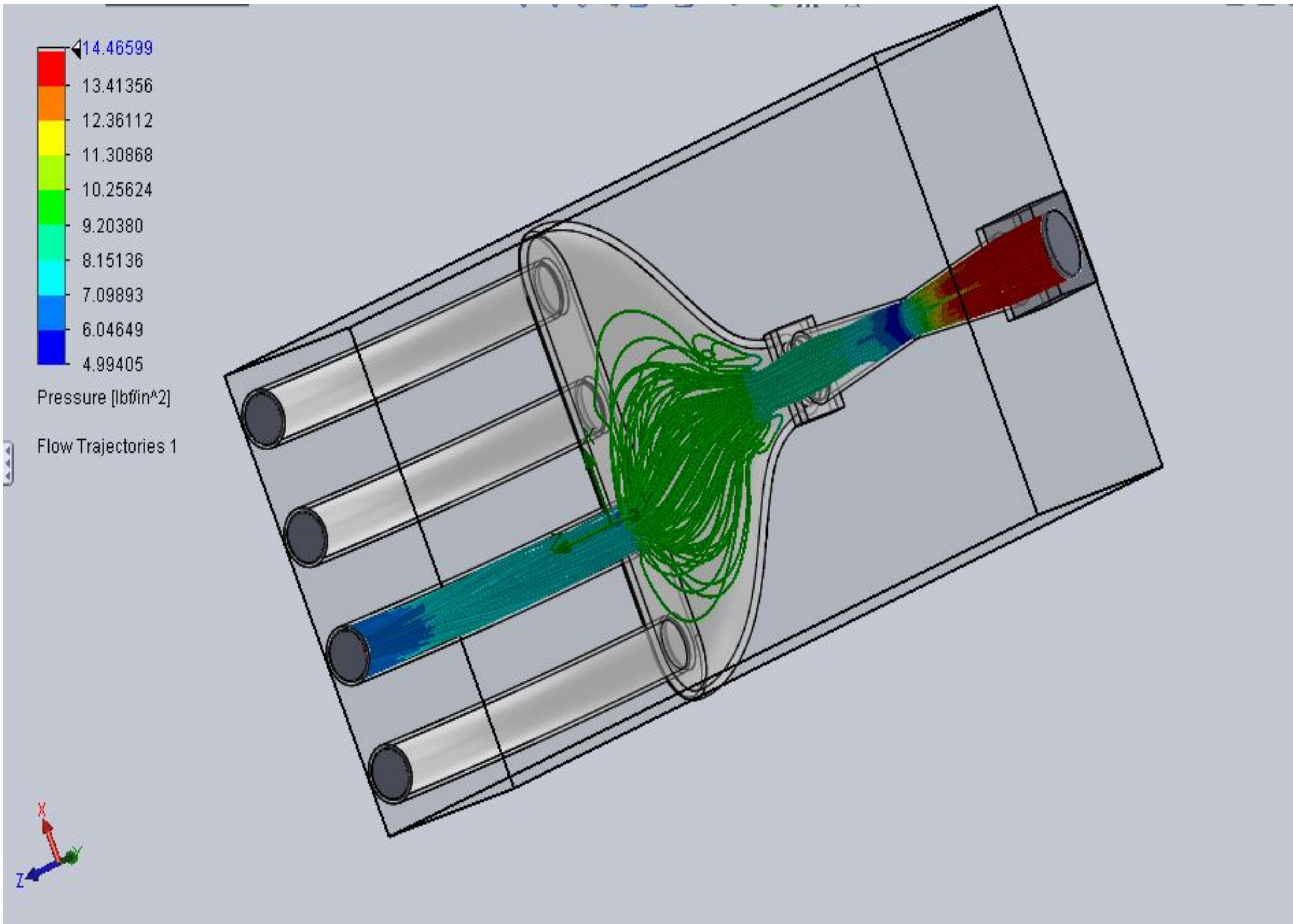


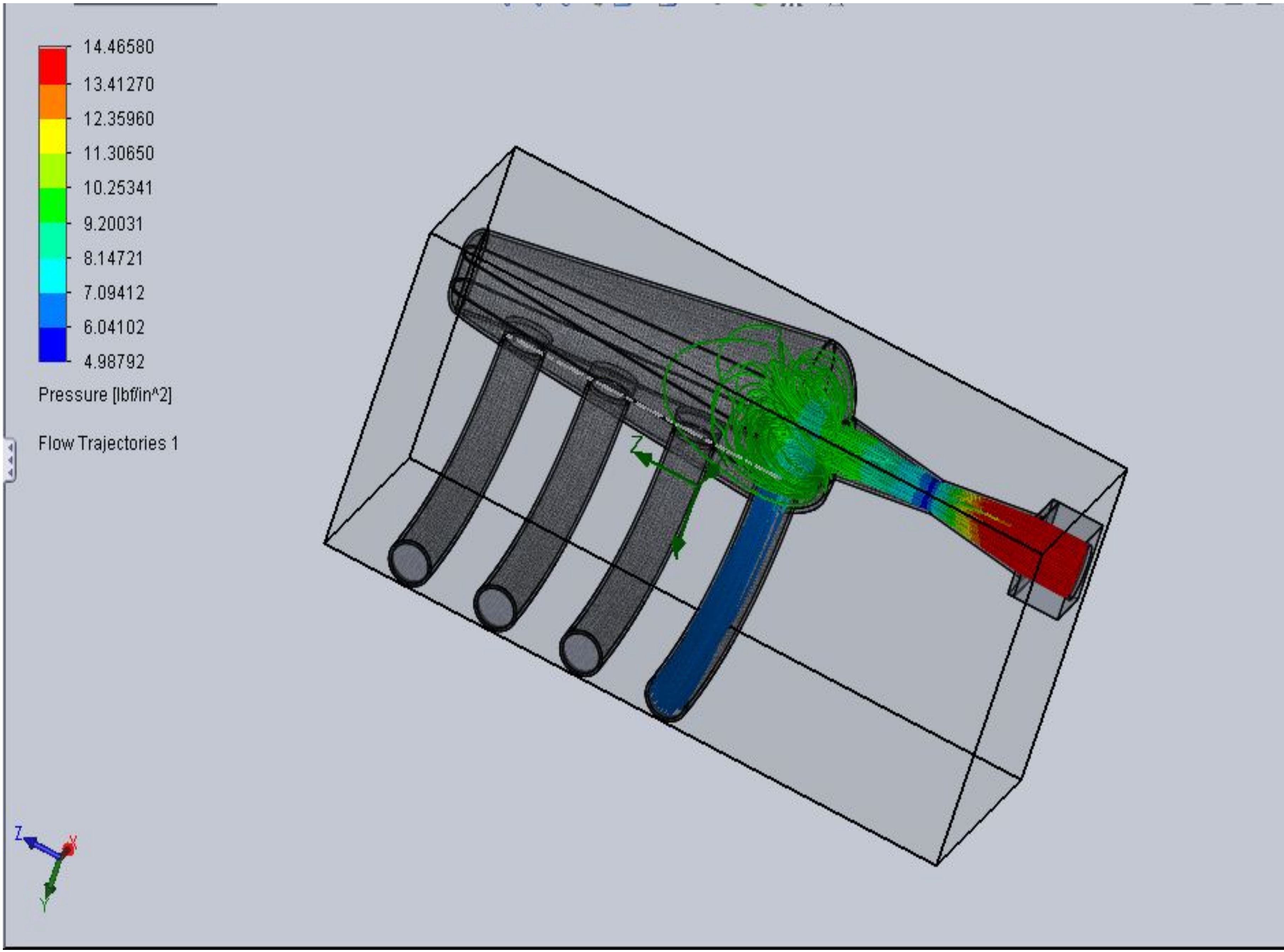
- Optimum shape for 4-cylinder w/ single throttle body
- Raised bell shaped runners mouths
- Tapered plenum shape

Testing/Validation: CFD Analysis

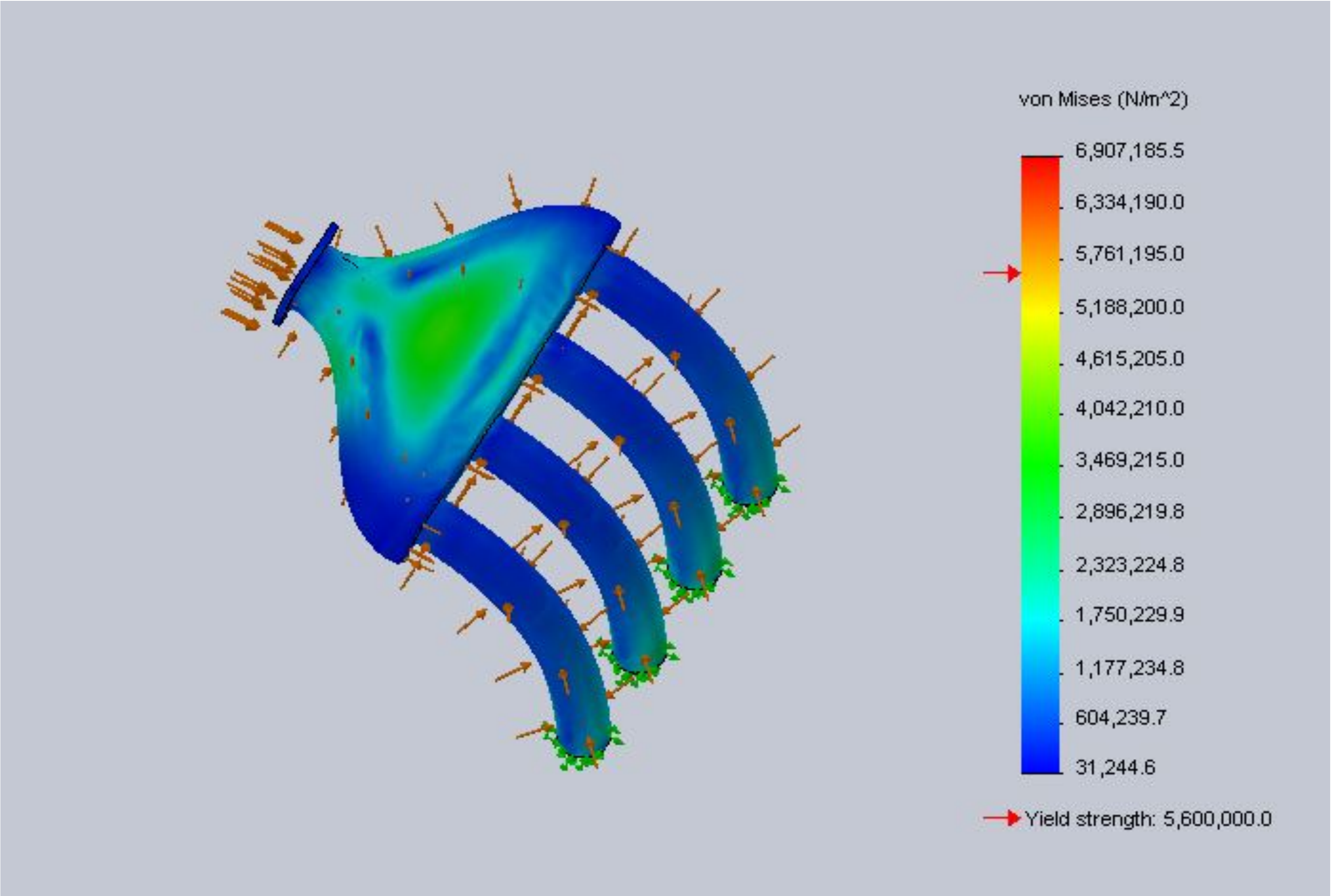
- Objectives
  - Pressure drop
  - Flow distribution throughout the geometry
  - Flow velocity



