

# *Low Boom Flight Demonstrator Project*



**SAFE Symposium**  
**October 14-16, 2019**



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



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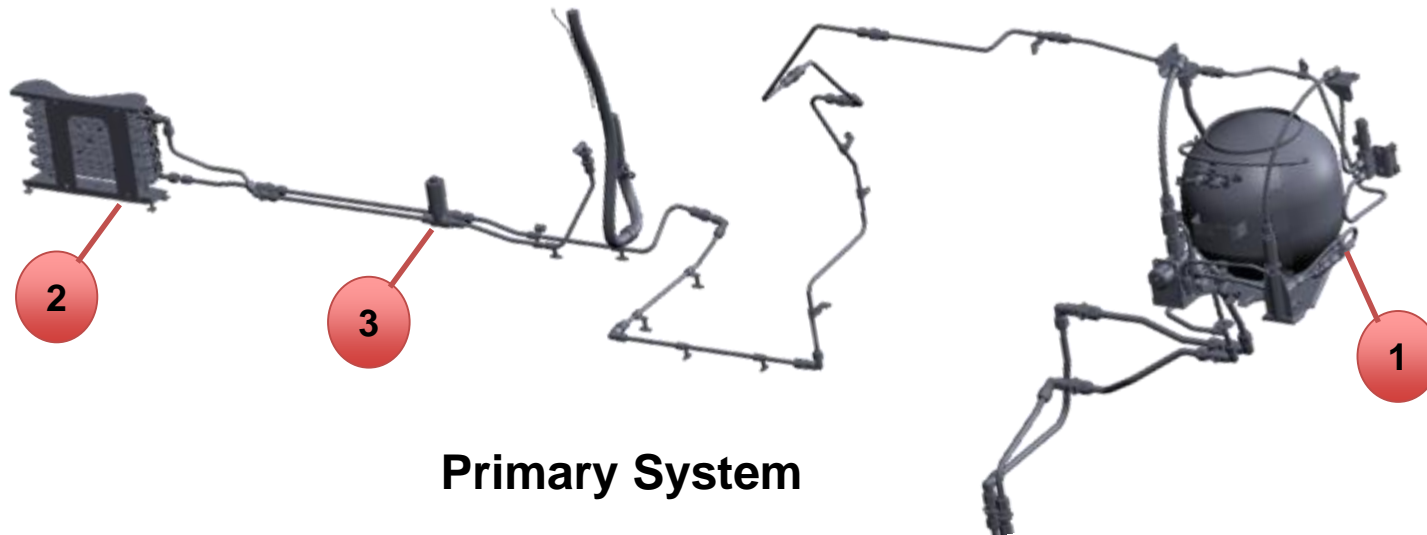
# Outline

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- 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	<b>Pressure Reducer</b>

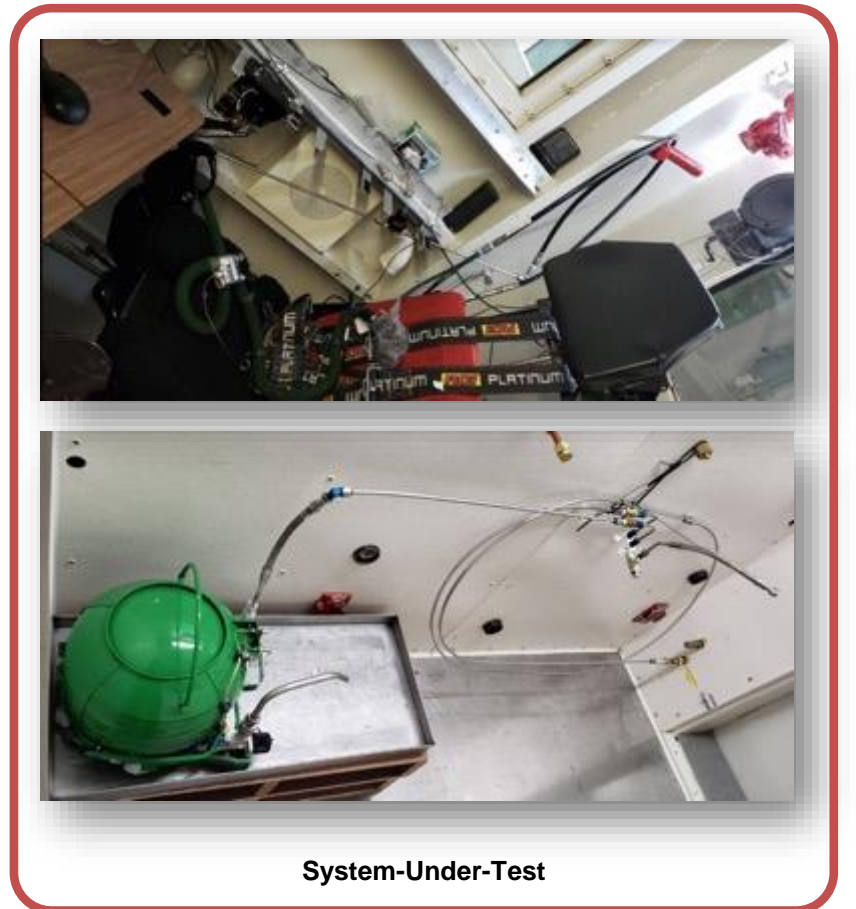
*Goal: “Test like we Fly”*

# 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

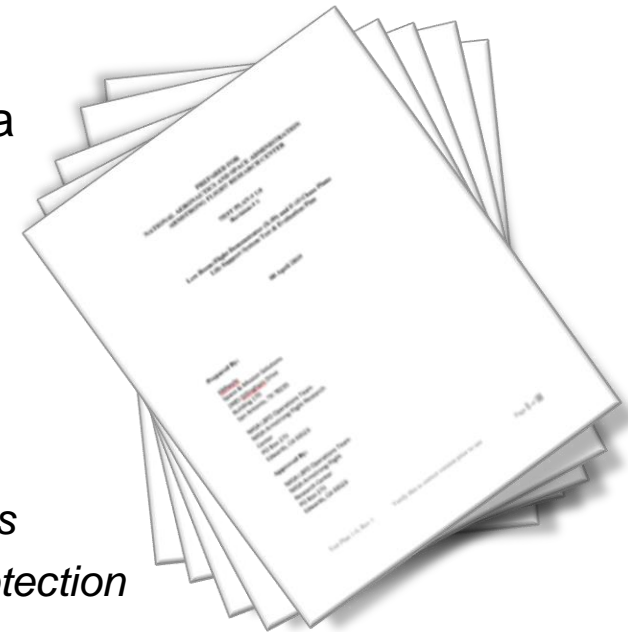
Tube Assembly	X-59 As-Designed Length (ft)	Fluid mechanically "Equivalent" Length (ft)
KBR tube 1 (LOX supply hose to LOX manifold)	0.7	1.9
KBR tube 2 (LOX manifold to Hx)	14.5	21.5
KBR tube 3 (Hx to Press Sensor Tee)	1.8	3.2
KBR tube 4 (Press Sensor Tee to Press Reducer)	1.0	1.0
KBR tube 5 (Press Reducer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





# 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

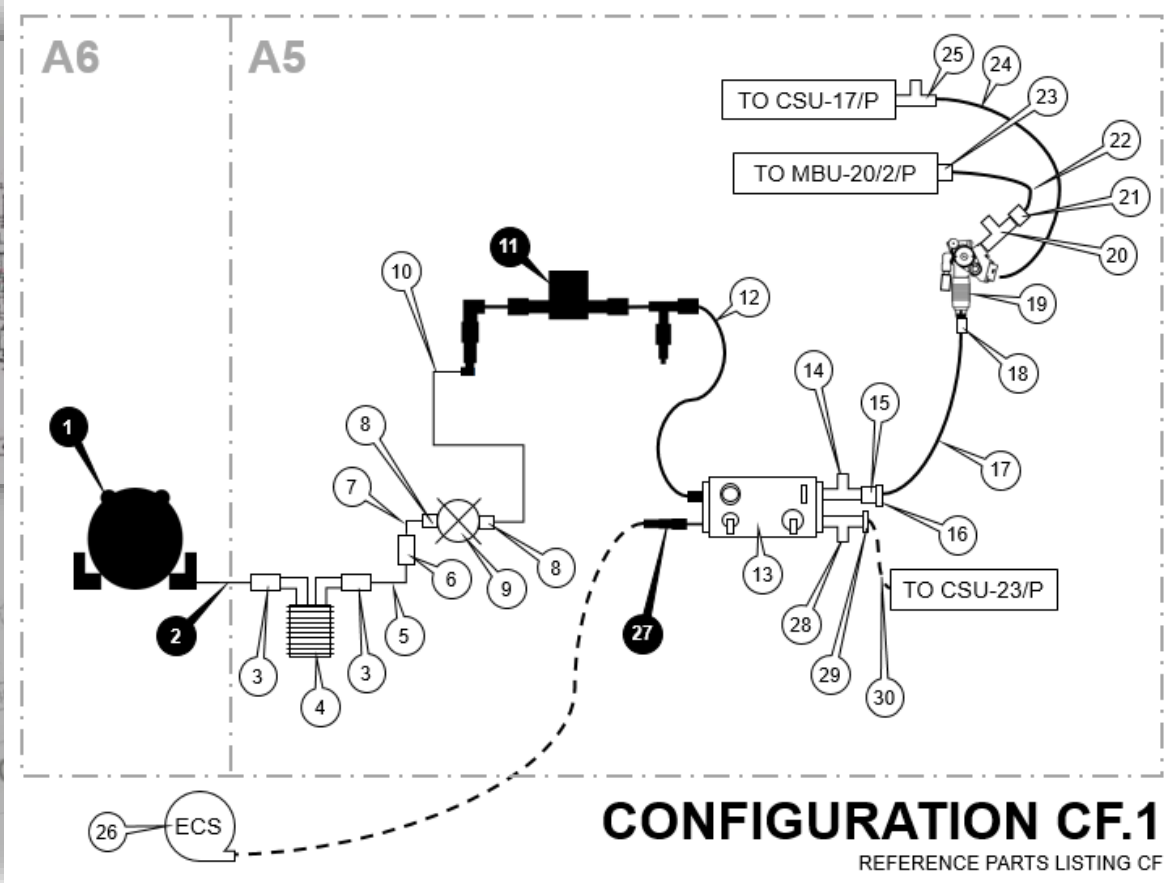
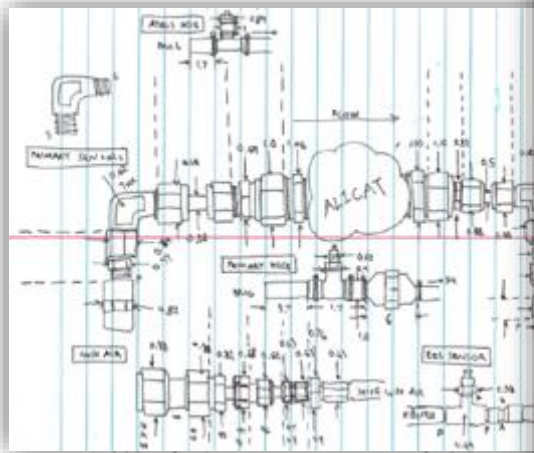
**VERY LARGE TEST MATRIX**

