DEVELOPMENT, VALIDATION AND APPROVAL OF A PLANETARY EXTRAVEHICULAR ACTIVITY PREBREATHE PROTOCOL: NASA EXPLORATION ATMOSPHERE TESTS 1 & 2

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Disclosure Information

94rd Annual Scientific Meeting

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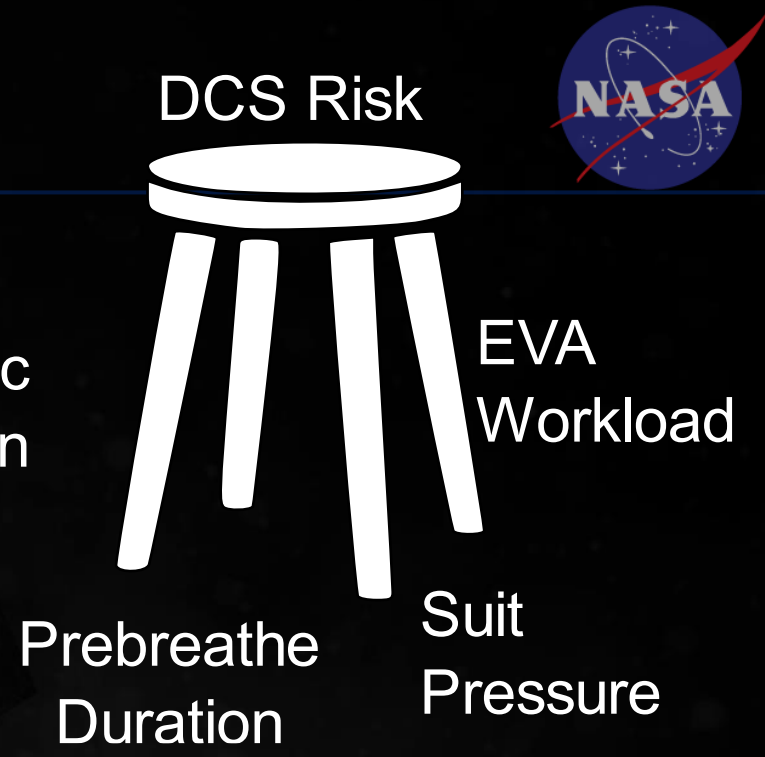
I have no financial relationships to disclose.

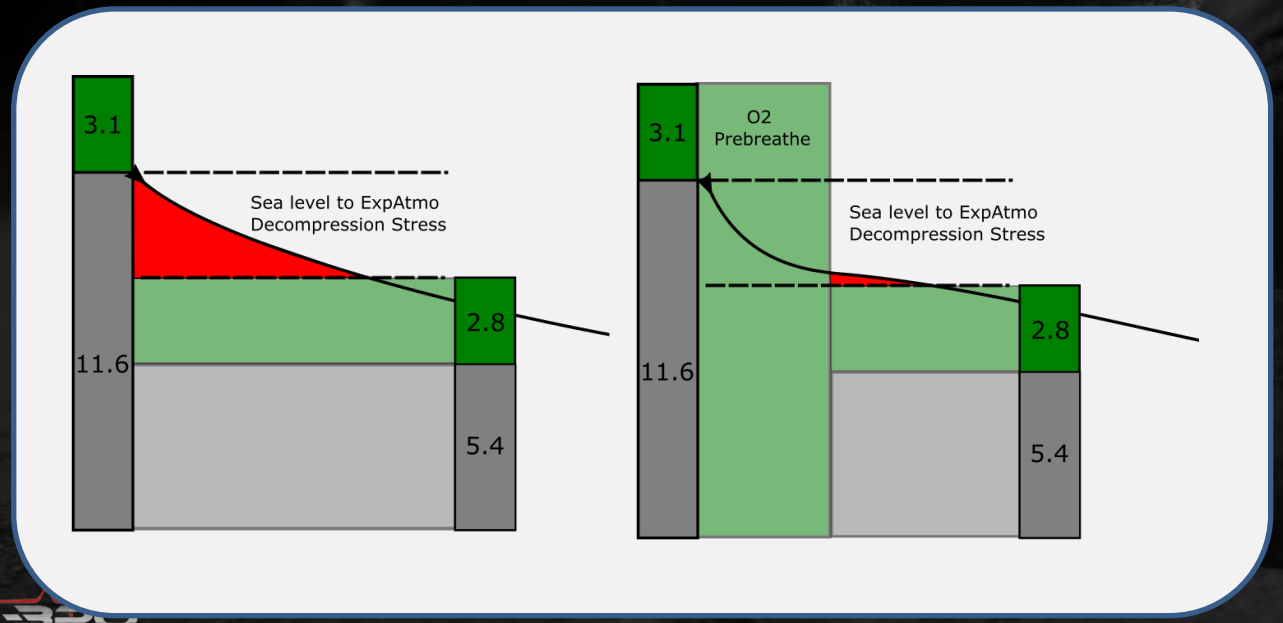
I will not discuss off-label use and/or investigational use in my presentation.

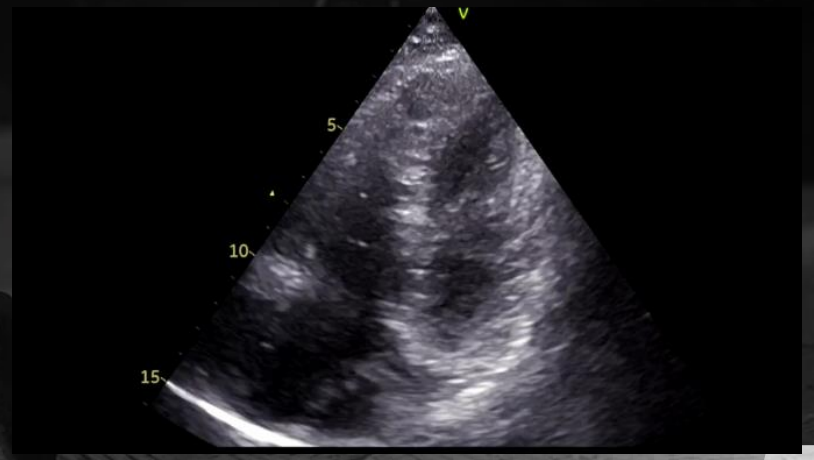
The opinions discussed are mine and mine alone, they do not represent those of GeoControl, KBR, NASA or the federal government

Fundamentals

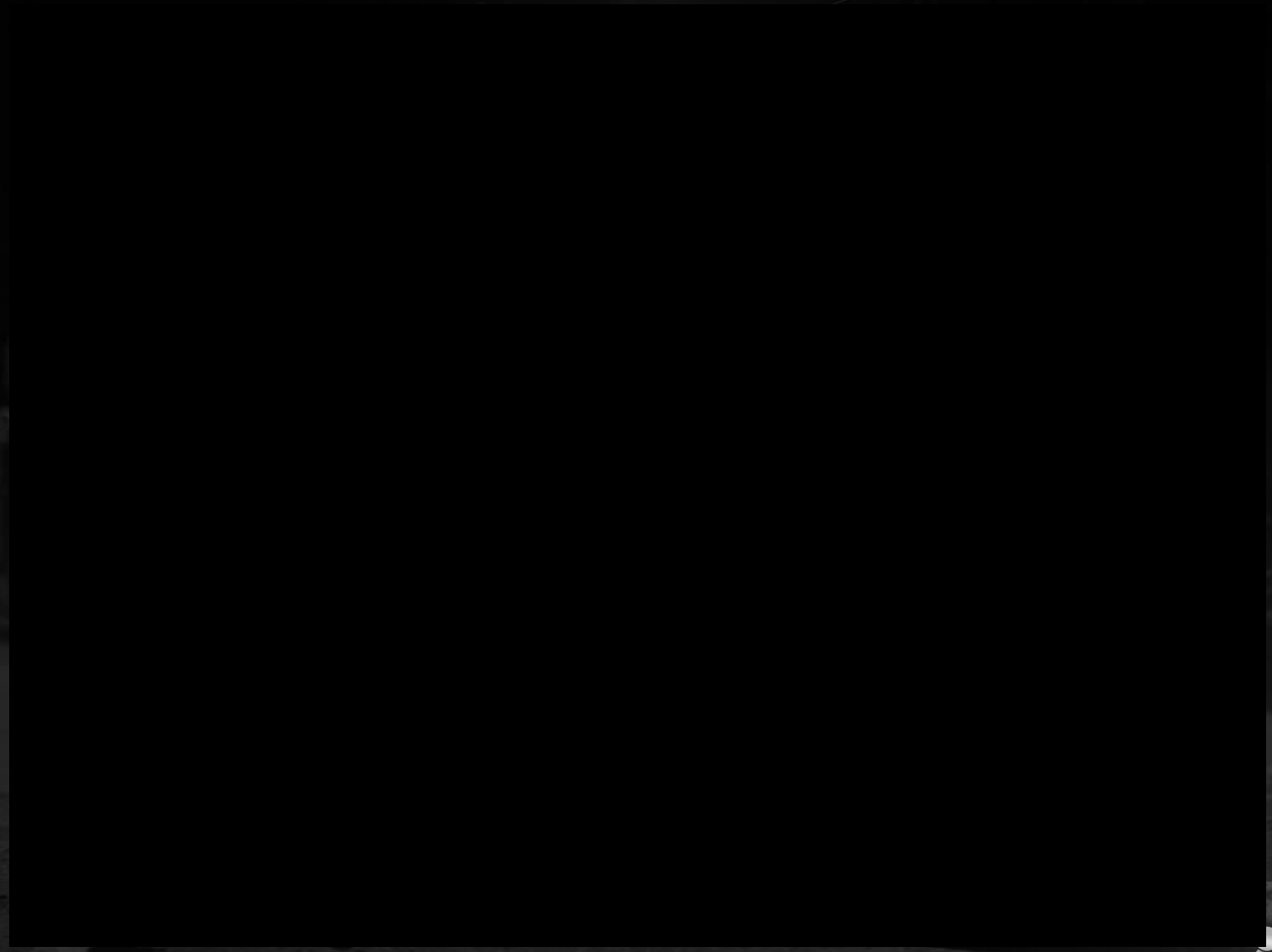
- ↓pressure:
  - tissues release nitrogen bubbles
  - Too much bubbling: Decompression Sickness
    - **Type I DCS: Mild/Joint pain**
    - **Type II DCS: Severe/life threatening**
  - Pre-EVA denitrogenation via oxygen <u>prebreathe</u> *reduces* DCS risk during EVA
- High workload/ambulation = higher risk







High Grade VGE



Why Exploration Atmosphere?

- Significantly increased frequency of EVAs is expected during planetary ops vs. ISS
  - Up to 24 hrs / person / week
- DCS risk is increased by ambulation and physical activity vs microgravity[1]

Current ISS prebreathe protocols would add significant timeline overhead and are NOT validated for planetary EVA

– Shuttle & ISS protocols are applicable to microgravity only

Apollo had 100% O_2 cabin and zero EVA prebreathe

[1]Conkin J, et al. Venous gas emboli and ambulation at 4.3 psia. Aerosp Med Hum Perform. 2017; 88(4):370–376.

Rationale for Exploration Atmosphere

Saturation Atmosphere	Microgravity Prebreathe* (h:mm)	Planetary Prebreathe*
14.7 psi, 21% O2	4:00 (resting)	6:30-7:00 [2]
10.2 psi, 26.5% O2	0:40	3:00-3:30 [3]
8.2 psi, 34% O2	**0:00-0:15**	**0:00-0:30** [4,5]
5.0 psi, 100% O2 (Apollo, Gemini)	0:00	0:00

***Assumes 6hr EVA @ 4.3 psia and approximately equal DCS risk level**

Unvalidated estimates
(i.e., not yet available for flight use)

This Study

[2] Abercromby et al. *Suited Ground Vacuum Chamber Testing Decompression Sickness Tiger Team Report,* (2019) NASA Technical Report. NASA/TP-2019–220343
[3] Abercromby et al. *Using the Shuttle Staged Prebreathe Atmosphere and Variable Pressure Spacesuits for Exploration Extravehicular Activity*, (2018) AsMA.
[4] Abercromby et al. *Modeling Oxygen Prebreathe Protocols for Exploration EVA Using Variable Pressure Suits,* (2017) AsMA.
[5] Abercromby et al. *Modeling a 15-min extravehicular activity prebreathe protocol using NASA 's exploration atmosphere (56.5 kPa/34% O2).* Acta Astronautica, 109 (2015), pp.76-87.