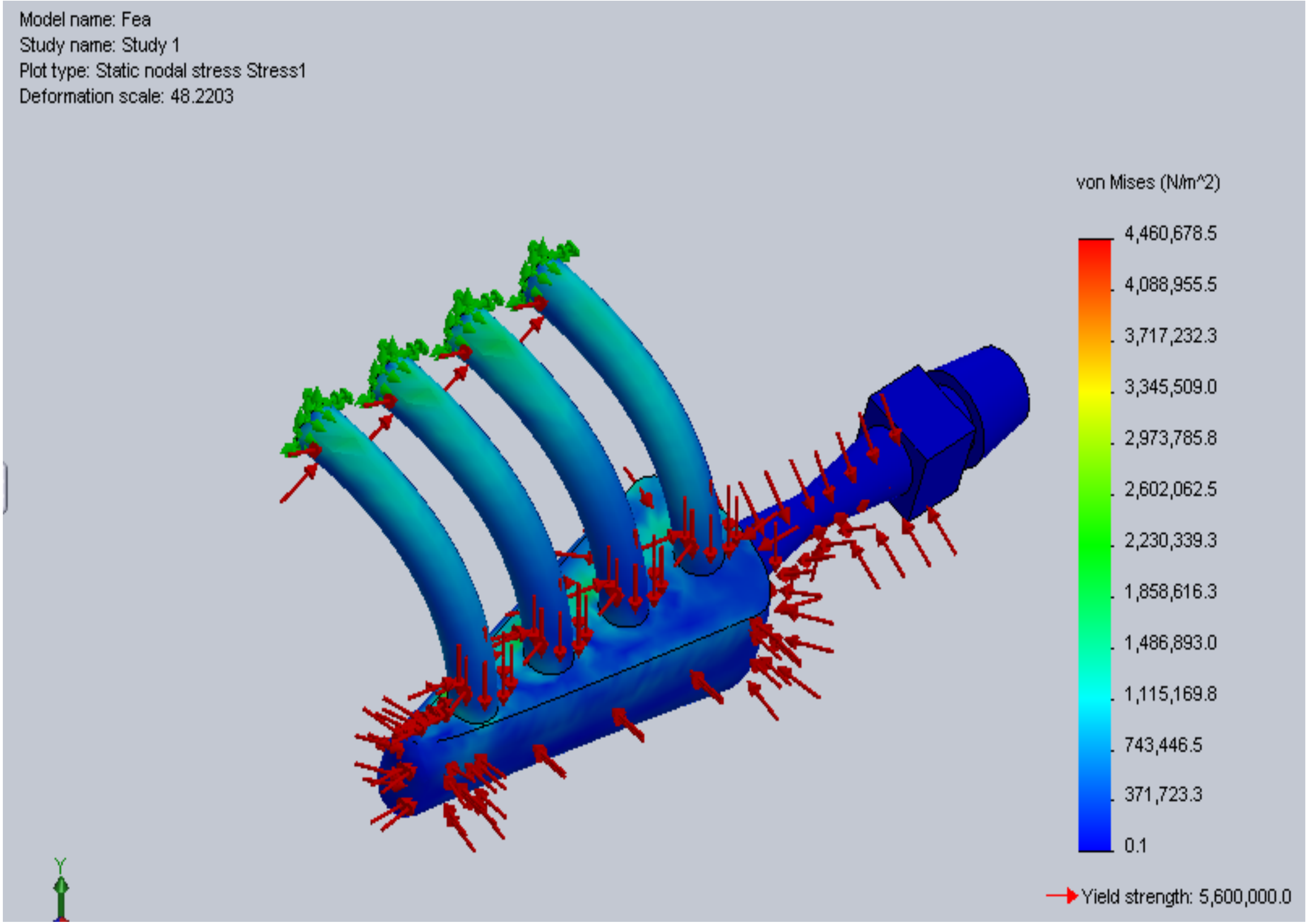

14.46599
13.41356
12.36112
11.30868
10.25624
9.20380
8.15136
7.09893
6.04649
4.99405
Pressure [lbf/in^2]
Flow Trajectories 1
X
Y
Z


14.46580
13.41270
12.35960
11.30650
10.25341
9.20031
8.14721
7.09412
6.04102
4.98792
Pressure [lbf/in^2]
Flow Trajectories 1

FEA



von Mises (N/m^2)
6,907,185.5
6,334,190.0
5,761,195.0
5,188,200.0
4,615,205.0
4,042,210.0
3,469,215.0
2,896,219.8
2,323,224.8
1,750,229.9
1,177,234.8
604,239.7
31,244.6
Yield strength: 5,600,000.0


Model name: Fea
Study name: Study 1
Plot type: Static nodal stress Stress1
Deformation scale: 48.2203
von Mises (N/m^2)
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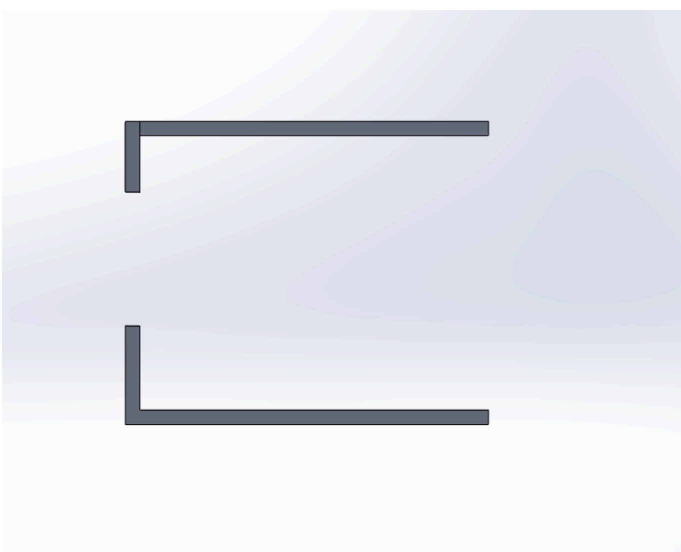
4,088,955.5
3,717,232.3
3,345,509.0
2,973,785.8
2,602,062.5
2,230,339.3
1,858,616.3
1,486,893.0
1,115,169.8
743,446.5
371,723.3
0.1
Yield strength: 5,600,000.0
Y

Restrictor Concept Generation

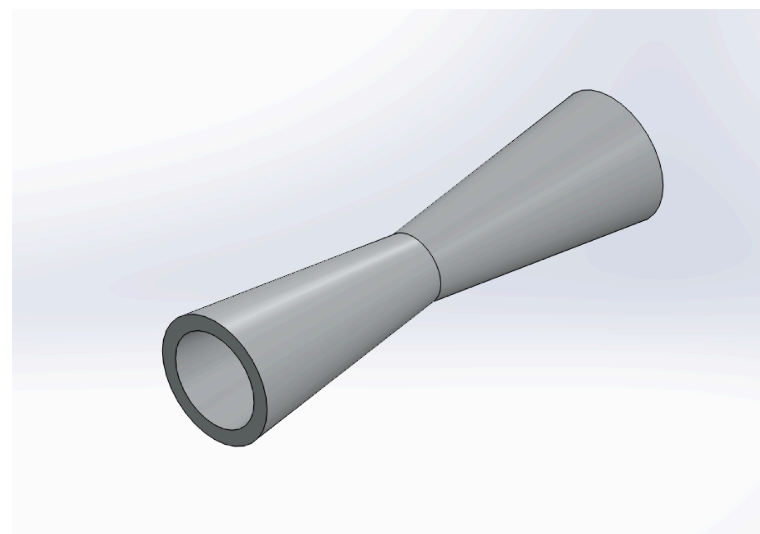
Orifice Plate

- Low cost
- Easy to install/replace
- High flow separation
- High head losses



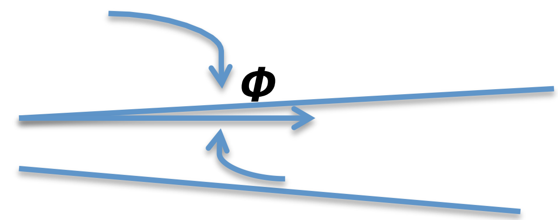
Converging-Diverging Nozzle

- Low head losses
- Increase in fluid's velocity
- High cost
- Popular among FSAE teams



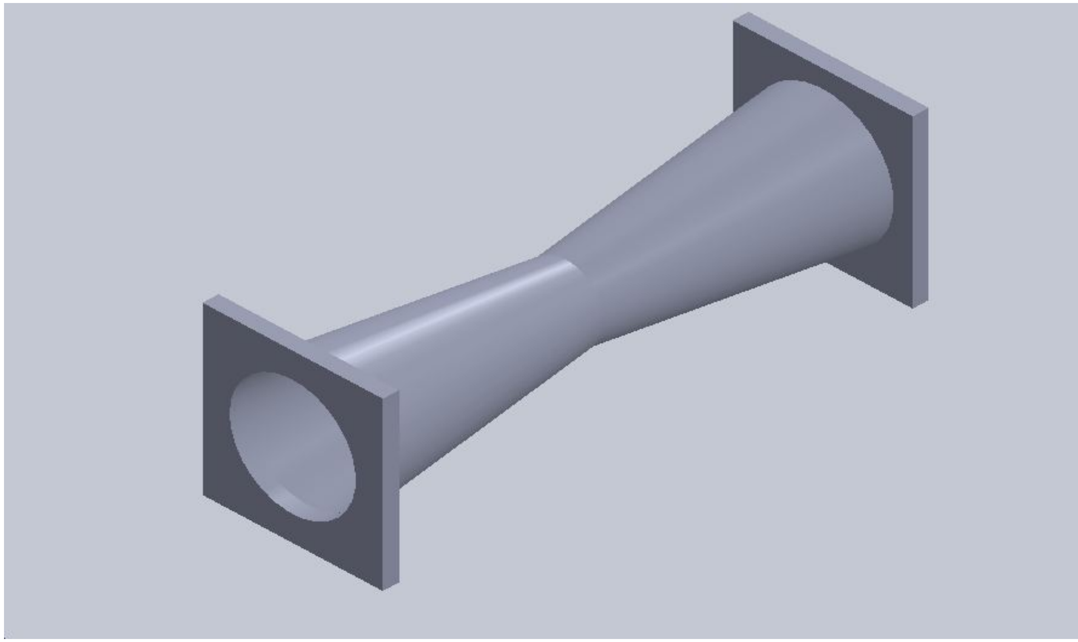
Restrictor Analysis

- Diffuser Effect
  - Small divergence angle (3°-7°),***Φ***
  - Maximum pressure recovery coefficient, C_p
- $m_{choked} = A_t \, p_o \left(\frac{2}{k+1} \right)^{\frac{k+1}{2(k-1)}}$
  - m_{choked}= 0.0736kg/s
  - V_{choked}=0.0614m^3/s
  - u_t= 195.554 m/s



Restrictor Selection

- Outer Diameter: 40mm
- Tapered at 7°
- Length: 6.41in



Throttle Body Analysis

$$TB(mm) = \sqrt{\frac{154 * Number\ of\ cylinders * Stroke * RPM\ @Max\ HP * bore^2}{67547}}$$

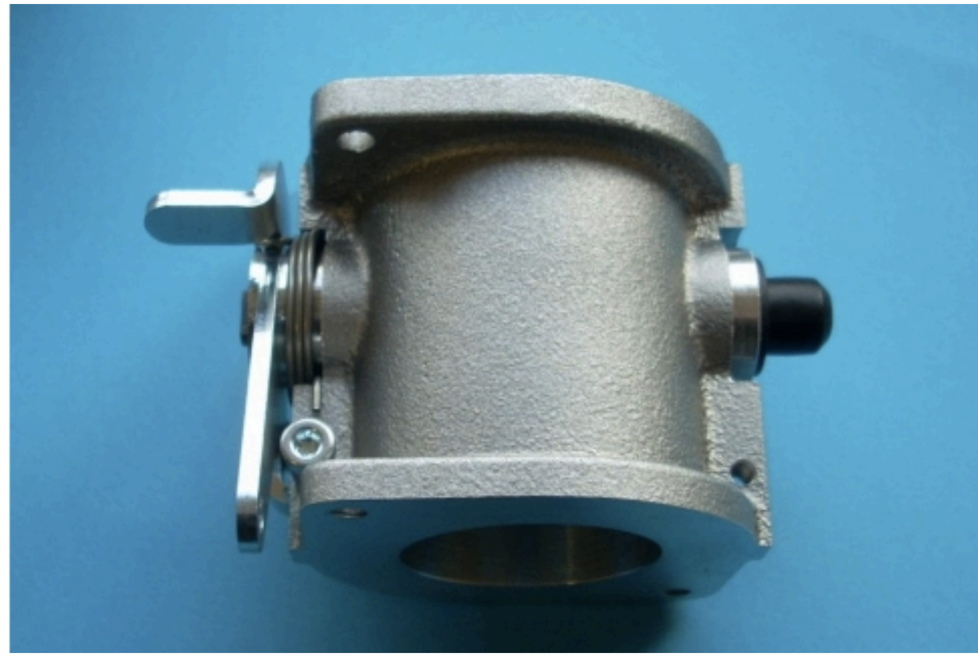
Engine Characteristics			
Number of Cylinders	Stroke (in)	Bore (in)	RPM @ max hp
4	1.67	2.64	13500