*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



ITEM #	DESCRIPTION	MFR PART #	QTY
1	LOX CONVERTER & INTERFACE (REF. SCHEMATIC 41) - LOX CONVERTER - COUPLING LOX CONVERTER TO LSPH - LOX SUPPLY FLEX HOSE (LSPH) - 5 AN MM ELBOW - 5 AN M TO 1/4" NPT M STRAIGHT UNION - 1/4" NPT F/F STRAIGHT COUPLING - 1/4" NPT M TO 5 AN M STRAIGHT UNION - MISCELLANEOUS 4 AN TUBING ASSEMBLY - LOX SUPPLY MANIFOLD UNION FITTING - SUPPLY MANIFOLD - OVERPRESSURE RELIEF VALVE - 1/2" NPT M TO 5 AN M TO 5 AN M TEE - CAP - LOX SUPPLY FLEX HOSE (LSPH FOR VALVE VENTING) - COUPLING LOX CONVERTER TO LOX VENT TUBING - LOX VENT TUBING	10C-6019-18 120000-7 M875379 K819442050 91577-001 AS51742054 AS4099302 AS51942064 AS51742058 AS4099302 20C-0050-2 AS198409209 M875379 200000-7 E52499-3	1860-00-071-4259 4730-00-030-0310 4730-01-128-0010 4730-00-545-1032 — 4730-00-842-6484 4730-00-541-6206 4730-00-011-7127 — 4730-00-100-2676 1860-01-000-6405 4820-00-000-7721 — 5340-00-004-0776 — 4730-01-128-0010 4760-00-010-5701 —
2	MALE/MALE UNION	AS51742058	4730-00-545-1032
3	LOX HEAT EXCHANGER	M8450017-1005	1860-00-266-1015
4	KBR TUBING ASSEMBLY 02 (01 1' LONG)	91577-001	—
5	5 AN MALE/MALE UNION	AS51742058	4730-00-545-1032
6	1/4" NPT TO 5 AN MM UNION	AS51942064	4730-00-842-6484
7	1/2" PRESSURE REDUCER/REGULATOR	10C-6040-2027	A31-APR83TVH12 E
8	KBR TUBING ASSEMBLY 02 (04 8' LONG)	91577-001	—
9	KBR PRESSURE SENSOR ASSEMBLY (REF. SCHEMATIC 05) - 5 AN M TO 1/4" NPT M ELBOW - 1/4" NPT F/F STRAIGHT COUPLING - 1/4" NPT M TO 3/8" SWAGE F STRAIGHT ADAPTER - 3/8" SWAGE MM ELBOW - 3/8" SWAGE M TO 1/2" SWAGE F STRAIGHT EXPANDER - 1/2" SWAGE M TO 1/2" SWAGE F STRAIGHT ADAPTER - ALICAT FLOW METER - 3/4" NPT M TO 3/4" NPT M STRAIGHT ADAPTER - 3/4" SWAGE F TO 1/2" SWAGE M STRAIGHT EXPANDER - 1/2" TUBING LENGTH - 1/2" SWAGE MM/M TEE - 1/2" SWAGE F TO 3 AN M ADAPTER - 1/2" SWAGE F TO 1/2" SWAGE M REDUCER - 3/8" SWAGE F TO 1/2" NPT F ADAPTER - PRESSURE TAP TO "POST BRAG" VALVE/DYNE PRESSURE TRANSDUCER	AS51942064 AS4099302 B-400-1-4 B-400-9 B-400-R-10 B-1013-1-12 M8000001P4-D B-1210-1-12 B-010-4-12 — B-219-3 B-400-1-4 B-400-R-6 B-6-0A-7-3 DP19-12	4730-00-841-6206 4730-01-000-0043 — — — — 4730-00-706-0754 — — 4730-00-061-7098 4730-01-128-0310 4730-01-473-0046 4730-01-328-0008 —
10	FLEX HOSE (LSPH) TYPE 2	800710	—
11	BRAG VALVE	77307419-0001	—
12	TEK ASSEMBLY TO "POST BRAG" VALVE/DYNE PRESSURE TRANSDUCER	DP19-12	—

**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*

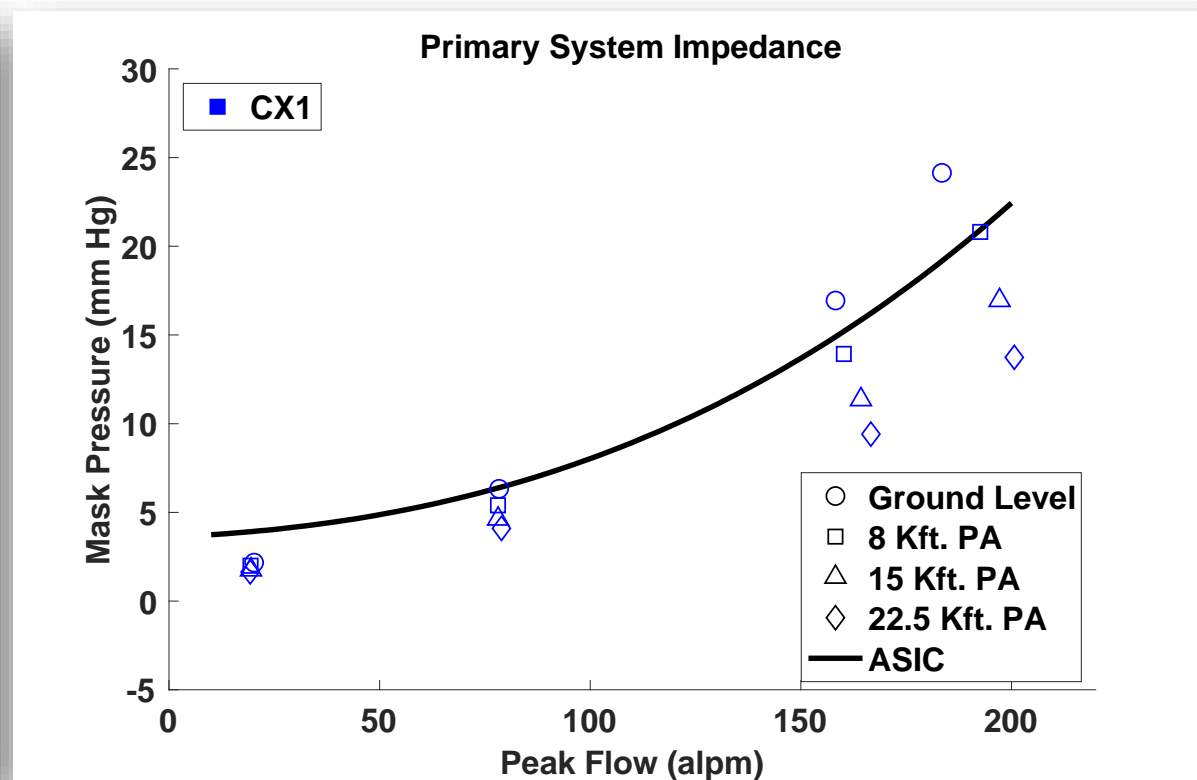
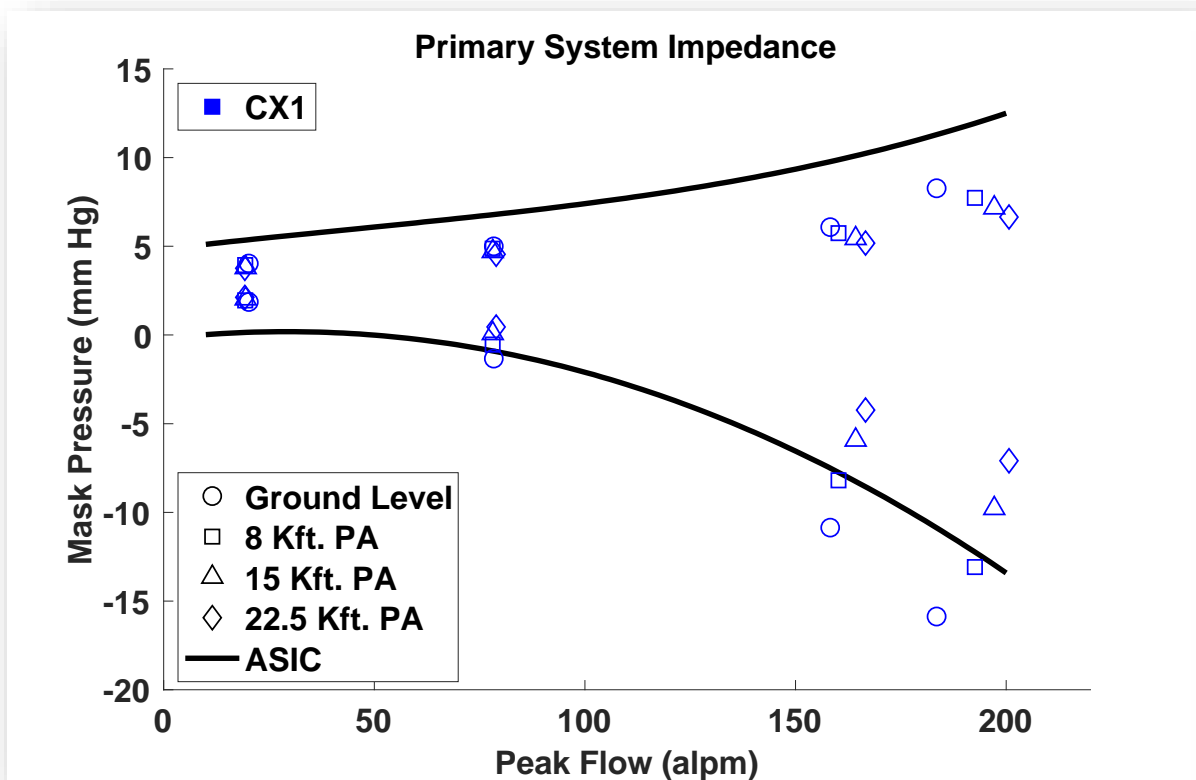
*Plots on following slides illustrate this process*



