Low Boom Flight Demonstrator Project

SAFE Symposium

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X-59 Aircraft Life Support System Integrated Test Planning, Execution, and Results

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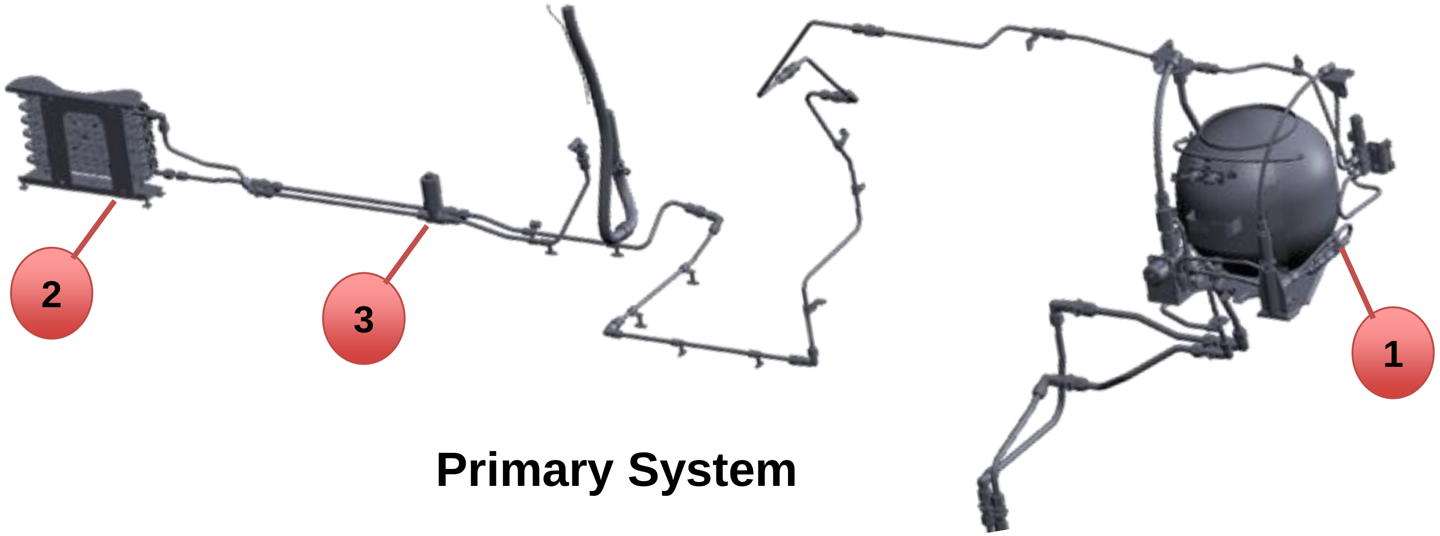
Outline

- Breathing Path Flow Analysis
- Test Planning
- Test Execution and Results
  - Test Driven Design
  - Manned Impedance
  - Manned Rapid Decompression
- Recent Emergency Oxygen System (EOS) Developments
  - Description
  - Initial Testing Results
- Summary

Breathing Path Flow Analysis

- Objectives
  - Ensure breathing system maintains sufficient pressure upstream of the pressure reducer feeding the primary Panel Mounted Breathing Regulator (PMBR) in the X-59 designed installation configuration\
  - Ensure the fluid mechanically "equivalent" system-under-test maintains sufficient similarity to the X-59 designed installation configuration with margin.
- Two (2) independent analyzes were performed to drive "system-under-test" build



Primary System

1	LOX Converter (10 Liter)
2	Heat Exchanger
3	**Pressure Reducer**

Goal: "Test like we Fly"

Breathing Path Flow Analysis

- Assumptions
  - Desired output volume flow rate (very conservative at sustained 40 liters/min breathing rate)
  - Use of conservative performance parameters ***(those that produce largest pressure drop along flow path)***

Summary of Integrated Testing Tube Lengths

Tube Assembly	X-59 As-Designed Length (ft)	Fluid mechanically "Equivalent" Length (ft)
KBR tube 1 (LOX supply hose to LOX manifold)	0.7	1.9
KBR tube 2 (LOX manifold to Hx)	14.5	21.5
KBR tube 3 (Hx to Press Sensor Tee)	1.8	3.2
KBR tube 4 (Press Sensor Tee to Press Reducer)	1.0	1.0
KBR tube 5 (Press Reducer to BRAG)	1.3	1.7
Sum of all lengths	**19.1**	**29.3**

System-Under-Test

Test Planning

- Test Objectives
  - Validate the full X-59 and F-15 Life Support Systems (LSS) as “Safe-to-Fly”
  - Verify the X-59 LSS requirements that are applicable to the integrated testing
  - Test capacity X-59 and F-15 LSS to meet, where applicable, evaluation criteria
- Evaluation Criteria
  - Air and Space Interoperability Council (ASIC) Air Standards (AIR STDs):
    - 1052, *Minimal Protection for Aircrew Exposed to Altitude Above 50,000 Feet*
    - 4038, *Physiological Evaluation of Aircraft Oxygen Delivery Systems*
    - 4039, *Minimum Physiological Requirements for Aircrew Demand Breathing Systems*
    - 4083 Ed 1 v1, *Methodology of Partial Pressure Suit Evaluation for High Altitude Protection*
  - JSSG-2010-10, *Crew Systems Oxygen Systems Handbook*

Comprehensive test plan

Test Planning

- Plan Development
  - Collaboratively developed using Iterative process lasting a few months
  - Test Facility: KBR Space & Mission Solutions; Brooks City Base, San Antonio, TX

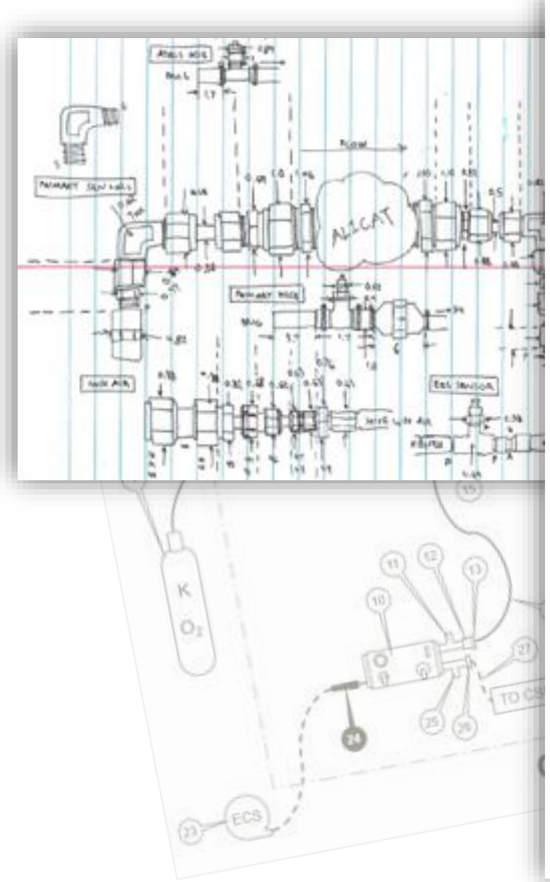
System	Primary, Emergency
Breathing Rates: Peak / Avg [L/min]	17, 72, 157, 200 / 4, 22.5, 50, 75
Steady Altitudes [k ft]	GL, 8, 15, 22.5
Rapid Decompressions [10k ft/min]	14.5 – 35, 18.5 – 44, 20 – 50, 22.5 – 60
Breathing Regulator	PMBR, CRU-122
Breathing Apparatus	Breathing Machine, Live Test Subjects
Live Subject Workload [Watts]	Rest, 50, 100, sometimes with reading

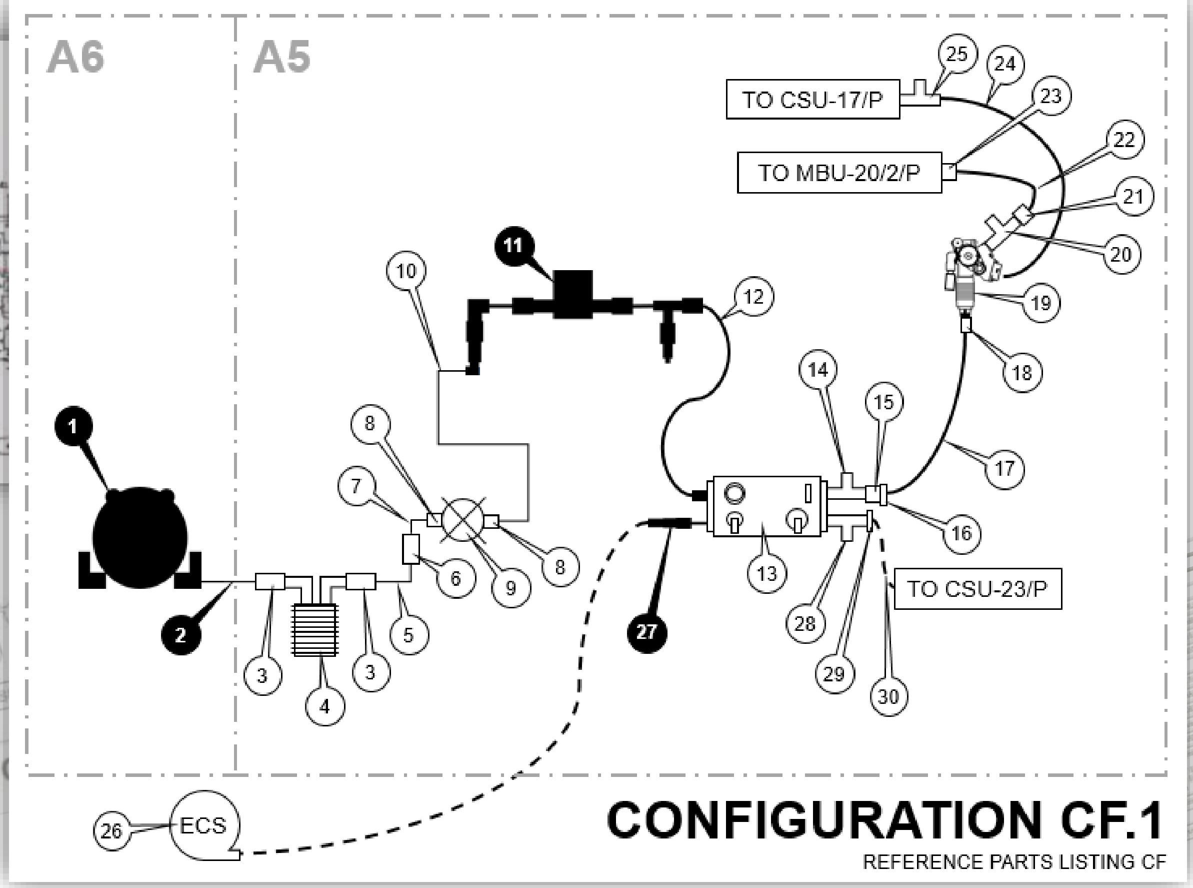
VERY LARGE TEST MATRIX

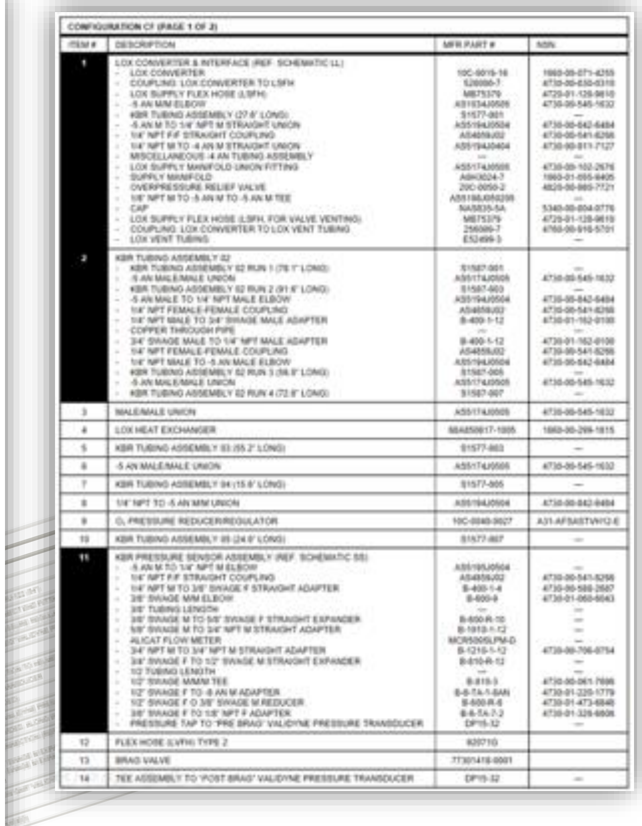
Collaborative development to ensure comprehensive test plan