TB size = 37.88mm

Choose between 35-40mm Throttle Body

Jenvey Throttle Body

- Butterfly vs. Barrel
- Easy assembly
  - 0 injectors
  - 2 bolt flange
- Price €133 ($172)
  - FSAE teams receive 50% off
  - Fast shipping



K&N Air Filter

- Protects intake system from dirt and debris
- Increases engine performance
- Costs $28.99
- Follows rule of thumb for sizing:
    - short/lg. diameter
    - 1.5-2x larger than throttle body sizing

Intake Manufacturing

- Realize, Inc
  - Uses stereolithography to 3D print plenum, runners, and restrictor
  - Manufactures with tolerances between +/- 0.001-0.0015in
  - Takes 2-4 business days to manufacture
  - Can upload CAD drawing for quote

Intake Material Selection

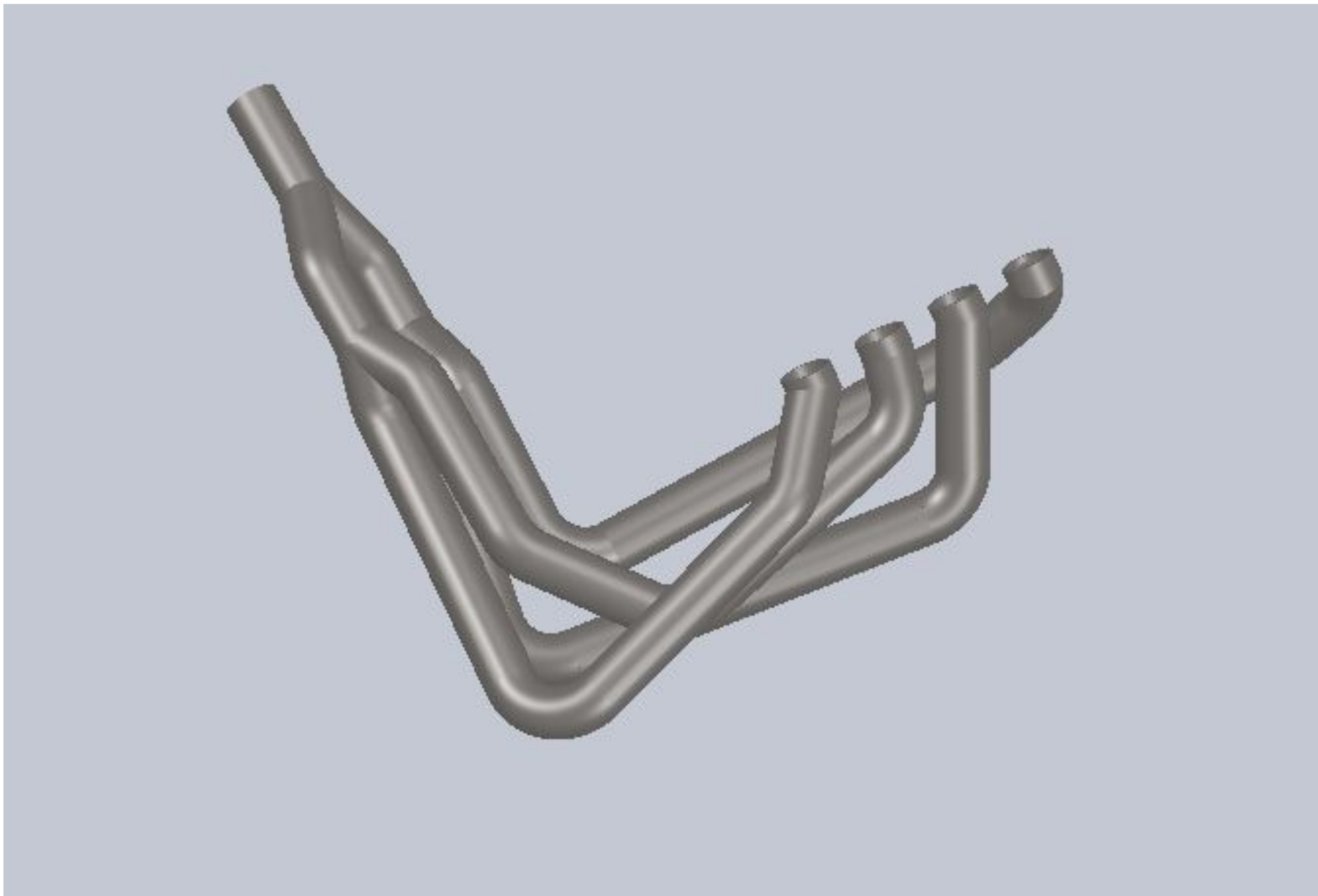
Accura Xtreme Plastic

- Density: 1.19g/cm^3
- Tensile Strength: 38-44MPa
- Modulus of Elasticity: 1790-1980MPa
- Heat deflection temperature
  - @ 455kPa: 62°C (144°F)
  - @ 1820kPa: 54°C (129°F)

Somos NeXt

- Density: 1.13g/cm3
- Tensile Strength: 41.1-43.3MPa
- Modulus of Elasticity: 2370-2490MPa
- Heat deflection temperature
  - @ 460MPa: 55-57°C (131-134°F)
  - @ 1810MPa: 48-51°C (118-124°F)

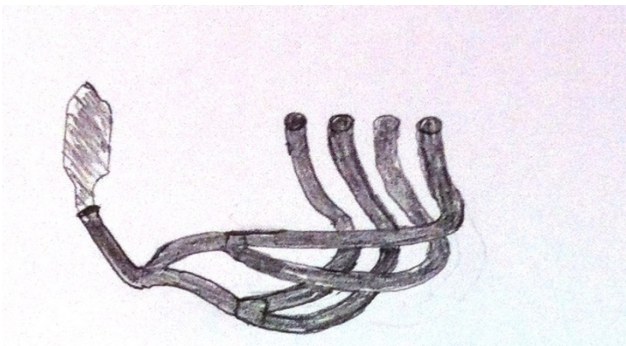
Exhaust Selection



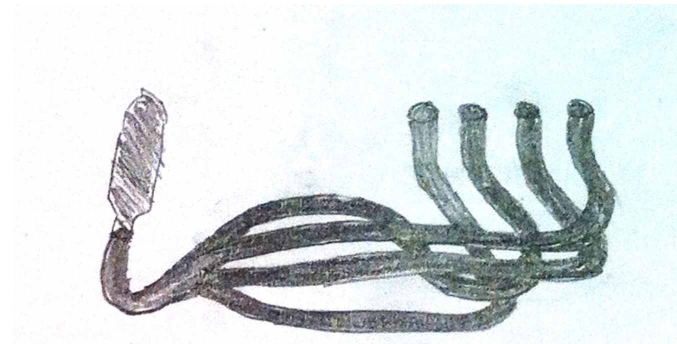
Exhaust Objectives

- Should dispose of the used air-fuel mixture from the engine
- Should reduce the noise level below the required 110 dB level
- Should be able to withstand exhaust temperature of 457°F

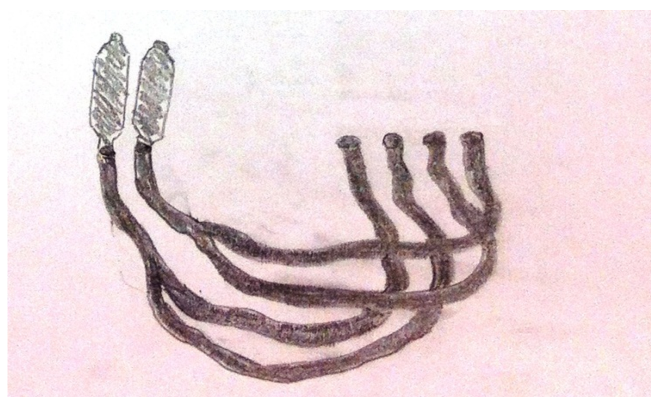
Exhaust Concepts Generation



4-2-1 Setup



4-1 Setup



4-2 Setup

Exhaust Concept Selection

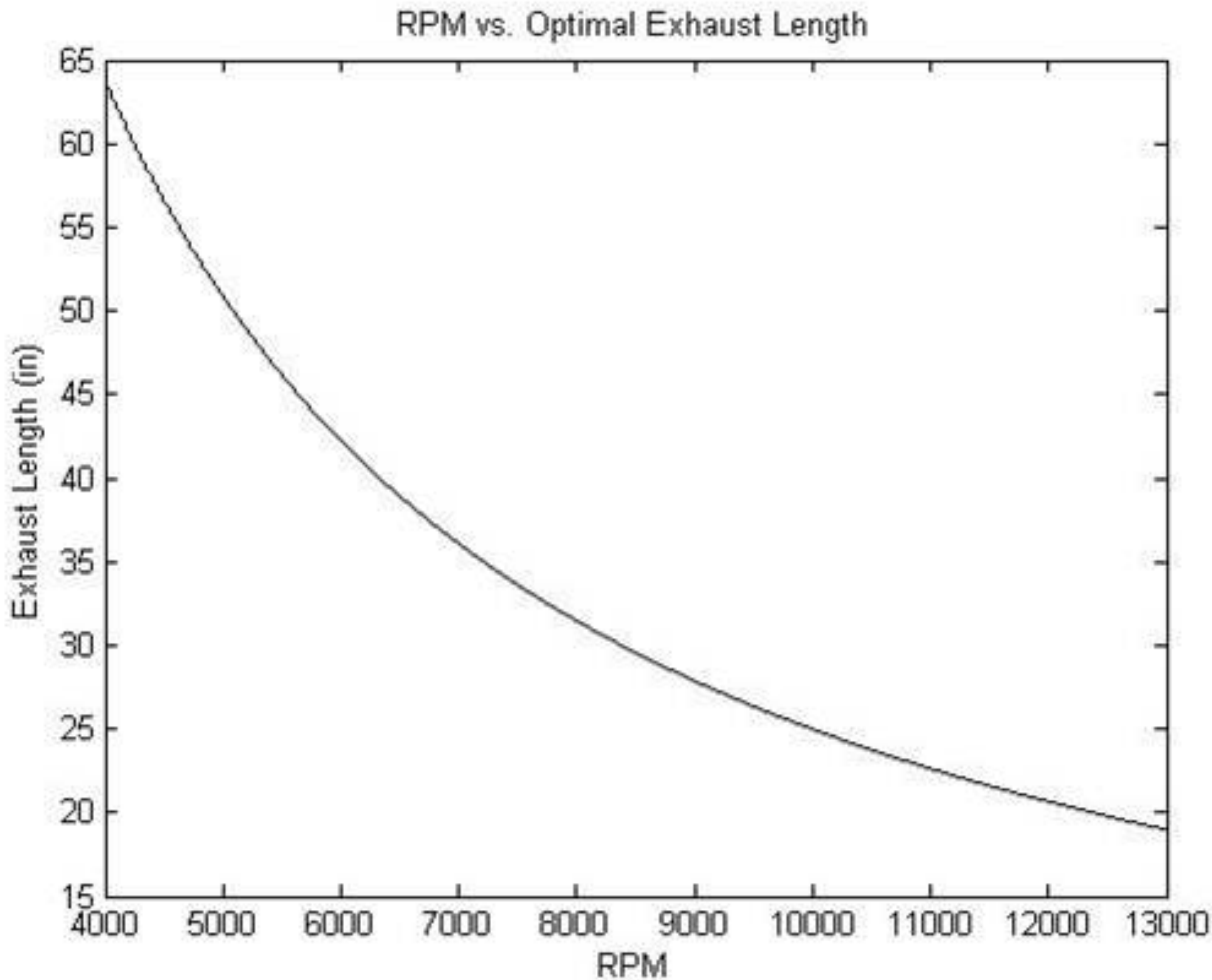
4-2-1

- Some flow restriction
- Average noise reduction
- Easily adapted
- Average cost

4-1

- A lot of flow restriction
- Good noise reduction
- Easily adapted
- Average cost

Exhaust Analysis


RPM vs. Optimal Exhaust Length
Exhaust Length (in)
RPM
65
60
55
50
45
40
35
30
25
20
15
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000

Muffler Comparisons

Reflective

- Most effective for attenuating noise
- Expensive
- Only work at certain frequencies

Restrictive

- Easily available
- Cheap
- Effective at reducing sound level
- Easy to modify to reduce sound level even further.