What is NASA-STD-3001

- NASA-STD-3001 requires human testing to
  - ≤ 15% incidence of Type I DCS (@95% CL)
  - ≤ 20% incidence of Grade IV VGE (@95% CL)
  - No Type II DCS

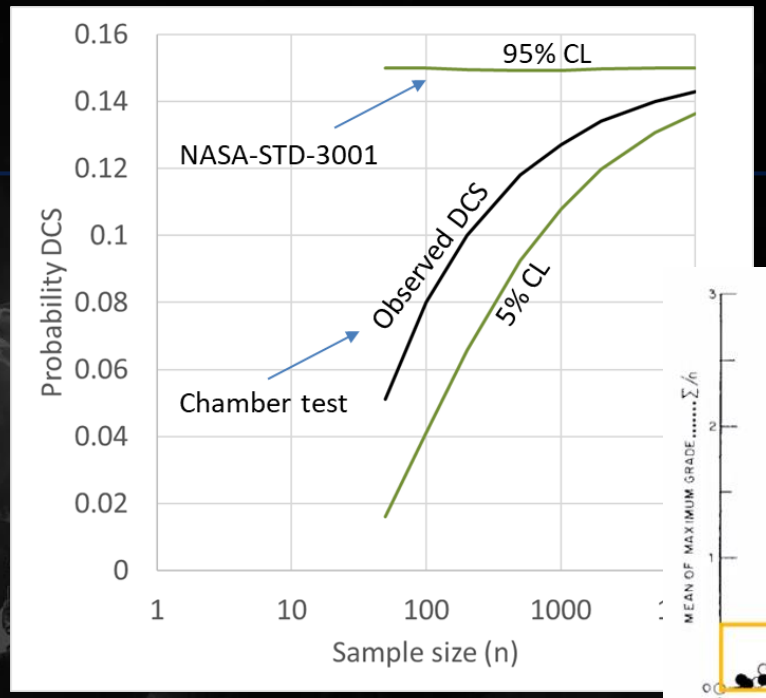
- Prebreathe study yields:

$$\frac{\#\ DCS\ cases}{\#\ of\ exposures}$$

- Statistical conversion to:
  - % DCS risk and Confidence Limits at 5%-95%
  - Confidence limits are driven by N moreso than actual risk
  - Thus, reaching 3001 req'ts is contingent on sample size

NASA-STD-3001 does NOT address Cumulative Risk:

- Loss of EVA is a *mission* risk – determined by mission
- ***Artemis does not currently have mission-wide DCS risk***



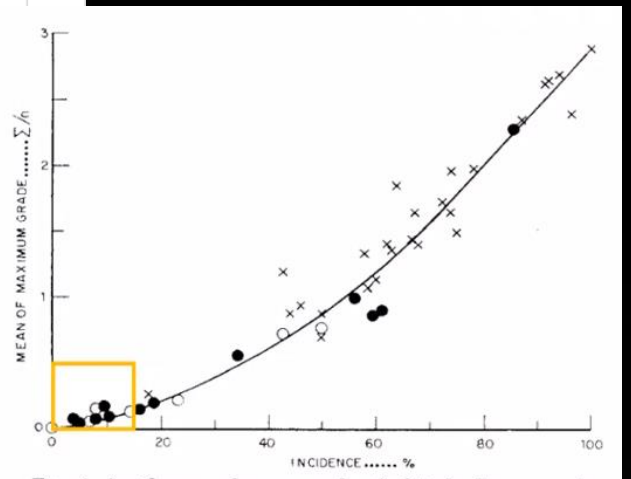
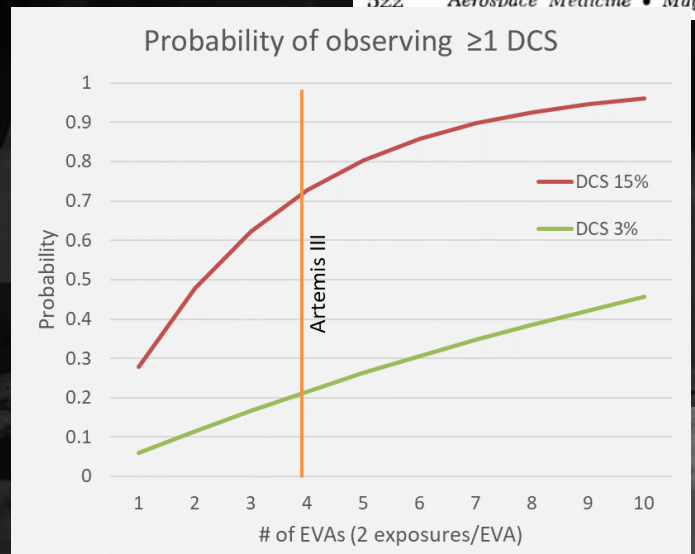


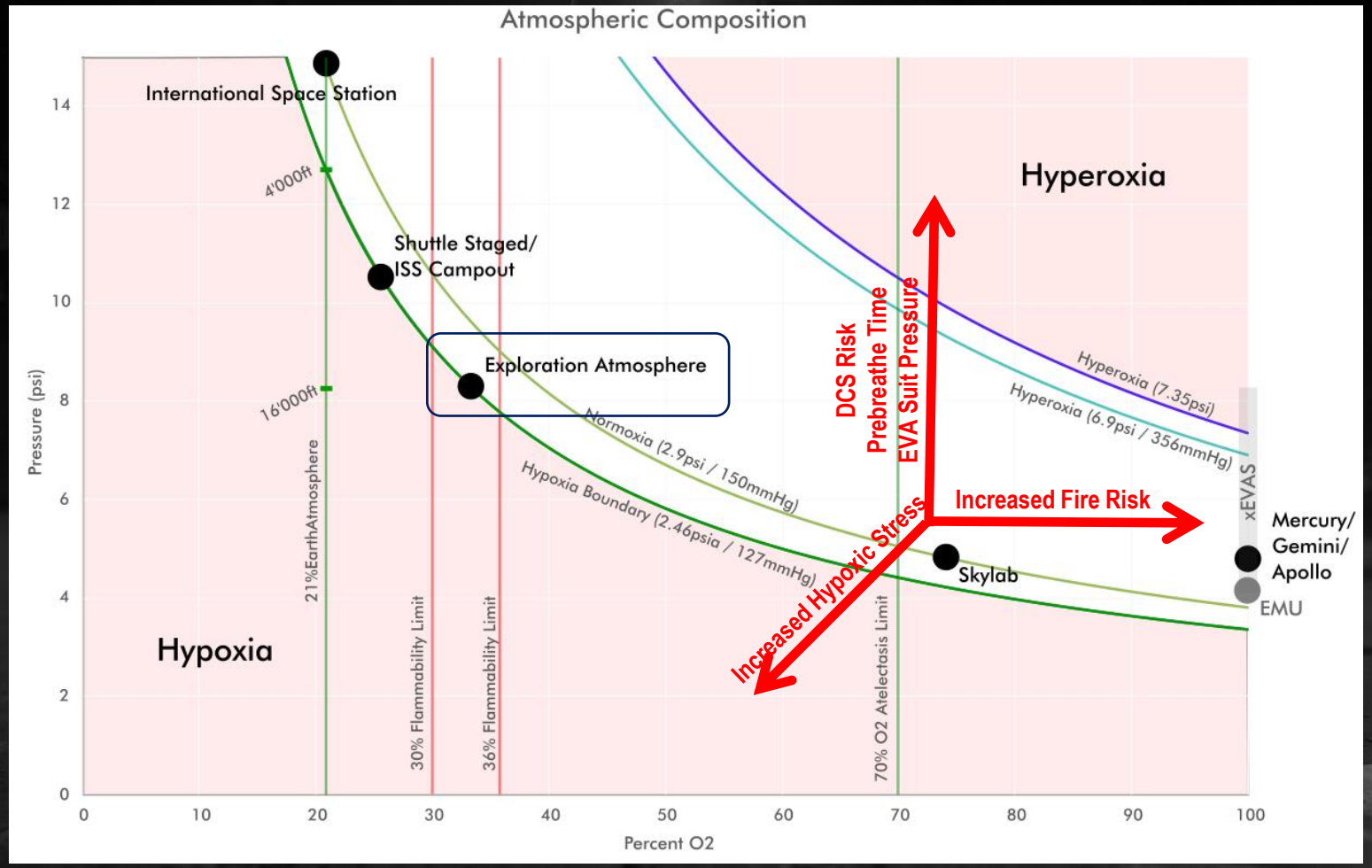
Fig. 4. Incidence and mean grade of altitude decompression sickness from 1942 to present: Crosses, 26 types of exposure with no information on body fat (Table II); Circles, 13 types of exposures (Table I), if filled F > 12 kg, if not filled F < 12 kg.

522 *Aerospace Medicine • May, 1971*



Cabin Atmosphere Constraints

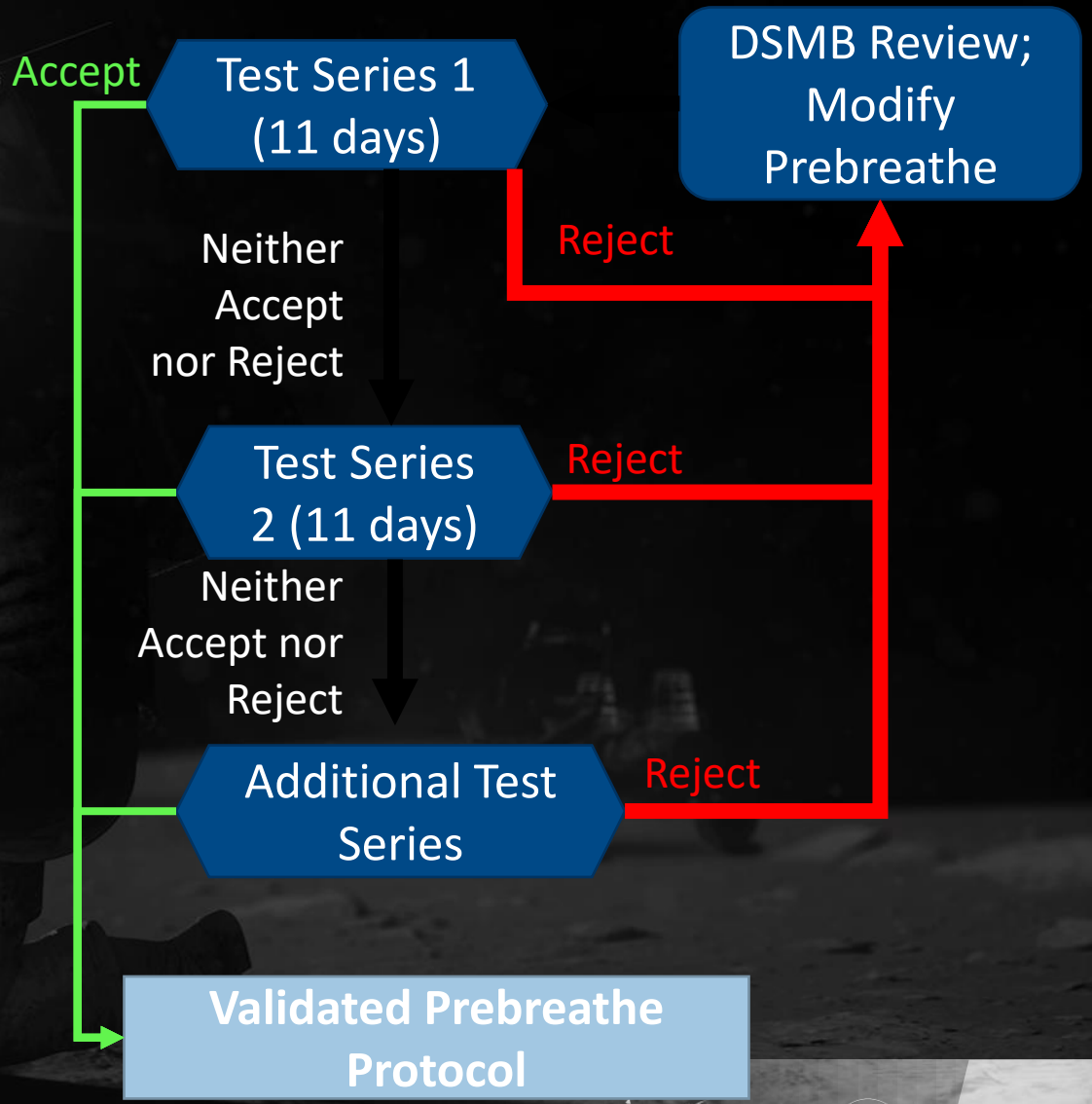
- Exploration Atmosphere Working Group (2006, 2012): 8.2psia / 34% O_2
  - Compromise between flammability, hypoxia, DCS risk, prebreathe time



How do we actually test?

Exploration Atmosphere Validation

- Accept Criteria (per NASA-STD-3001):
  - ≤ 15% incidence of Type I DCS (@95% CL)
  - ≤ 20% incidence of Grade IV VGE (@95% CL)
  - No Type II DCS
- Reject Criteria
  - > 15% incidence of Type I DCS (@70% CL)
  - > 20% incidence of Grade IV VGE (@70% CL)
  - Any Type II DCS
- Neither
  - Requires review and additional data