Test Planning

- Test Schematic Development
  - Assisted readiness assessment
  - Assisted test setup, teardown, shipping/receiving, and as-run configuration documentation







Schematics Proved Essential for Successful Test Ops

Test Execution and Results – Test Driven Design

- Unmanned Testing: Breathing Impedance Problem Discovered
  - Systematic changes to configuration to isolate source: LOX -> Regulator -> Mask
  - Assumed source was newly introduced hardware
  - Problem was isolated to the ejection seat mounted quick disconnect check valve

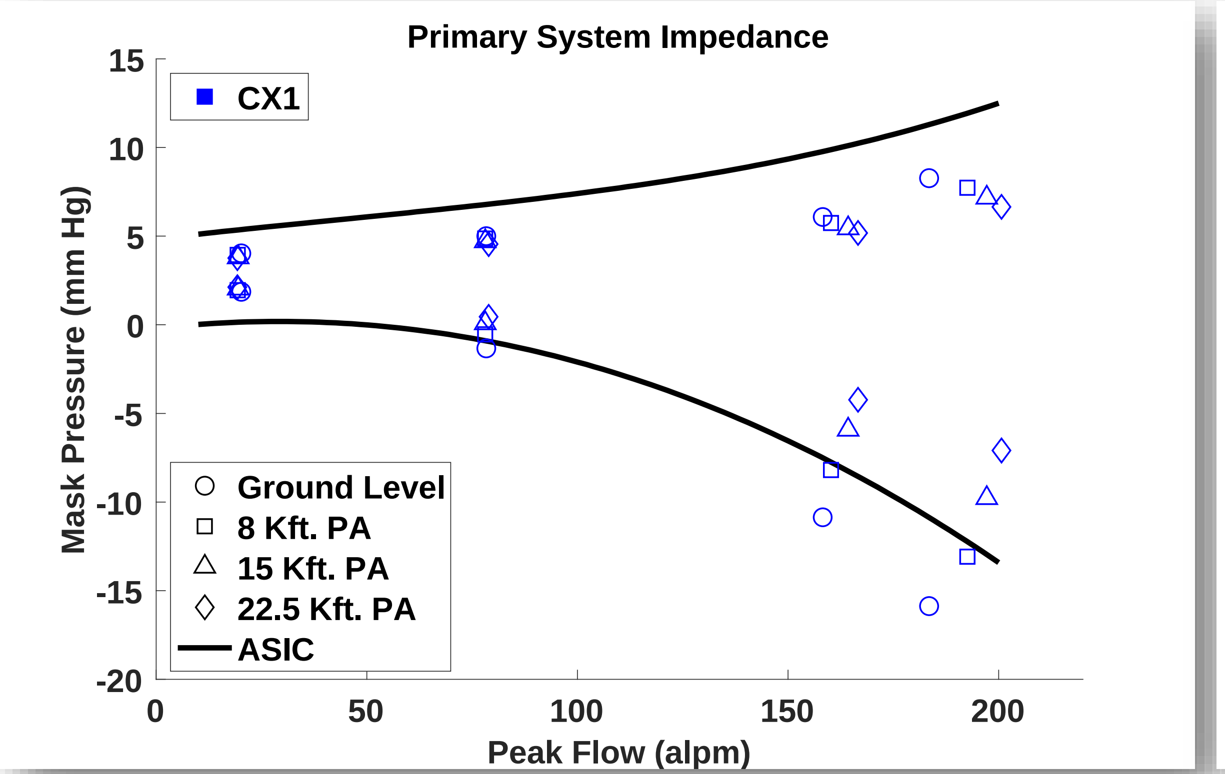
Solution:
Remove Check Valve from Life Support System Design

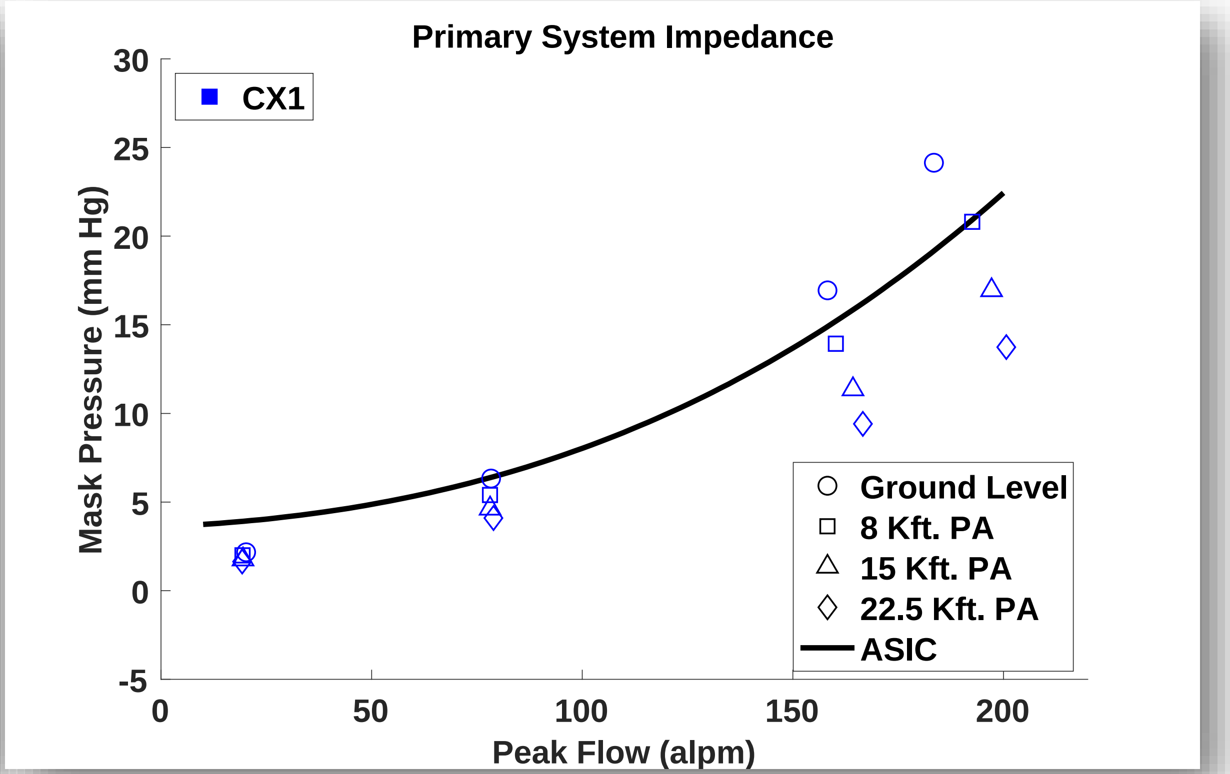
Benefits:
Maintains similarity to our F-15 Chase Life Support System Design

Plots on following slides illustrate this process

Test Execution and Results – Test Driven Design

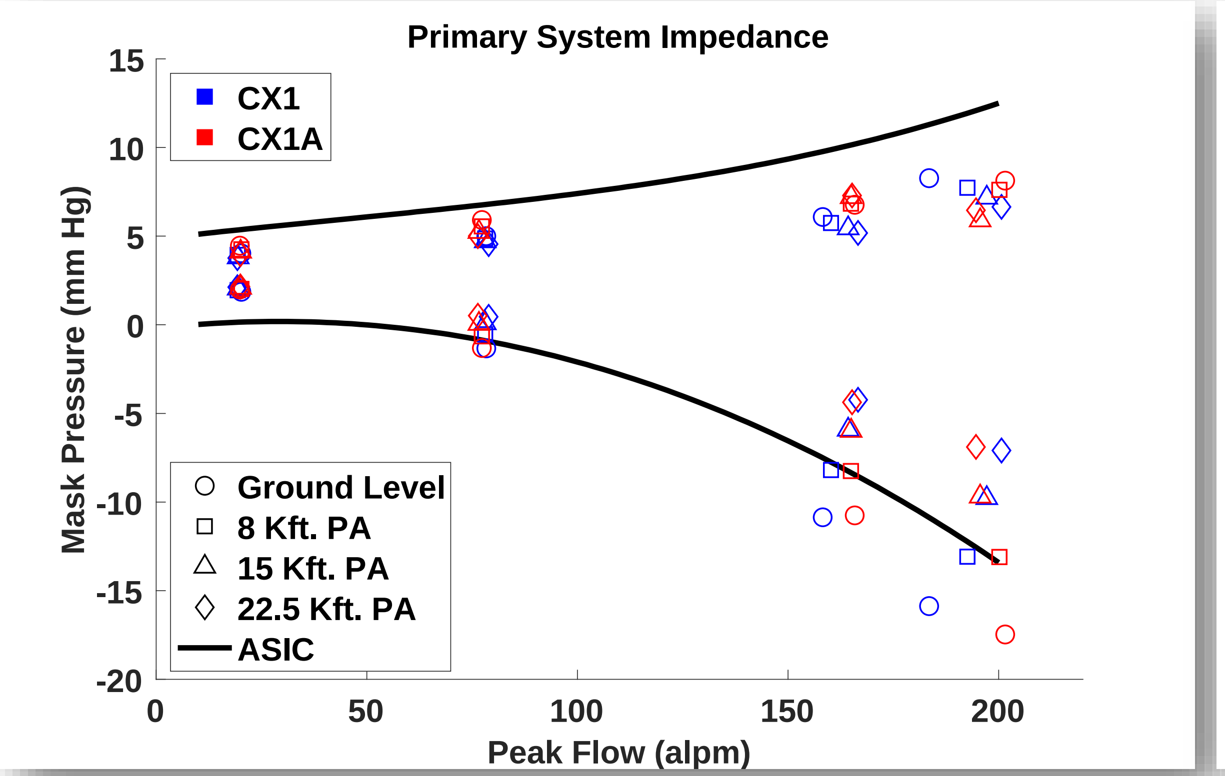
- CX.1: X-59 full system; including check valve