Frequency Analysis

Frequency through Exhaust

- $f = \frac{(2n-1)c}{4L}$
- Varies on resonance number “n”
- Lowest frequency of 86.1 hz

Mufflers

- Restrictive mufflers are designed to reduce sound at frequencies between 0-600 Hz.

Exhaust Material Selection

304 Stainless Steel

- Ultimate Strength: 505MPa
- Yield Strength: 215MPa
- Modulus of Elasticity: 193-200GPa
- Specific heat: 500J/kg-K
- Melting Point: 1400-1455°C
- Price: $12.10/ft

1008 Carbon Steel

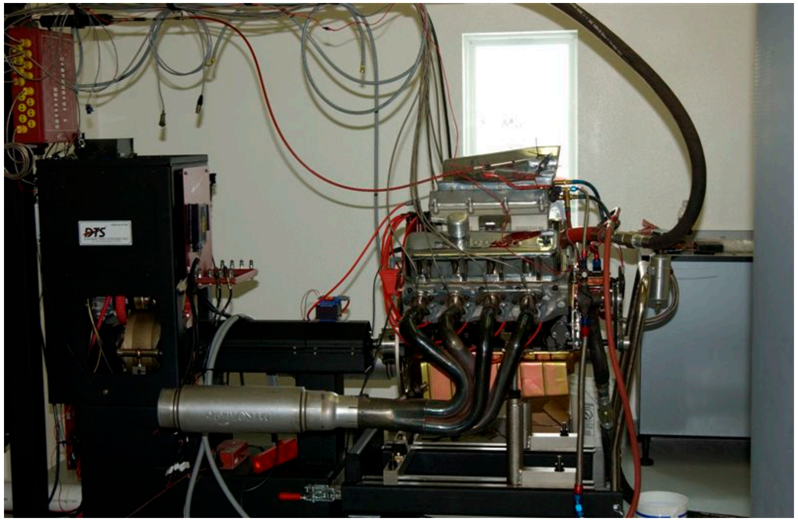
- Ultimate Strength: 304MPa
- Yield Strength: 285MPa
- Modulus of Elasticity: 190-210GPa
- Specific heat: 481J/kg-K
- Melting Point: 1510°C
- Price: $4.94/ft

Exhaust Manufacturing

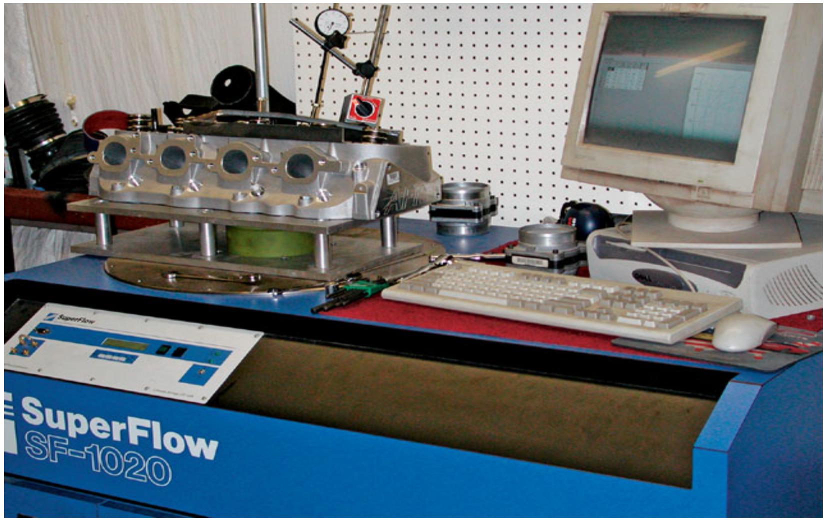
- Purchase steel tubing from vendor (spdexhaust)
- Bend tubing to match exhaust drawings
- Connect to exhaust collectors
- Attach muffler and modify if necessary

Testing

- Sound
  - Modifying exhaust packaging
- Power and Performance
  - Dynamometer (a)
  - Flow bench (b)
  - Power Commander



a



b

Safety

- Intake and Exhaust Port Connections
  - Bolt calculations
- FSAE Rules
  - 20 mm restrictor (reduces horsepower)
  - Safety Envelope (intake and exhaust)
  - Exhaust muffler must be pointed away from driver
  - Noise level <110dB
  - Engine specs:
    - 4 stroke
    - Displaced Volume < 610cc
- Exhaust-pipe thermal wrapping

Bolt analysis

- Intake Bolts

$$\sigma_b = \frac{CP + F_i}{A_t}$$

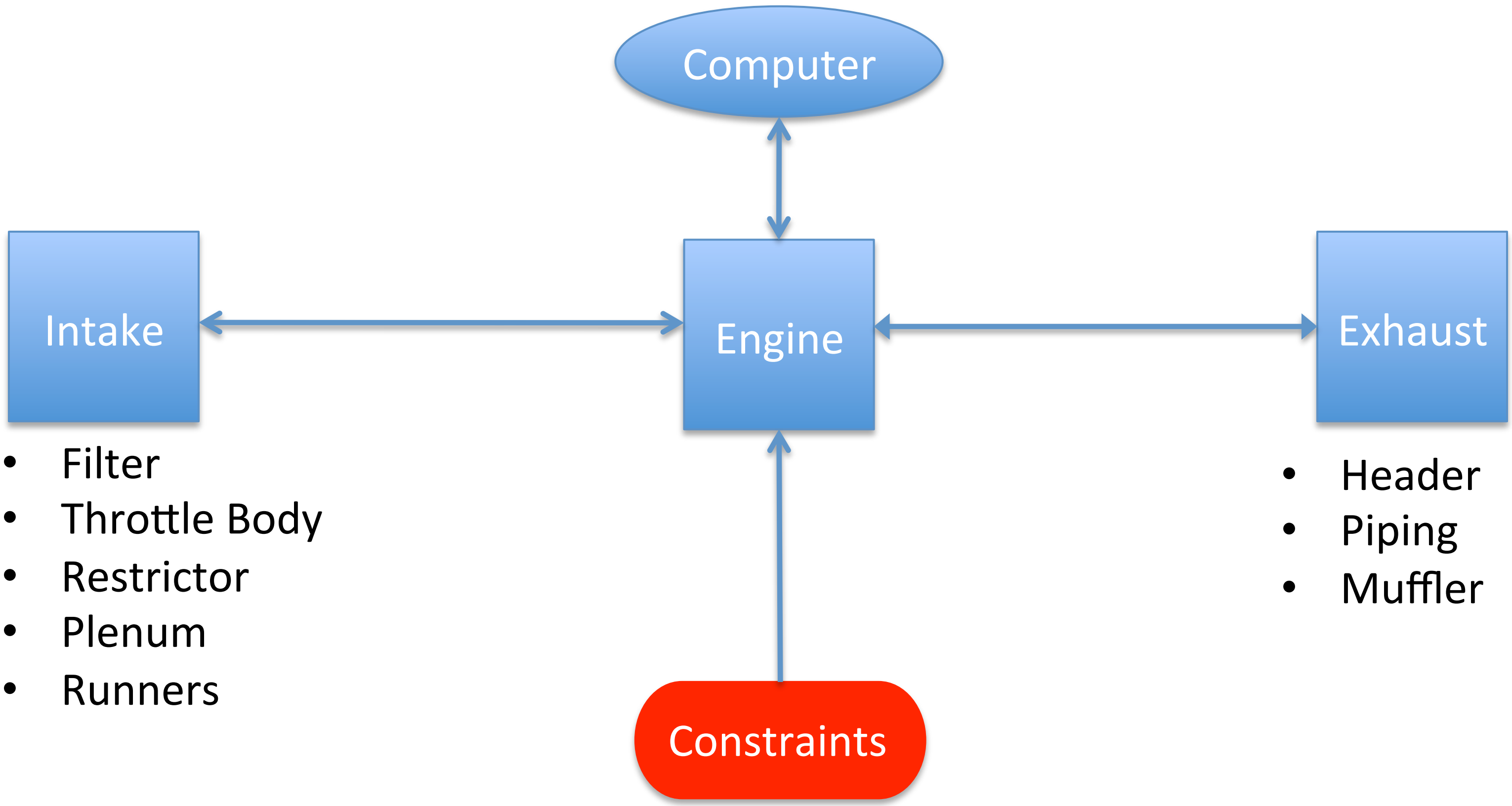
$$\sigma_b = 100.2\ psi$$

- Exhaust Bolts

$$\sigma_b = \frac{CP + F_i}{A_t}$$

$$\sigma_b = 108.2\ psi$$

Product Architecture



- Filter
- Throttle Body
- Restrictor
- Plenum
- Runners

- Header
- Piping
- Muffler

- 20mm restrictor
- 610cc engine displacement
- 110dB exhaust note

Project Management

Budget

2014 Power Plant Budget			
System	***Component***	***Source***	***Cost***
Intake	Air Filter	K&N	$30.00
	Restrictor	Realized	$100.00
	Plenum/Runners	Realized	$700.00
	Injectors	Vendor	$300.00
	Throttle Body	Vendor	$150.00
Engine	CBR 600RR	Vendor	$1,400.00
	PC V	PC	$370.00
	Ignition Module	PC	$355.00
	Pressure Sensor	PC	$220.00
Exhaust	Piping	Vendor	$650.00
	Muffler	Vendor	$300.00
Misc	Bolts/Brackets	Vendor	$120.00
	Gaskets	Vendor	$20.00
	Approximate	*Subtotal*	***$4,715.00***
	20% Contingency		$943.00
	Approximate	***Total***	***$5,658.00***

December

- Design and analyze jig
- Order engine and ECU
- Order intake/exhaust components

January

- Assemble subsystems
- Receive manufactured parts

February

- Continue/Finish any assembling
- Begin testing

March

- Perform Engine Dyno testing
- Perform Flow Bench testing
- Modify prototype

April

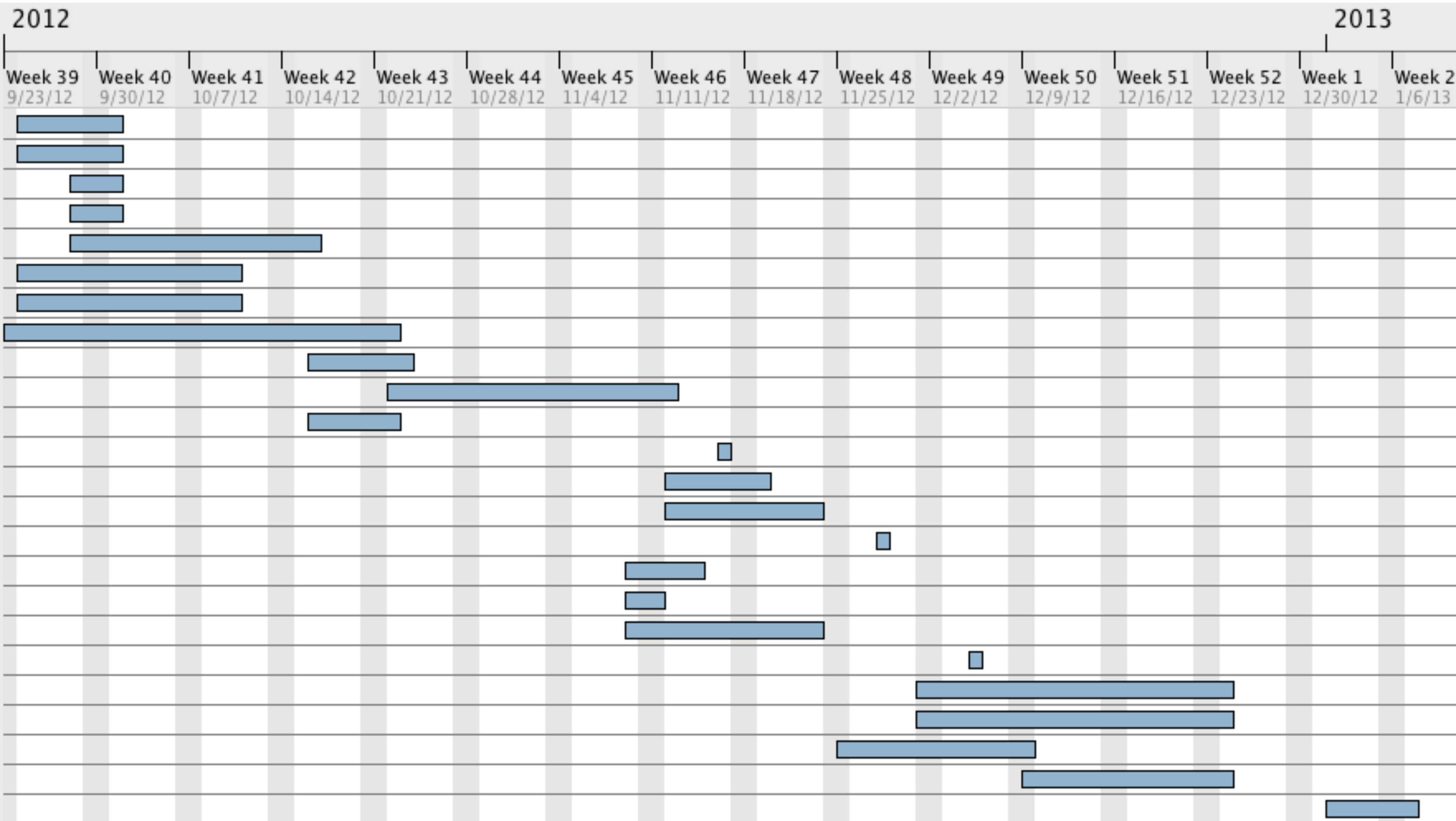
- Prepare results and reports
- Finalize prototype

