SABRE NOZZLE

Supersonic Air-Breathing Redesigned Engine Nozzle

Manufacturing Status Review

Customer
Air Force Research Lab

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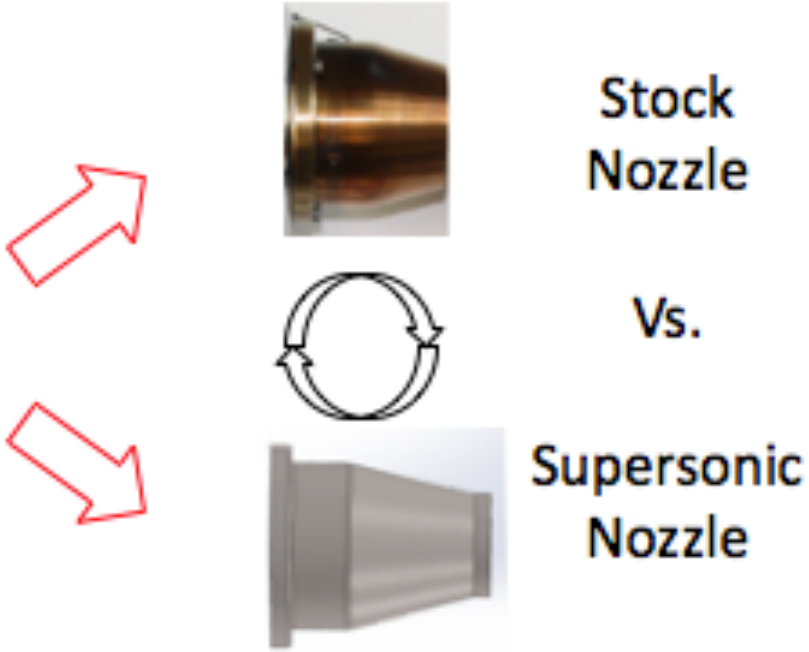
Presentation Outline

- **Project Overview**
  - Description/Objectives
  - Updated Test Bed Design
- **Schedule**
- **Manufacturing**
  - Test Bed/Nozzles
  - Sensors
- **Budget**

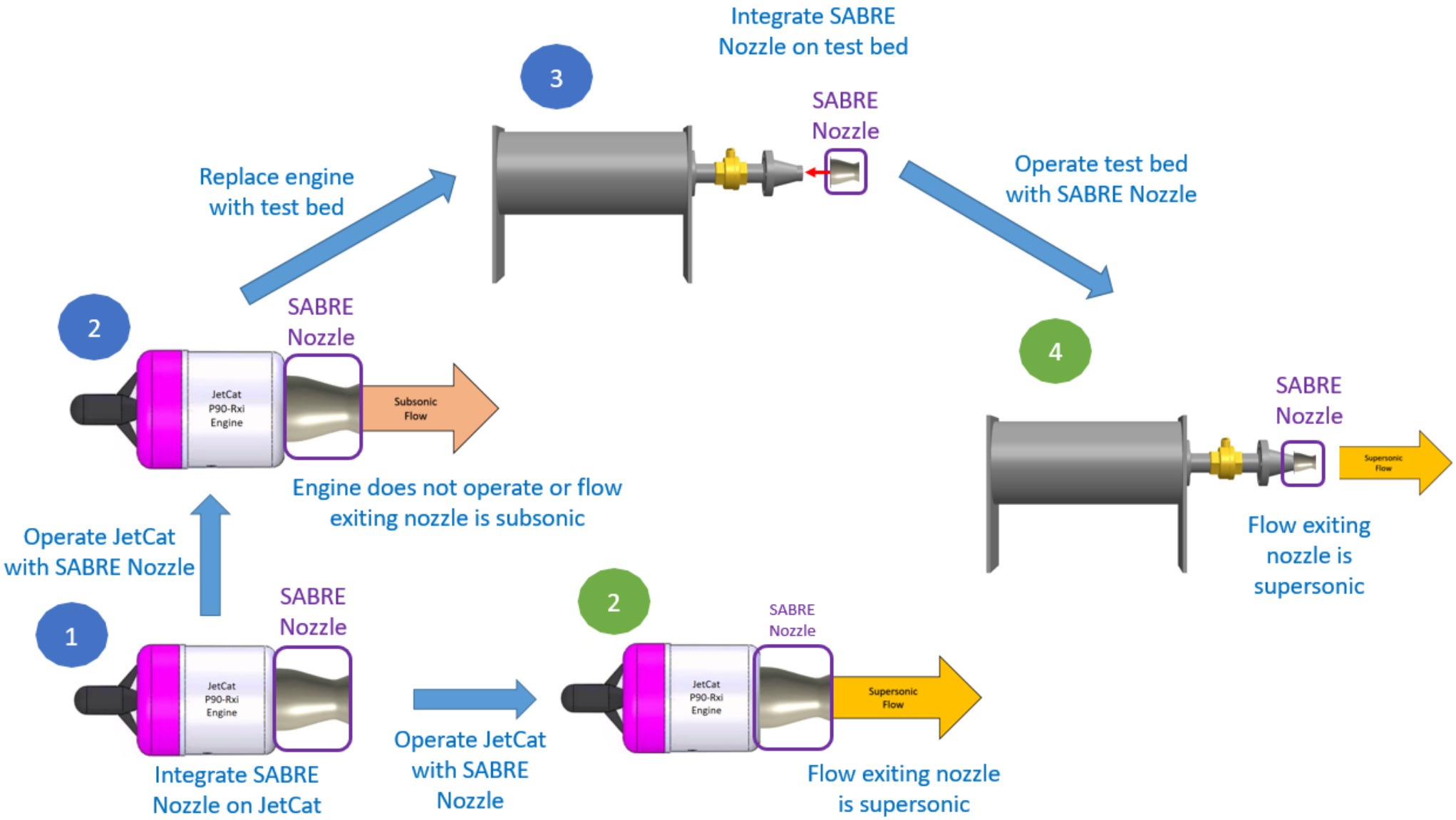
Project Overview

Project Description

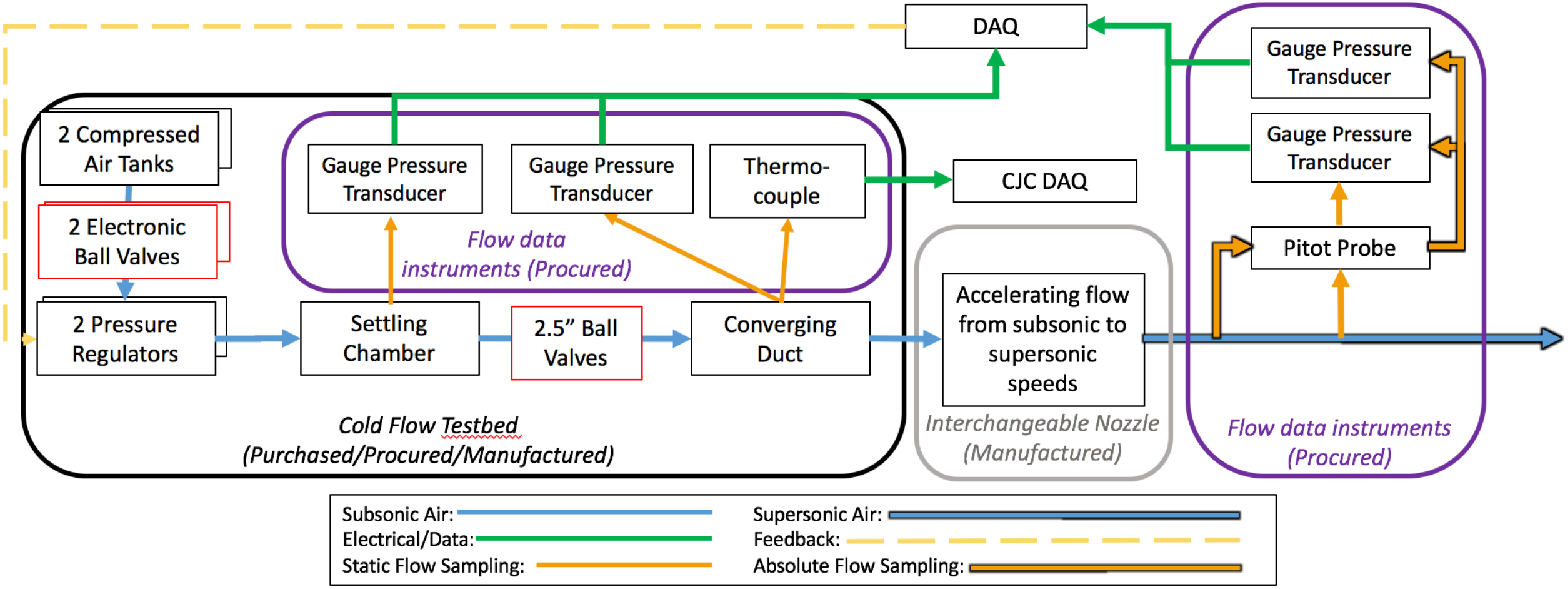
Model, manufacture, and **verify** an **additive manufactured nozzle** capable of accelerating flow to **supersonic exhaust** produced by a **P90-RXi JetCat** engine maintaining the **T/W ratio** from its stock configuration.