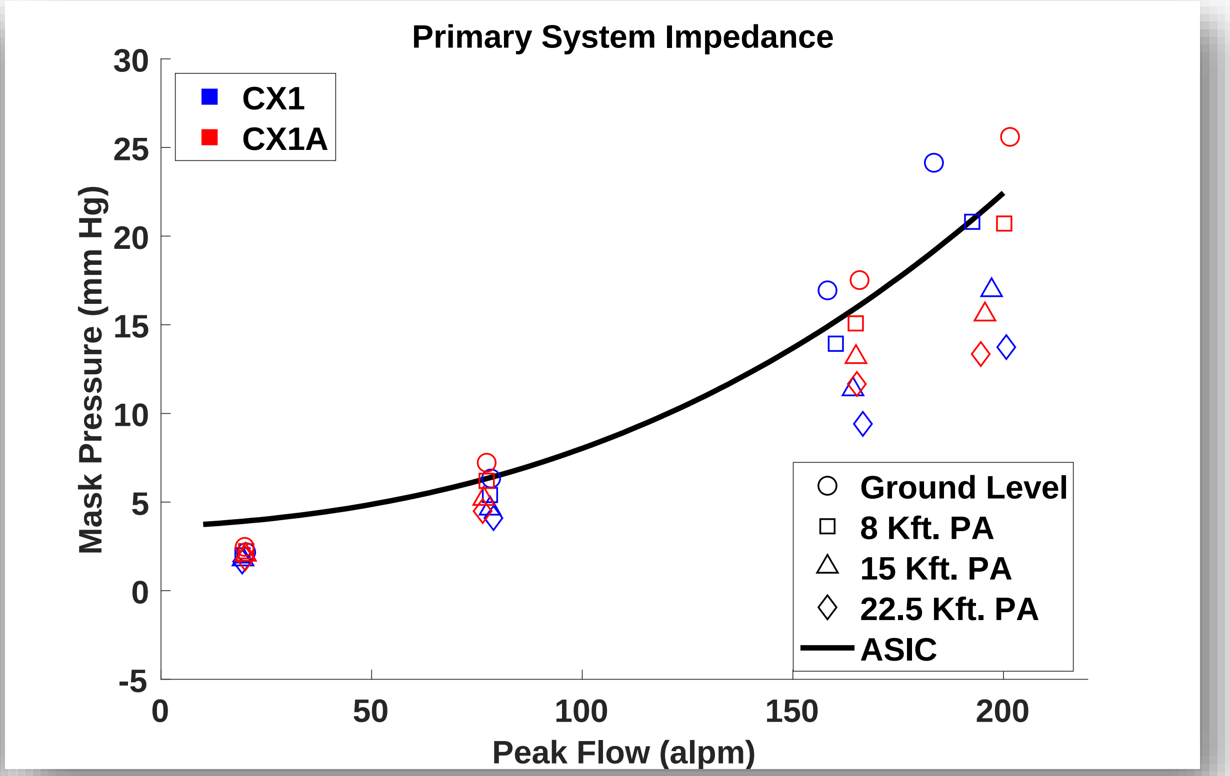




Test Execution and Results – Test Driven Design

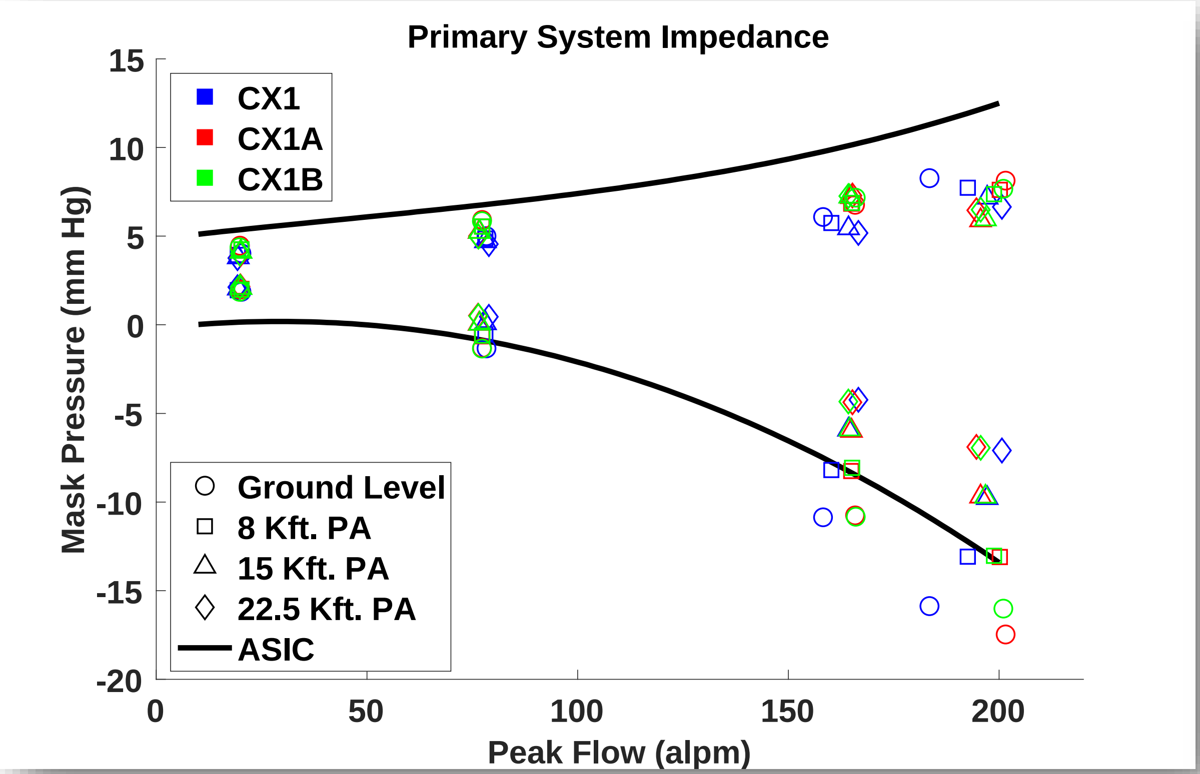
- CX.1A: X-59 full system; shorter LOX delivery line

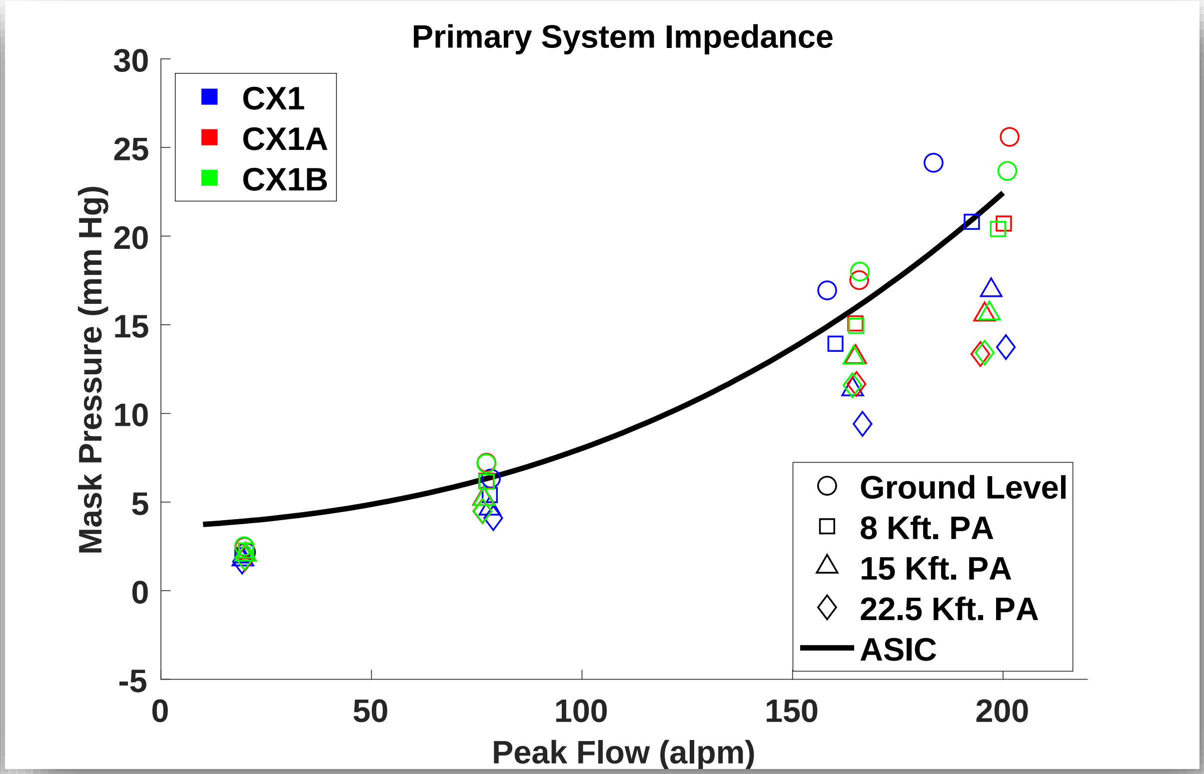




Test Execution and Results – Test Driven Design

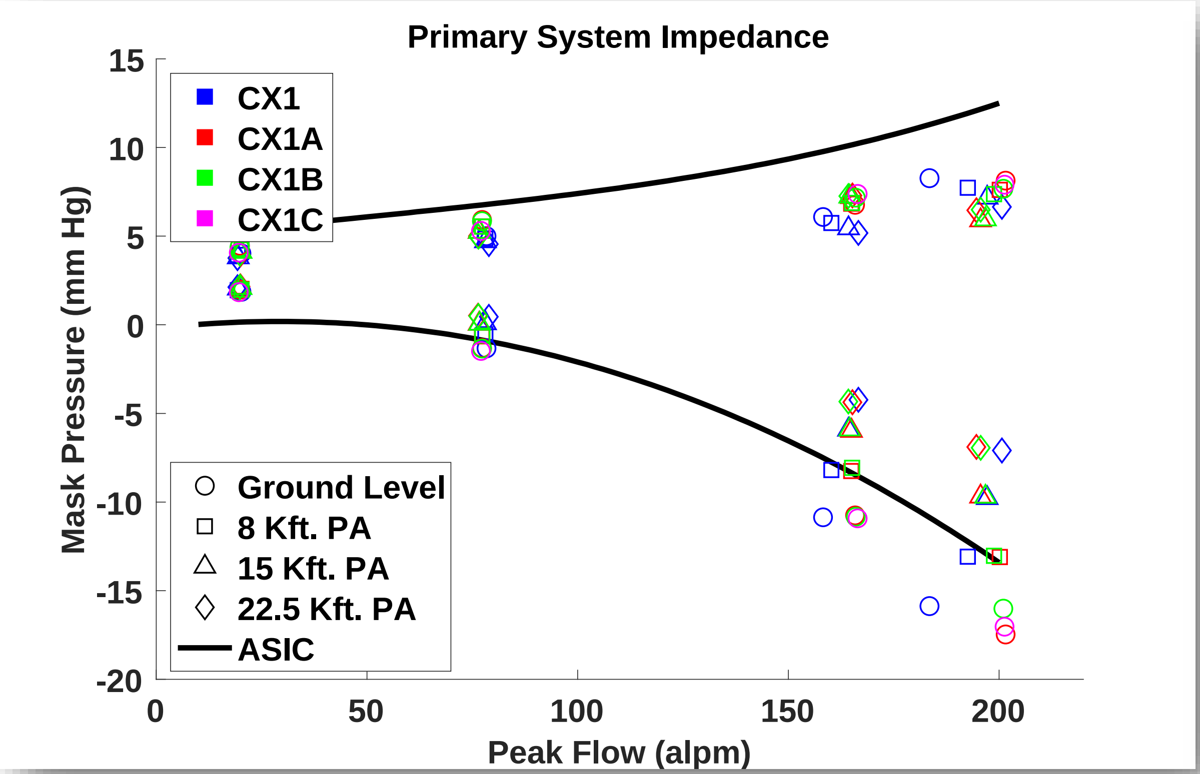
- CX.1B: X-59 full system; shorter LOX delivery line; changed heat exchanger