May

- Present final prototype to department/FSAE team

Appendix

Name	Begin date	End date
Research and Select Engine	9/24/12	10/1/12
Decision Matrix 5 Engines	9/24/12	10/1/12
Select Engine	9/28/12	10/1/12
Engine/Intake Analysis	9/28/12	10/1/12
Cost Analysis	9/28/12	10/16/12
Engineering Specs	9/20/12	10/1/12
Engineering Specs Report	9/24/12	10/10/12
Embodiment Proposal Outline	9/10/12	10/22/12
Oral Project Review	10/16/12	10/23/12
Embodiment Proposa	10/22/12	11/12/12
Design and Practice Presentation	10/16/12	10/22/12
Final Project Outline	11/16/12	11/16/12
Project Poster	11/12/12	11/19/12
Slides for Final Presentation	11/12/12	11/23/12
Final Presentation	11/28/12	11/28/12
CFD Analysis	11/9/12	11/14/12
Exhaust Routing	11/9/12	11/11/12
Bill of Materials	11/9/12	11/23/12
Final Report	12/5/12	12/5/12
Purchase Engine	12/1/12	12/24/12
Purchase Power Commander	12/1/12	12/24/12
Obtain quote from Realized	11/25/12	12/9/12
Place Realized order	12/9/12	12/24/12
Contact Sponsor for second round of funding	1/1/13	1/7/13



2012
2013
Week 39 9/23/12
Week 40 9/30/12
Week 41 10/7/12
Week 42 10/14/12
Week 43 10/21/12
Week 44 10/28/12
Week 45 11/4/12
Week 46 11/11/12
Week 47 11/18/12
Week 48 11/25/12
Week 49 12/2/12
Week 50 12/9/12
Week 51 12/16/12
Week 52 12/23/12
Week 1 12/30/12
Week 2 1/6/13

Engine Decision Matrix

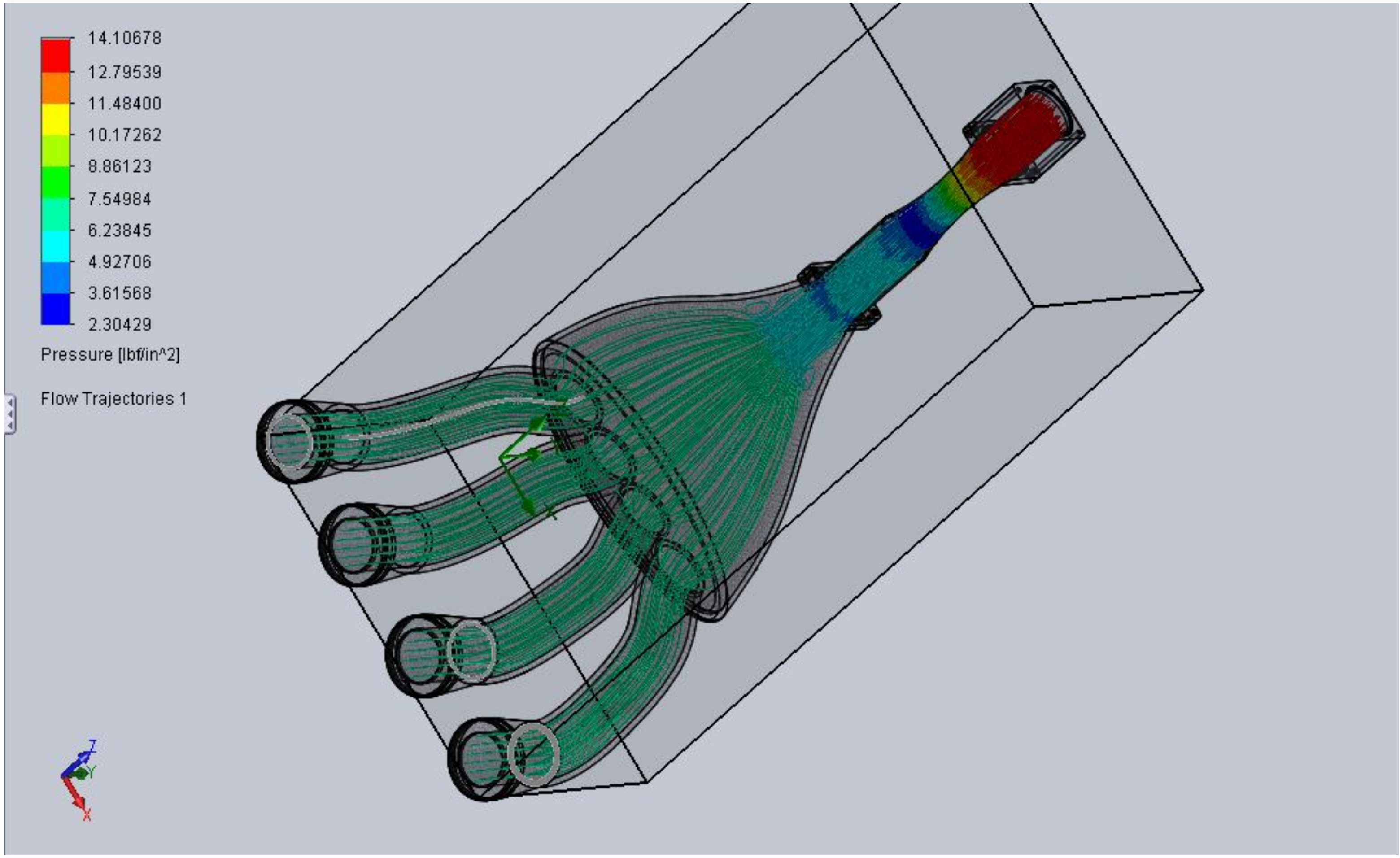
Criterion	Weight	Engines			
		I	II	III	
Cost	10	-	-	-	DATUM
Compression Ratio	10	-	+	+	
Intake valve diameter	5	+	+	+	
Exhaust valve diameter	5	S	S	+	
Valve overlapping	10	+	-	S	
Max. Intake valve lift	5	-	-	-	
Max. exhaust valve lift	5	-	-	-	
Intake Valve angle	5	+	+	+	
Exhaust valve angle	5	S	S	S	
Transmission ratio	5	+	+	+	
Peak HP	10	+	+	-	
Peak Torque	10	+	-	S	
Max. RPM	10	S	+	+	
Availability	5	S	S	-	
Total +		6	6	6	
Total -		4	5	5	
Overall total		2	1	1	
Weighted total	100	15	-5	5	

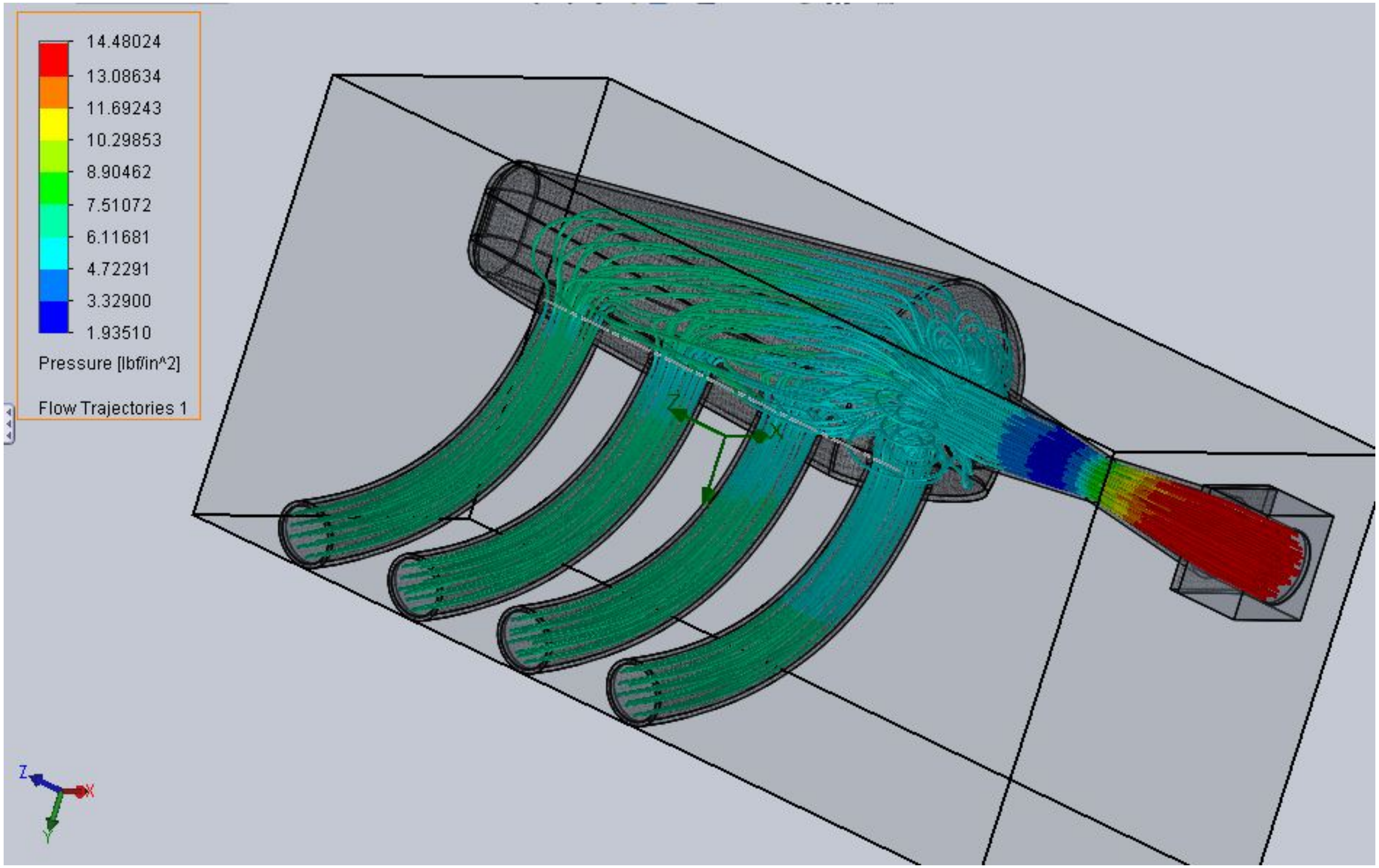
DATUM	Suzuki GSXR 600
I	Honda CBR 600 RR
II	Yamaha YZF R6
III	Kawasaki ZX-6R

Existing Technologies

- Design analysis
  - CFD analysis
    - SolidWorks flow simulation
    - Ricardo's VECTIS or ANSYS Fluent
  - Engine Dyno
  - Flowbench
- Fabrication
  - 3D printing
  - Realize Inc. (rapid intake prototype company)