CONOPS

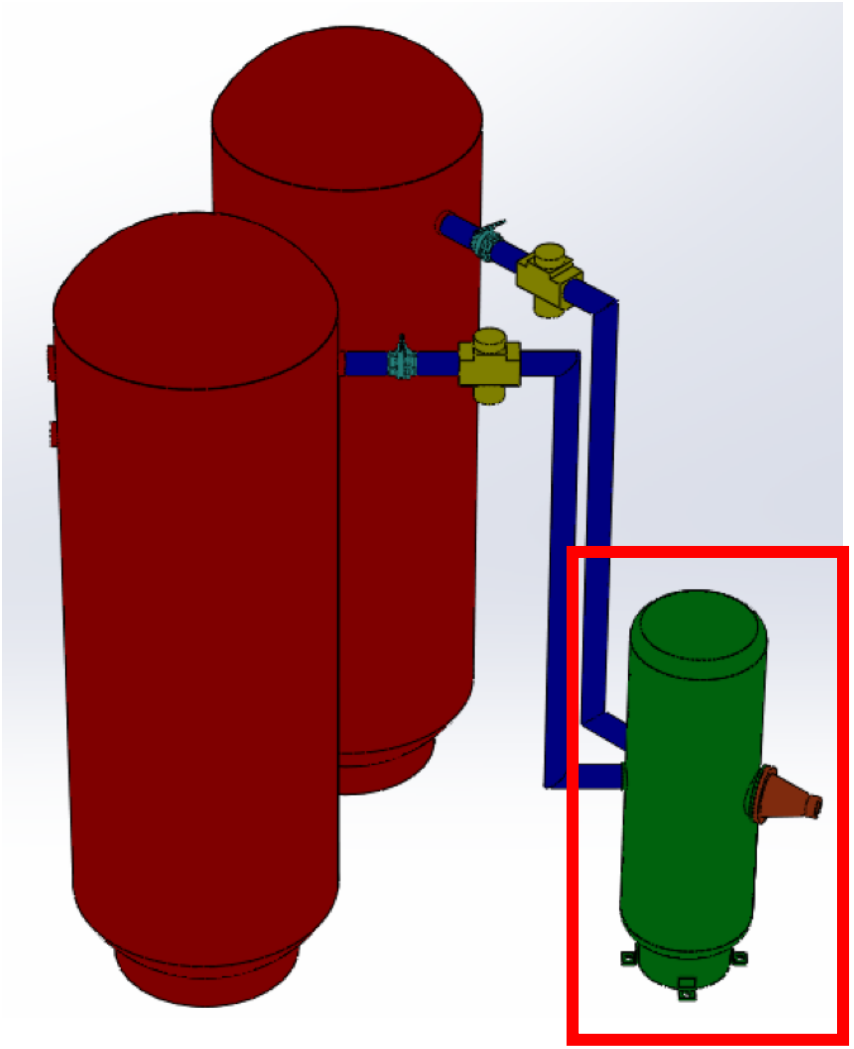

Integrate SABRE Nozzle on test bed
3
SABRE Nozzle
Replace engine with test bed
Operate test bed with SABRE Nozzle
2
SABRE Nozzle
JetCat P90-Rxi Engine
Subsonic Flow
4
SABRE Nozzle
Supersonic Flow
Engine does not operate or flow exiting nozzle is subsonic
Flow exiting nozzle is supersonic
Operate JetCat with SABRE Nozzle
1
SABRE Nozzle
JetCat P90-Rxi Engine
2
SABRE Nozzle
JetCat P90-Rxi Engine
Supersonic Flow
Integrate SABRE Nozzle on JetCat
Operate JetCat with SABRE Nozzle
Flow exiting nozzle is supersonic

Test bed FBD

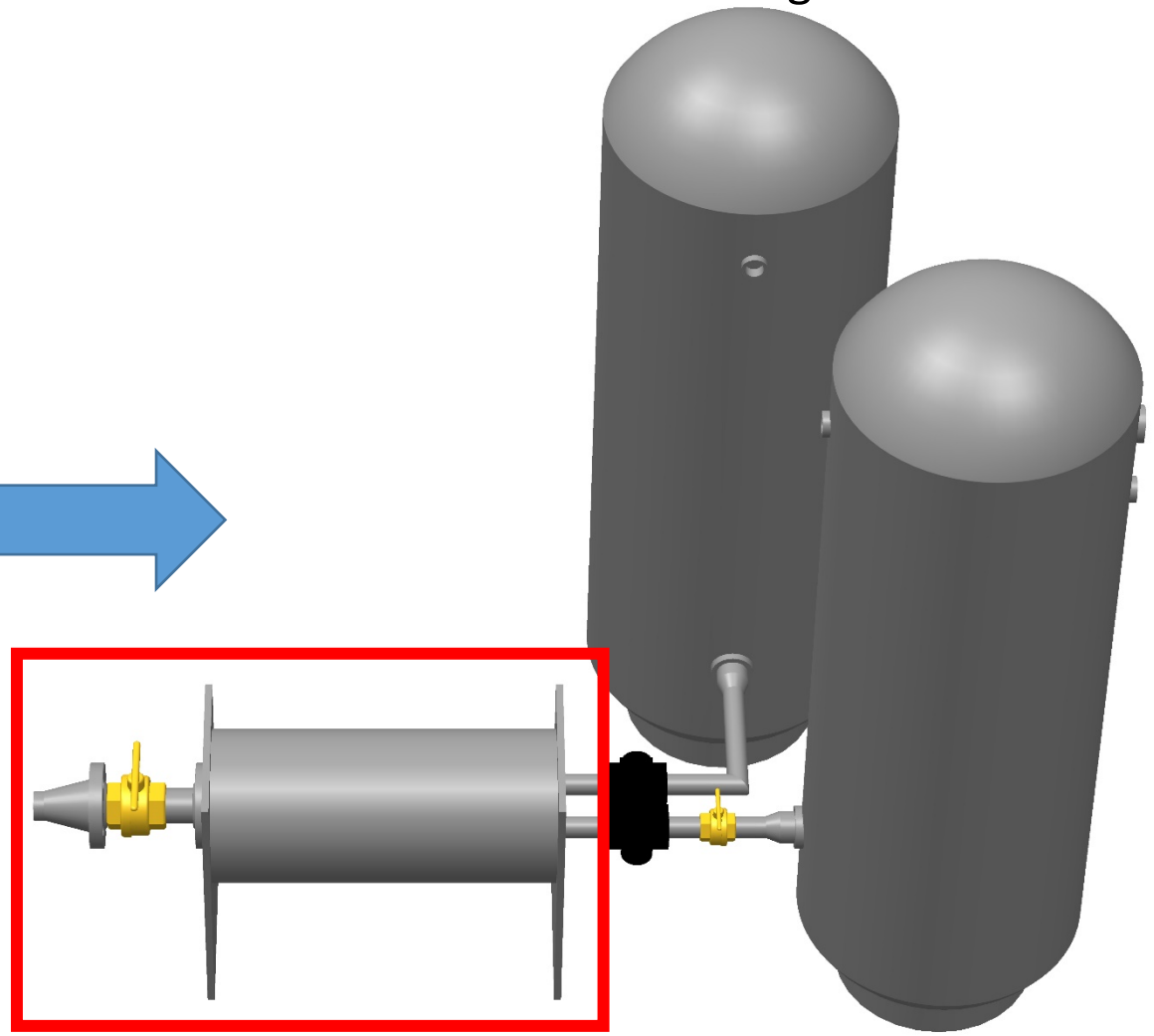

DAQ
2 Compressed Air Tanks
2 Electronic Ball Valves
2 Pressure Regulators
Gauge Pressure Transducer
Gauge Pressure Transducer
Thermo-couple
Flow data instruments (Procured)
Settling Chamber
2.5" Ball Valves
Converging Duct
Cold Flow Testbed
(Purchased/Procured/Manufactured)
CJC DAQ
Accelerating flow from subsonic to supersonic speeds
Interchangeable Nozzle
(Manufactured)
Gauge Pressure Transducer
Gauge Pressure Transducer
Pitot Probe
Flow data instruments
(Procured)
Subsonic Air:
Supersonic Air:
Electrical/Data:
Feedback:
Static Flow Sampling:
Absolute Flow Sampling:

New Testbed Design

CDR Testbed Design



New Testbed Design



Critical Project Elements

CPE 1: Engine Operation

Stock Test & Modified Test

Modified Nozzle Verification

Additive Manufacturing Validation & Survivability

CPE 2: Test Bed Operation

Test Bed Verification

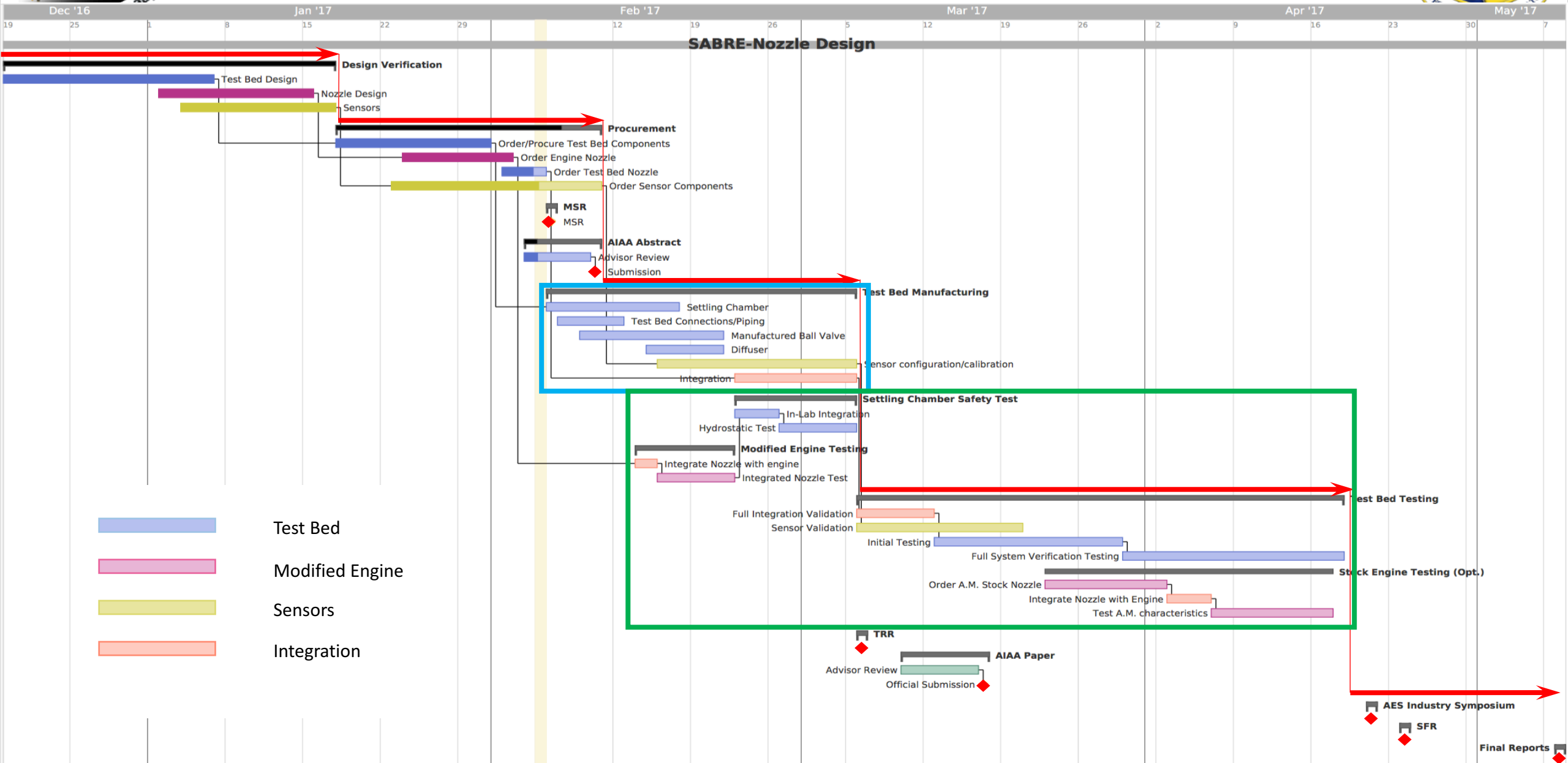
Nozzle Design Verification

Testing Safety & Protocol

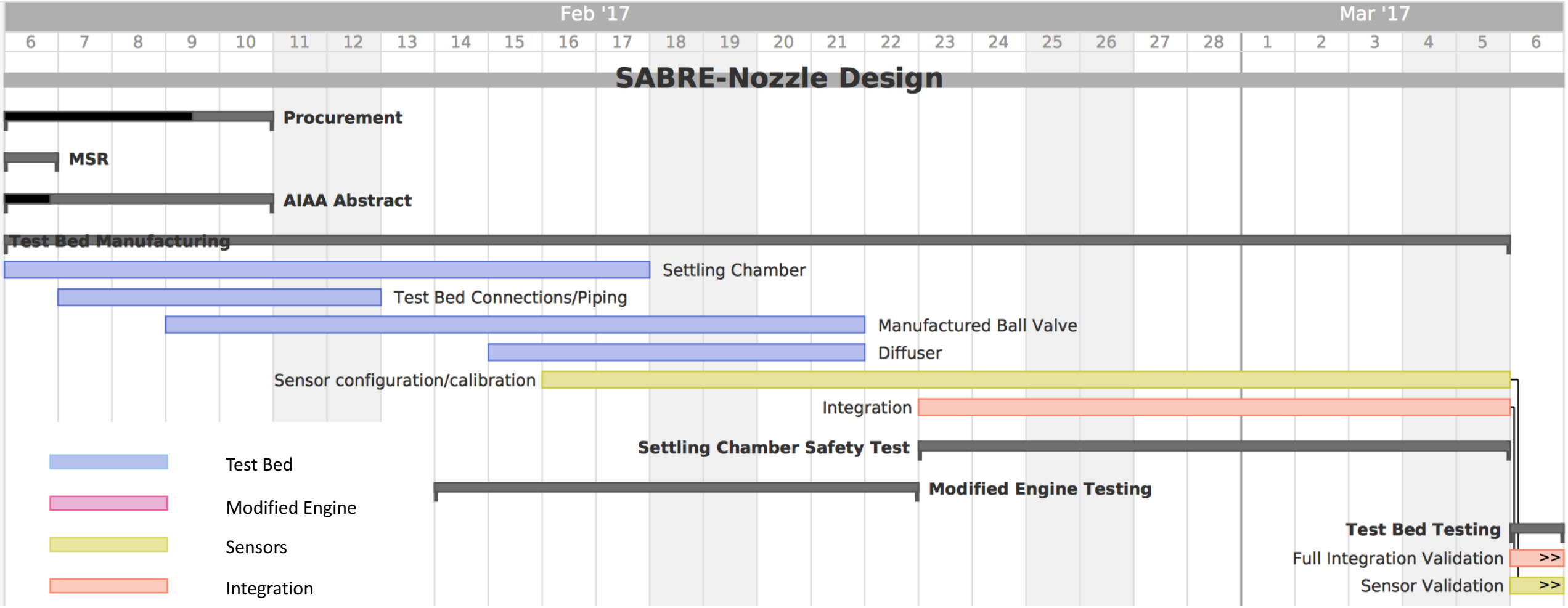