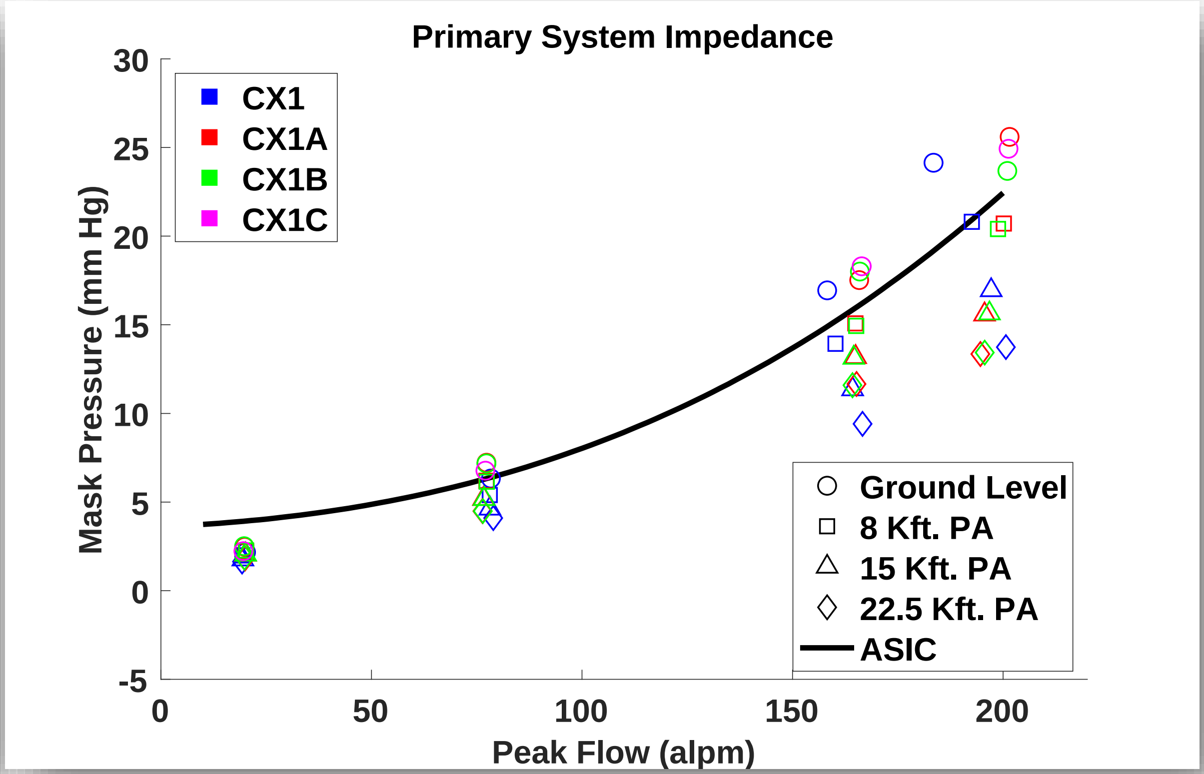




Test Execution and Results – Test Driven Design

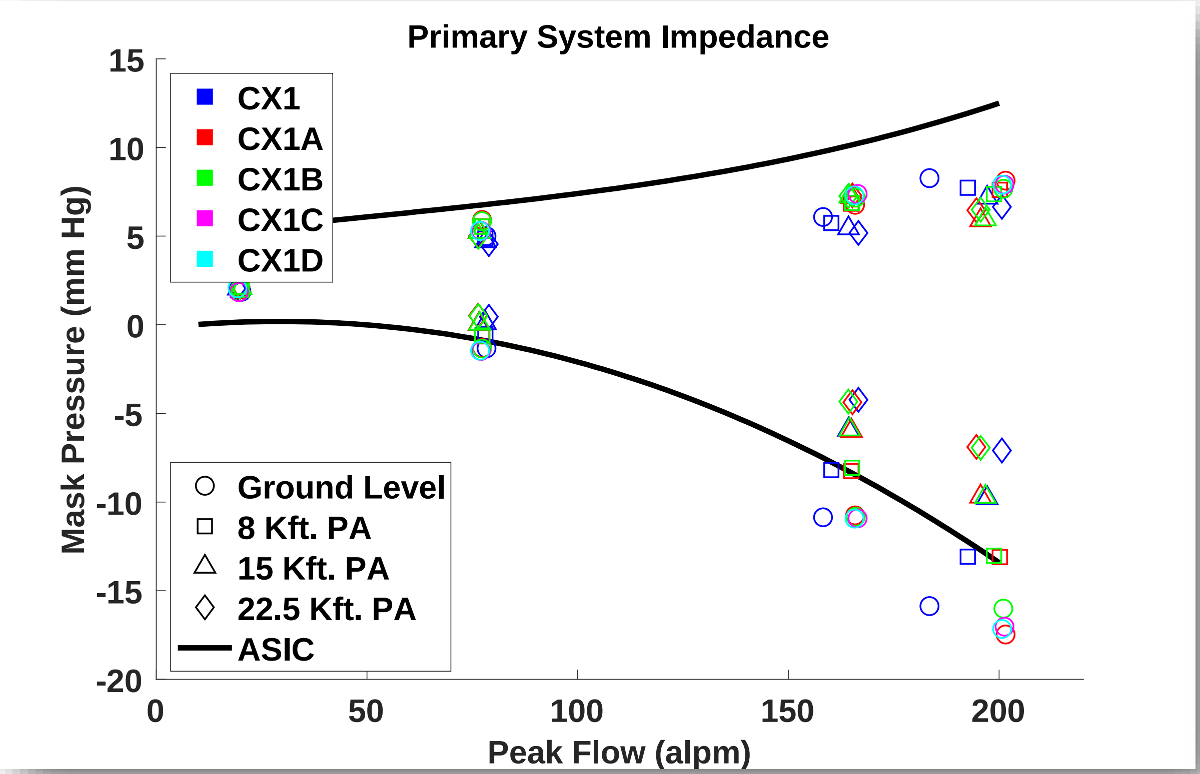
- CX.1C: X-59 full system; shorter LOX delivery line; changed heat exchanger; replaced LOX converter with K-bottle.