DSMB: Data Safety Monitoring Board

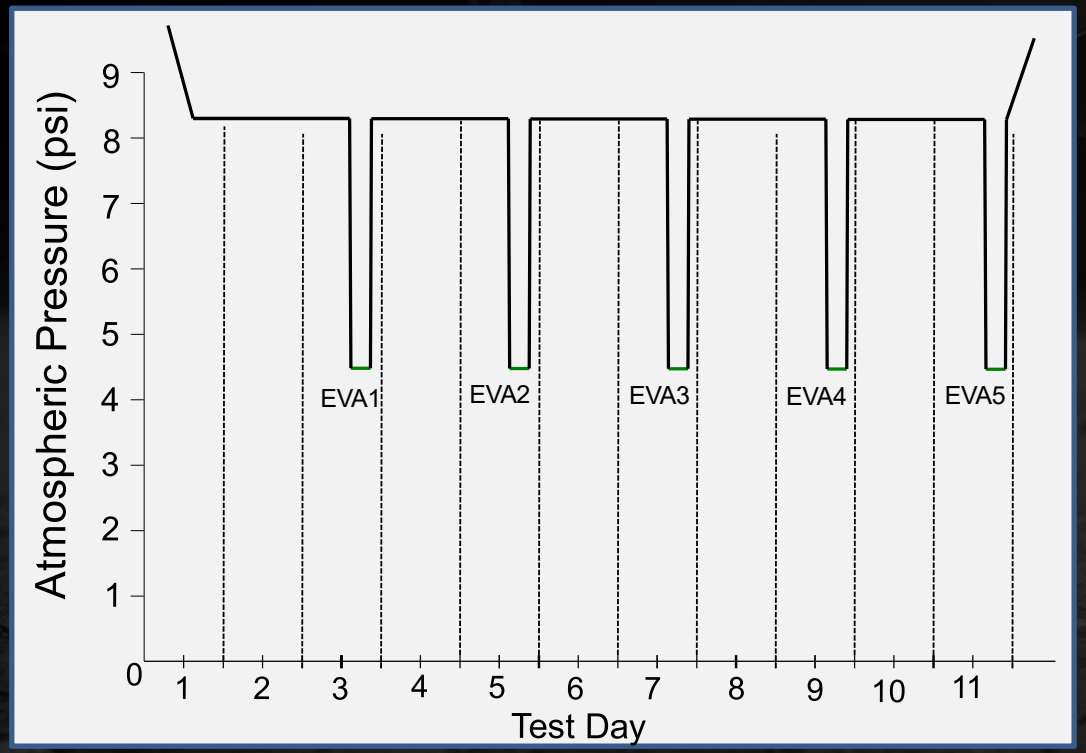
Protocol: EVA Simulations

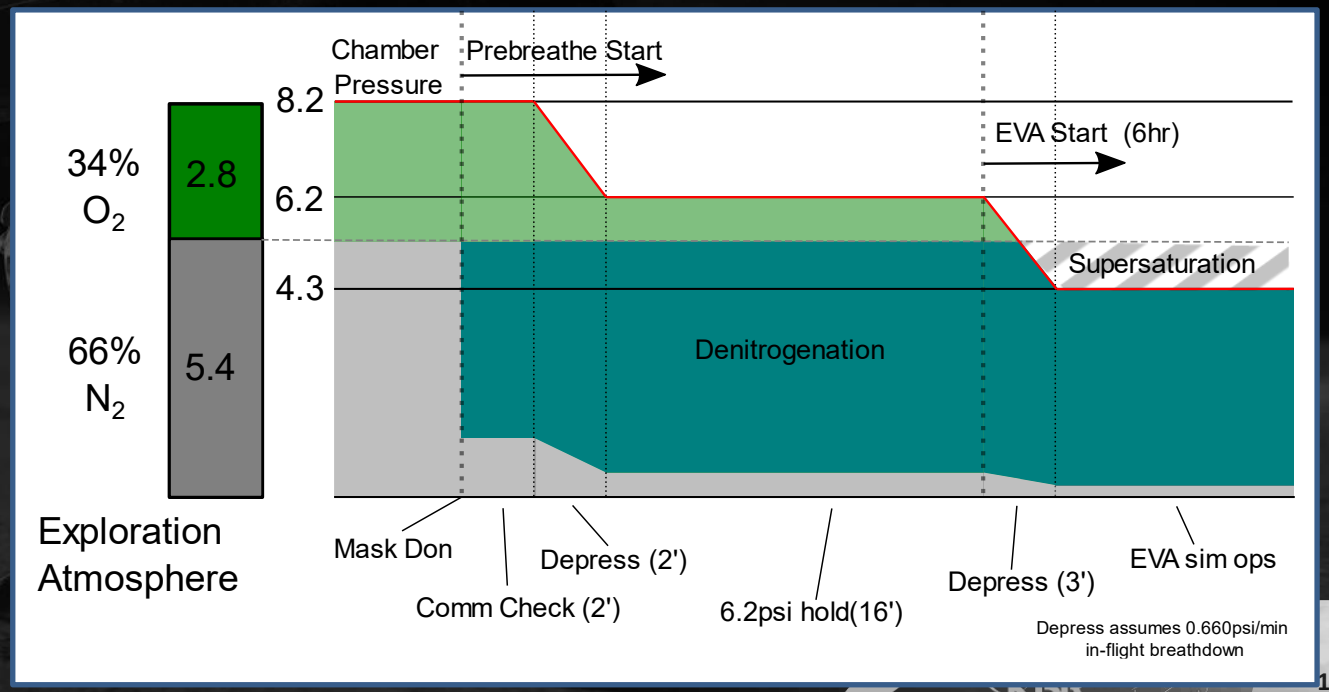
- Odd Days: EVA Simulations (N_{EVA} = 5)
  - Complete prebreathe and 6 hrs of prescribed simulated EVA activities
- Even Days: Rest + Hypoxia Characterization
  - Various physiologic and cognitive measurements will be taken to characterize the effects of hypobaric hypoxia in the exploration atmosphere.

Day 1	3hr PB @ 100% O2, 14.7 psia; Depress to 8.2 psia, equilibrate
Day 2	Equilibrate + Hypoxia Characterization
Day 3	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 4	Hypoxia Characterization
Day 5	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 6	Hypoxia Characterization
Day 7	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 8	Hypoxia Characterization
Day 9	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 10	Hypoxia Characterization
Day 11	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2

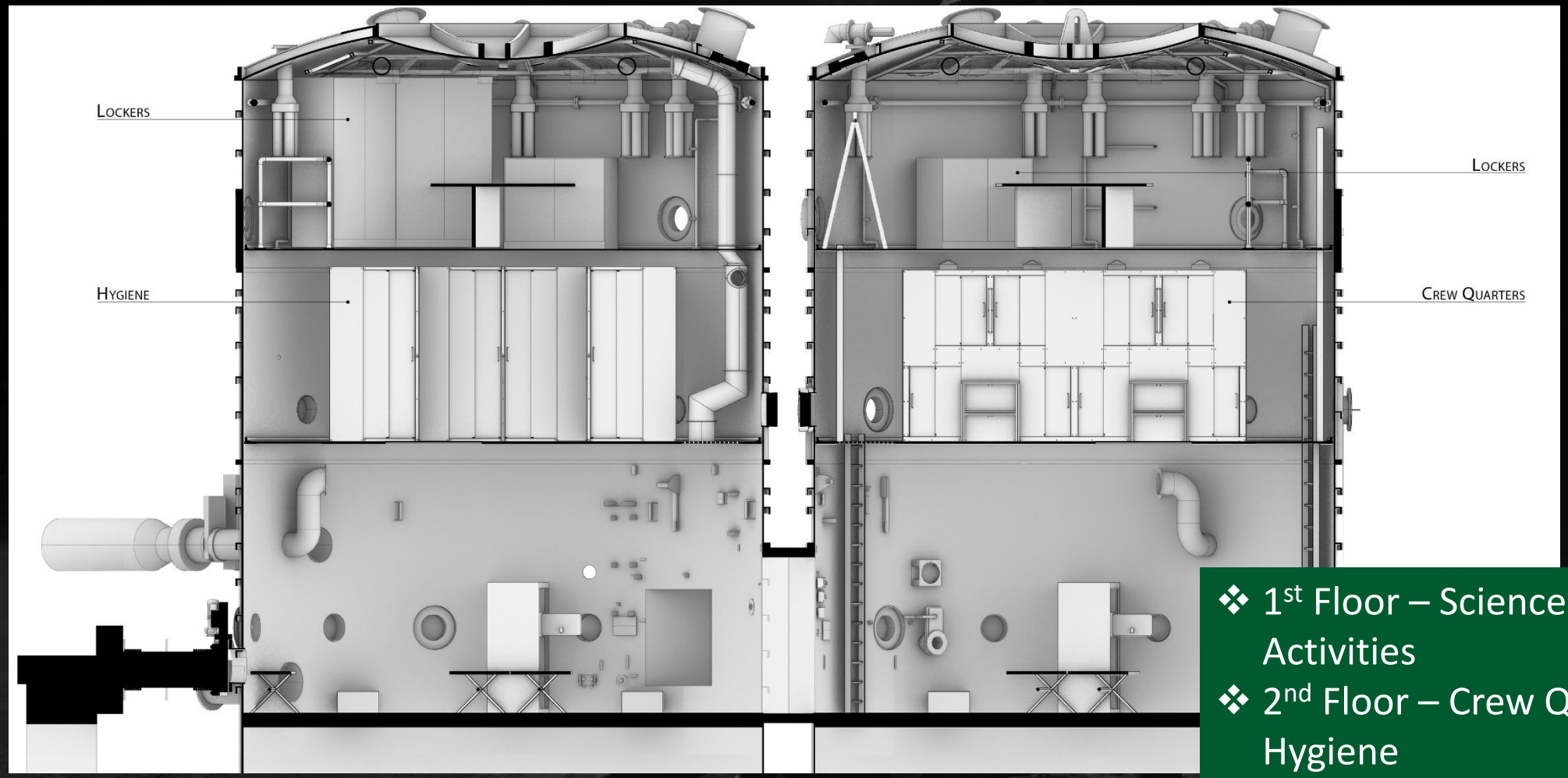
Prebreathe Validation Approach

- What prebreathe is sufficient to meet NASA-STD-3001 standards in a Lunar/Mars environment?
  - Equilibrate to Exploration Atmosphere: 8.2psi/34% O_2 for 48 hrs (after 3hr O_2 PB)
  - Minimum prebreathe duration: 20 min ≥ 6.2psi
  - Simulated EVA: 4.3psi/85% O_2
  - Simulate EVA workload: 6 tasks for 6hrs across workload ranges





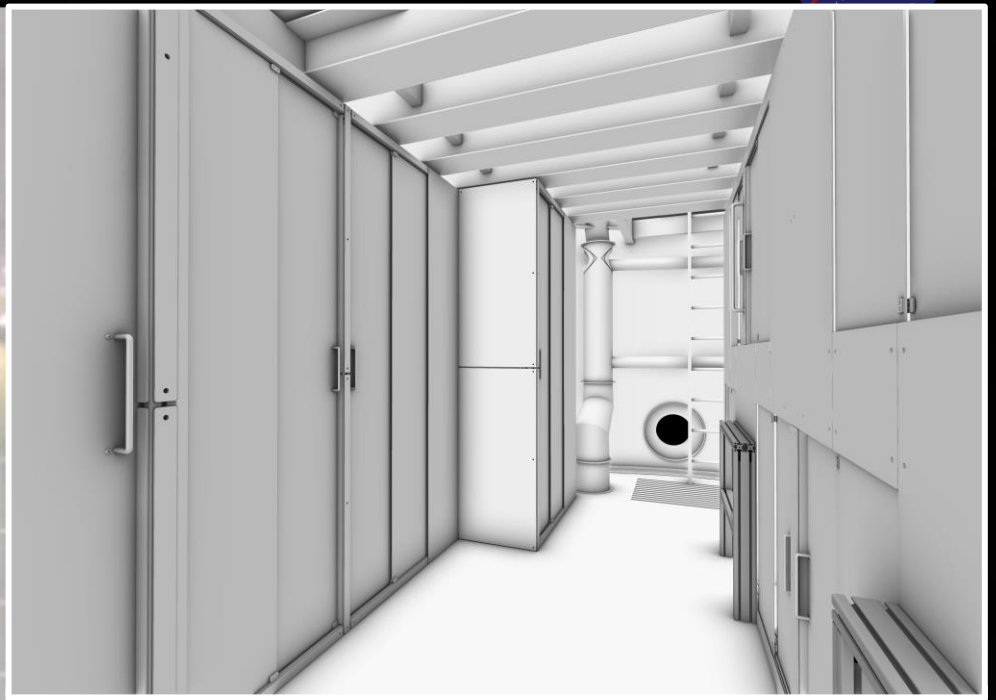
20FT Chamber Overview

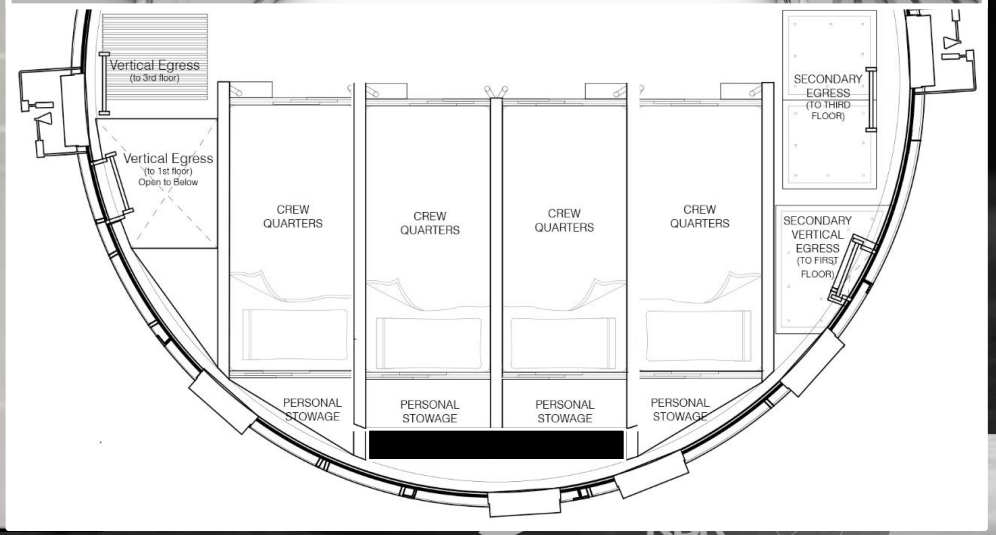


- 1st Floor – Science & EVA Activities
- 2nd Floor – Crew Quarters & Hygiene
- 3rd Floor – Stowage & Media Center