Appendix


14.10678
12.79539
11.48400
10.17262
8.86123
7.54984
6.23845
4.92706
3.61568
2.30429
Pressure [lbf/in^2]
Flow Trajectories 1
Z
Y
X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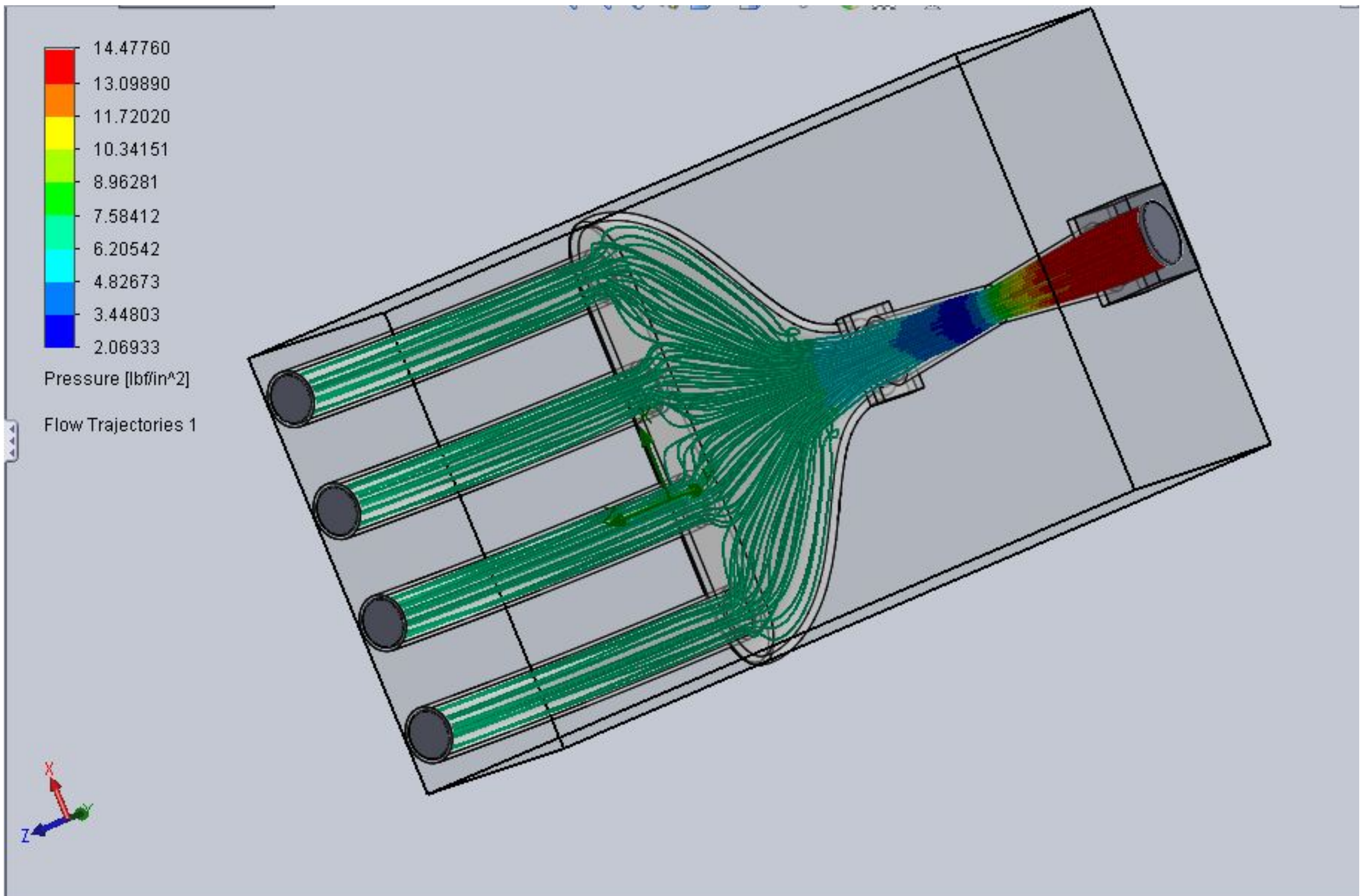
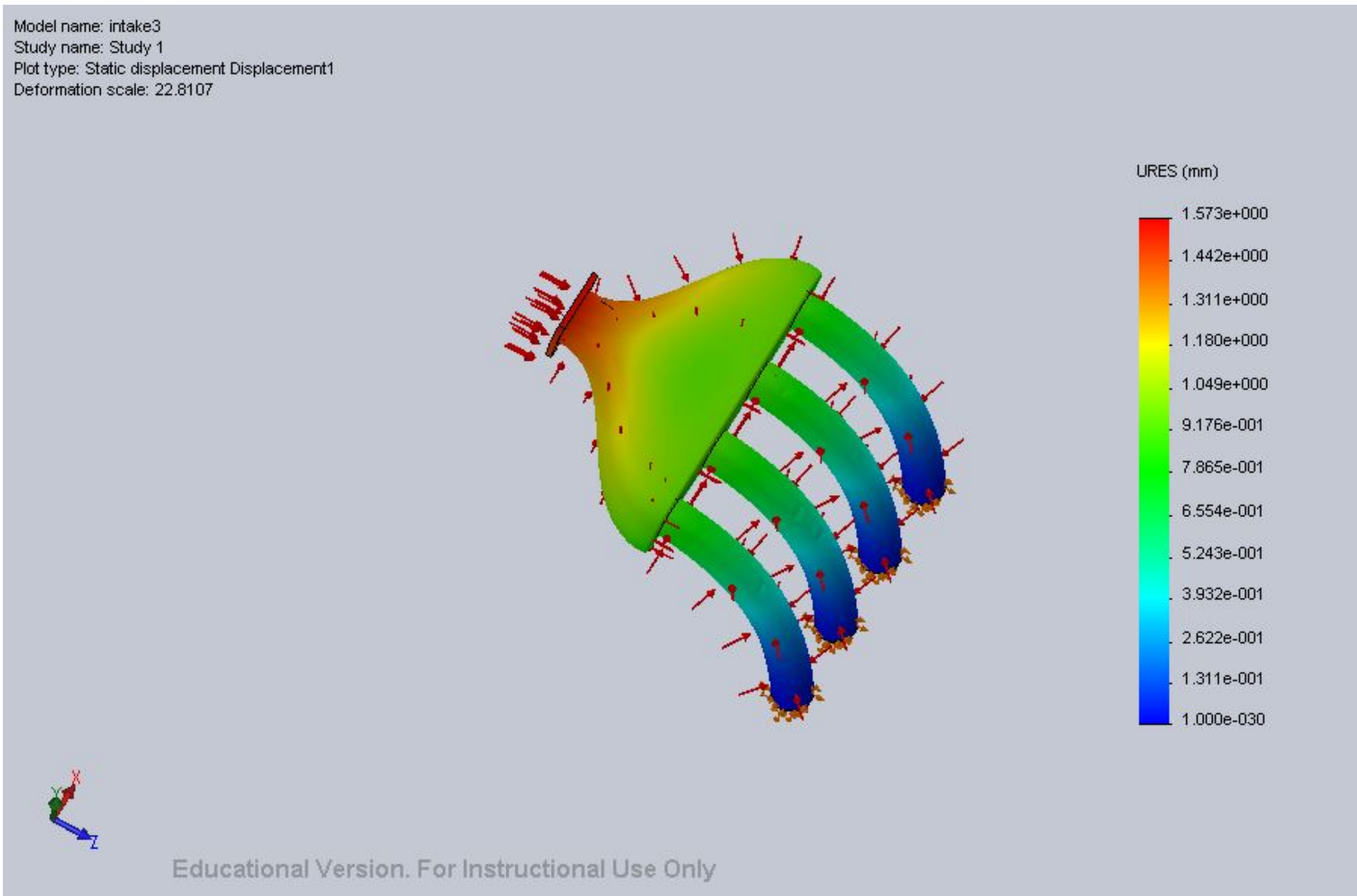
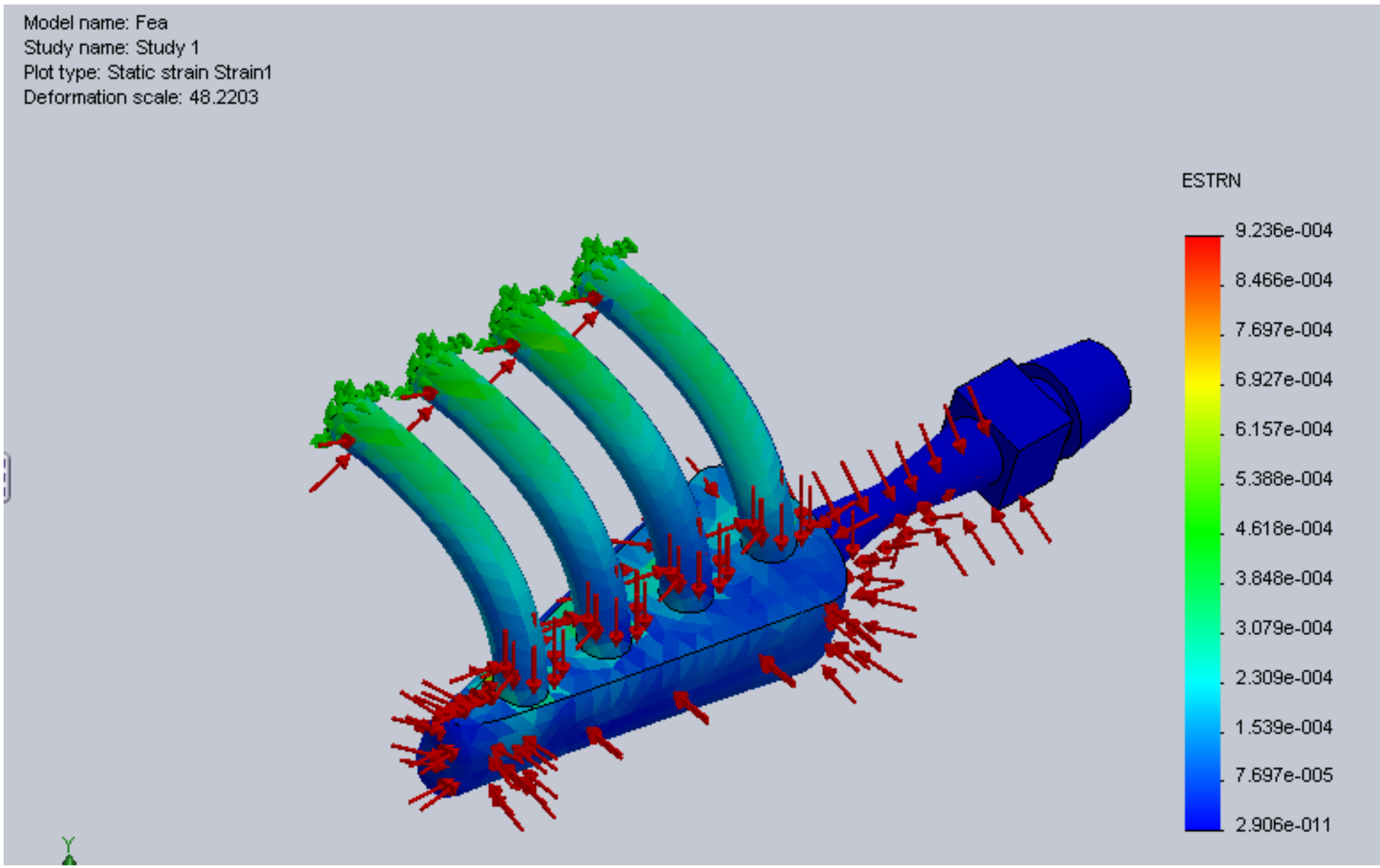
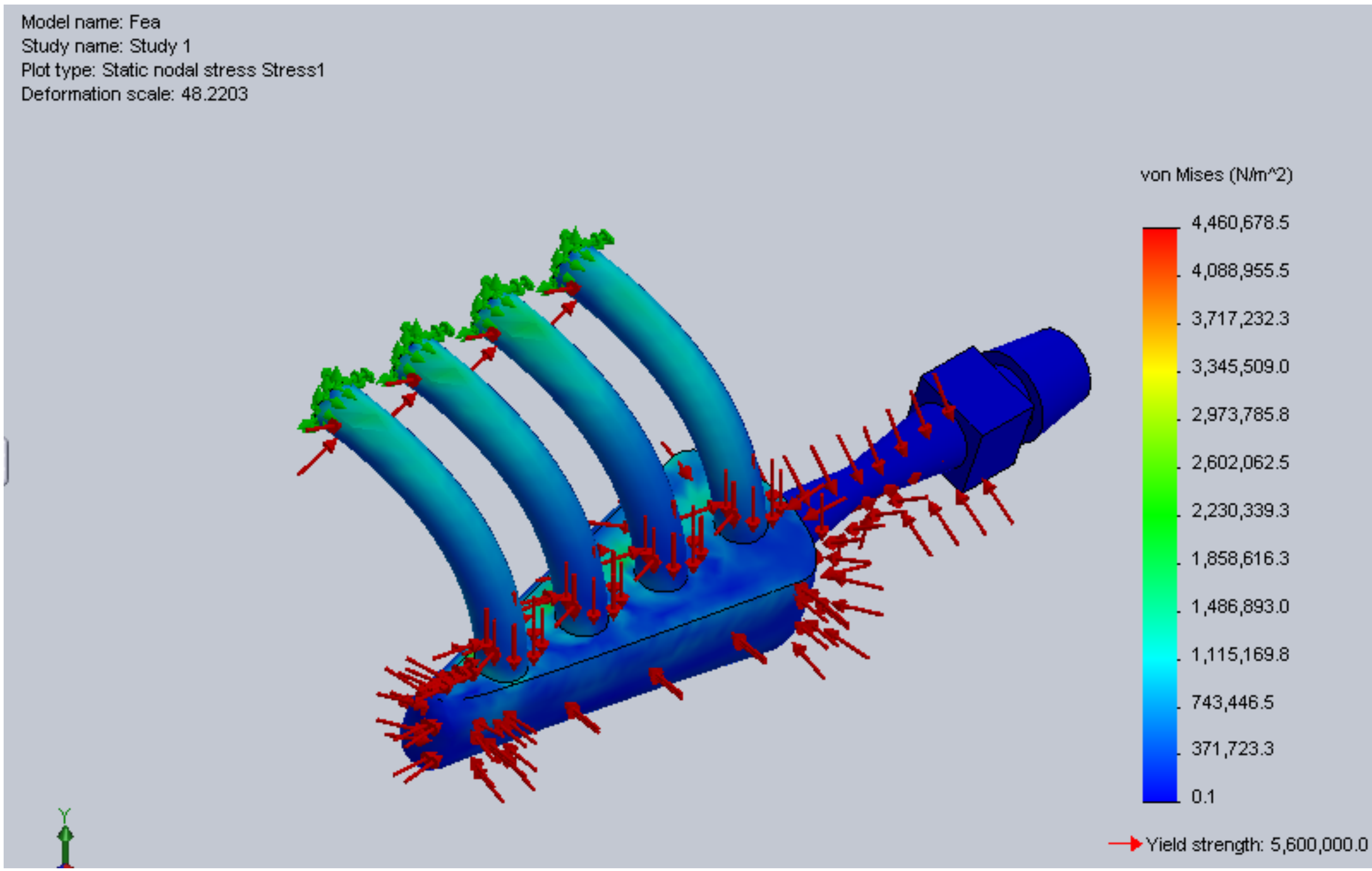
13.08634
11.69243
10.29853
8.90462
7.51072
6.11681
4.72291
3.32900
1.93510
Pressure [lbf/in^2]
Flow Trajectories 1