# Test Execution and Results – Test Driven Design



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

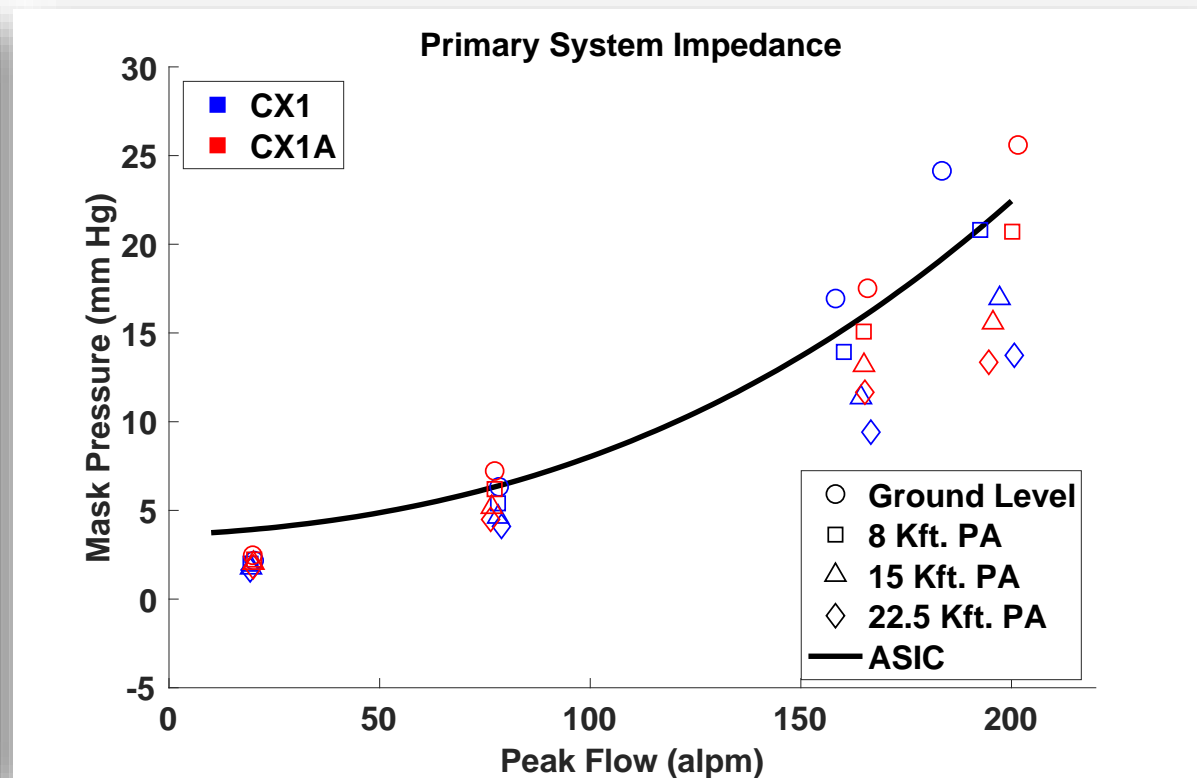
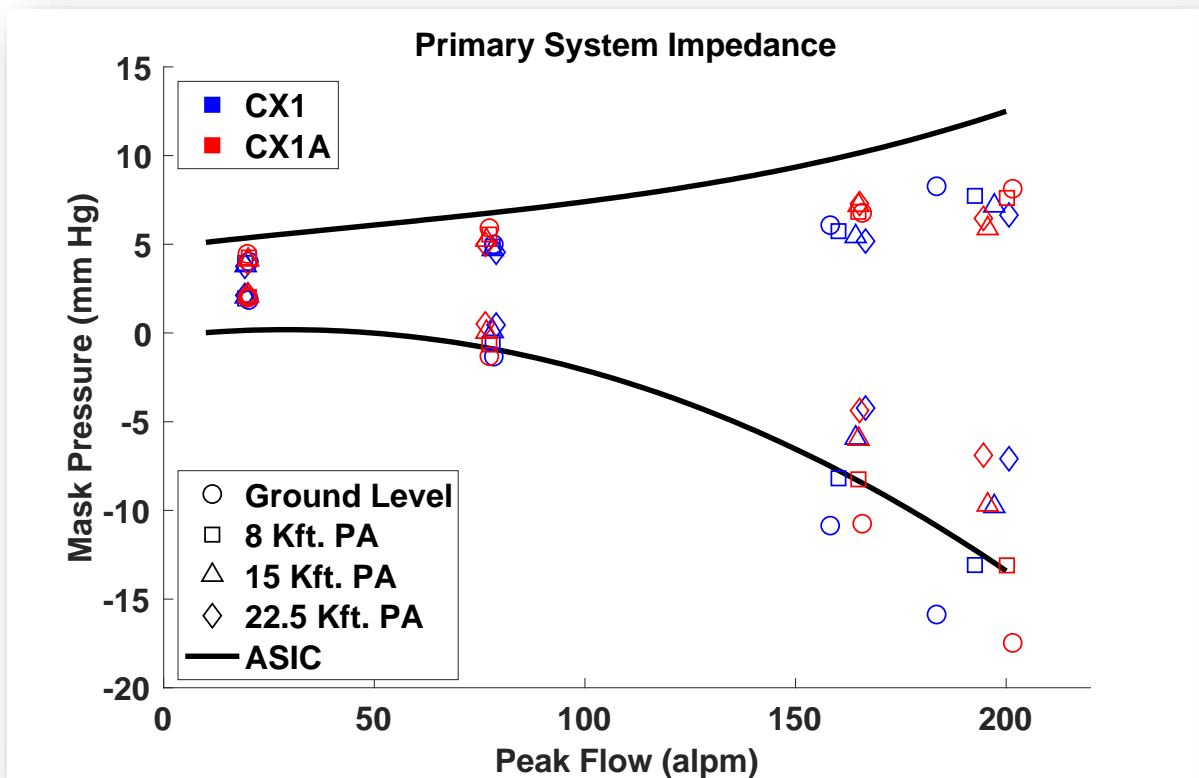




# Test Execution and Results – Test Driven Design



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

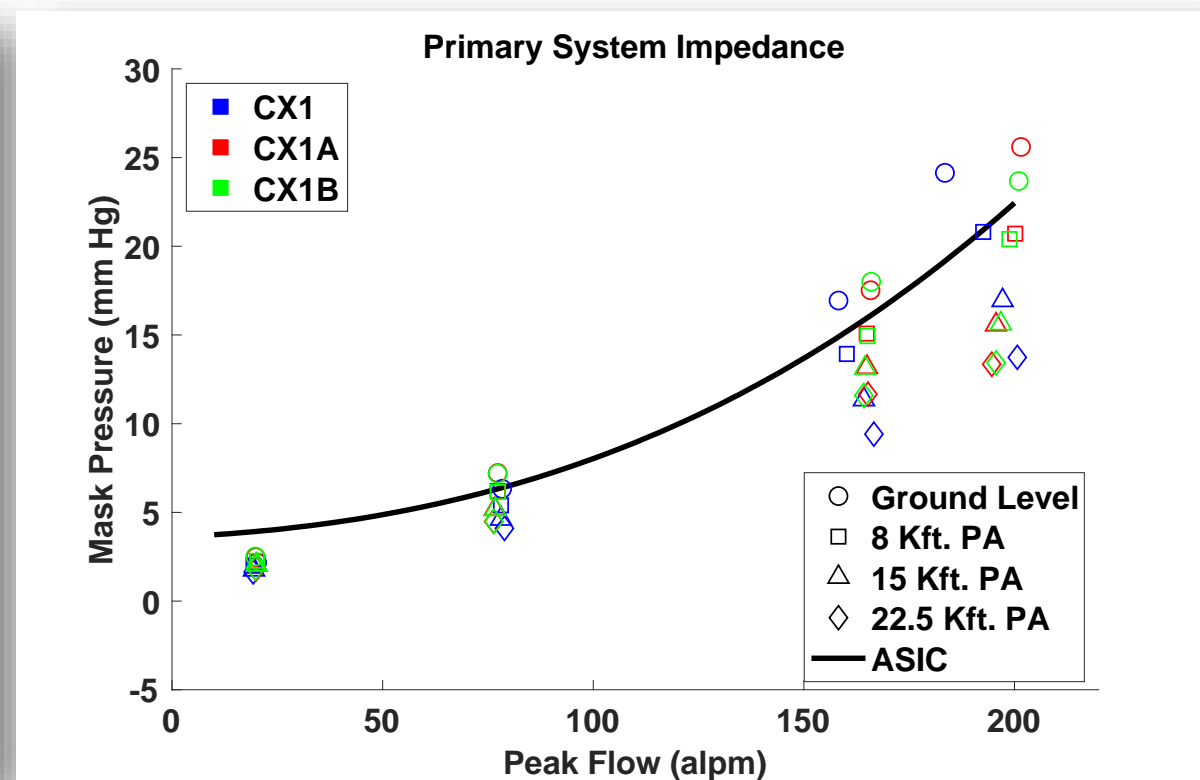
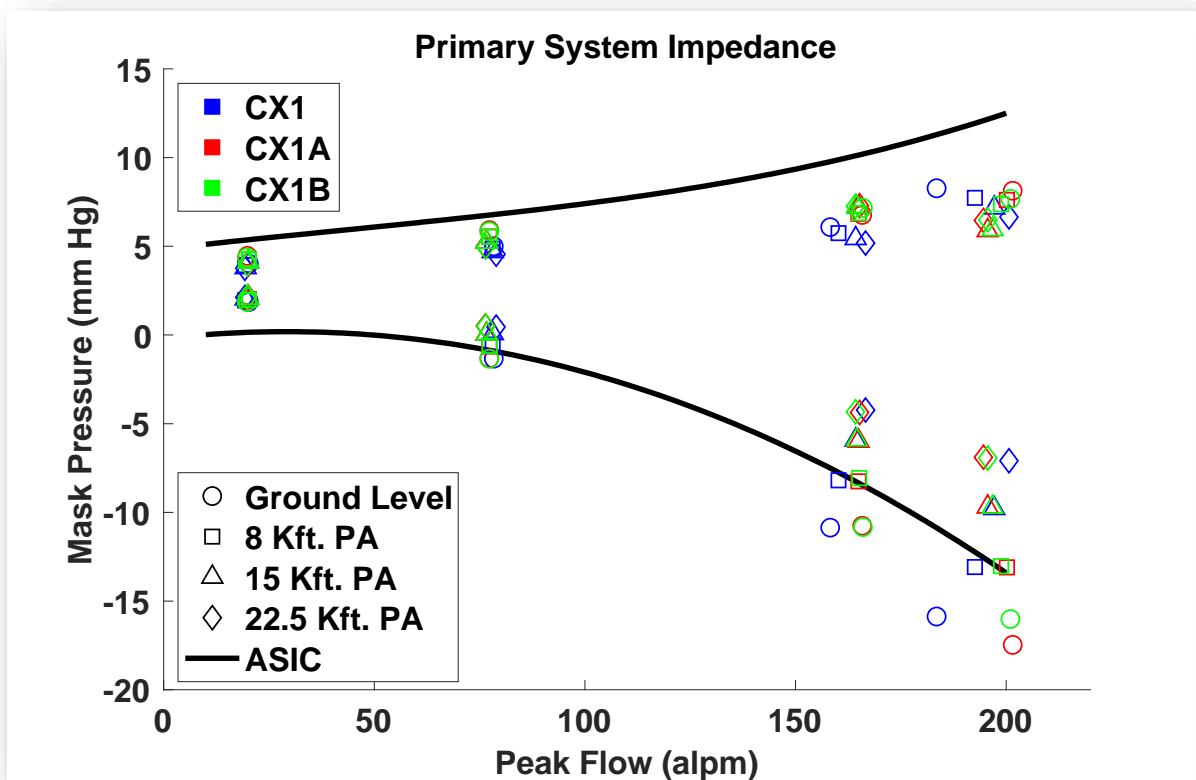