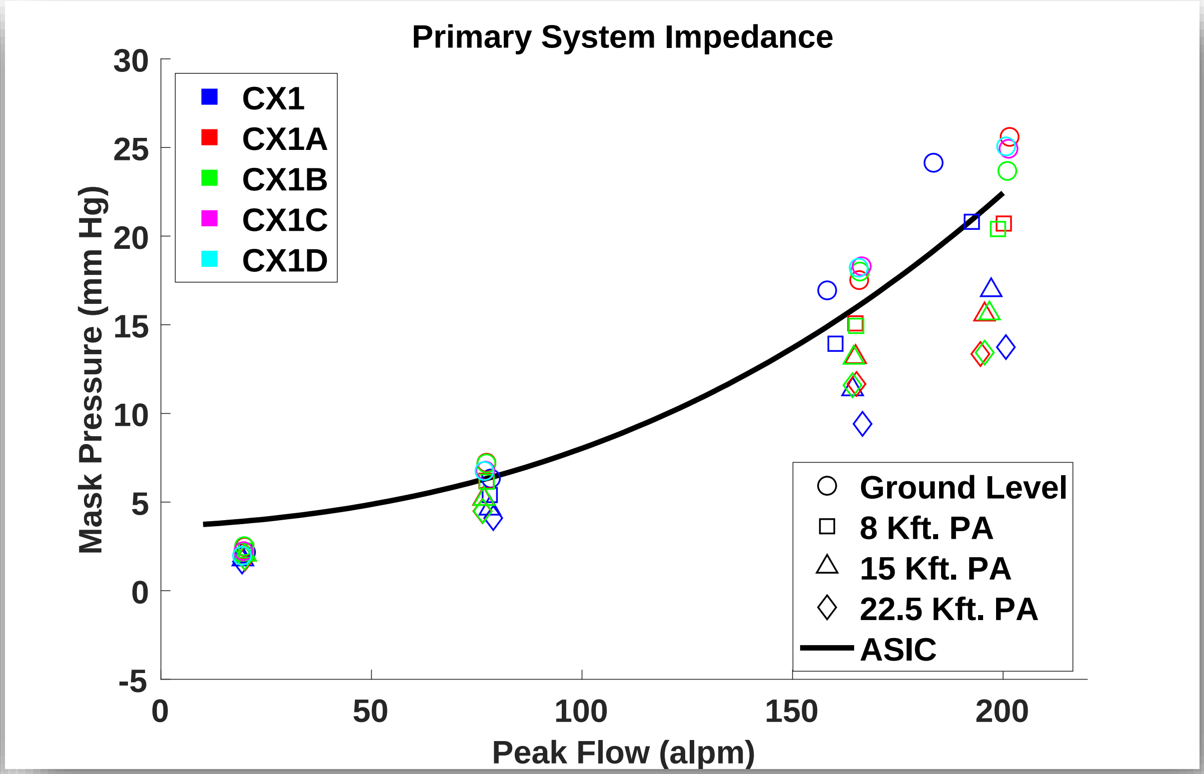




Test Execution and Results – Test Driven Design

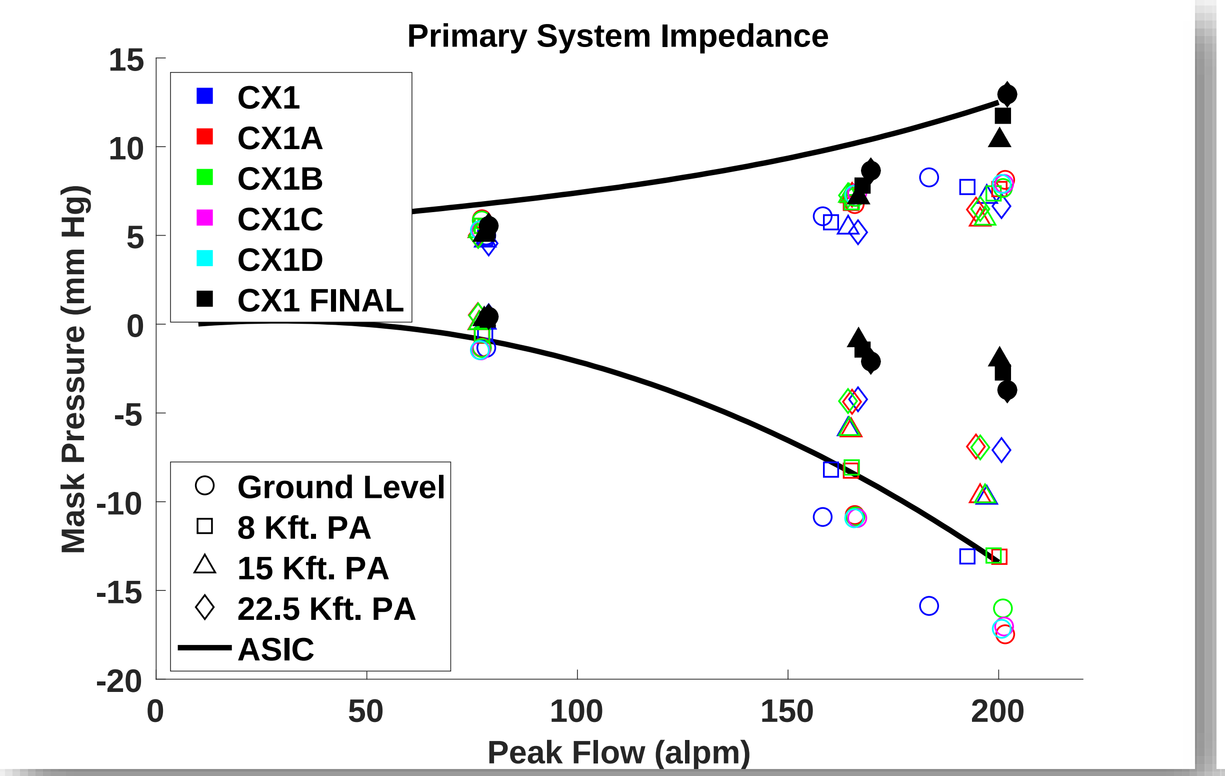
- CX.1D: X-59 full system; shorter LOX delivery line; changed heat exchanger; replaced LOX converter with K-bottle; pressure reducer removed before PMBR

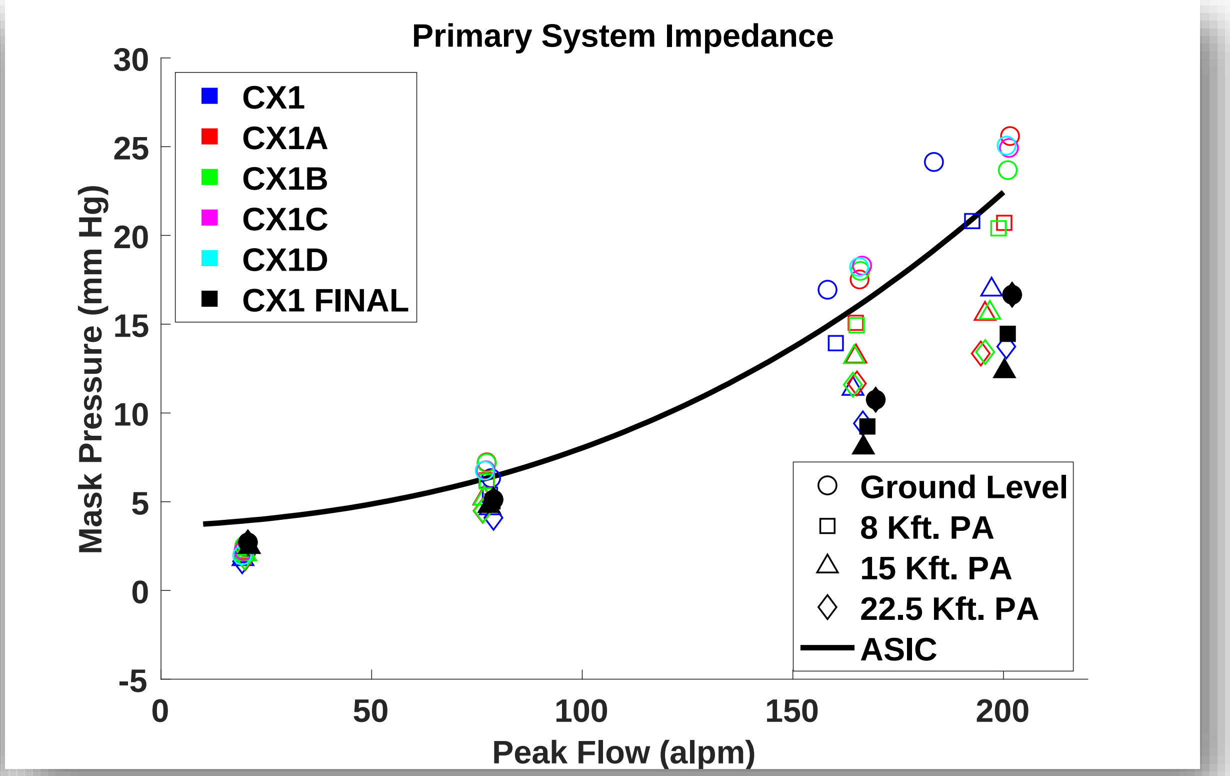




Test Execution and Results – Test Driven Design

- CX.1 FINAL: X-59 full system with check valve removed





Removal of ejection seat check valve reduced impedance and is incorporated into the final design

Test Execution and Results – Manned Testing

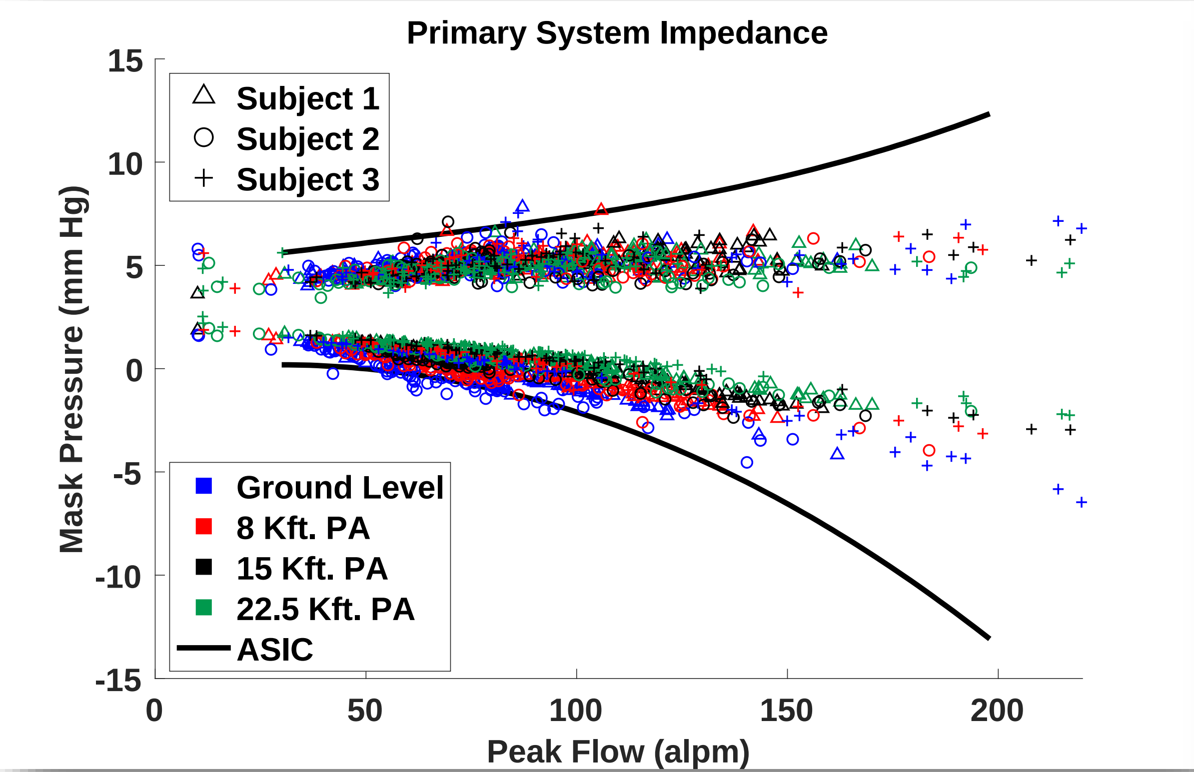
- Manned Impedance Testing
  - Primary Oxygen System (PMBR)
  - Emergency Oxygen System (EOS)

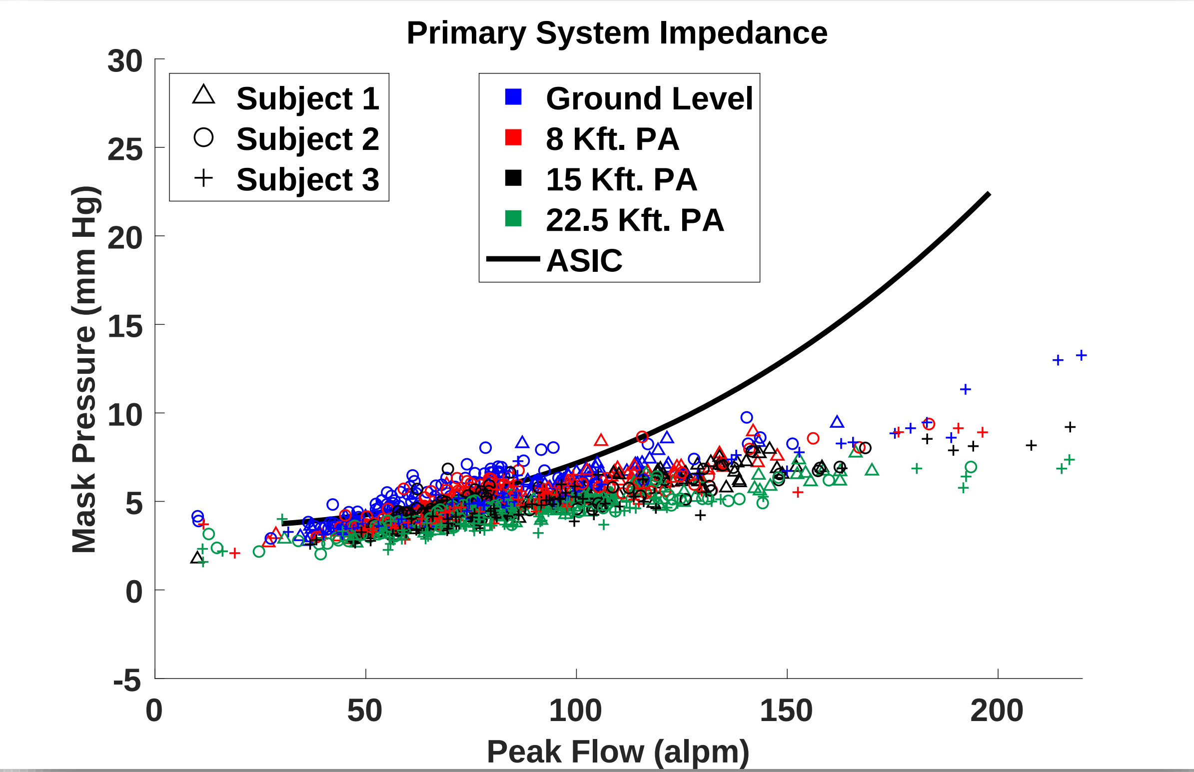
- Manned Rapid Decompression Testing
  - Primary Oxygen System (PMBR)
  - Emergency Oxygen System (EOS) (Forthcoming)