14.47760
13.09890
11.72020
10.34151
8.96281
7.58412
6.20542
4.82673
3.44803
2.06933
Pressure [lbf/in^2]
Flow Trajectories 1
X
Y
Z


Model name: intake3
Study name: Study 1
Plot type: Static displacement Displacement1
Deformation scale: 22.8107
URES (mm)
1.573e+000
1.442e+000
1.311e+000
1.180e+000
1.049e+000
9.176e-001
7.865e-001
6.554e-001
5.243e-001
3.932e-001
2.622e-001
1.311e-001
1.000e-030
Y
X
Z
Educational Version. For Instructional Use Only


Model name: Fea
Study name: Study 1
Plot type: Static strain Strain1
Deformation scale: 48.2203
ESTRN
9.236e-004
8.466e-004
7.697e-004
6.927e-004
6.157e-004
5.388e-004
4.618e-004
3.848e-004
3.079e-004
2.309e-004
1.539e-004
7.697e-005
2.906e-011
Y


Model name: Fea
Study name: Study 1
Plot type: Static nodal stress Stress1
Deformation scale: 48.2203
von Mises (N/m^2)
4,460,678.5
4,088,955.5
3,717,232.3
3,345,509.0
2,973,785.8
2,602,062.5
2,230,339.3
1,858,616.3
1,486,893.0
1,115,169.8
743,446.5
371,723.3
0.1
Yield strength: 5,600,000.0
Y

Restrictor Analysis

- @ Throat M=1
  - $\frac{P*}{P_o} = (1 + \frac{k-1}{2} M^2)^{\frac{-k}{k-1}}$
    - P*=53.51kPa
  - $\frac{T*}{T_o} = \frac{2}{k+1}$
    - T*=248.46K
  - $\frac{\rho *}{\rho_o} = (\frac{2}{k+1})^{\frac{1}{k-1}}$
    - $\rho *$=0.761kg/m^3

[4]

Restrictor Analysis

- Reynolds Number
  - $Re_D = \rho^* u_t D_t / \mu^*$
    - ρ^*=0.761kg/m^3
    - u_t=195.554m/s
    - D_t= 20mm=0.02m
    - μ^* =1.483x10^{-5} kg/m-s
    - Re_D=200,128

[4]

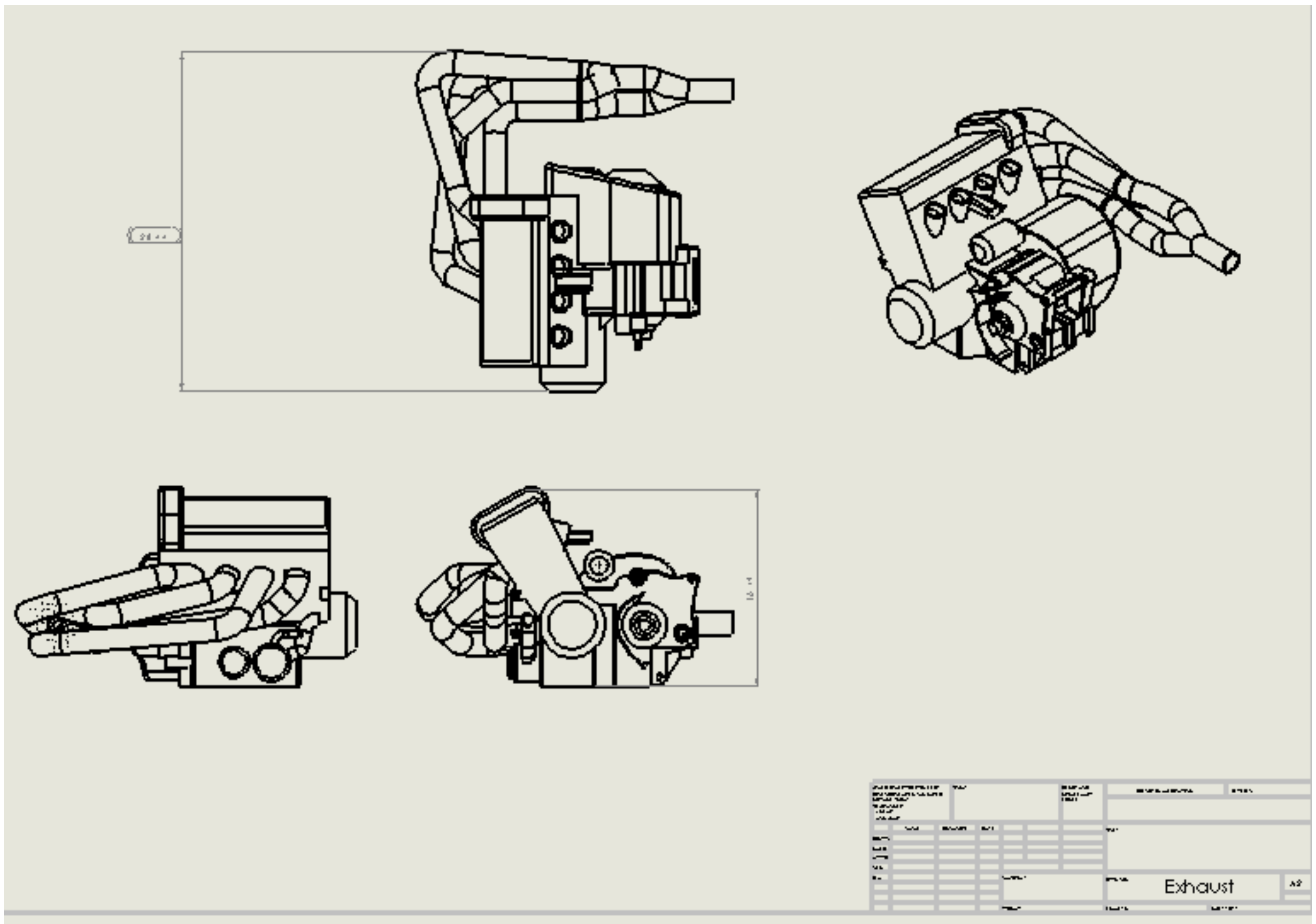
Exhaust Configuration Decision

Decision Matrix (Exhaust Configuration)				
	Weights	4 to 1	4 to 2 to 1	4 to 2
Air Flow	25	2	4	5
Cost	25	4	4	3
Sound Reduction	30	5	4	2
Space Requirement	20	4	4	2
Total		3.8	4	3

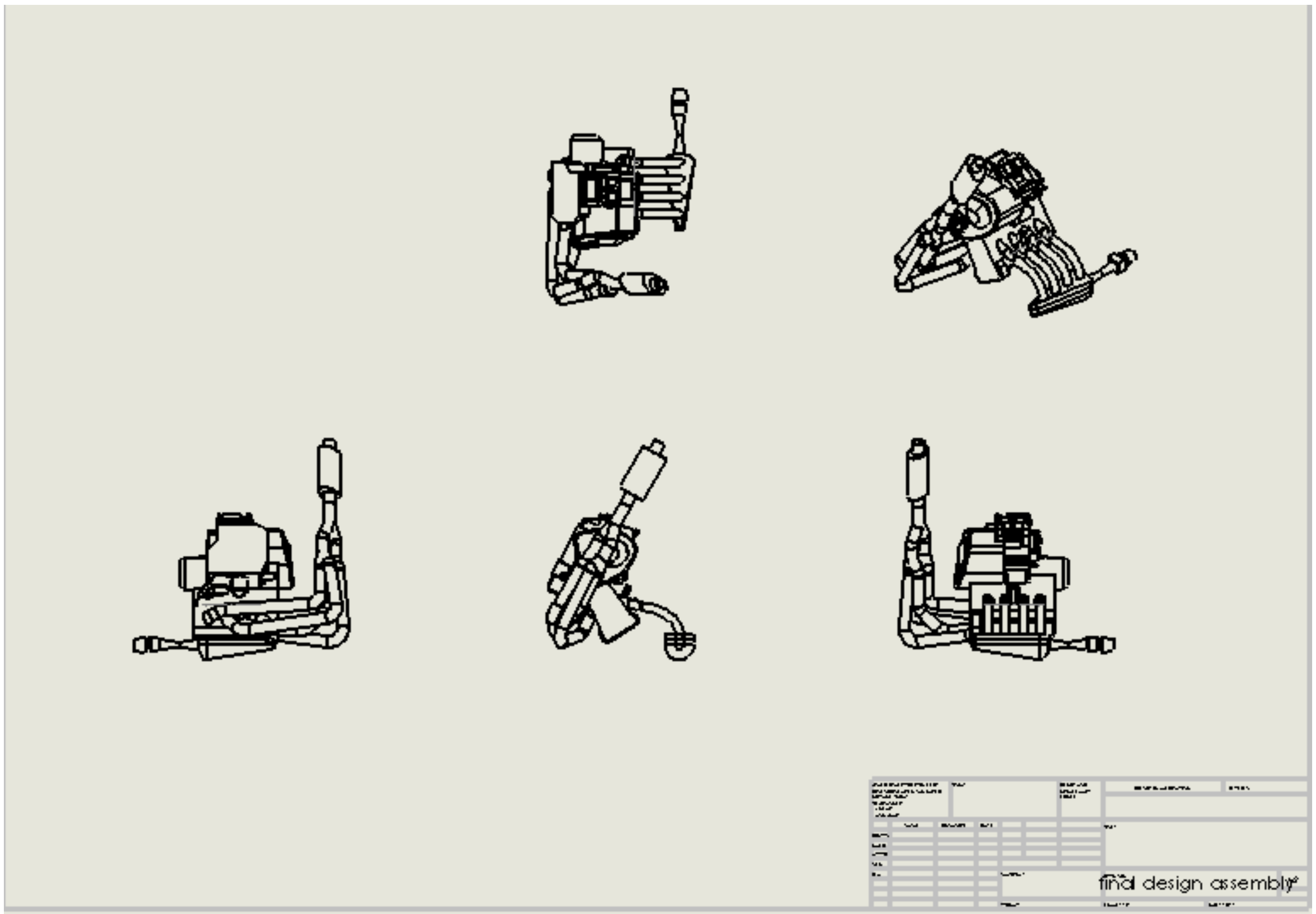
Muffler type Decision

Decision Matrix (Mufflers)					
	Weights	Absorptive	Reactive	Reflective
Sound Reduction	40	3	2	4
Cost	25	3	5	2
Availibility	20	4	5	4
Adaptability	15	5	5	5
Total		3.5	3.8	3.65