# Test Execution and Results – Test Driven Design

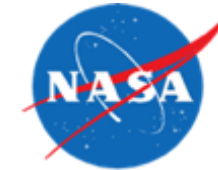


- CX.1B: X-59 full system; shorter LOX delivery line; changed heat exchanger

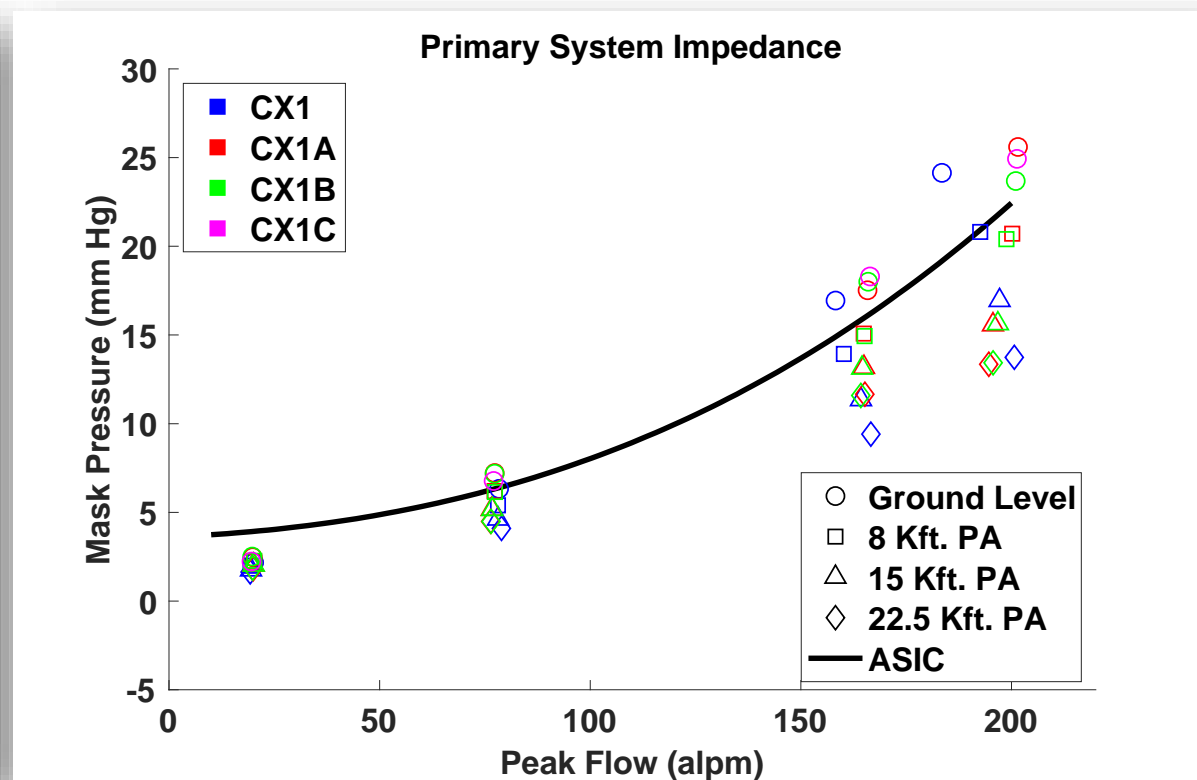
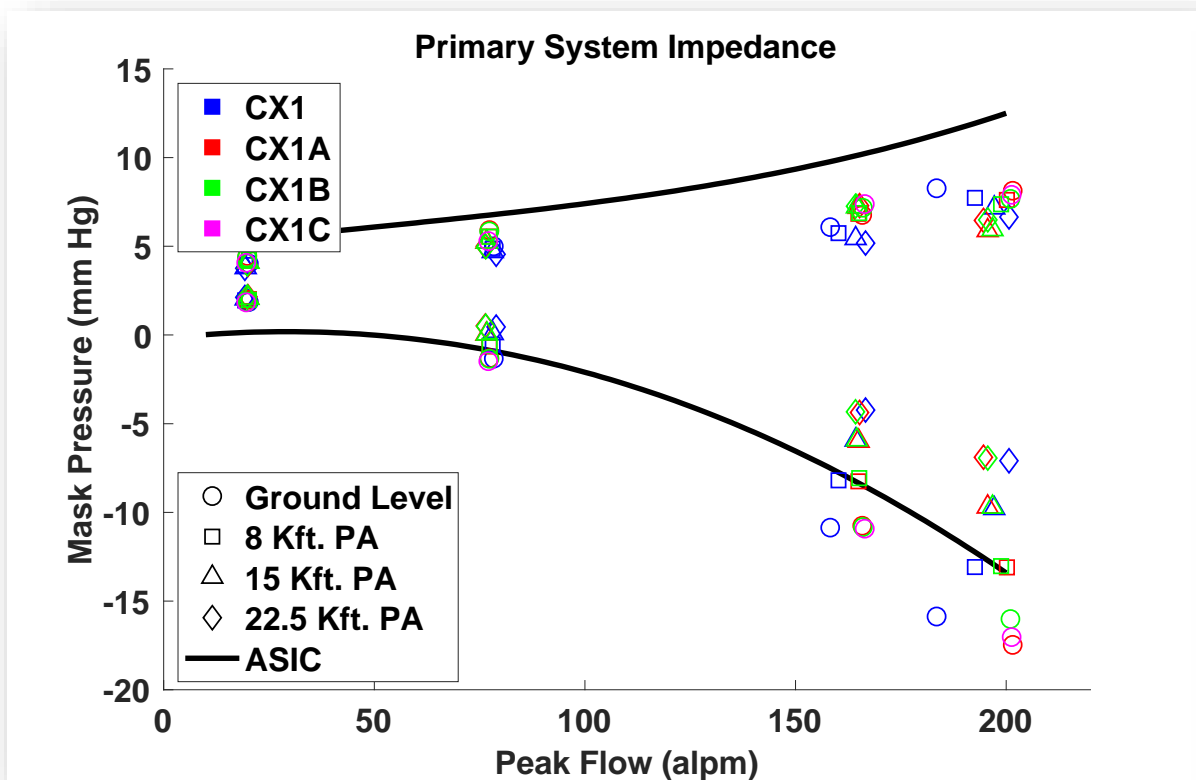




# Test Execution and Results – Test Driven Design



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

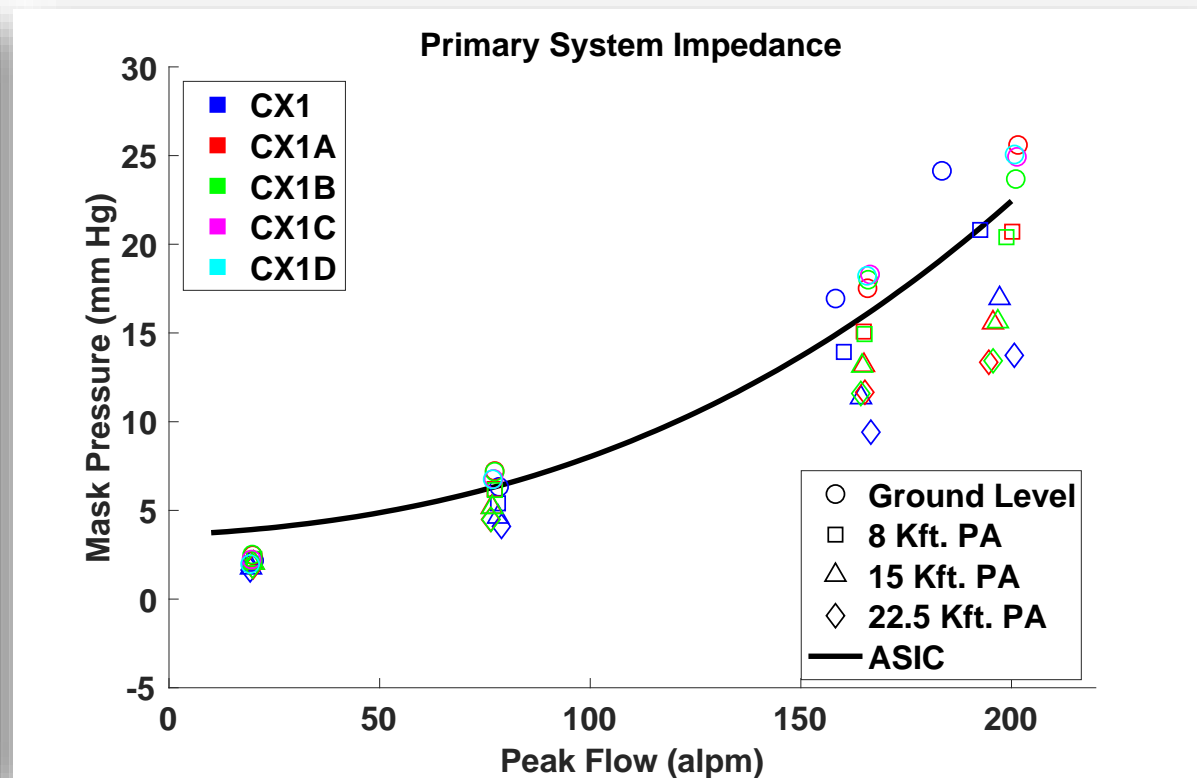
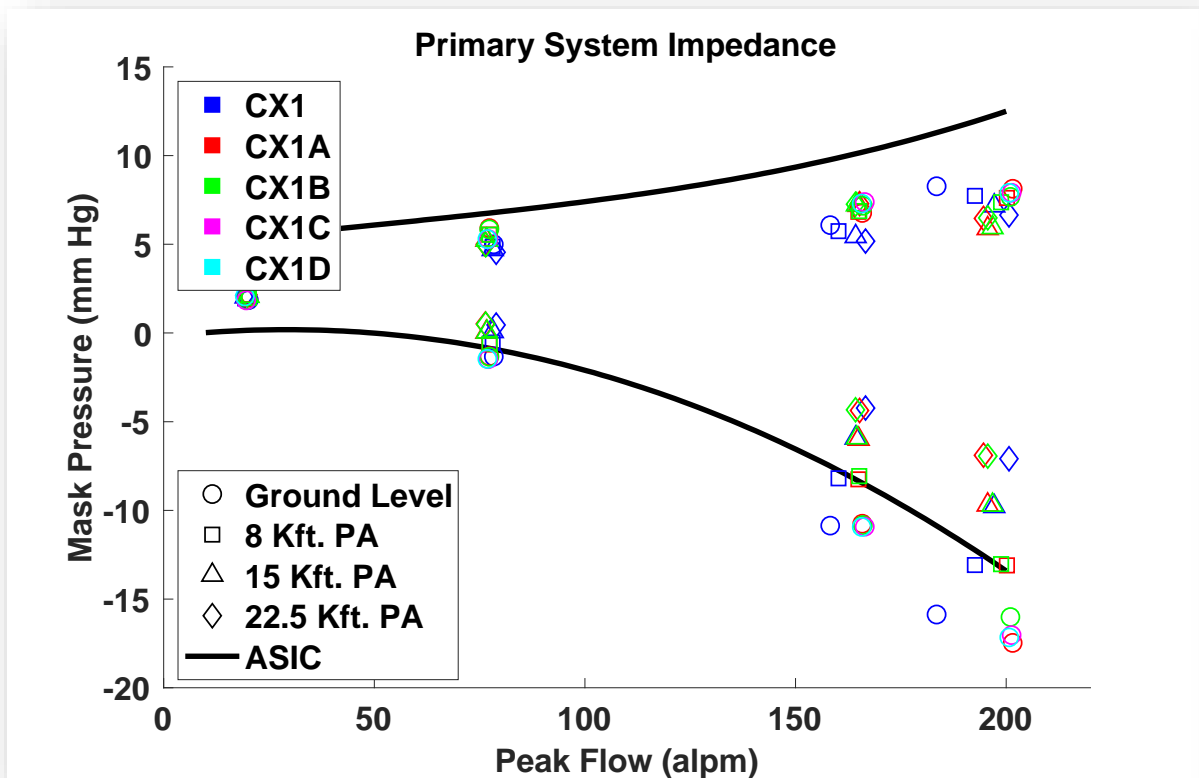