Final manned EOS testing to be performed early 2020

Test Execution and Results – Manned Testing

- Manned Impedance Testing
  - Primary Oxygen System (PMBR)

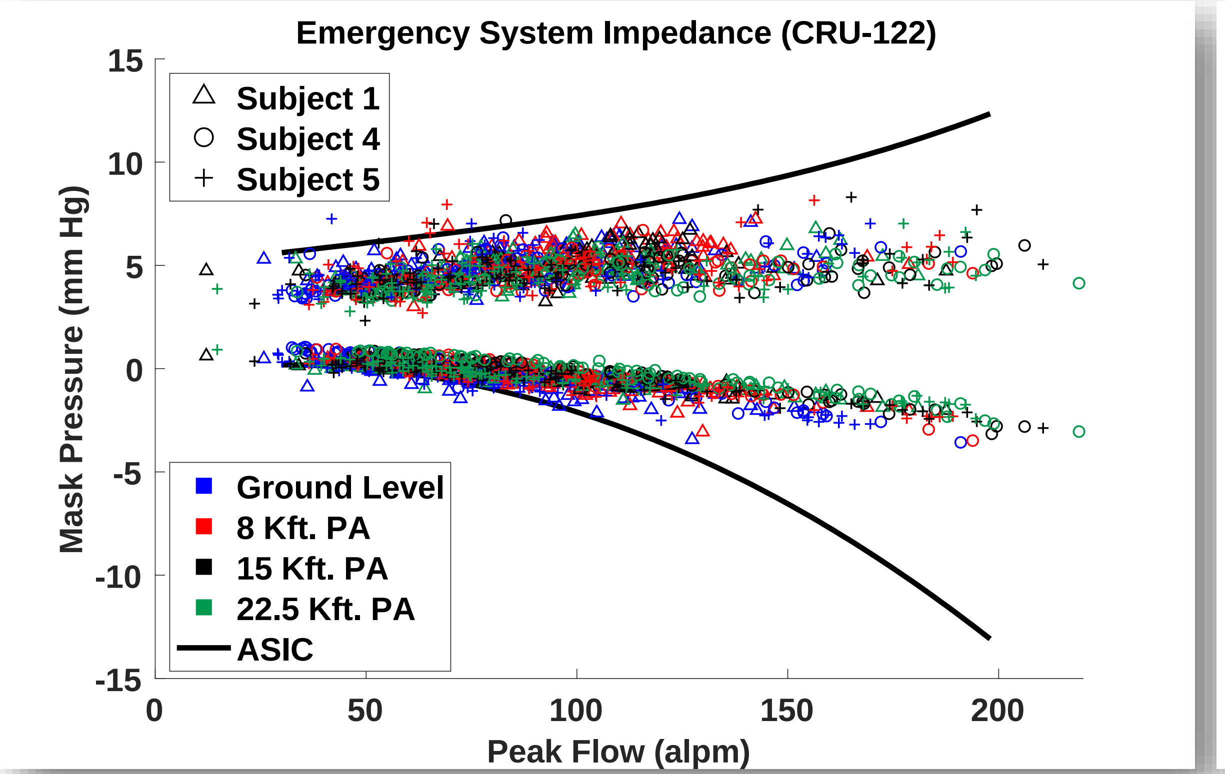


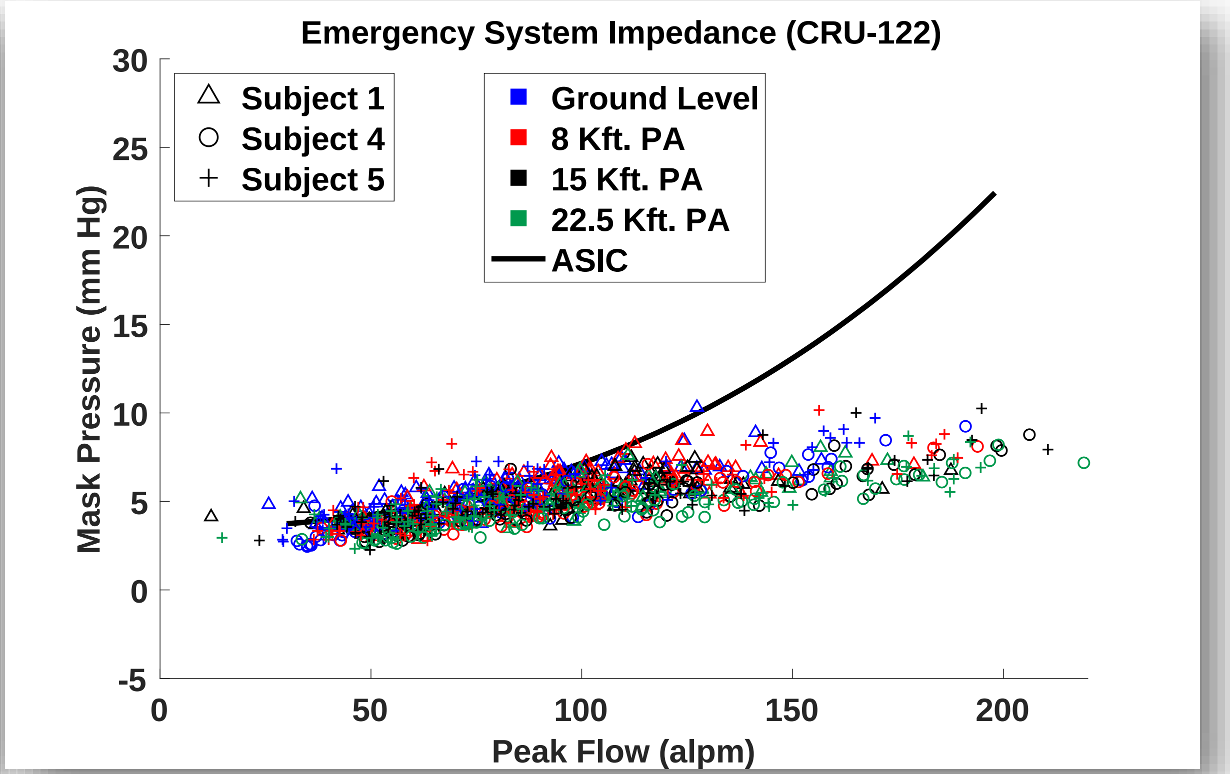


Great results from the manned PMBR impedance testing

Test Execution and Results – Manned Testing

- Manned Impedance Testing
  - Emergency Oxygen System (CRU-122)