3rd Floor Configuration

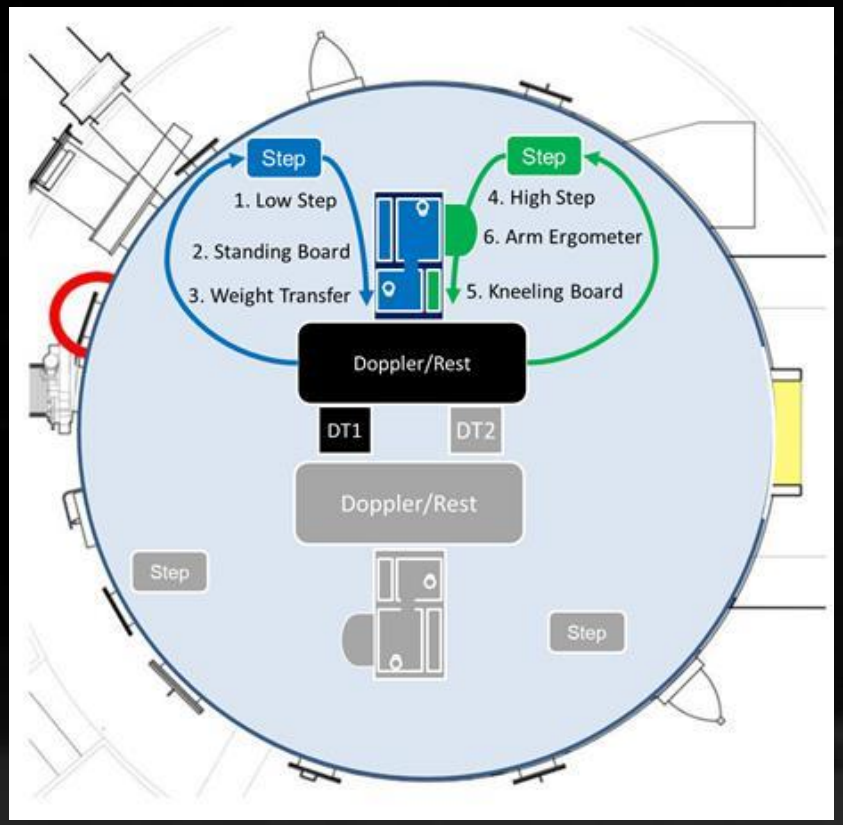
2nd Floor – Crew Quarter Layout

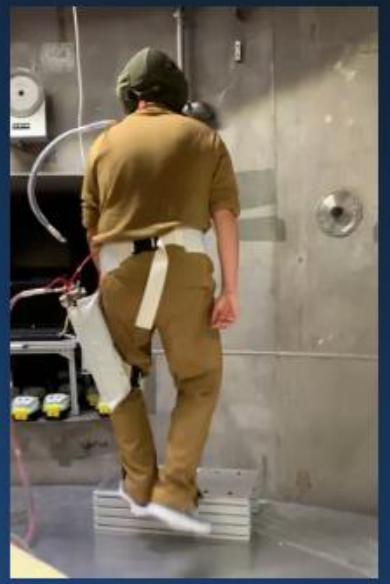




EVA Sim Stations

EVA Simulation

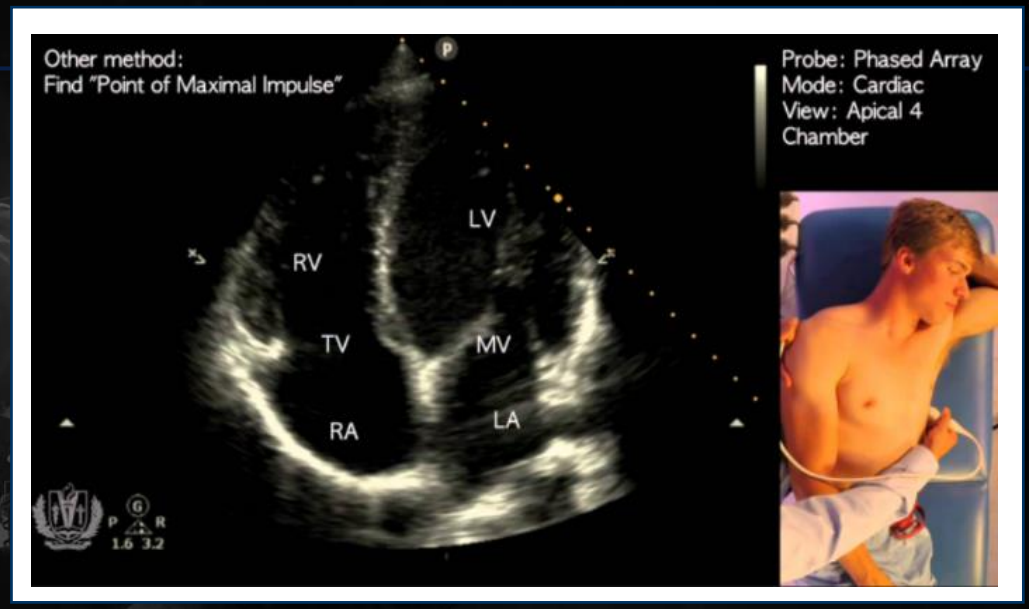


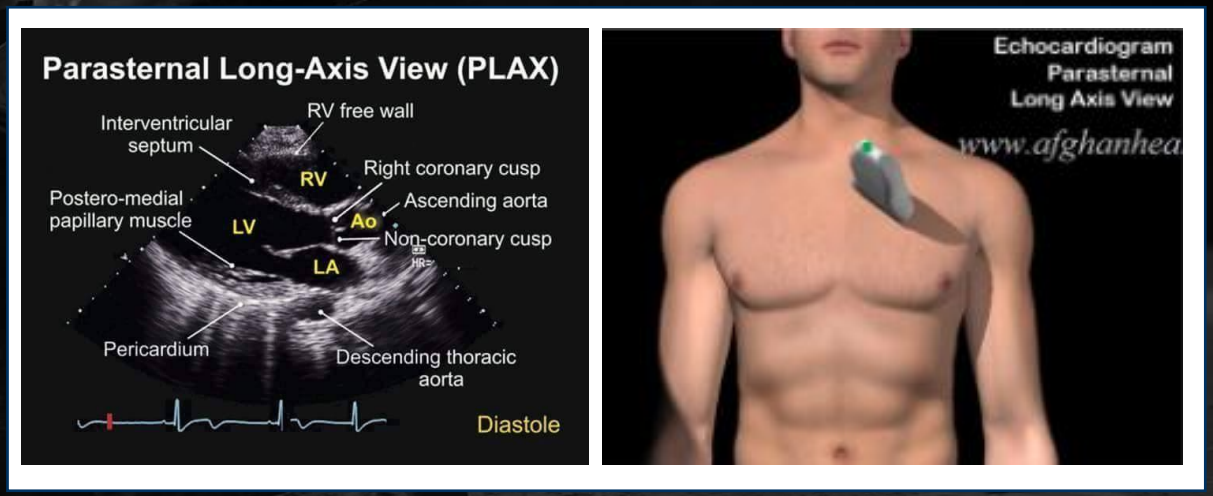


EVA Sim Presented at AsMA 2022
see *Estep et al.*

VGE Methods

- Every 15 min:
  - Subject lays on the cot in a left recumbent position
  - The operator gels the Vivid iQ ultrasound probe and acquires an apical cross-section view of the heart and heart chambers (top)
    - If the apical view is not easily visible, a parasternal long-axis view is imaged instead (bottom)
  - Alternates with Doppler auscultation of L parasternal border





Analysis and Scoring Methods

Ultrasound and Doppler Scoring

- Ultrasound videos were scored based on number of VGE / bubbles present during imaging over 10 cardiac cycles (Modified Eftedal Brubakk Score, right).
- Doppler audios were scored based on 'bubble signals', or audible peaks in doppler waveforms

Doppler Bubble Grading
Spencer Scale

Grade	Description
0	A complete lack of bubble signals
I	An occasional bubble signal with the great majority of cardiac periods free of bubbles
II	Many, but less than half, of the cardiac periods contain bubble signals, singly or in groups
III	All the cardiac periods contain showers of single-bubble signals, but not dominating or overriding the cardiac motion signals
IV	The maximum detectable bubble signal sounding continuously throughout systole and diastole of every cardiac period, and overriding the amplitude of the normal cardiac signals

Score	Definition
0	No visible bubbles
1	Occasional bubbles
2	At least 1 bubble every 4 heart cycles
3	At least 1 bubble every heart cycle
4	Not more than one third of every image
5	Not more than two thirds of every image
6	Near whiteout; individual bubbles still discerned
7	Whiteout; individual bubbles can't be discerned

Data Analysis / Graphs

- Scores for rests and leg flexes – left and right – were acquired via Vivid iQ Ultrasound w/ doppler wave acquisition application.
- Scores between cross-graders (n=3 to 4 per crew member at each time point) were averaged for the resting and flexing periods.
- Max scores and average scores of resting and flexing periods were graphed.
- Data is represented by mean ± standard deviation.

Results

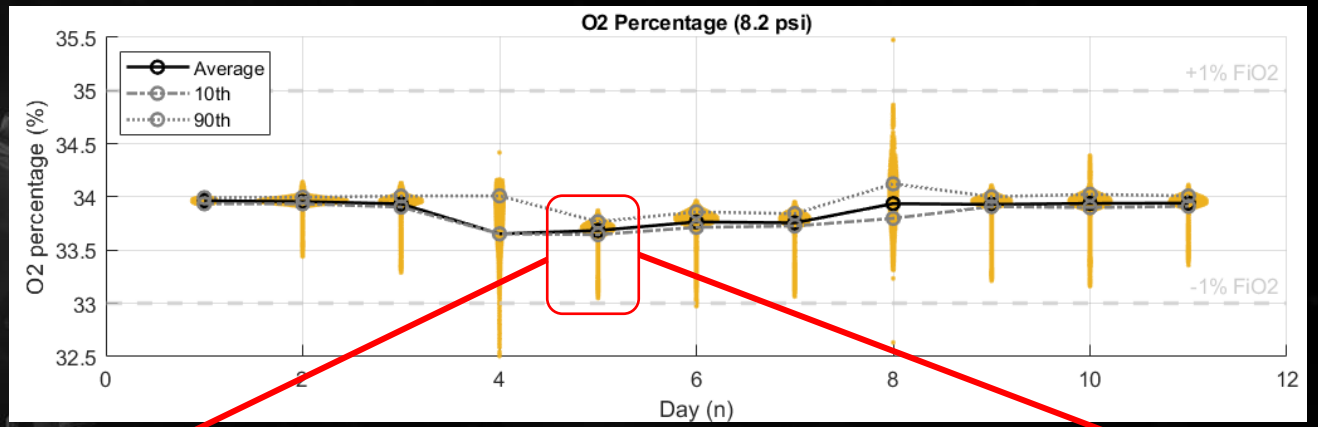
Test Campaign Summary

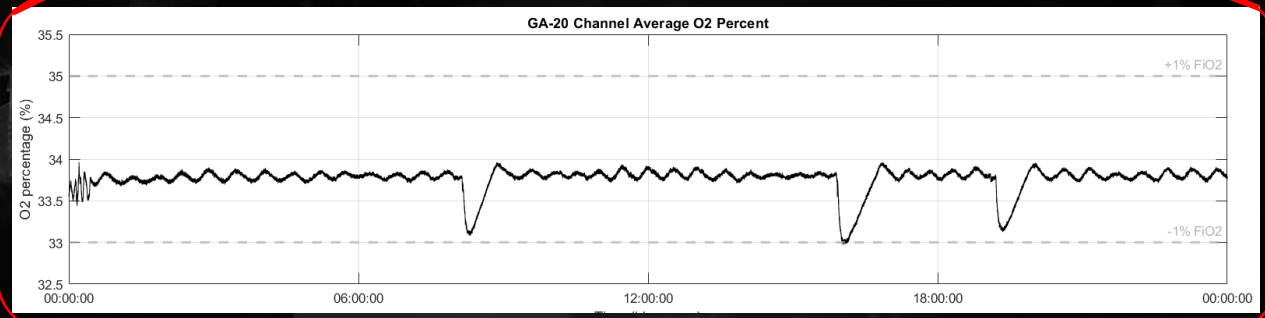
- 2005 – Initial proposal: 8.0psi/32% FiO_2
- 2012:
  - Updated to 8.2psi/34% FiO_2 (to decrease hypoxic stress)
  - Briefing to HEOMD – proceed with work on EA
- 2018 – Human validation studies in the building 7 20ft chamber green lit
- 2021 – Chamber readiness complete/initial HITL assessment
  - 2021-11: Overnight in Chamber (doors 'closed', no pressure change)

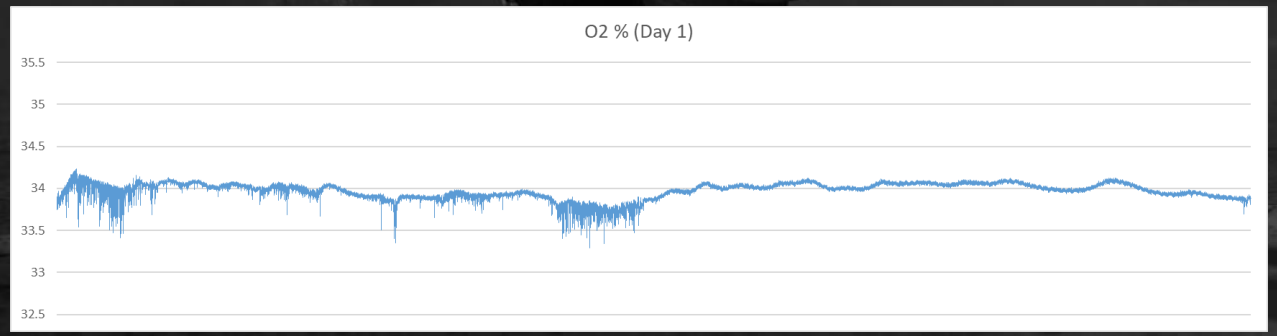
- 2022
  - Feb: 1-day equipment validation (n=2)
  - Mar: 3-day dress rehearsal (n=8)
    - DCS x1
  - Jun: 11-day test (n=8) **"EA1"**
    - No DCS Type II
    - Two DCS Type I cases; symptoms fully resolved with treatment
    - One DCS Type I in Doppler Tech
    - One VGE Grade IV
- 2023
  - Mar: 3-day dress rehearsal (n=8)
    - No DCS I/II
  - Jun: 11-day test (n=8) **"EA2"**
    - No DCS I/II
    - One Asymptomatic LVGE
    - One DCS Type I in external Doppler Tech