# Test Execution and Results – Test Driven Design



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

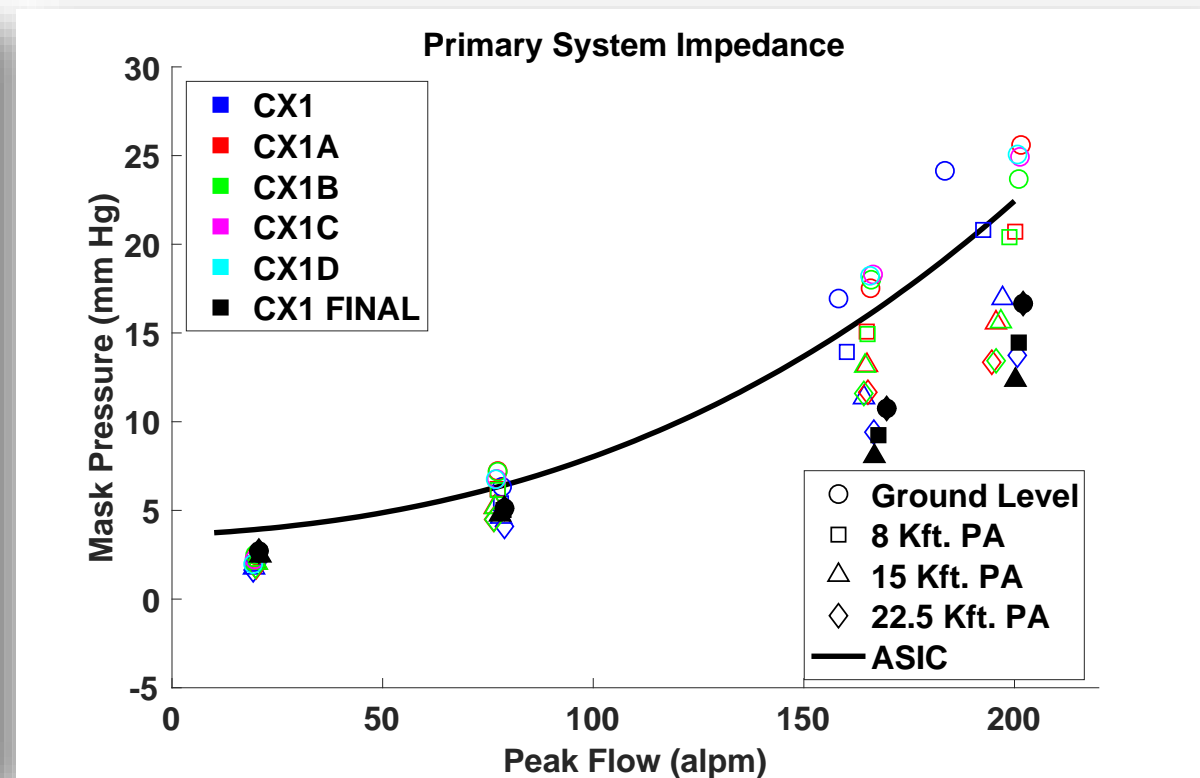
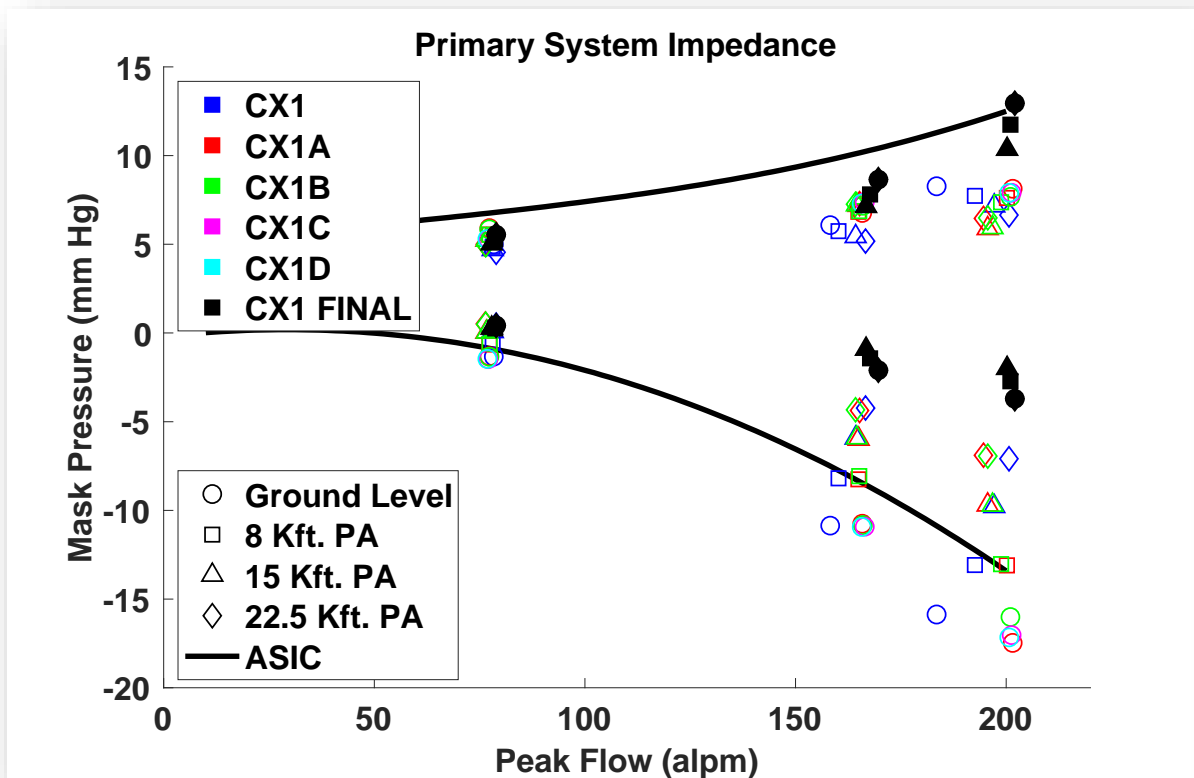




# Test Execution and Results – Test Driven Design



- 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

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- 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*

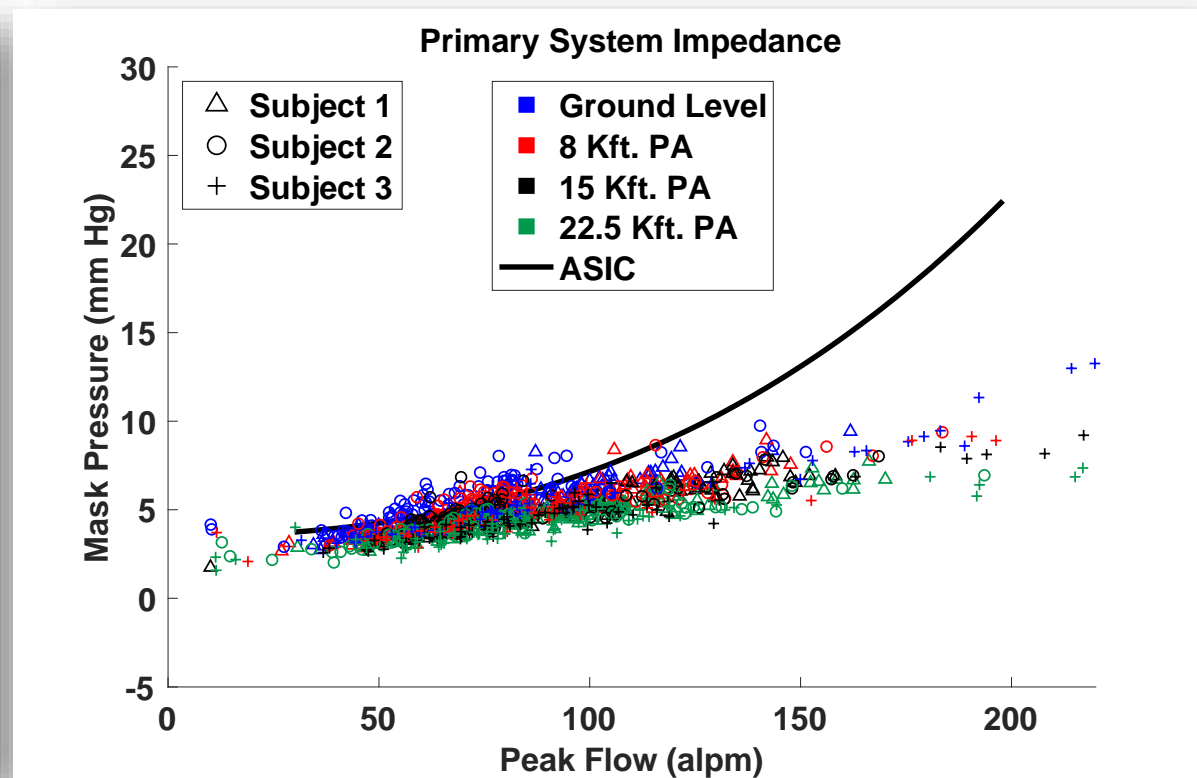
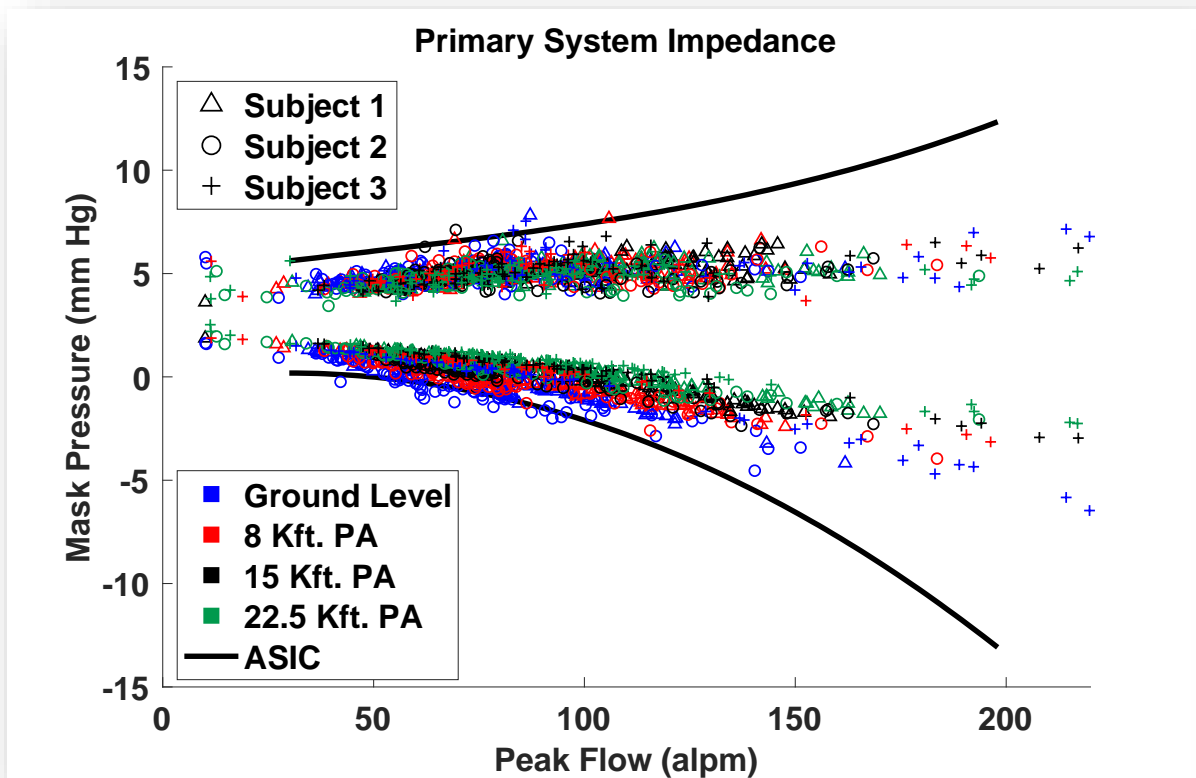