Supersonic Validation

Project Schedule

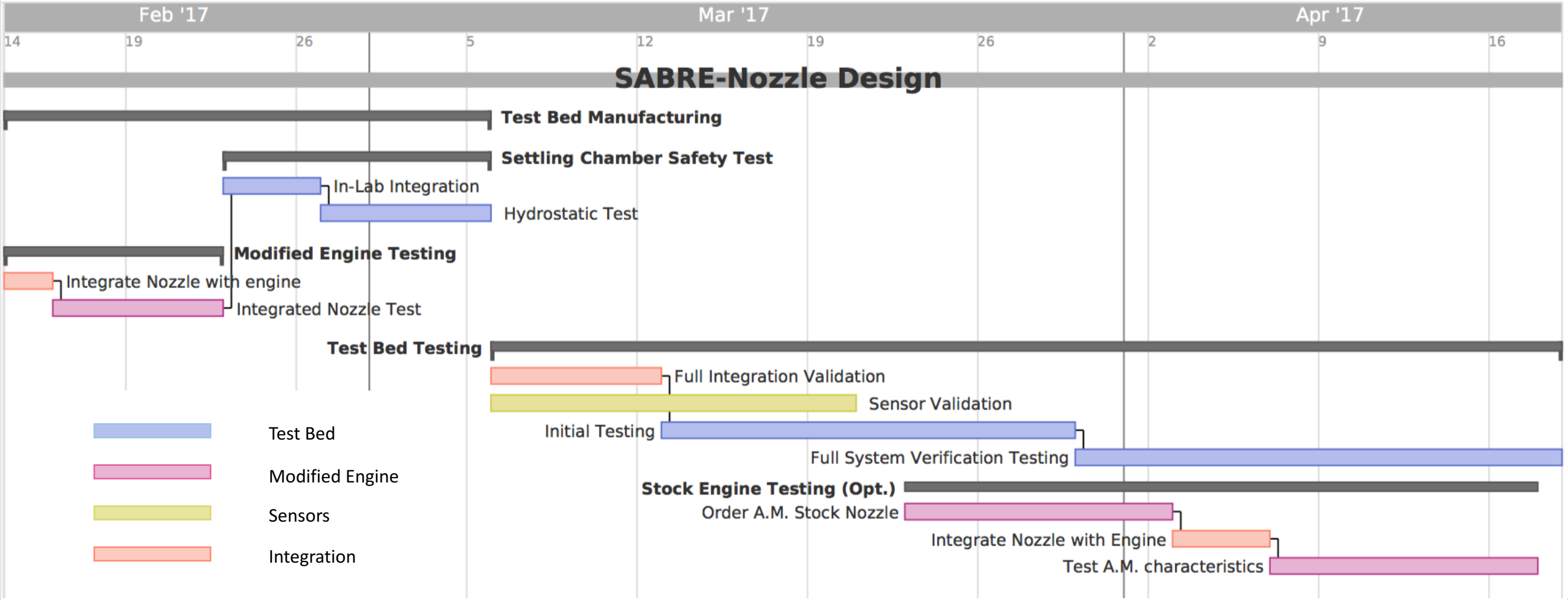
Overview Schedule



Manufacturing Schedule

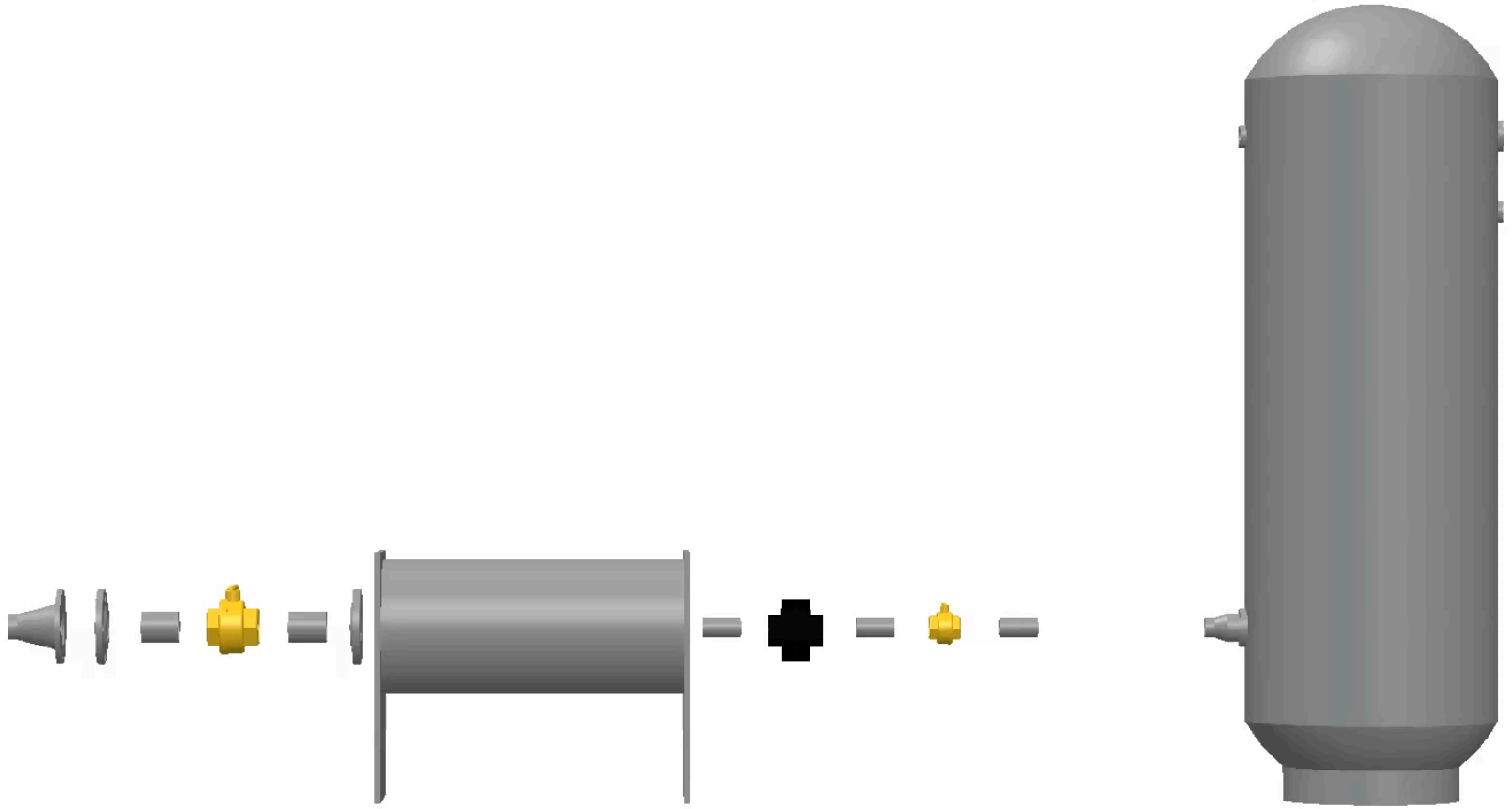


Testing Schedule



Project Manufacturing

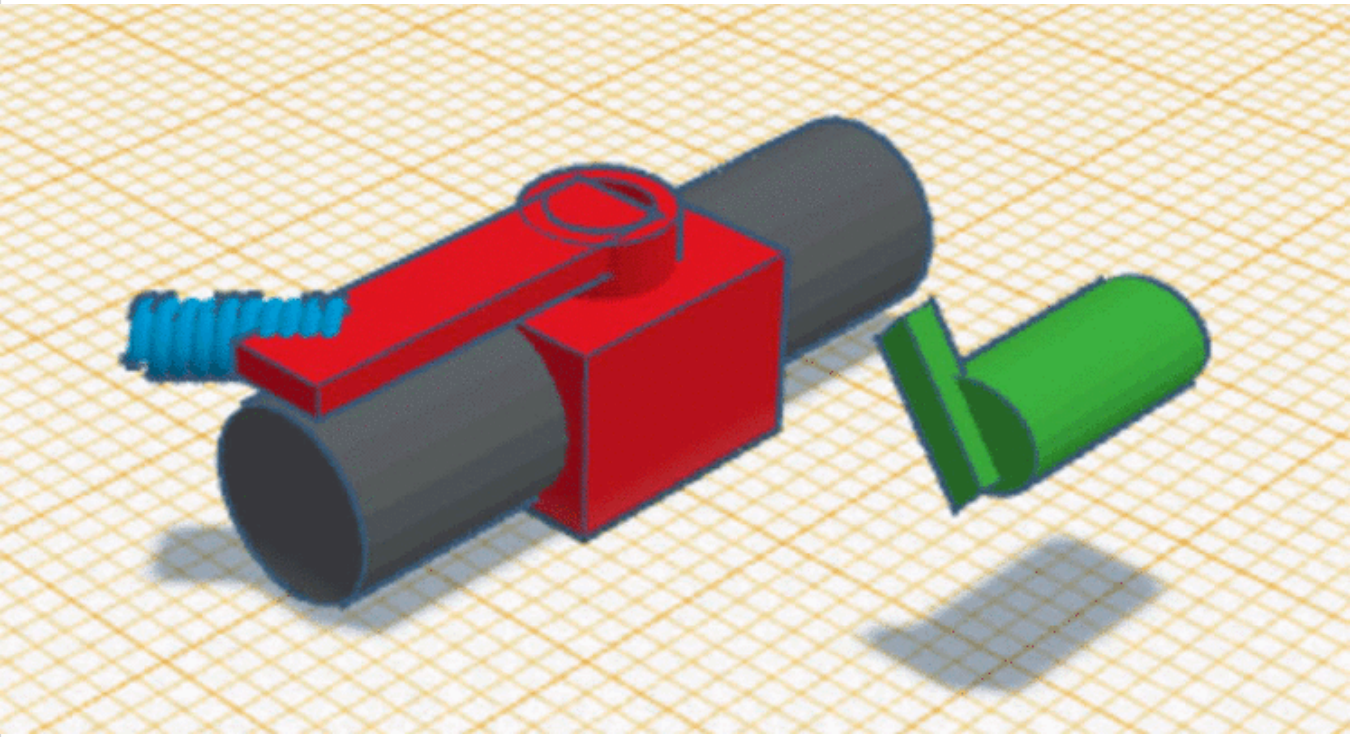
New Testbed Design



Manufacturing

- Manufacturing Overview
  - Manual Ball Valve
  - Settling Chamber
  - Diffuser
  - 3D printing nozzles
  - Sensor integration
  - Assembly