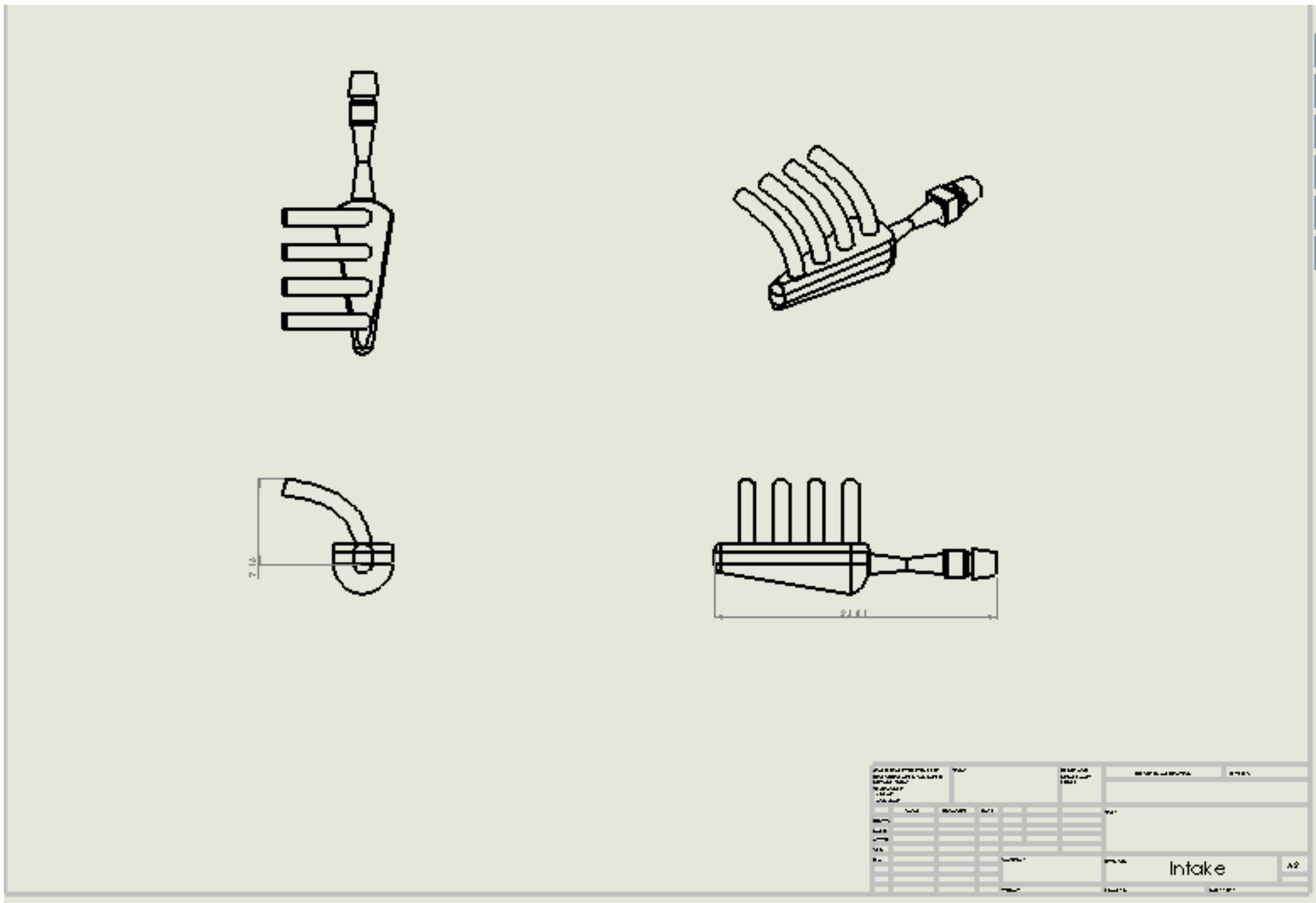
Final Assembly Drawing



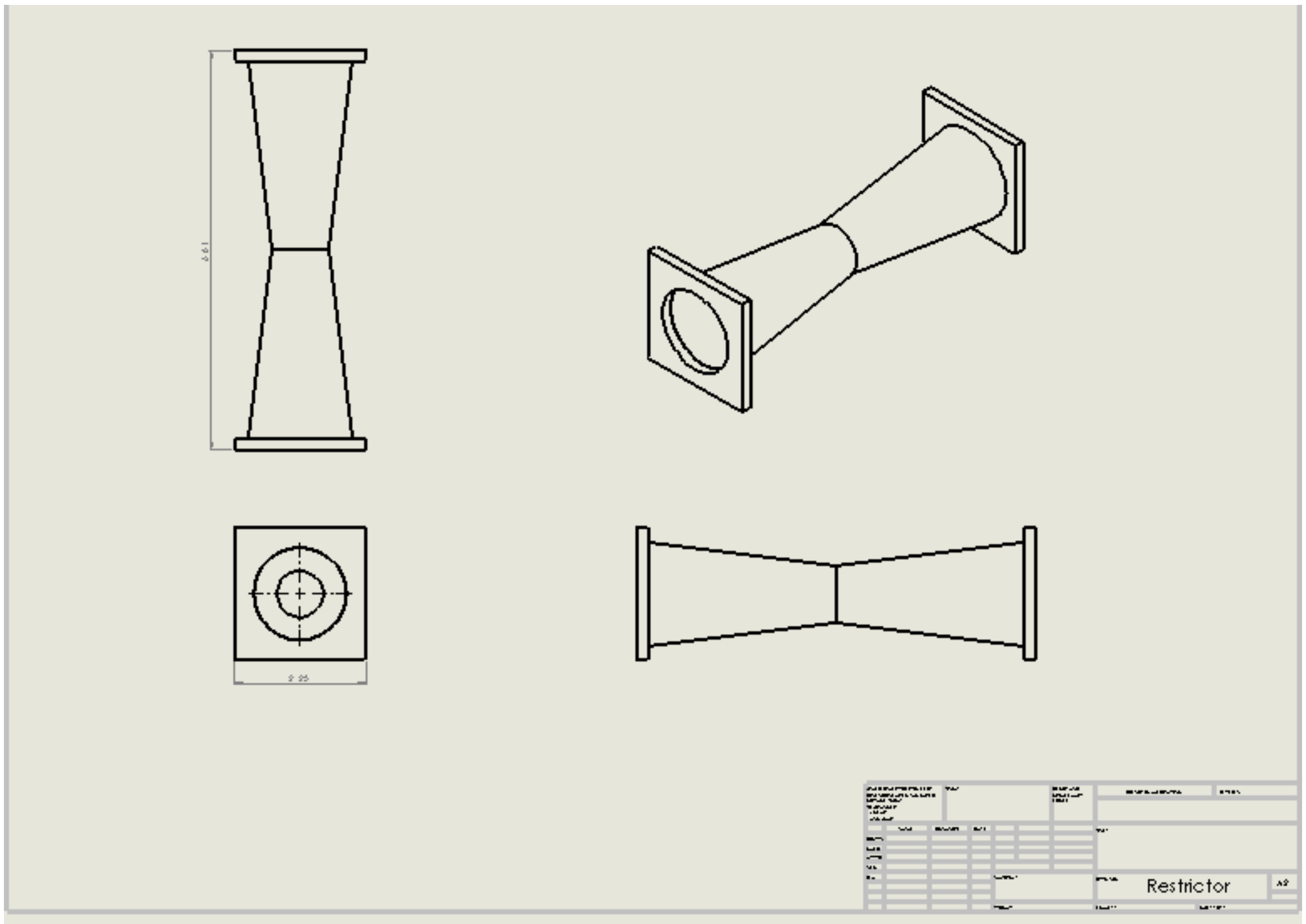
Final Assembly Drawing



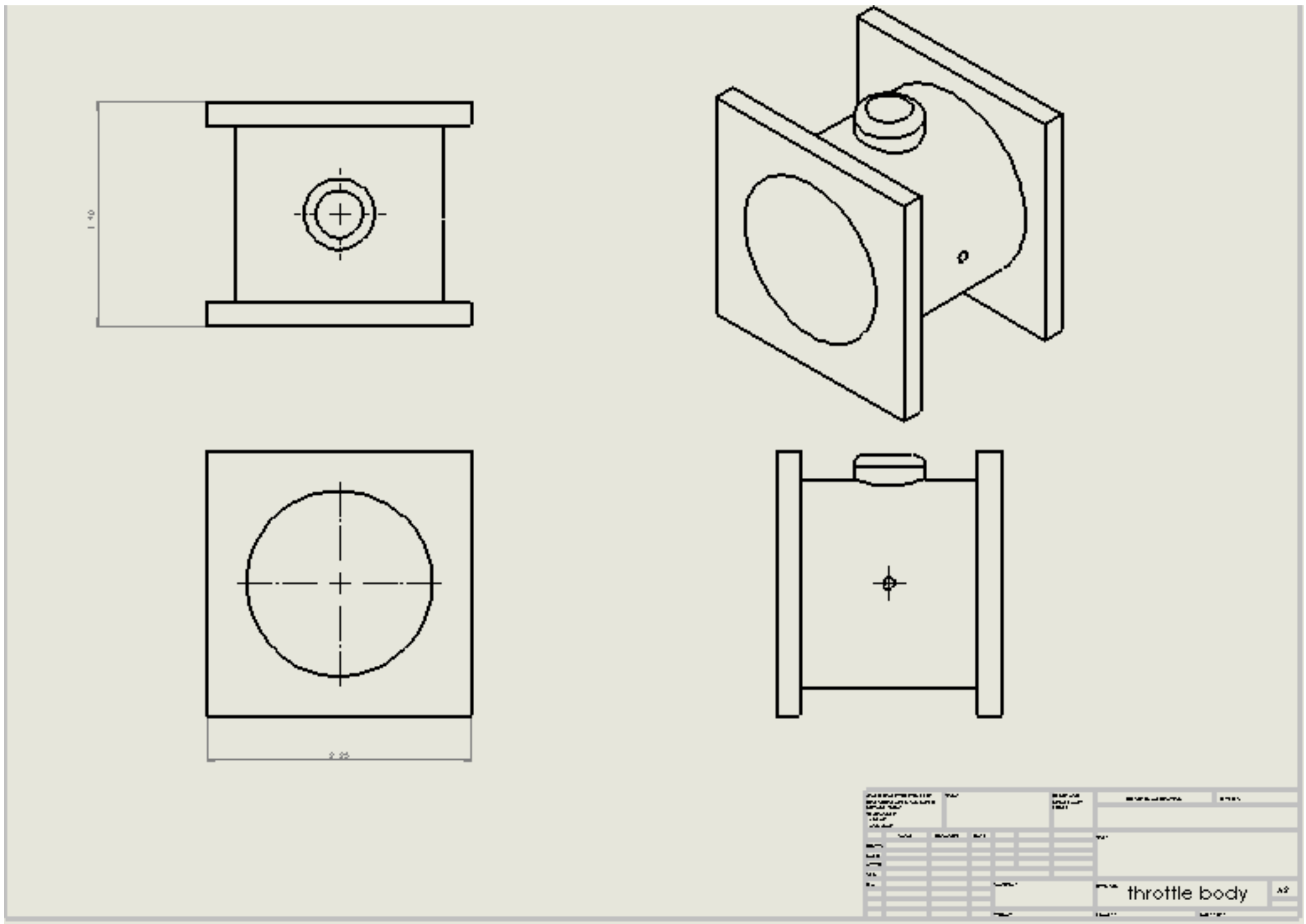
Intake Drawing



Nozzle Drawing



Throttle Body Drawing



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