# Test Execution and Results – Manned Testing



- Manned Impedance Testing
  - Primary Oxygen System (PMBR)

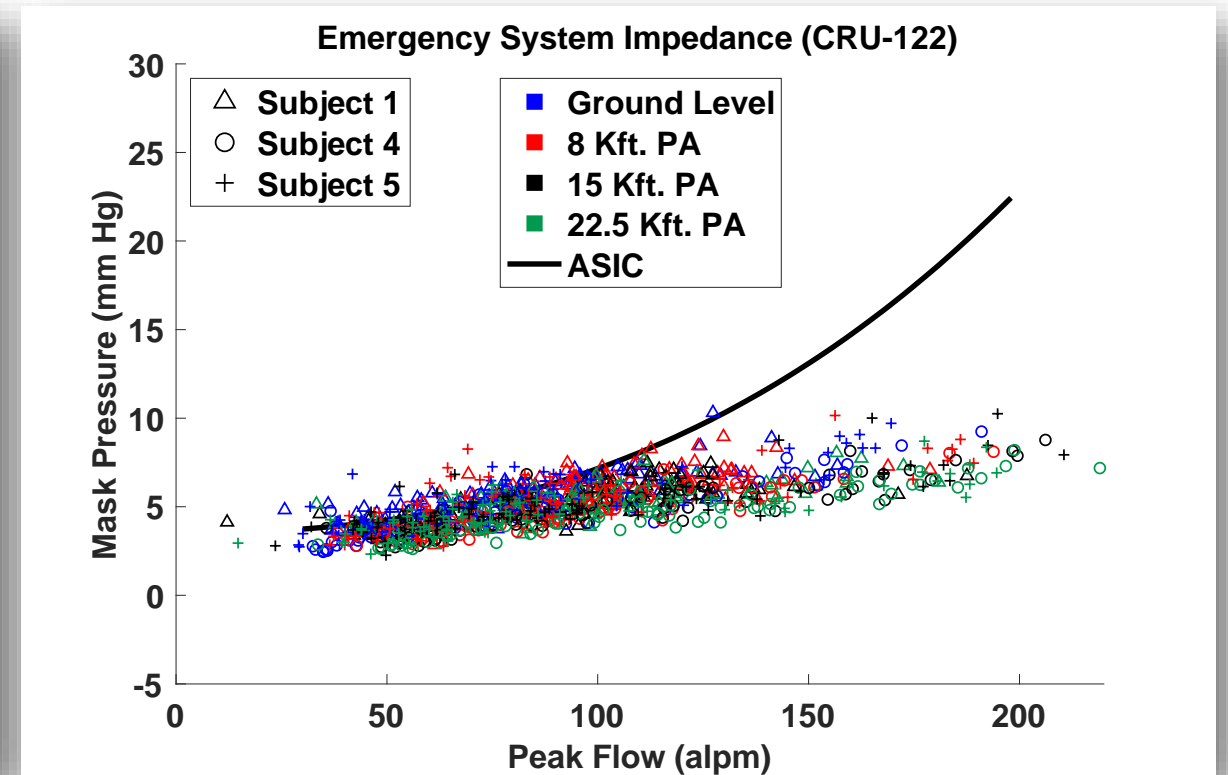
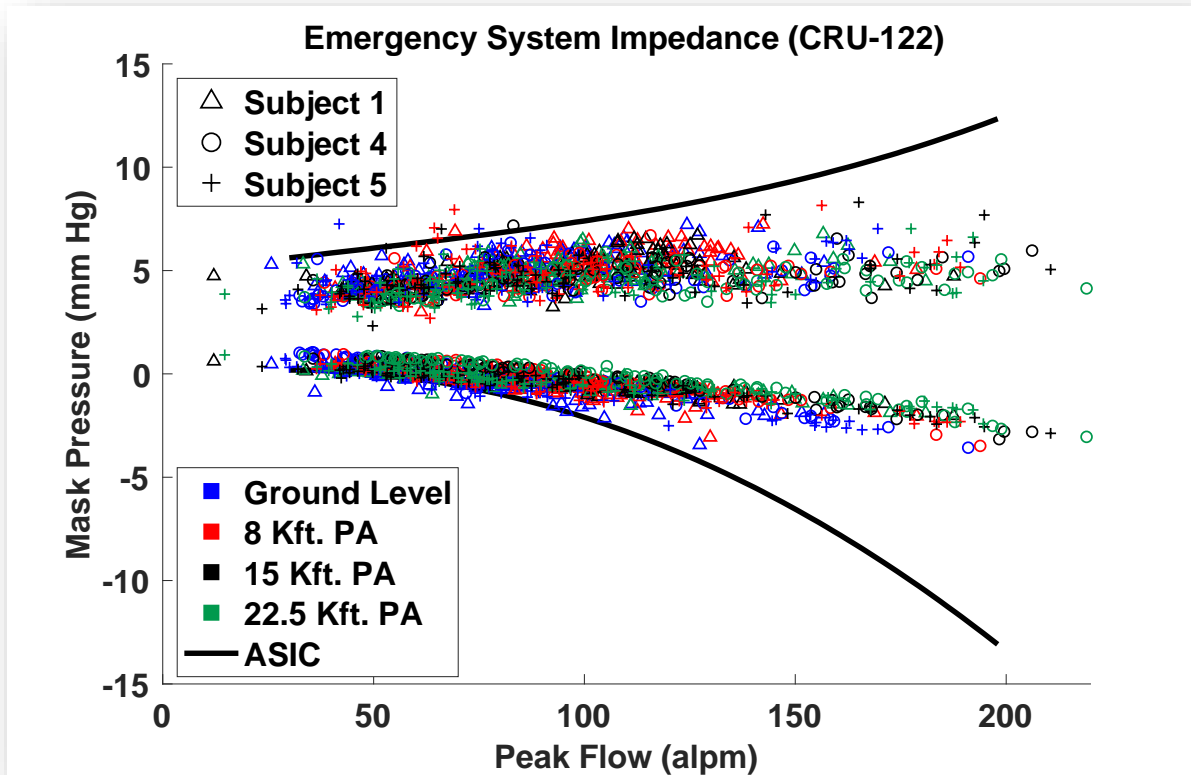