2.5" Ball Valve Actuation



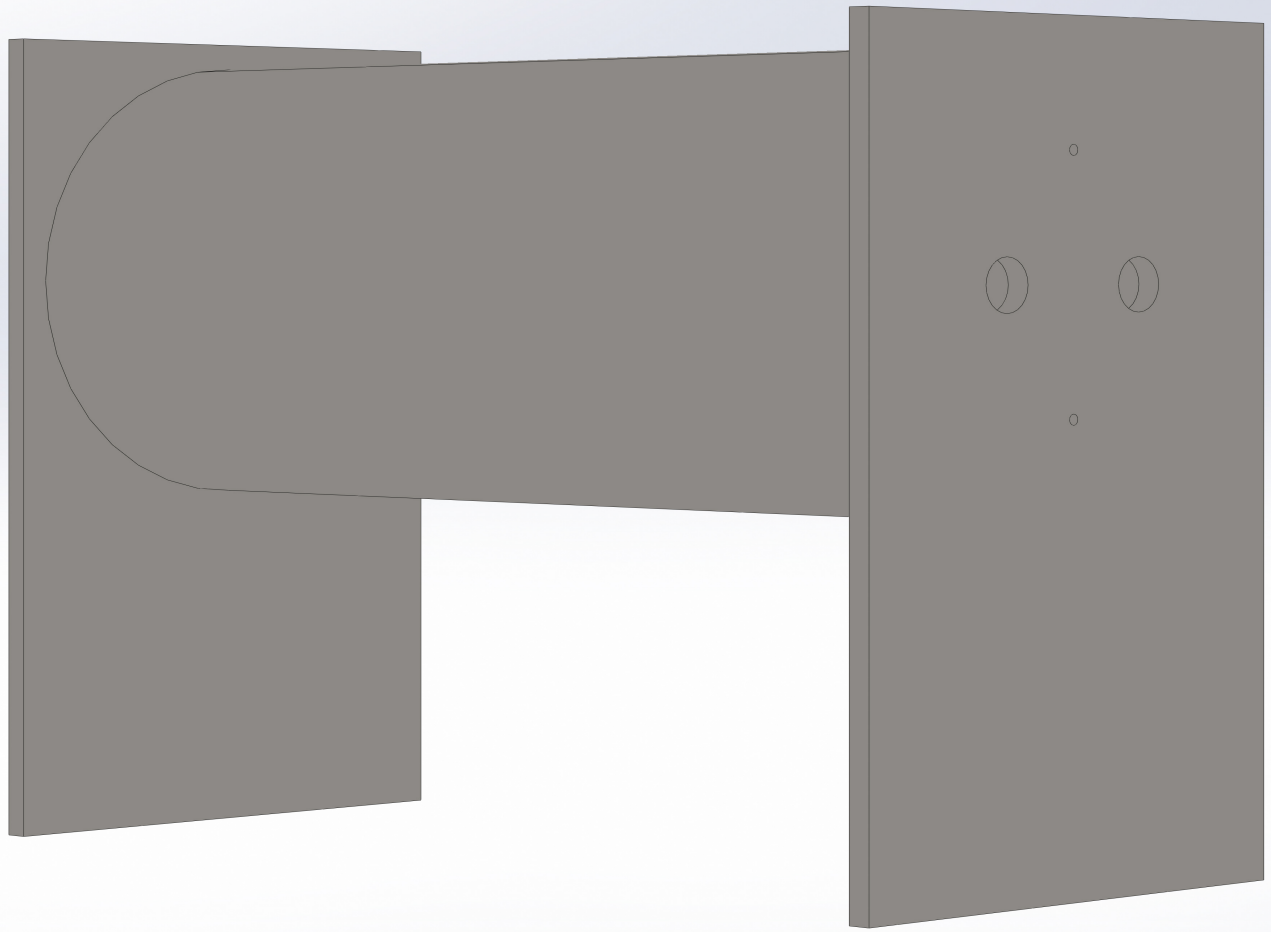
Stepper Motor w/ Release Pin

2.5” Manual Ball Valve

Preloaded Spring

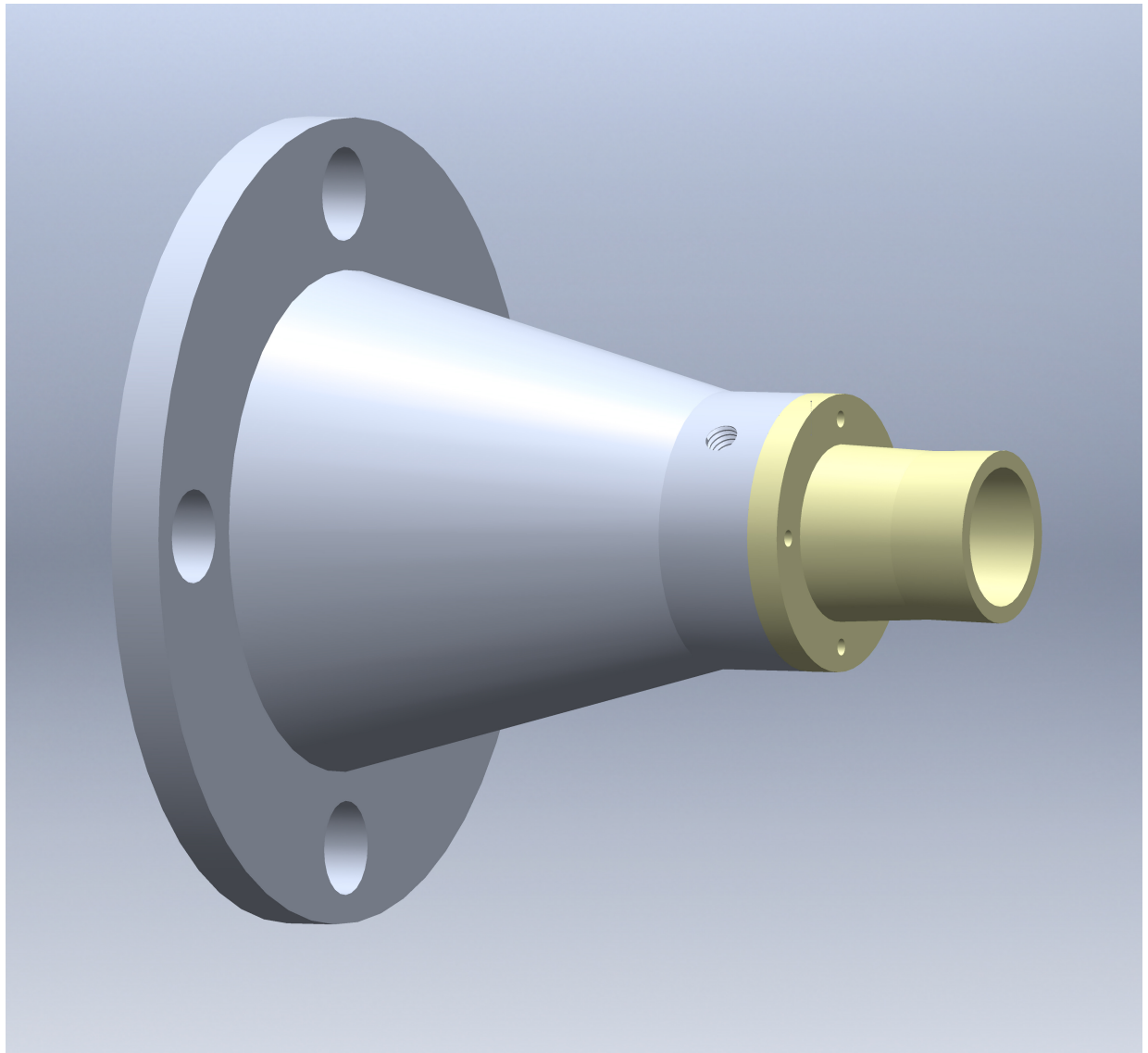
Duct between S/C and Nozzle

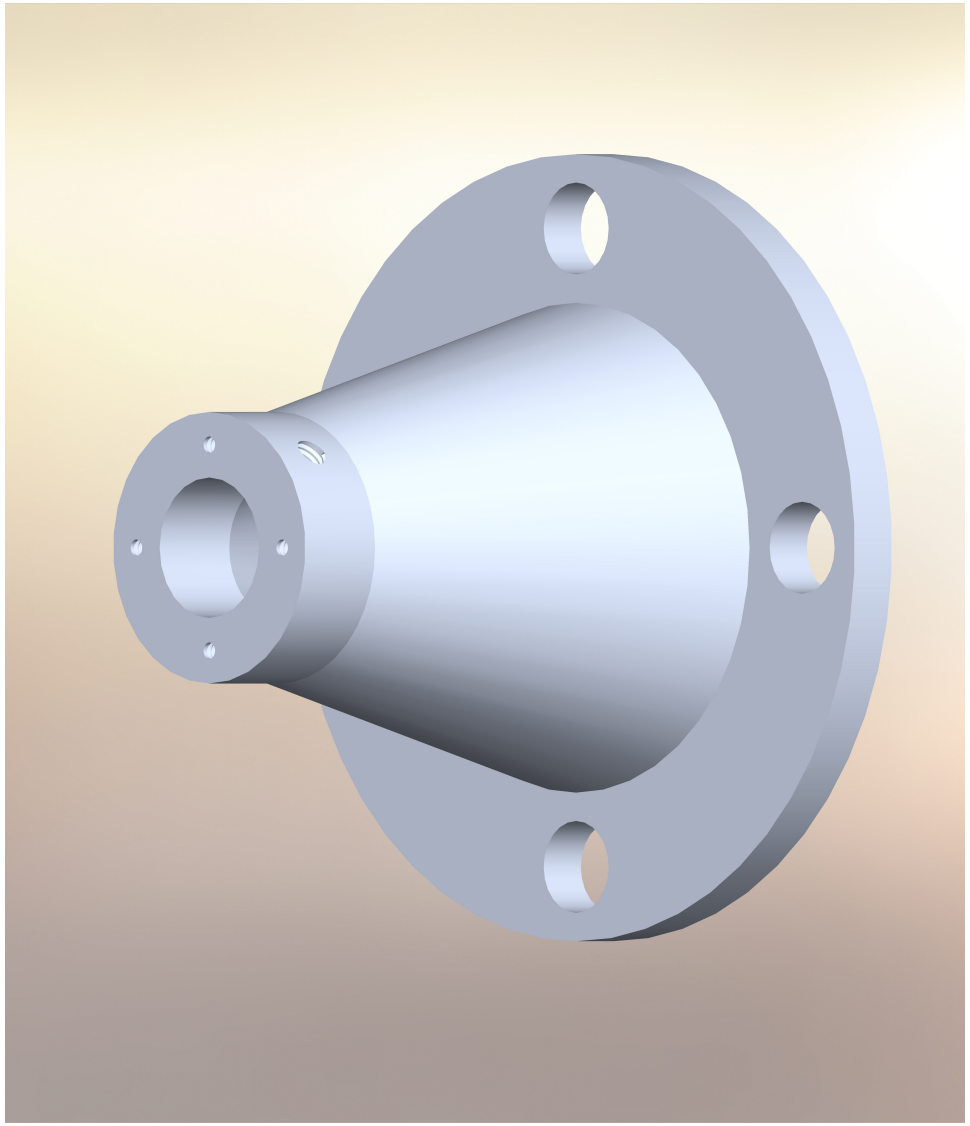
Settling Chamber