Chamber Environmental Controls

- "Did we test the atmosphere we said we would?"
  - Overall within parameters
  - Biggest effects:
    - Sensor Calibration:
      - Dec 2022 test showed <0.5% error
    - Airlock Gas Bolus:
      - Caused the largest swings (~0.7% O_2)
      - Fixed for EA-2 w/Airlock O_2 Injection
    - Pressure Control offset:
      - Cause systematic error of -0.05psi
      - Adjusted set point to 8.25psi



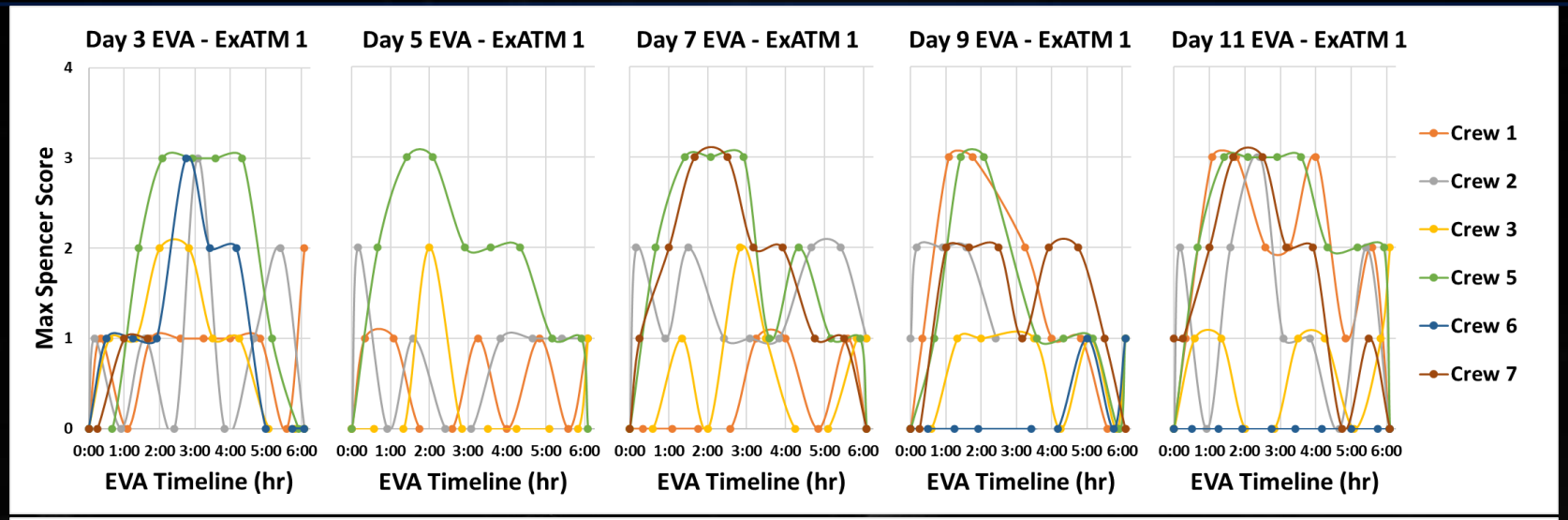


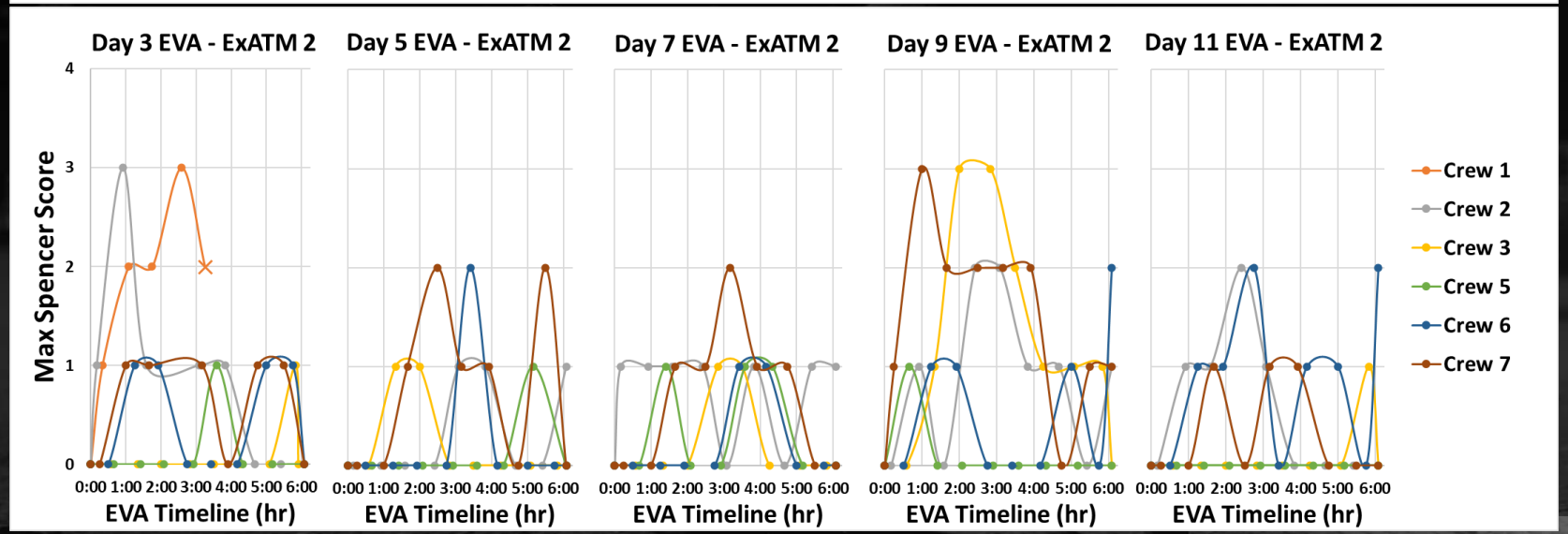


Doppler – Max Spencer Grade

EA1

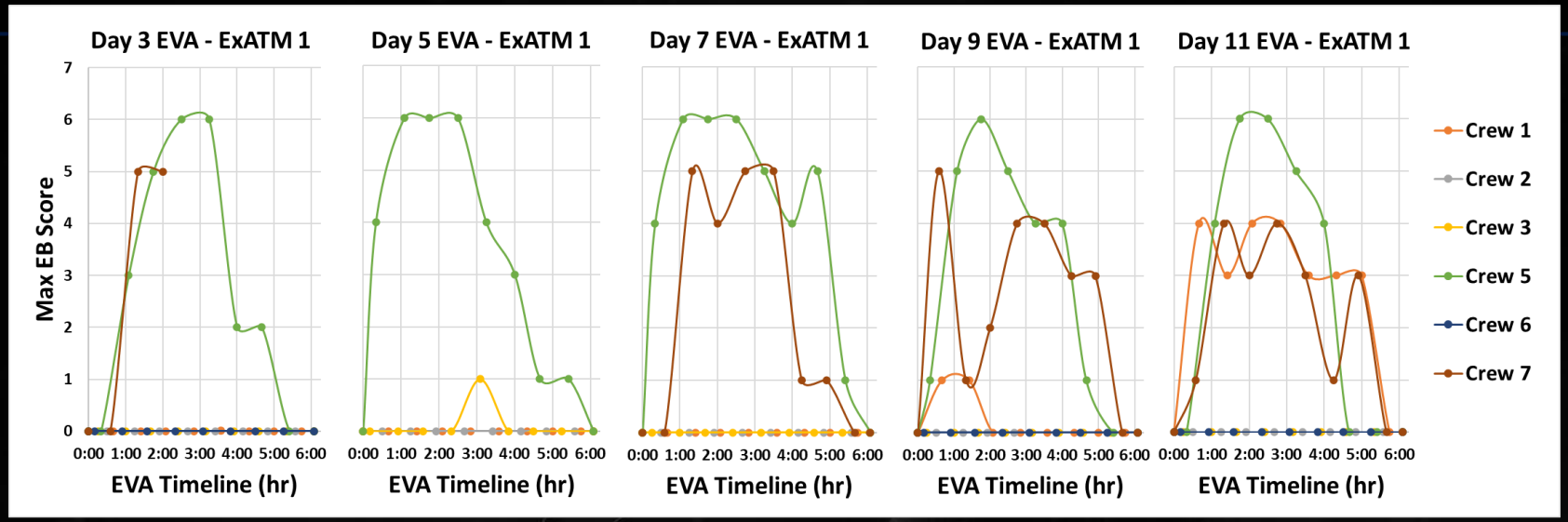
EA2



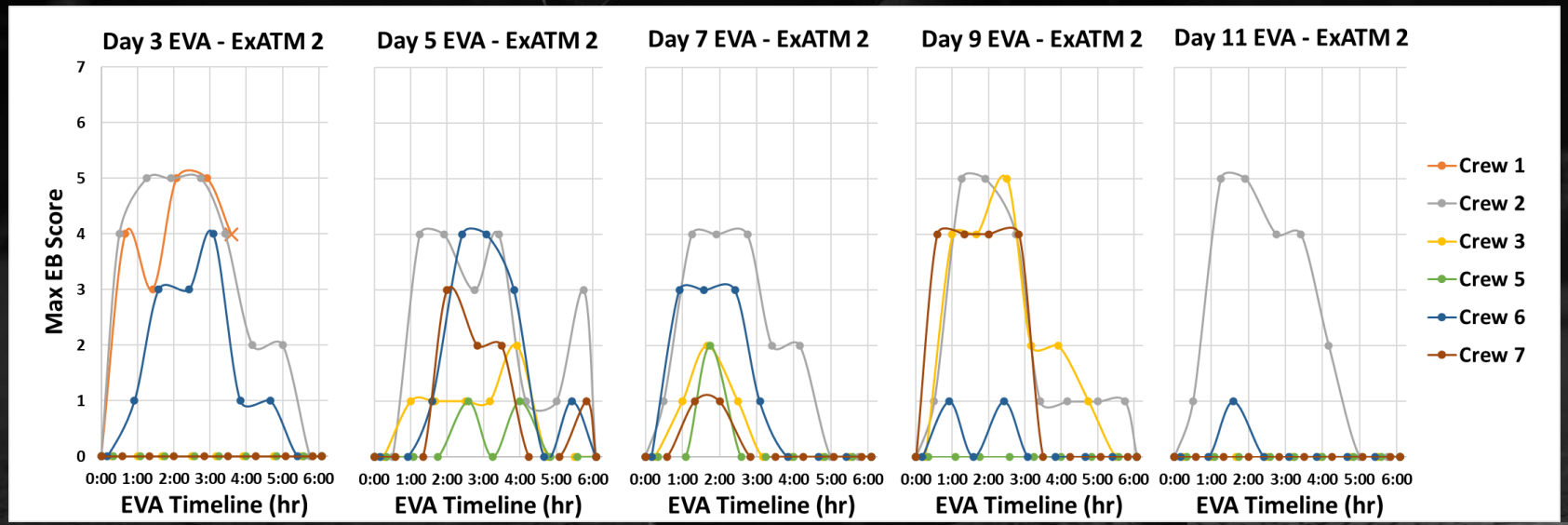


Ultrasound – Max EB Score

EA1



EA2



Mapping Doppler to Ultrasound

- U/S is a better tool to monitor VGE:
  - Decreased training time for grading
  - Can monitor for left-to-right shunts
  - Can be used for other medical/science goals
- Spence Grade IV correlates to E-B Score 6 & 7 in our data set

- NASA-STD-3001:
  - ≤ 15% incidence of Type I DCS (@95% CL)
  - ≤ 20% incidence of Grade IV VGE (@95% CL)
  - No Type II DCS