*Great results from the manned PMBR impedance testing*



# Test Execution and Results – Manned Testing

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

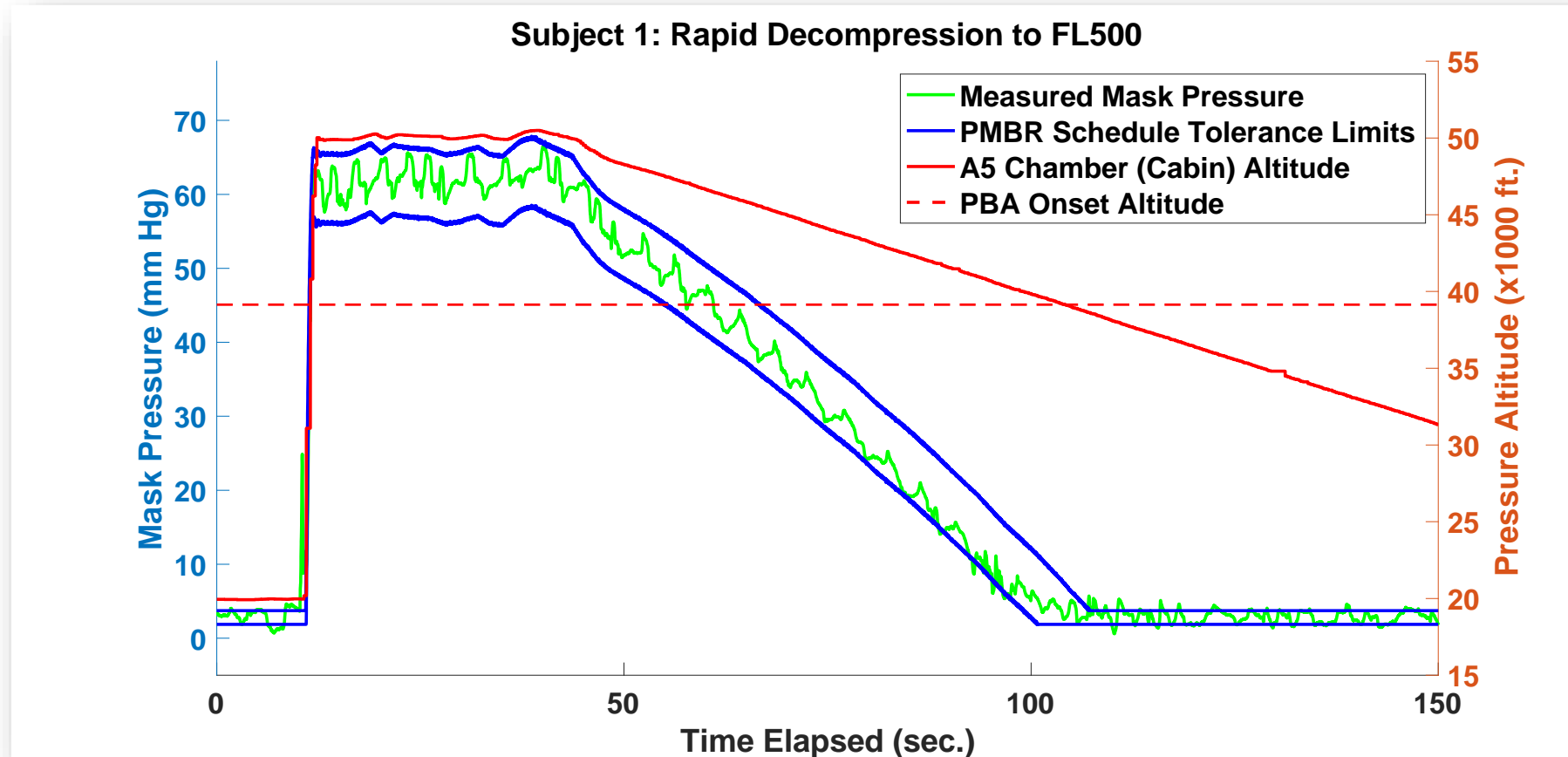


*Great results from the manned CRU-122 impedance testing*



# Test Execution and Results – Manned Testing

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



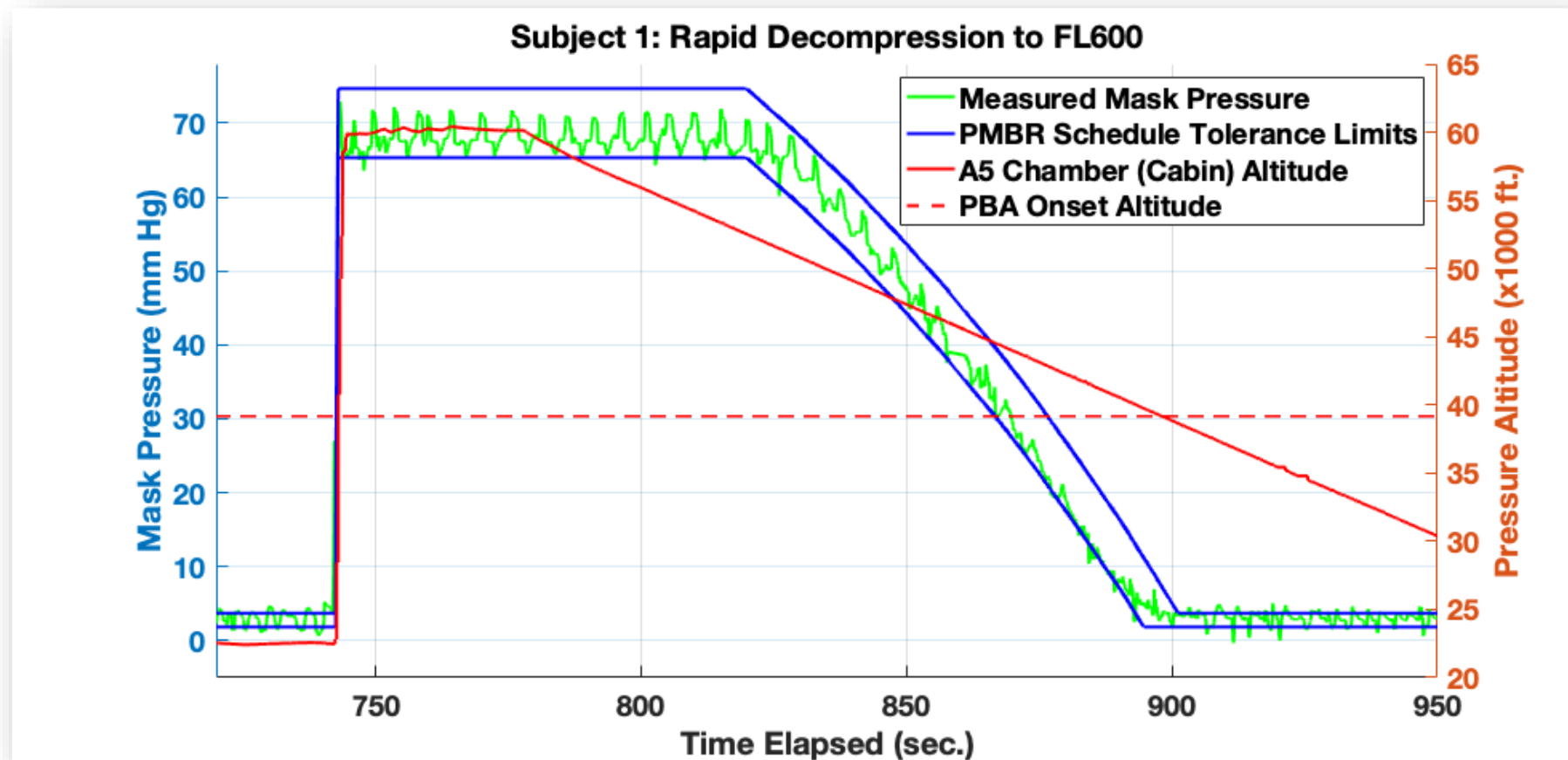
*PBA mask pressures as expected*



# 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*



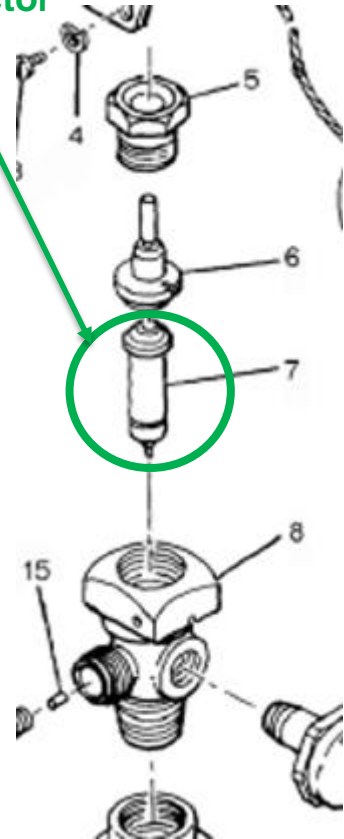
# Recent Emergency Oxygen System (EOS) Developments

- 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.

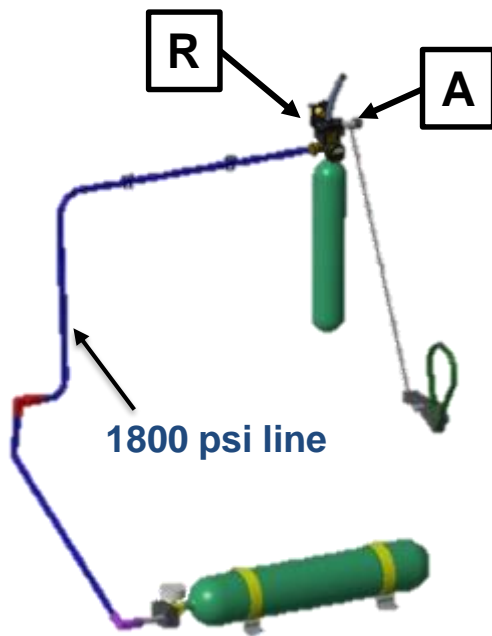
- **Solution**
  - Use a Regulated-EOS (REOS) head and bottle – delivers very stable pressures and flowrates required for the CRU-122
  - Remove flow restriction from the T-38 head – activation only
  - No major ejection seat modifications required

T-38 Head  
Flow Restrictor



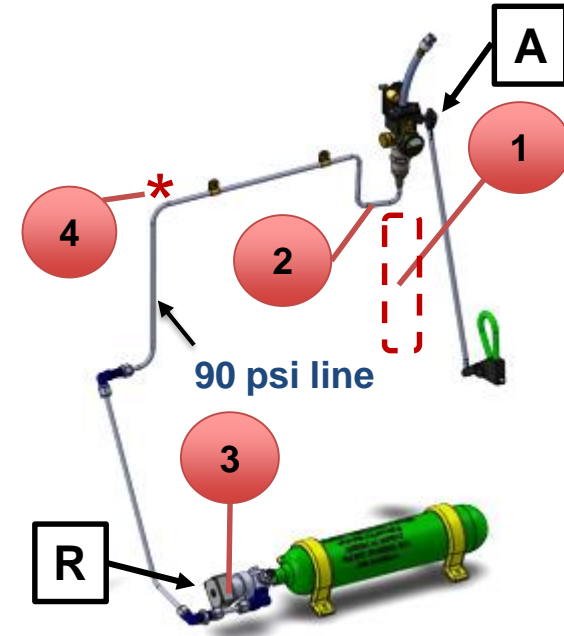
*Developed a workable design without major ejection seat modifications*