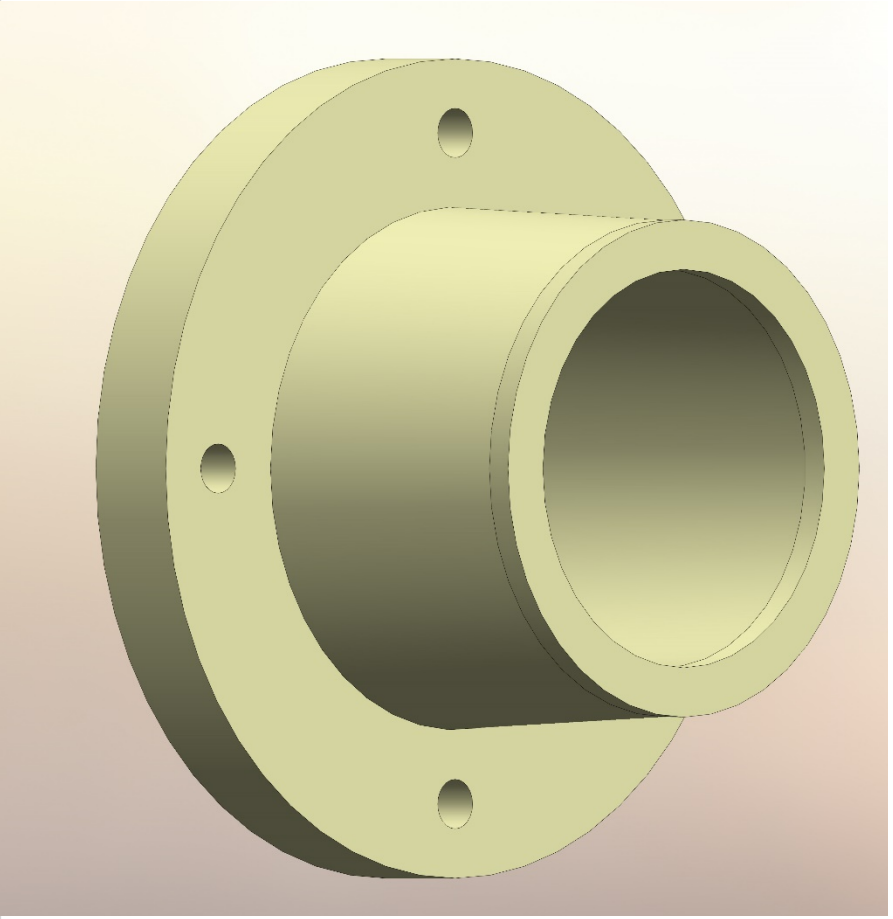
- Steel
- 2 plates 1 cylinder
- 25"x10"
- 5 holes total
- Welded in house
- Pressure testing required

Diffuser





Additive Manufacturing



Left:

M = 1.06

D_{throat} = 1.005

D_{exit} = 1.006

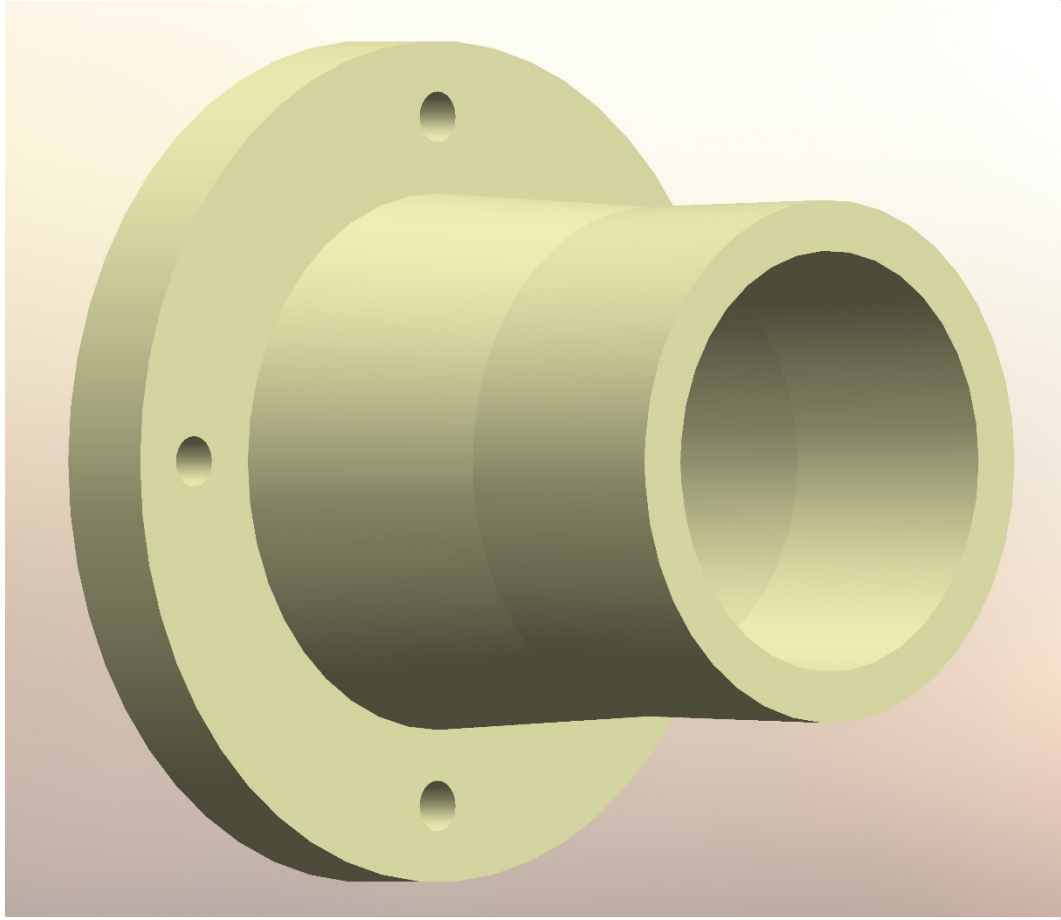
Clear FLGPCL02

Right:

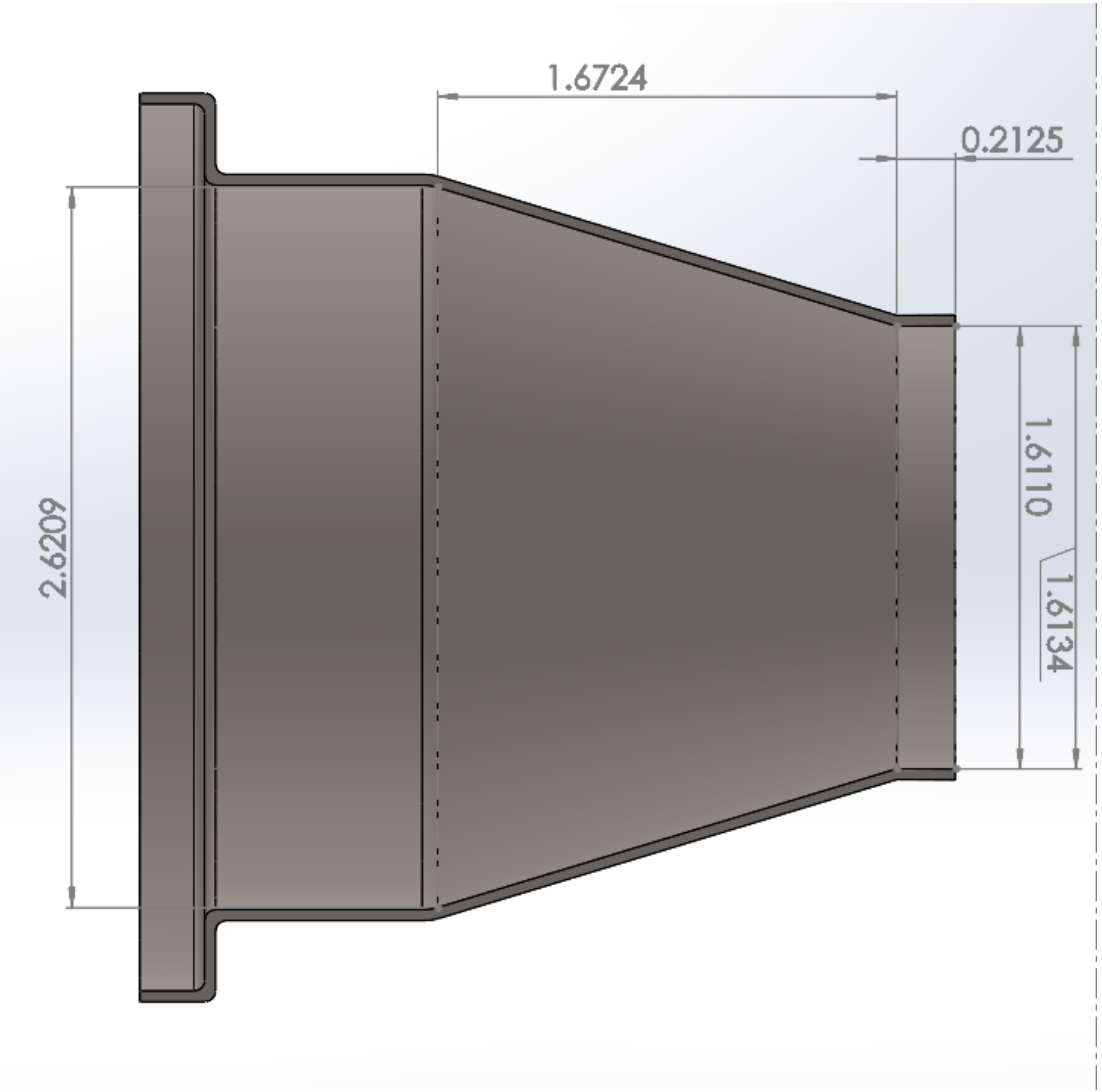
D_{throat} = 1.005

D_{exit} = 1.037

Clear FLGPCL02



Additive Manufacturing

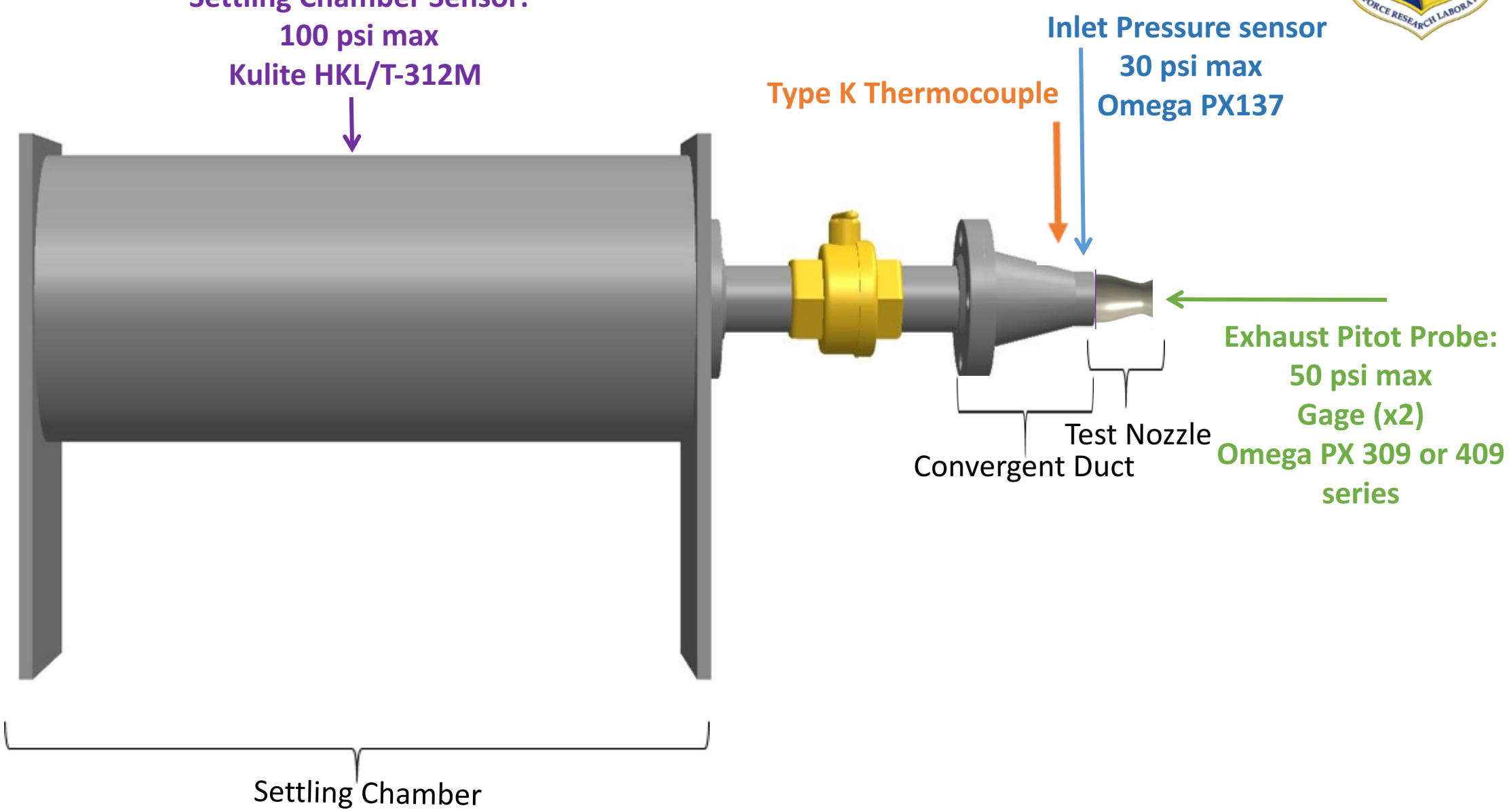


Additive Manufacturing:
Direct Metal Laser Sintering

Material:
Cobalt Chrome

Manufacturer:
GPI Prototype

Sensor Integration

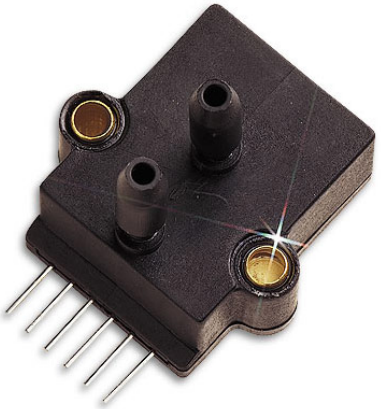


Sensor Selection

Type K Thermocouple (Inlet)

Omega PX137 (Inlet)

- On hand at CU
- Accurate within +/- 1.5 psi



Kulite HKL/T-312M (Settling Chamber)

- On hand at CU
- Accurate within +/- 0.5 psi

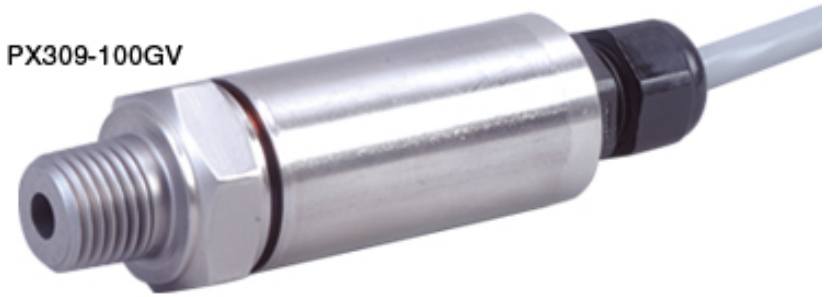
Nozzle Exit Pressure Sensor

Ideal Sensor (Budget Permitting)