Doppler Bubble Grading
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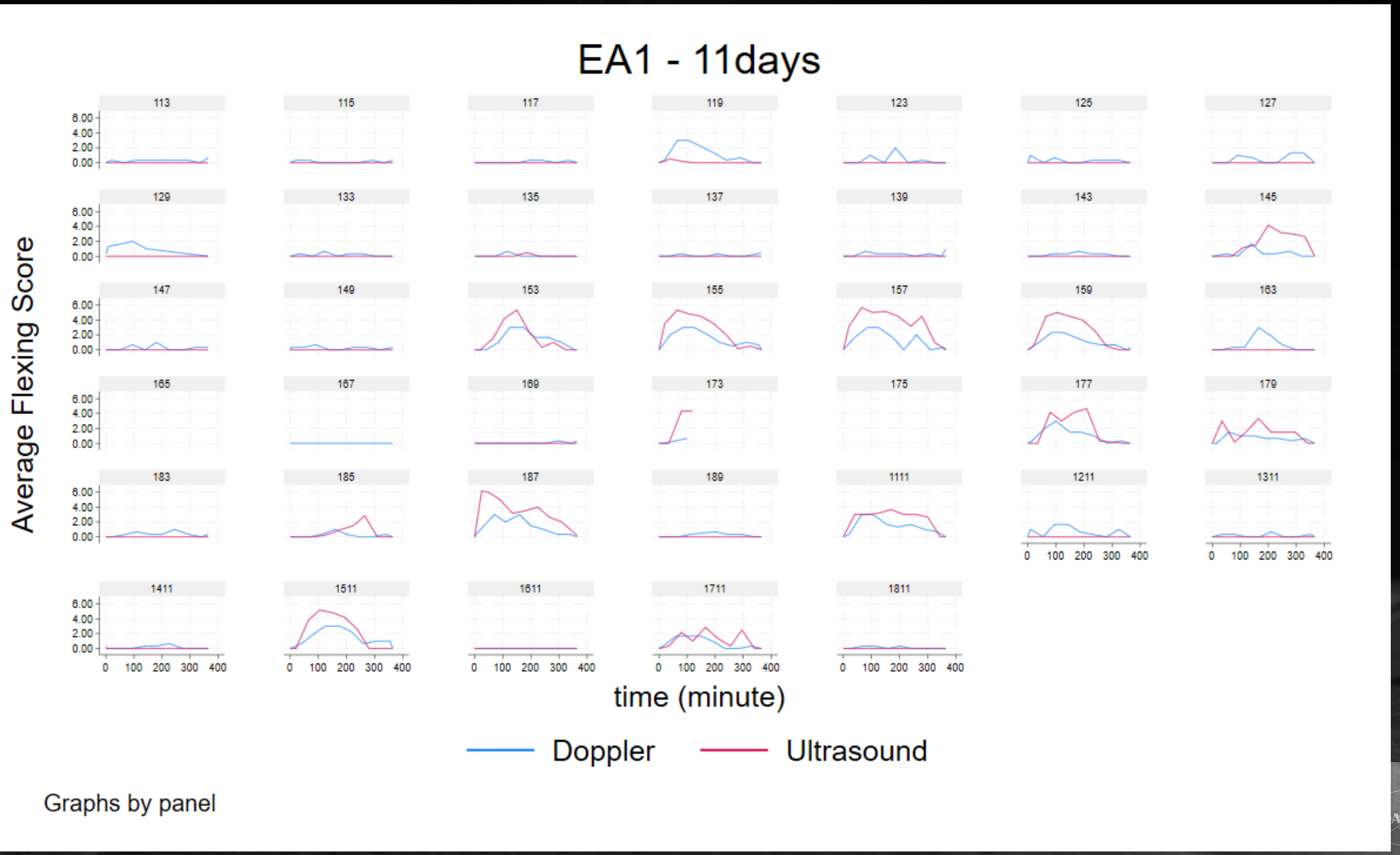
Average Flexing Score



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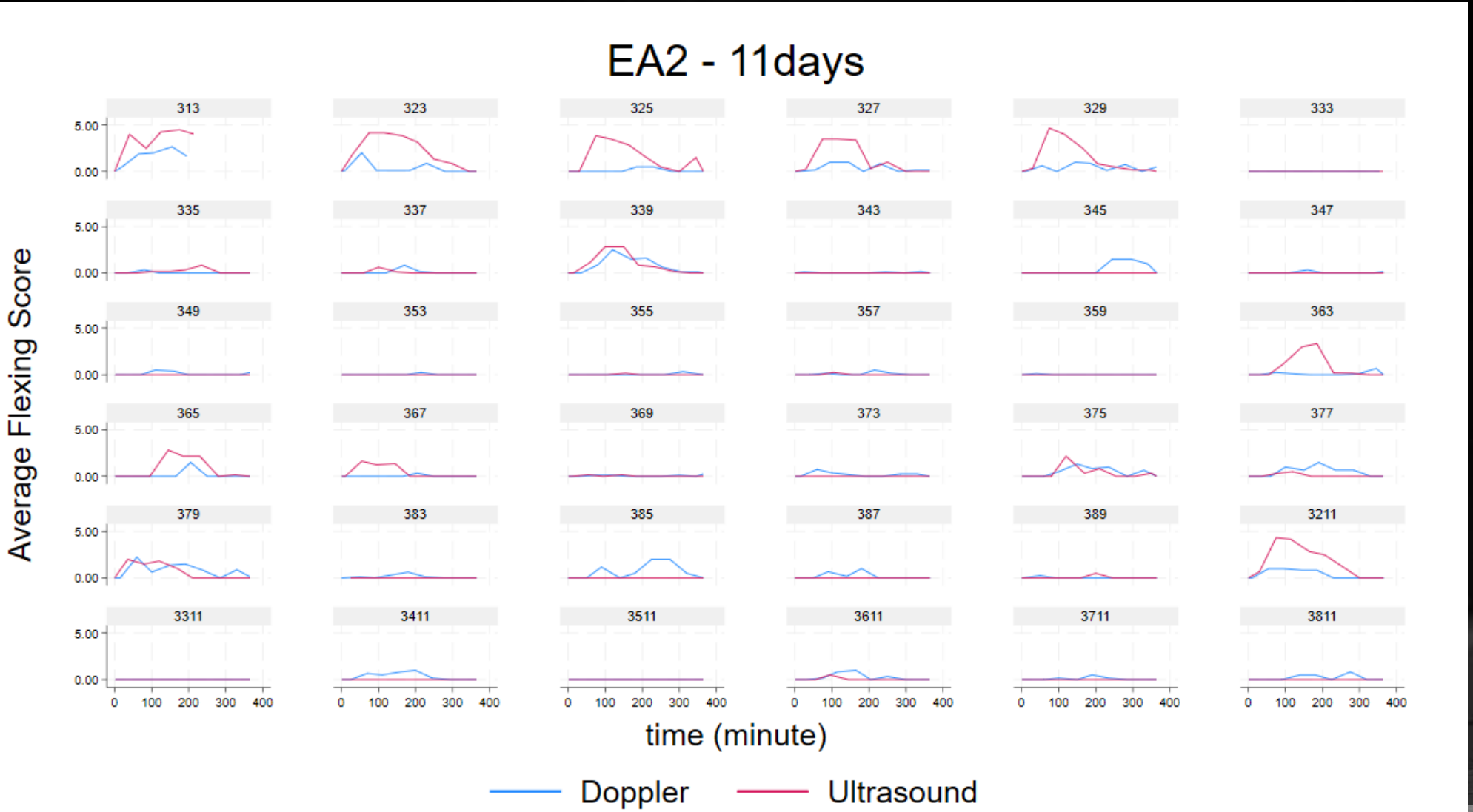
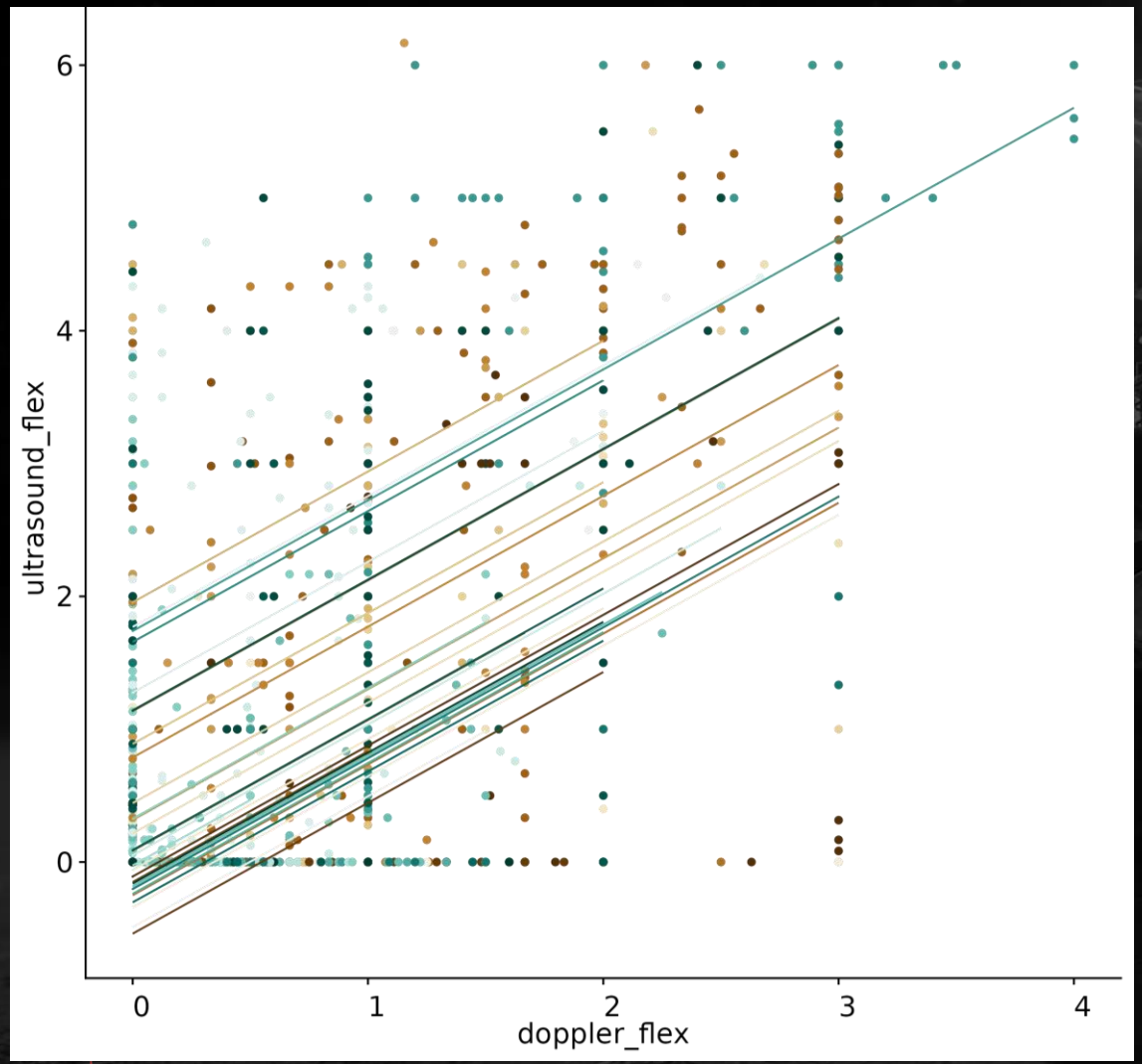


Average Flexing Score



- Repeated measures correlation:
  - 0.572 (0.543, 0.603)
- Concordance correlation coefficient:
  - 0.535 (SE = 0.012)
- Spearman rank-order correlation:
  - 0.5004
- Models may be biased due to not meeting some assumptions depending on the measures of correlation:
  - Not independent and identically distributed due to repeated measures
  - Errors normally distributed due to the categorical nature of the underlying variables

Total Exposures

EA1 (2022):

- **EVA 1**: 6 subjects participated, 1 DCS case
- **EVA 2**: 4 subjects participated, no DCS*
  - 1 subject sat out EVA per protocol on ground level oxygen due to DCS on EVA1
  - 1 subject sat out EVA due to mask fit issues
- **EVA 3**: 5 subjects participated, no DCS
  - 1 subject sat out EVA due to mask fit issues
- **EVA 4**: 5 subjects participated, no DCS
  - 1 subject sat out EVA due to musculoskeletal issues
- **EVA 5**: 6 subjects participated, 1 DCS case
  - 1 subject excluded due to musculoskeletal issues

Finally Tally: 2 DCS cases, 50 exposures

EA2 (2023):

- **EVA 1**: 6 subjects participated
  - 1 LVGE case removed
- **EVA 2**: 5 subjects participated, no DCS
- **EVA 3**: 5 subjects participated, no DCS
- **EVA 4**: 5 subjects participated, no DCS
- **EVA 5**: 5 subjects participated, no DCS

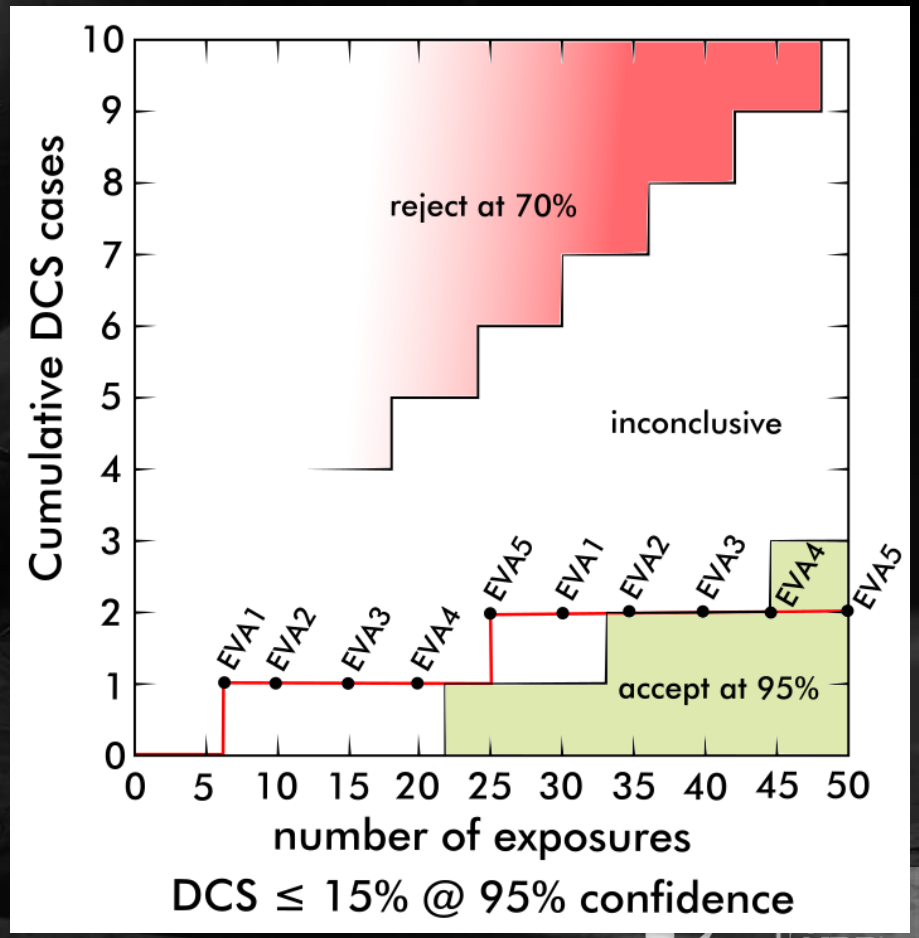
* DCS case in Doppler Technician – not a study subject