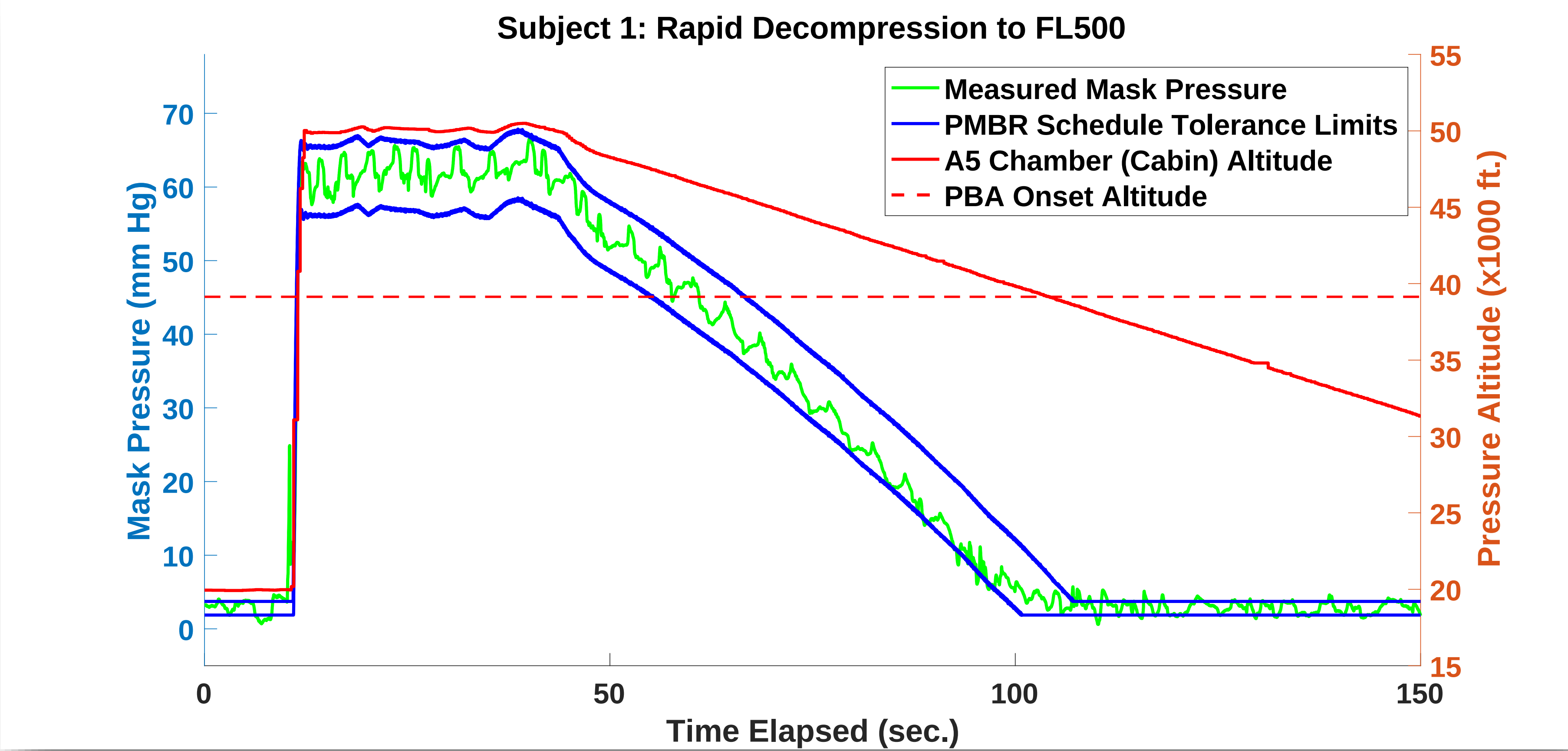




Great results from the manned CRU-122 impedance testing

Test Execution and Results – Manned Testing

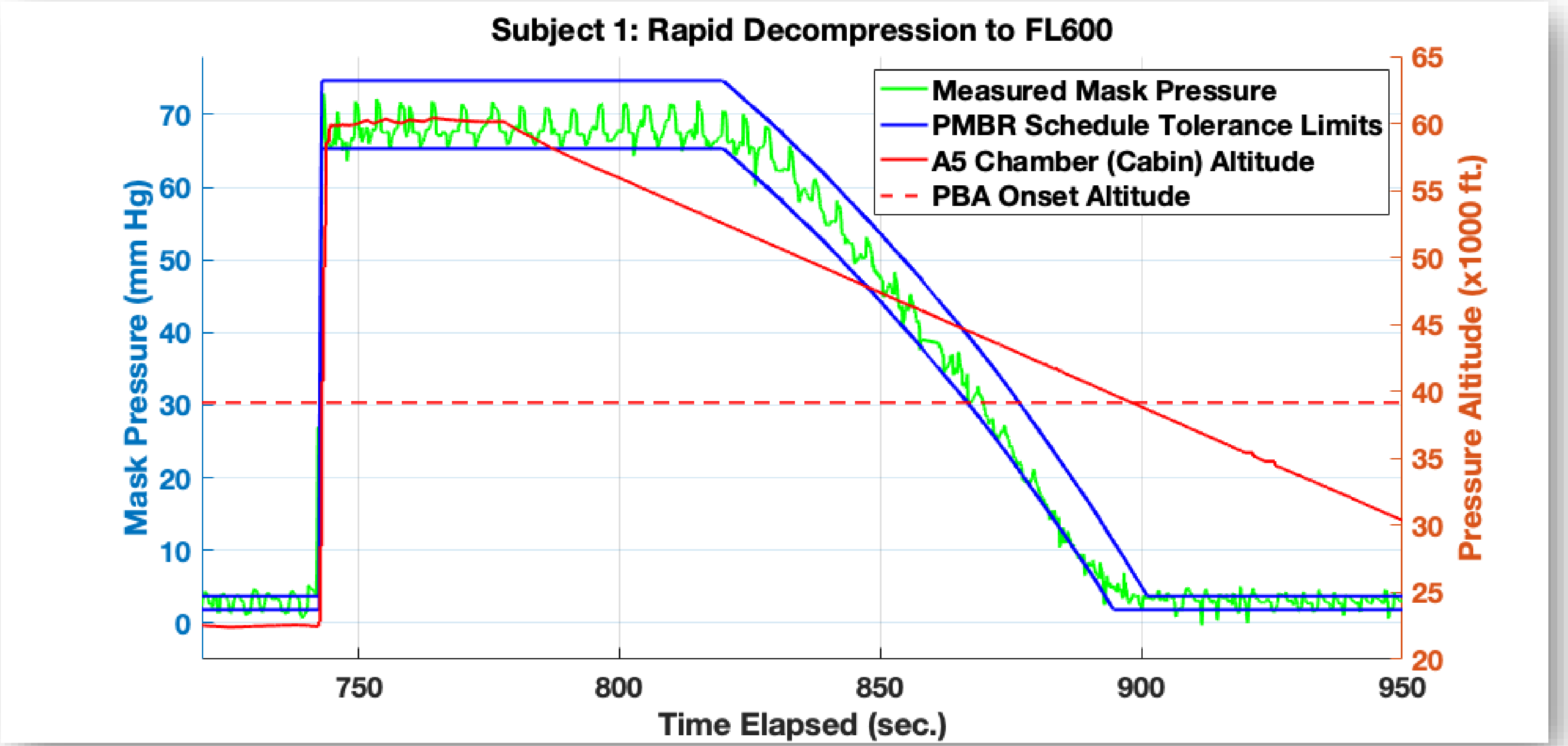
- Manned Rapid Decompression Testing
  - Time history of live subject RD from FL200 to FL500



PBA mask pressures as expected

Test Execution and Results – Manned Testing

- Manned Rapid Decompression Testing
  - Time history of live subject RD from FL225 to FL600



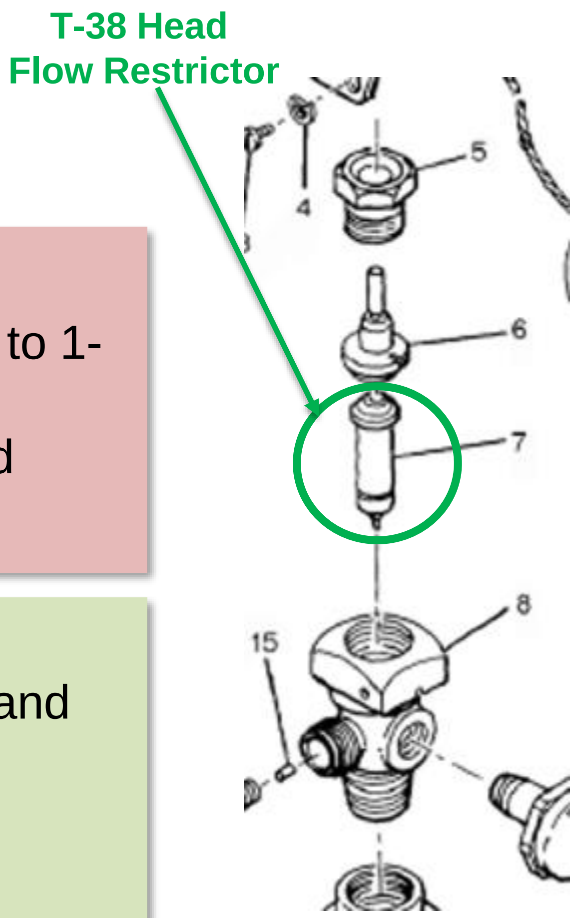
PBA mask pressures as expected

Recent Emergency Oxygen System (EOS) Developments

- System Goals & Objectives
  - O2 capacity large enough to sustain operations up to FL600
  - Provide pressures & flows required by CRU-122 RITB input
  - Minimize ejection seat modifications, to include ***NO*** change to EOS activation

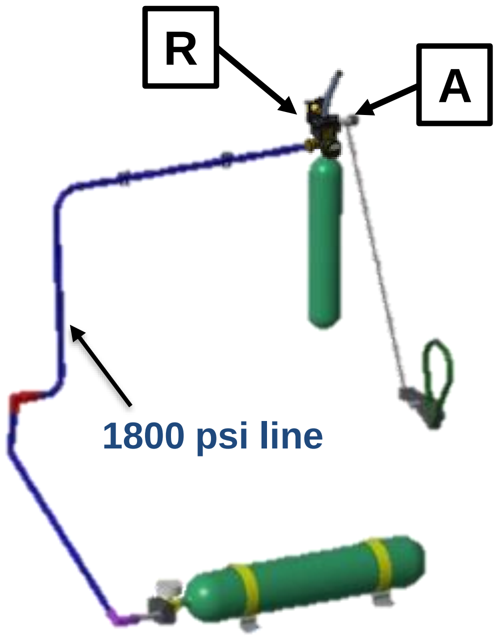
- Problems during LSS integration and Bench Testing.
  - Seat mounted EOS bottle head flow restrictor throttled too much pressure (down to 1-2 psi)
  - Modifications to this head proved challenging to provide reliable performance and introduced airworthiness challenges.

- **Solution**
  - Use a <u>Regulated</u>-EOS (REOS) head and bottle – delivers very stable pressures and flowrates required for the CRU-122
  - Remove flow restriction from the T-38 head – activation only
  - No major ejection seat modifications required

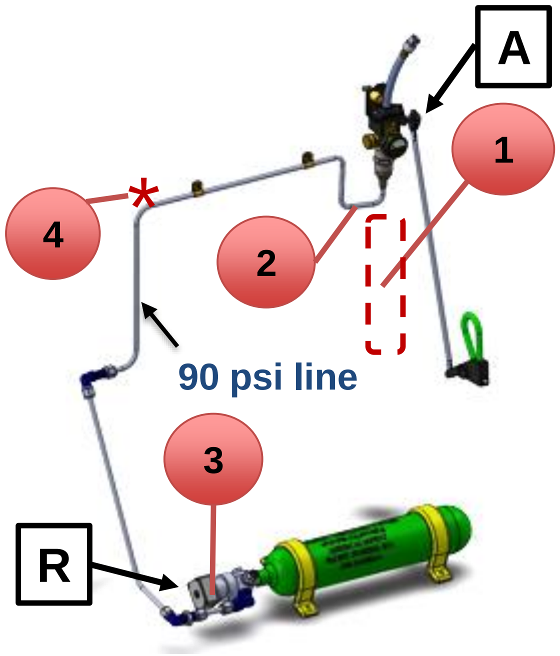


Developed a workable design without major ejection seat modifications

Recent Emergency Oxygen System (EOS) Developments



Initial to Current Configuration



A = activation

R = regulation

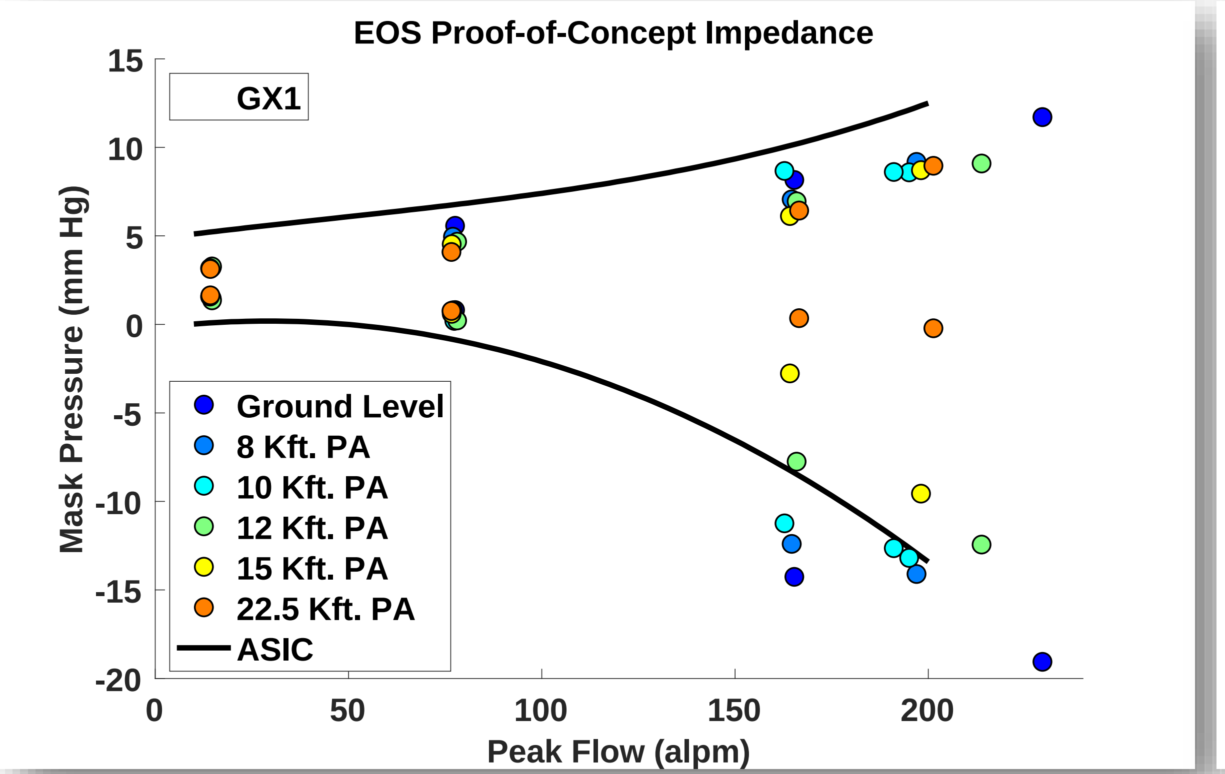
1	22.5 cu inch bottle removed, but its head (ports and activation mechanism) are retained
2	Input from 50 cu inch bottle routed from 22.5 head’s fill port to bottle source port
3	50 cu in bottle head changed from simple valve to a Regulated EOS (REOS) head.
4	No need for gauge to monitor 50 cu in bottle in this location.