Omega PX409, range of 50 psig
$500
Accuracy within +/- 0.04 psi

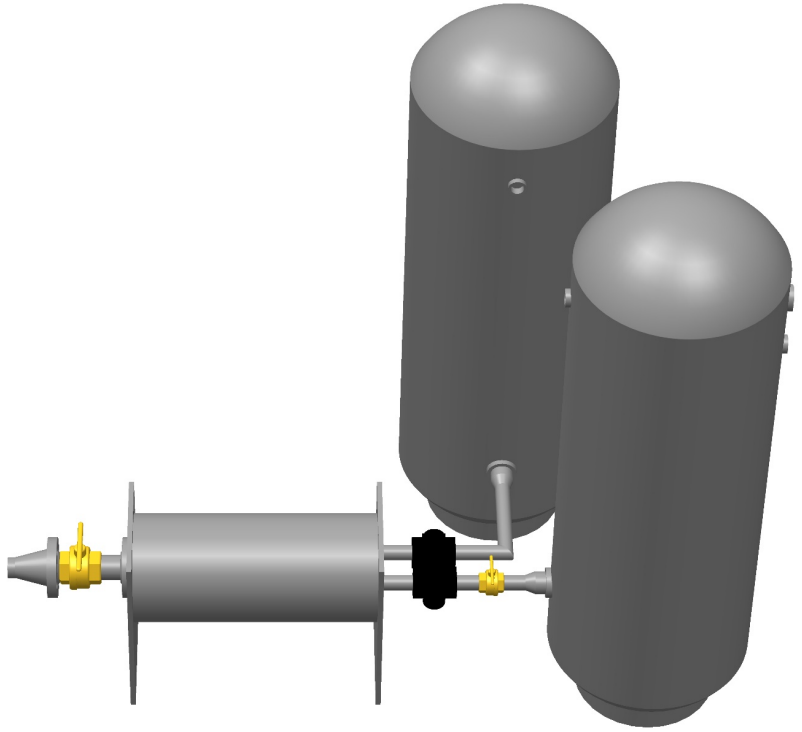
Back Up Plan

Omega PX309, range of 50 psig
$200
Accuracy within +/- 0.12 psi



Final Assembly

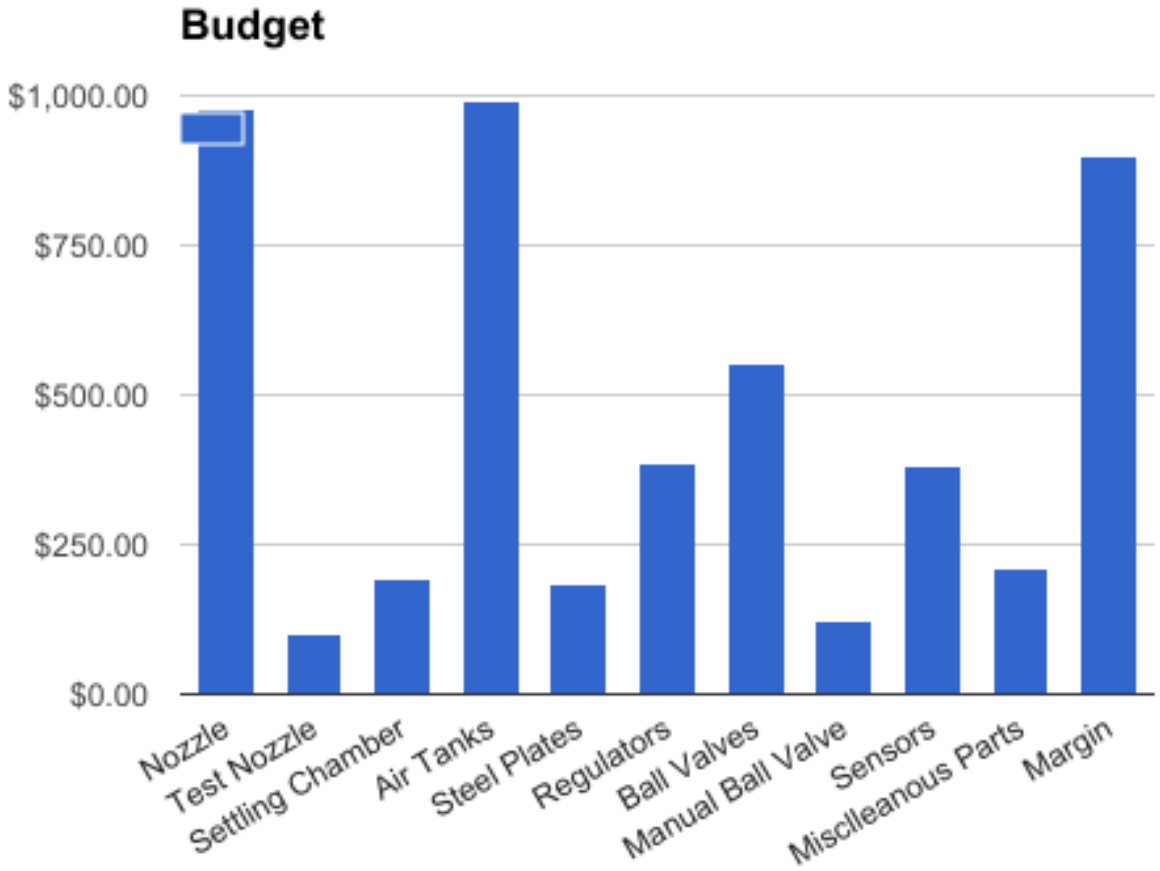
- Mounting diffuser on settling chamber
- Connecting all pipes, regulators, and valves
- Full CAD assembly picture



Project Budget

Current Finances

- Margin: $897.47
- Potential cost sharing of air tanks with hypergolic team
- Applying for additional funding from EEF



Procurement Status

Category		
	Status	Item
Nozzles		
	Ordered	Nozzle
3D print →	Not Yet Ordered	Test Nozzle
Test Bed		
	Not Yet Ordered	1.25" NPL
	Not Yet Ordered	1.25" NPL 6"
	Not Yet Ordered	Bushing
	Not Yet Ordered	1.5" to 1.25" bell
	Not Yet Ordered	1.25" Flange
	Not Yet Ordered	300 psi Max Gauge
	Not Yet Ordered	1.25" SPA Flex
	Not Yet Ordered	1.25" Plug
	Not Yet Ordered	2" Plug
	Not Yet Ordered	Pressure Release Valve
	Not Yet Ordered	.5" Plug

To be purchased at McGuckin's

Test Bed (cont.)		
	Delivered	Settling Chamber (10" Steel Pipe)
	Delivered	ISC 80@ 200 PSI tank
	Delivered	Steel Plates (Settling Chamber)
	Delivered	Regulators
	Delivered	Ball Valves
To be ordered from Grainger →	Not Yet Ordered	Manual Ball Valve
	Not Yet Ordered	Sensors

To be ordered from Omega

Appendix

Hydrostatic Testing

- Pressurize vessel to FOS test pressure with incompressible liquid
- Investigate pressure drop and leaks
- Investigate any permanent deformations
- Benefit of non-explosive rupture
- NWIS Hydrostatic Burst November 21, 2014

Safety: Energy and Blast

- Energy Stored in Settling Chamber: 79501 J = 0.01374 Lbs. TNT

$$W = p_o v_o (ln\frac{p_o}{p_a} - 1) + p_a v_o$$

- FEMA: Unit IV Explosive Charges
  - Shatters windows: 160 ft.
  - Eardrum rupture: 30 ft.
  - 1% fatality point: 10 ft.
- "Blast Overpressure and Survivability Calculations for Various Sized of Explosive Charges"
  - Threshold lung damage facing blast: 9 ft.
  - Threshold lung damage facing sideways to blast: 6 ft.

Safety: Shrapnel

- Maximum Speed of Smallest Object: 1628 m/s = 3642 mph

$$E_{kinetic} = \frac{1}{2}mv^2$$

- Terminal Velocity: 29.86 m/s = 66.79 mph

$$v_t = \sqrt{\frac{2mg}{\rho A c_d}}$$

- Maximum Horizontal Distance of Travel: 3683 m = 2.289 mi

$$x_{max} = \frac{v_o v_t cos(\theta)}{g}$$

Error Propagation Analysis

$$\delta P0_2 = P1 * \sqrt{(\frac{\partial P0_2}{\partial M}\frac{\partial M}{\partial A/A}\delta A/A)^2 + (\frac{\partial P0_2}{\partial M}\frac{\partial M}{\partial A/A}\frac{\partial A/A}{\partial \dot{m}}\delta \dot{m})^2 + (\frac{\partial P0_2}{\partial M}\frac{\partial M}{\partial A/A}\frac{\partial A/A}{\partial P0}\delta P0)^2}$$

- 0.075 psi of Error with 0.5% Mathematical Error
- Required 0.12 psi of Resolution to Capture 0.004 +/- Mach
- Ideal 0.04 psi of Resolution to Capture 0.0013 +/- Mach