Summary – 8.2/34% Campaign

- Accept Criteria (per NASA-STD-3001):
  - ≤ 15% incidence of Type I DCS (@95% CL)
  - ≤ 20% incidence of Grade IV VGE (@95% CL)
  - No Type II DCS

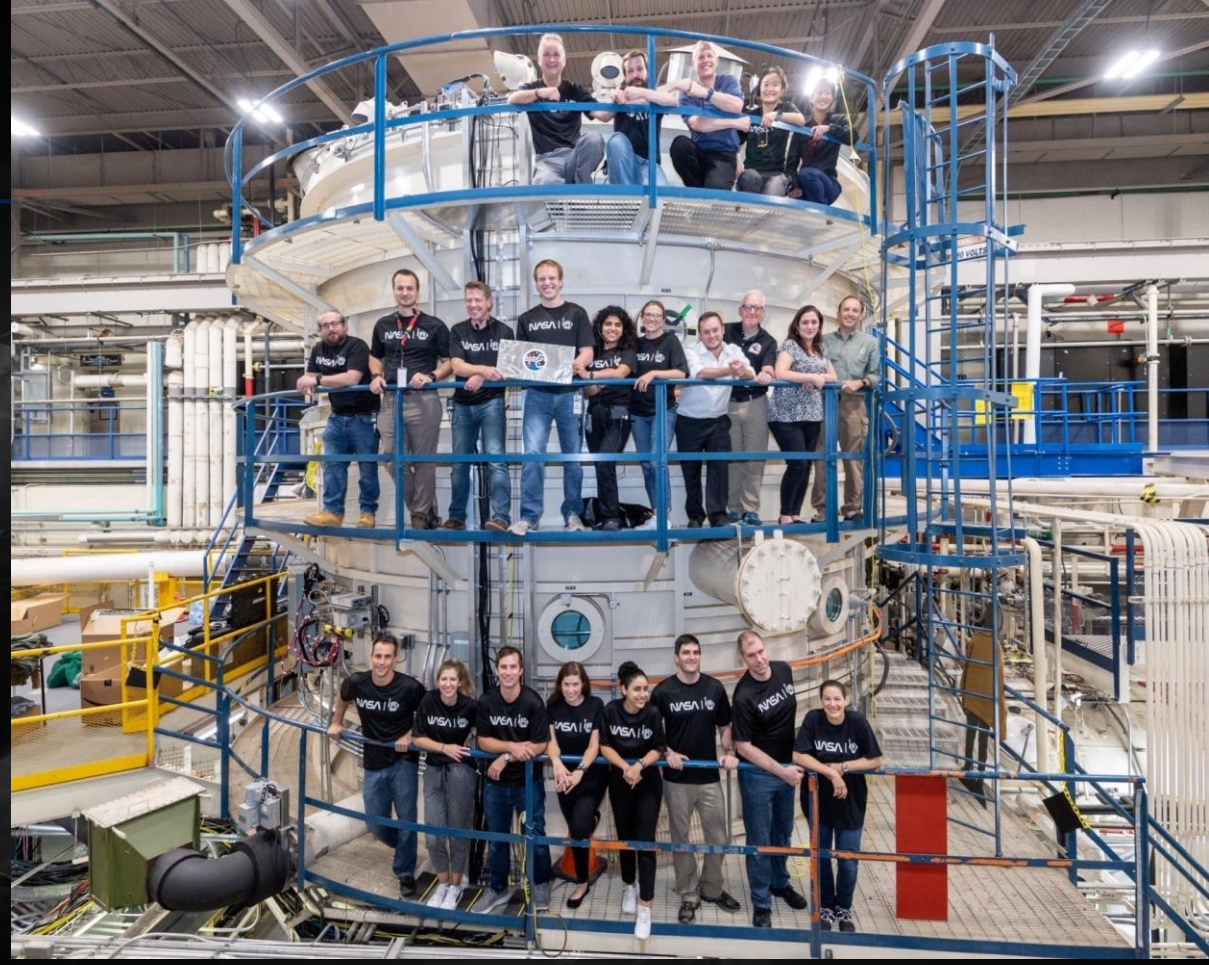
- Observed:
  - DCS Type I: 2/50 = 4% (1.1%-13.5%)
  - DCS Type II: 0
  - VGE IV: 0
    - (EB Grade 7: 1/50)

- No Type II Cases
- Two Type I Cases (out of 50 exposures)



Conclusion

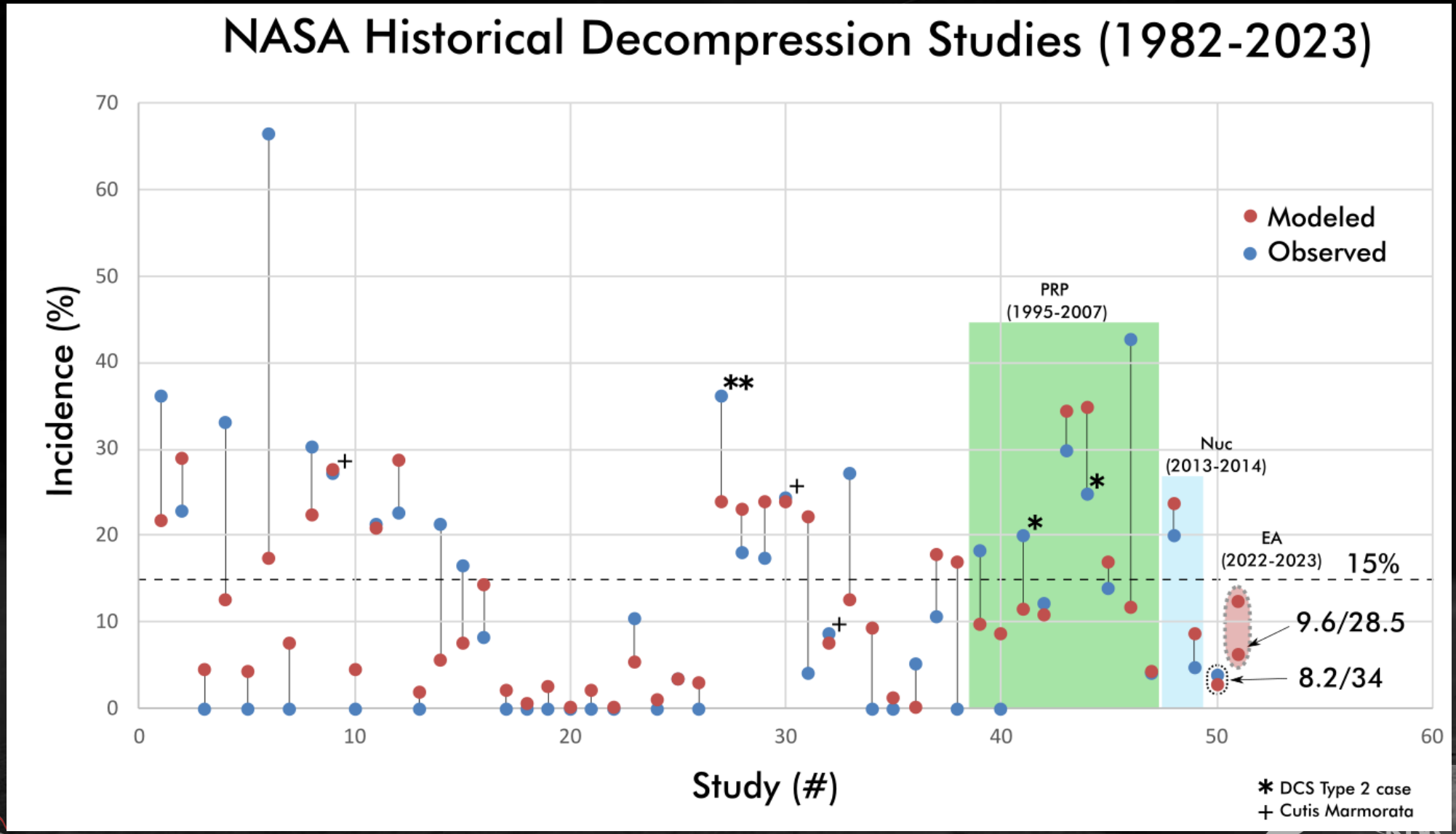
- A **20 min prebreathe** from a 56.5kPa (8.2 psi), 34% O2 atmosphere meets NASA-STD-3001 for EVAs at 30kPa (4.3psia)
  - The observed DCS risk is 4% (1.1%-13.5%) per person per EVA
- Doppler and U/S both show significant VGE stress during EVA
- Will transition to allow E-B score as an alternative to Spencer Grade



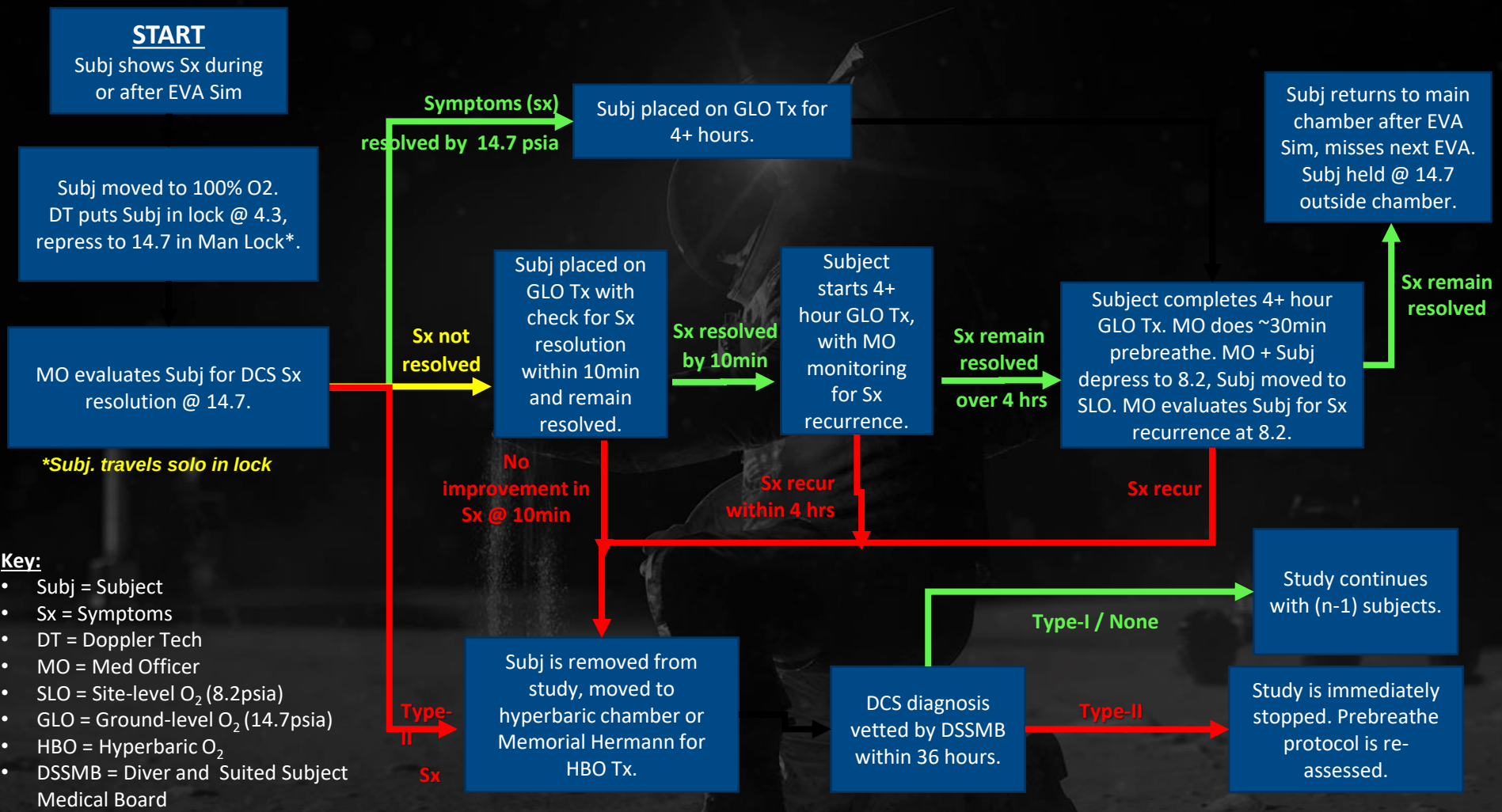
Thank you!