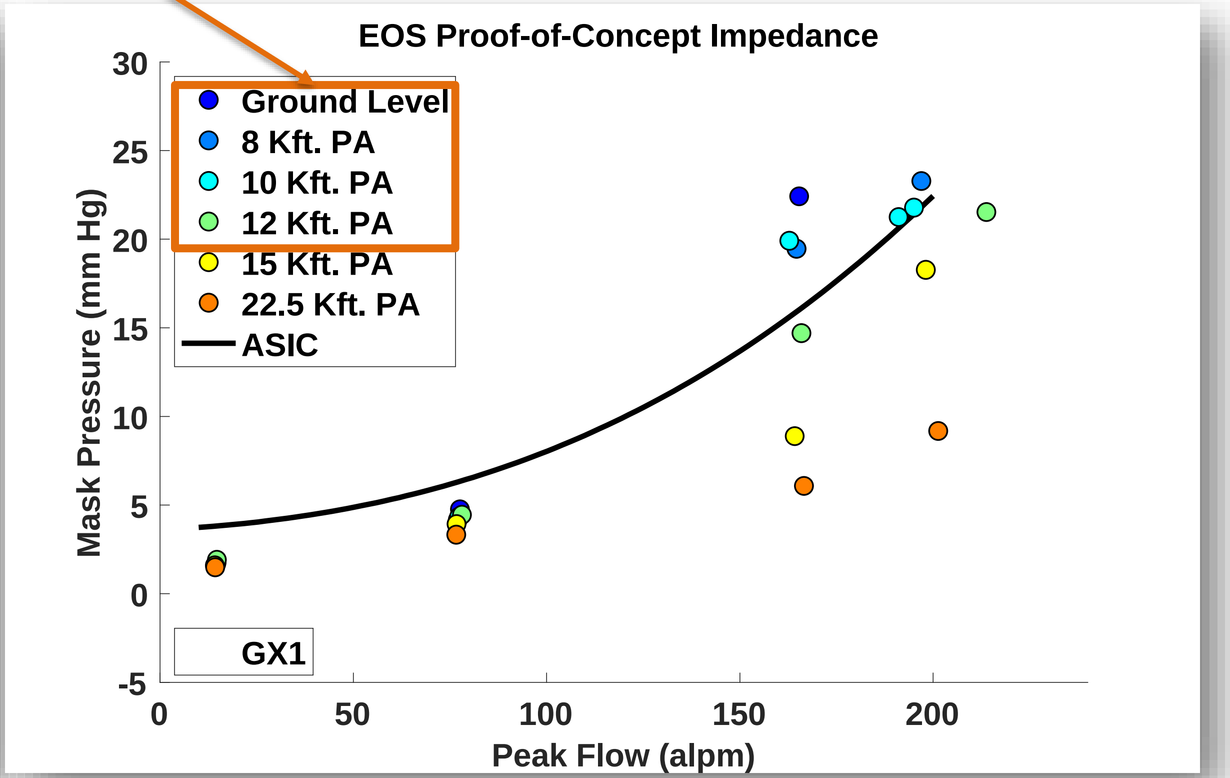
Meets goals and satisfied requirements, Testing underway

Recent Emergency Oxygen System (EOS) Developments

- GX.1: EOS Proof-of-Concept initial impedance testing results

Altitudes below which EOS isn't required

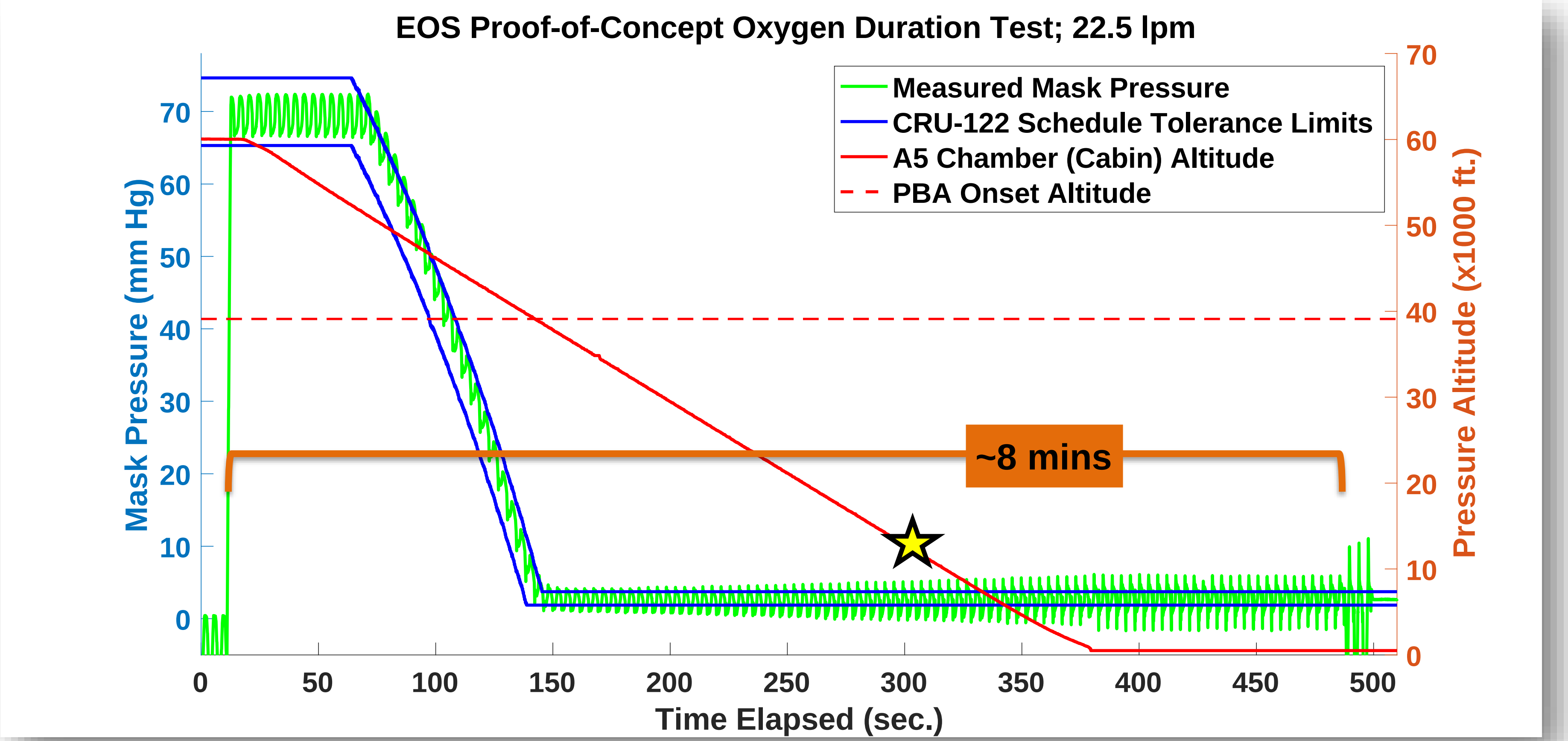




Great impedance results down to altitude where EOS is not required

Recent Emergency Oxygen System (EOS) Developments

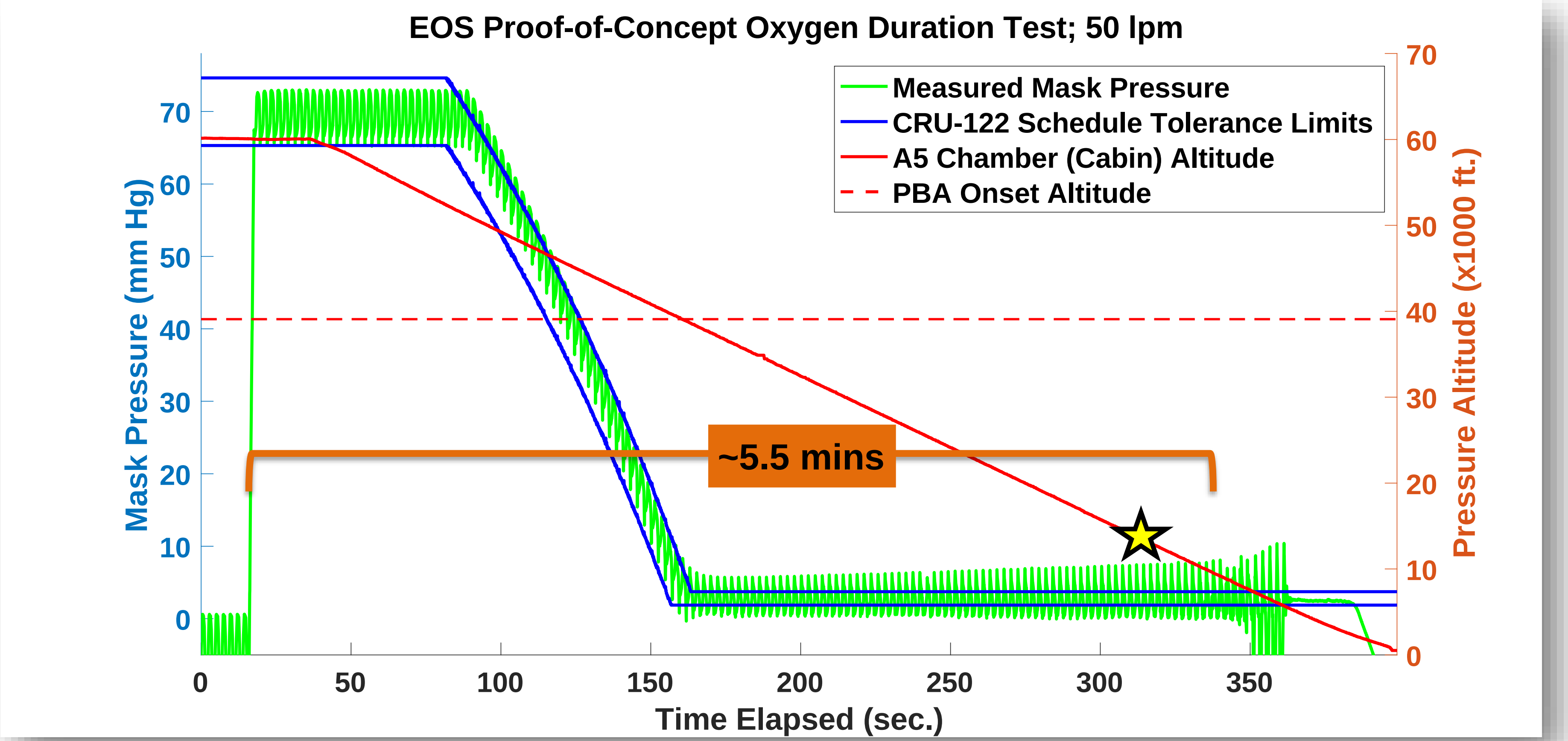
- Unmanned EOS Proof-of-Concept Oxygen Duration Testing – Initial Results
  - Time history of breathing simulator; profile 2: 22.5 lpm, 10,000 fpm descent



Significant oxygen remaining below 12,000 ft.

Recent Emergency Oxygen System (EOS) Developments

- Unmanned EOS Proof-of-Concept Oxygen Duration Testing – Initial Results
  - Time history of breathing simulator; profile 3: 50 lpm, 10,000 fpm descent



Additional oxygen remaining below 12K

Summary

- Flow analysis completed and supported system test planning
- Primary Oxygen system has completed testing and has meet all requirements
- Emergency Oxygen System design solution found and initial proof-of-concept tests completed successfully
- Final EOS testing to be completed in early 2020

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QUESTIONS