# 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**

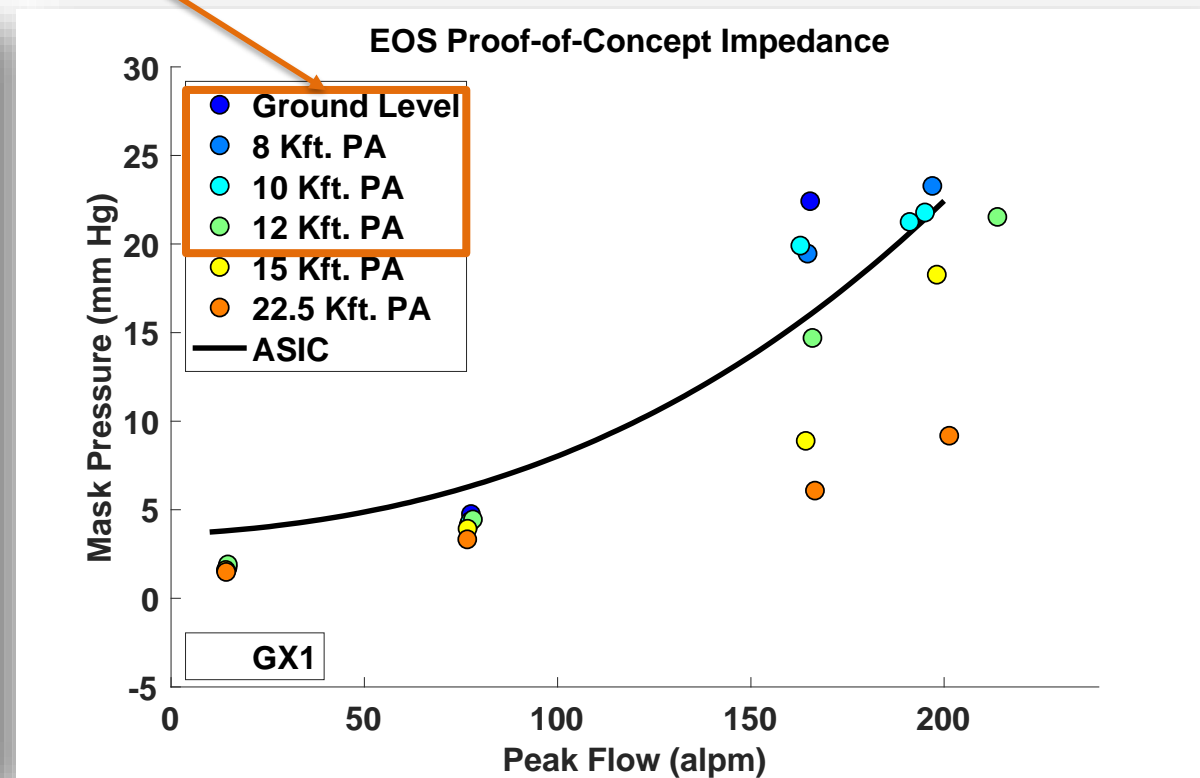
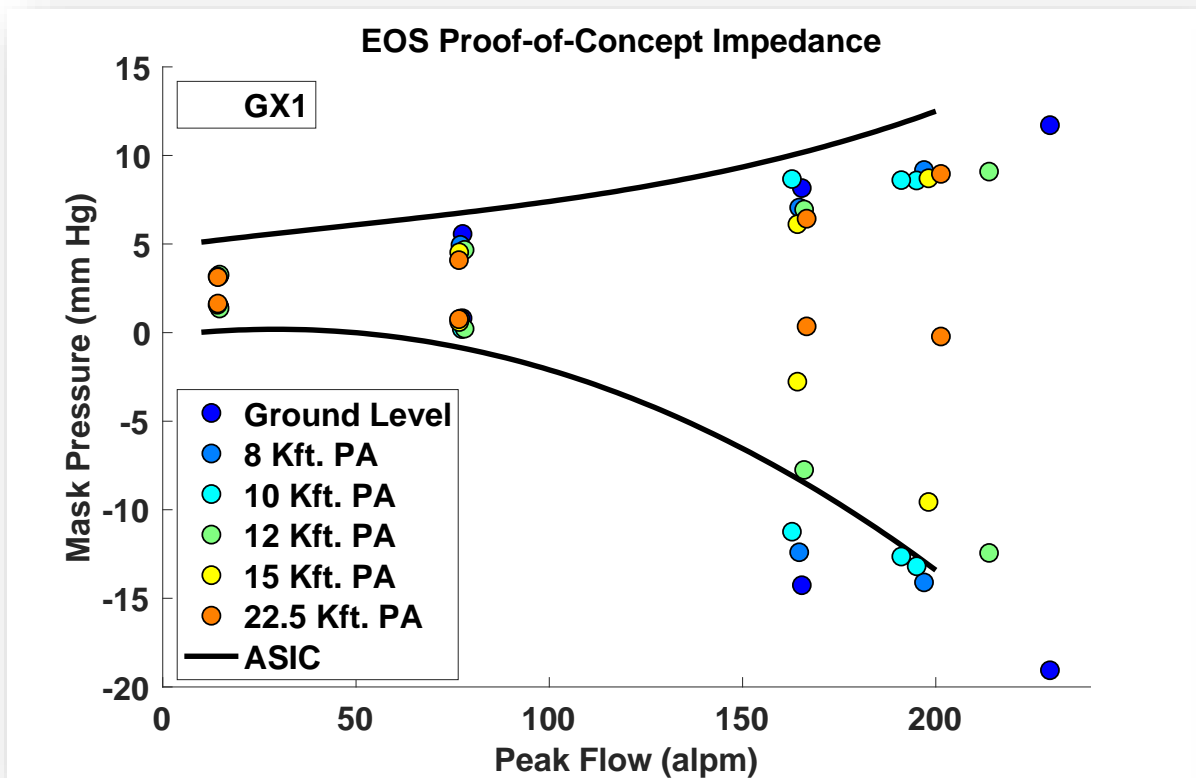


# Recent Emergency Oxygen System (EOS) Developments



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

*Altitudes below which EOS isn't required*

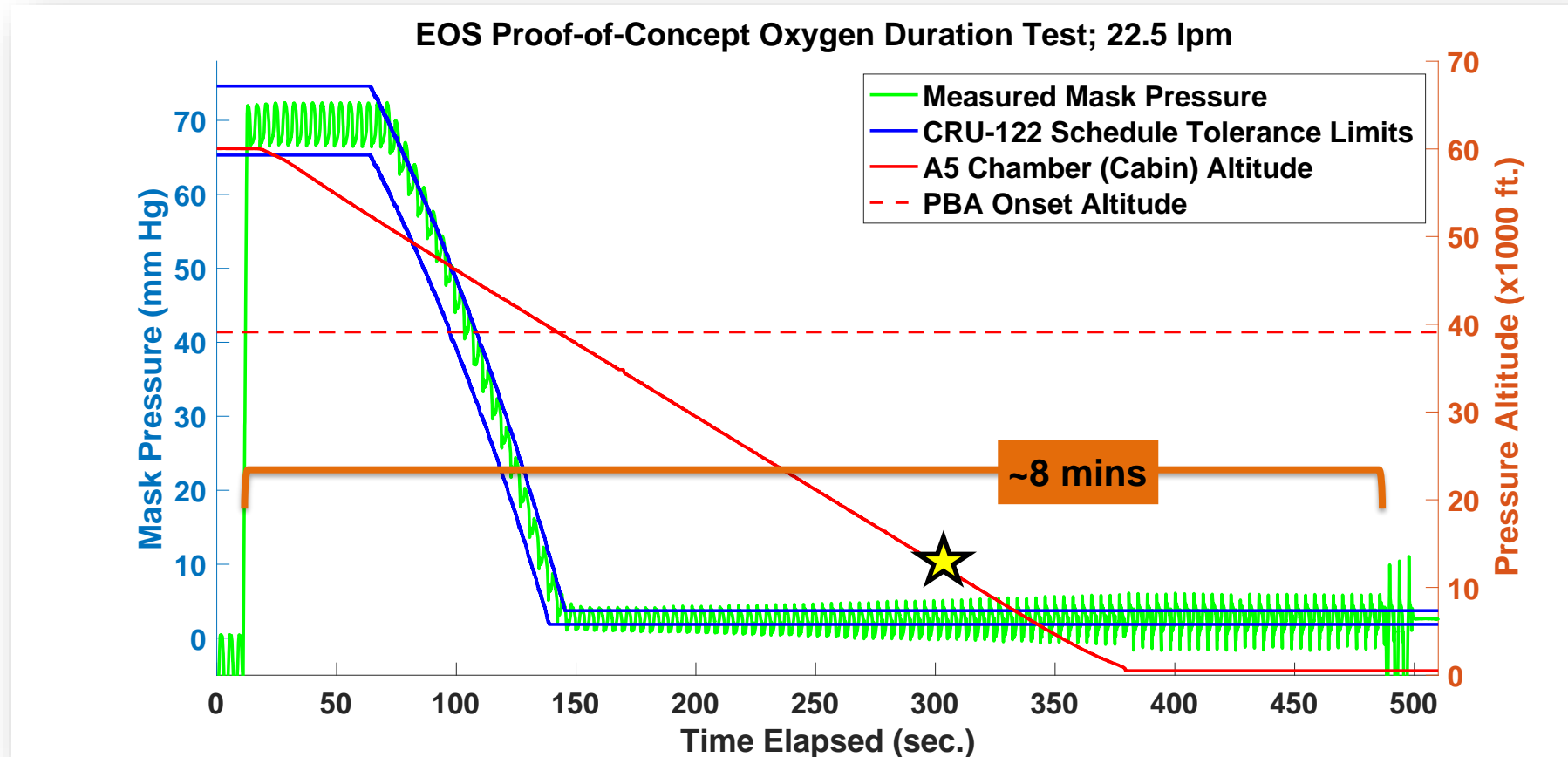


***Great impedance results down to altitude where EOS is not required***



# 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



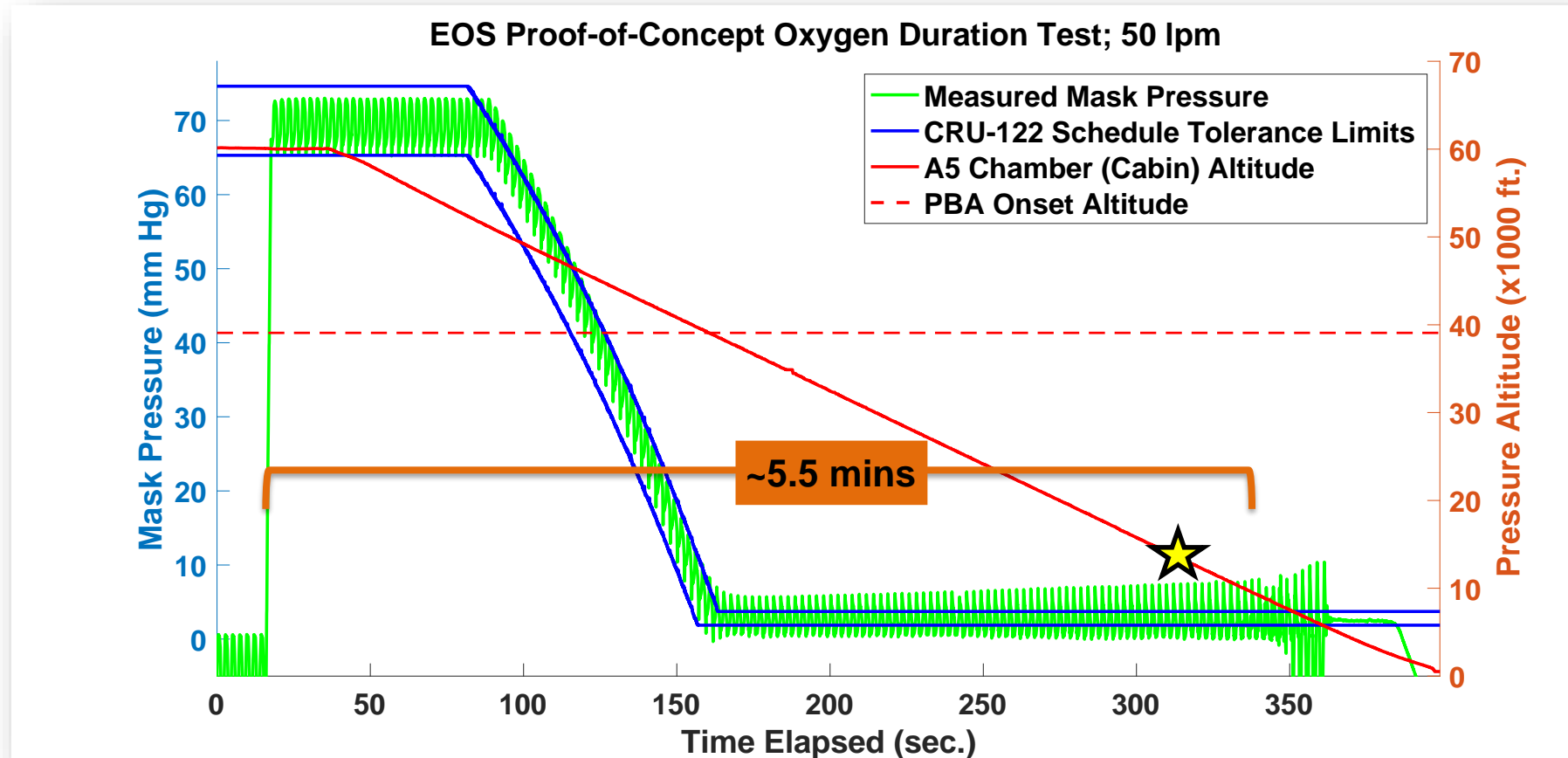
**Significant oxygen remaining below 12,000 ft.**





# 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

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- 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**