Backup/Reference

Historical NASA Testing

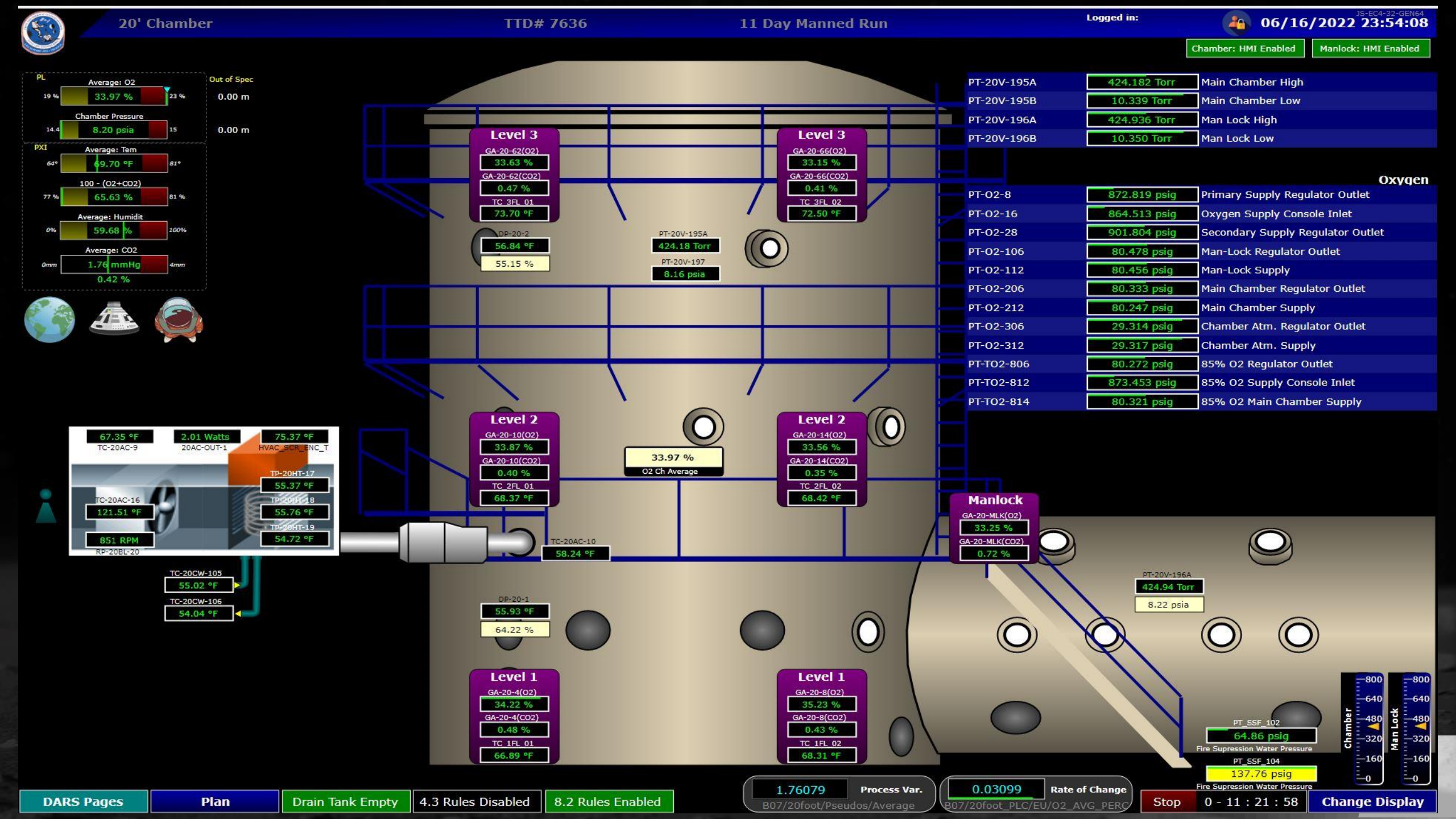


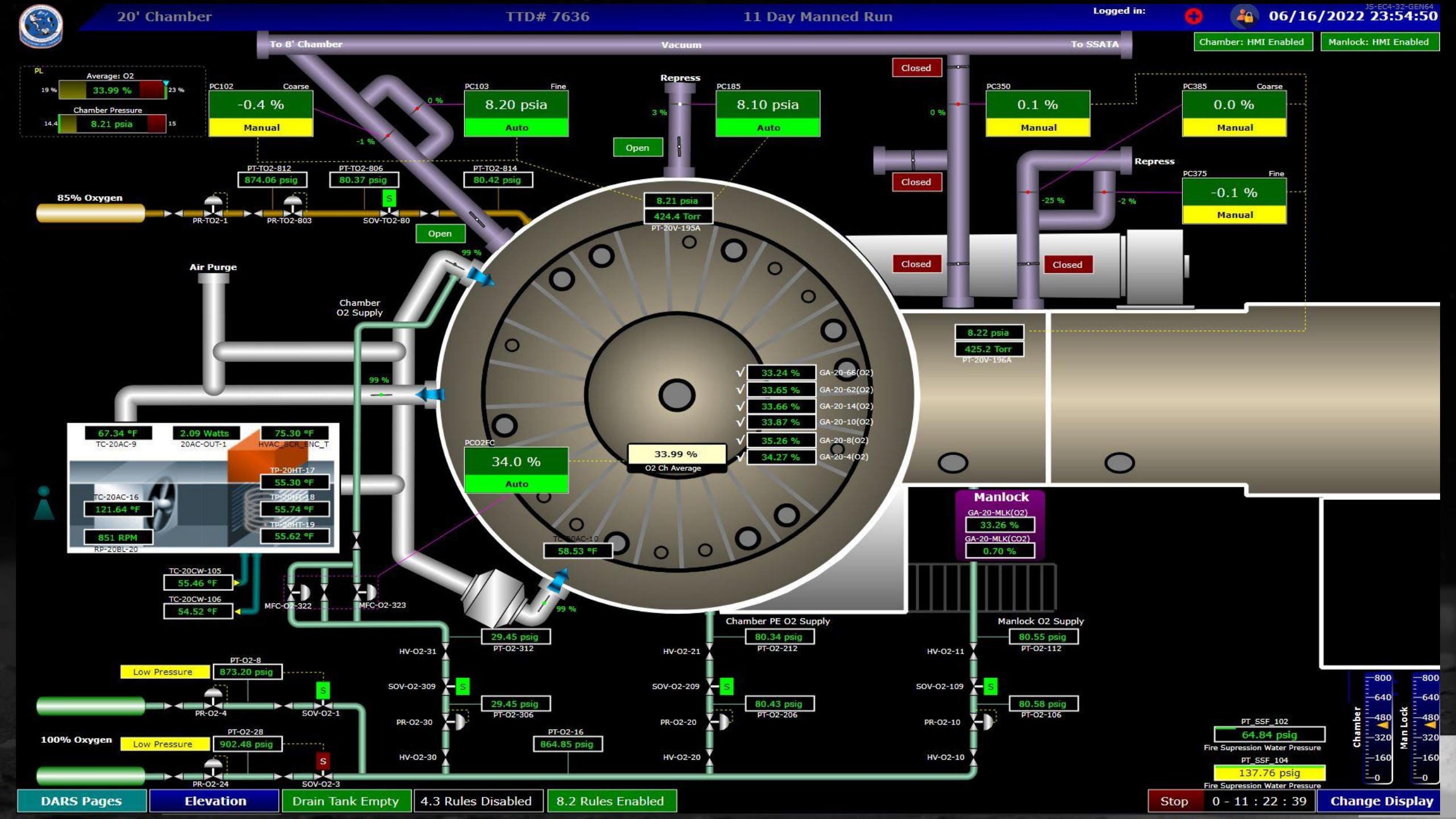
Revised DCS Treatment Flow Diagram



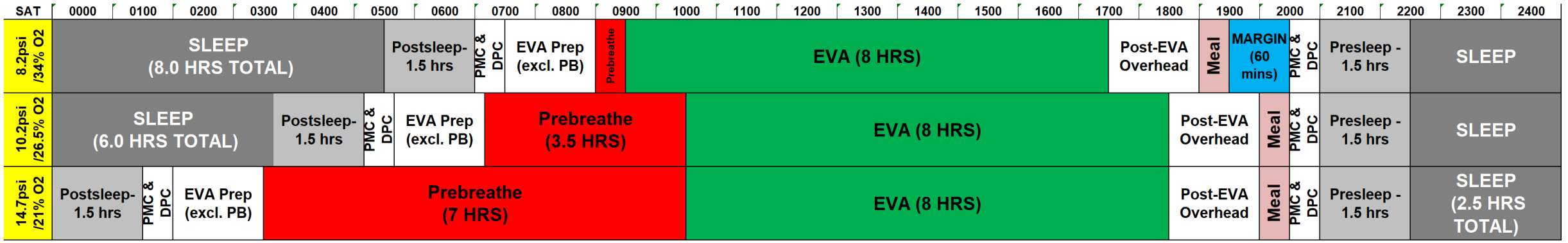
Key:

- Subj = Subject
- Sx = Symptoms
- DT = Doppler Tech
- MO = Med Officer
- SLO = Site-level O_2 (8.2psia)
- GLO = Ground-level O_2 (14.7psia)
- HBO = Hyperbaric O_2
- DSSMB = Diver and Suited Subject Medical Board


20' Chamber
TTD# 7636
11 Day Manned Run
Logged in:
JS-EC4-32-GEN64
06/16/2022 23:54:08
Chamber: HMI Enabled
Manlock: HMI Enabled
PL
Average: O2
19 %
33.97 %
23 %
Out of Spec
0.00 m
Chamber Pressure
14.4
8.20 psia
15
0.00 m
PXI
Average: Tem
64°
69.70 °F
81°
100 - (O2+CO2)
77 %
65.63 %
81 %
Average: Humidit
0%
59.68 %
100%
Average: CO2
0mm
1.76 mmHg
4mm
0.42 %
PT-20V-195A
424.182 Torr
Main Chamber High
PT-20V-195B
10.339 Torr
Main Chamber Low
PT-20V-196A
424.936 Torr
Man Lock High
PT-20V-196B
10.350 Torr
Man Lock Low
Oxygen
PT-O2-8
872.819 psig
Primary Supply Regulator Outlet
PT-O2-16
864.513 psig
Oxygen Supply Console Inlet
PT-O2-28
901.804 psig
Secondary Supply Regulator Outlet
PT-O2-106
80.478 psig
Man-Lock Regulator Outlet
PT-O2-112
80.456 psig
Man-Lock Supply
PT-O2-206
80.333 psig
Main Chamber Regulator Outlet
PT-O2-212
80.247 psig
Main Chamber Supply
PT-O2-306
29.314 psig
Chamber Atm. Regulator Outlet
PT-O2-312
29.317 psig
Chamber Atm. Supply
PT-TO2-806
80.272 psig
85% O2 Regulator Outlet
PT-TO2-812
873.453 psig
85% O2 Supply Console Inlet
PT-TO2-814
80.321 psig
85% O2 Main Chamber Supply
Level 3
GA-20-62(O2)
33.63 %
GA-20-62(CO2)
0.47 %
TC_3FL_01
73.70 °F
Level 3
GA-20-66(O2)
33.15 %
GA-20-66(CO2)
0.41 %
TC_3FL_02
72.50 °F
DP-20-2
56.84 °F
55.15 %
PT-20V-195A
424.18 Torr
PT-20V-197
8.16 psia
Level 2
GA-20-10(O2)
33.87 %
GA-20-10(CO2)
0.40 %
TC_2FL_01
68.37 °F
33.97 %
O2 Ch Average
Level 2
GA-20-14(O2)
33.56 %
GA-20-14(CO2)
0.35 %
TC_2FL_02
68.42 °F
67.35 °F
TC-20AC-9
2.01 Watts
20AC-OUT-1
75.37 °F
HVAC_SCR_ENC_T
TP-20HT-17
55.37 °F
TP-20HT-18
55.76 °F
TP-20HT-19
54.72 °F
TC-20AC-16
121.51 °F
851 RPM
RP-20BL-20
TC-20AC-10
58.24 °F
Manlock
GA-20-MLK(O2)
33.25 %
GA-20-MLK(CO2)
0.72 %
TC-20CW-105
55.02 °F
TC-20CW-106
54.04 °F
DP-20-1
55.93 °F
64.22 %
PT-20V-196A
424.94 Torr
8.22 psia
Level 1
GA-20-4(O2)
34.22 %
GA-20-4(CO2)
0.48 %
TC_1FL_01
66.89 °F
Level 1
GA-20-8(O2)
35.23 %
GA-20-8(CO2)
0.43 %
TC_1FL_02
68.31 °F
PT_SSF_102
64.86 psig
Fire Supression Water Pressure
PT_SSF_104
137.76 psig
Fire Supression Water Pressure
Chamber
Man Lock
800
640
480
320
160
0
DARS Pages
Plan
Drain Tank Empty
4.3 Rules Disabled
8.2 Rules Enabled
1.76079
Process Var.
B07/20foot/Pseudos/Average
0.03099
Rate of Change
B07/20foot_PLC/EU/O2_AVG_PERC
Stop
0 - 11 : 21 : 58
Change Display


20' Chamber
TTD# 7636
11 Day Manned Run
Logged in:
06/16/2022 23:54:50
JS-EC4-32-GEN64
Chamber: HMI Enabled
Manlock: HMI Enabled
To 8' Chamber
Vacuum
To SSATA
PL
Average: O2
19 %
33.99 %
23 %
Chamber Pressure
14.4
8.21 psia
15
PC102
Coarse
-0.4 %
Manual
PC103
Fine
8.20 psia
Auto
Repress
PC185
8.10 psia
Auto
Open
Closed
PC350
0.1 %
Manual
PC385
Coarse
0.0 %
Manual
Repress
PC375
Fine
-0.1 %
Manual
PT-TO2-812
874.06 psig
PT-TO2-806
80.37 psig
PT-TO2-814
80.42 psig
85% Oxygen
PR-TO2-1
PR-TO2-803
SOV-TO2-80
Open
8.21 psia
424.4 Torr
PT-20V-195A
8.22 psia
425.2 Torr
PT-20V-196A
Air Purge
Chamber
O2 Supply
99 %
33.24 % GA-20-66(O2)
33.65 % GA-20-62(O2)
33.66 % GA-20-14(O2)
33.87 % GA-20-10(O2)
35.26 % GA-20-8(O2)
34.27 % GA-20-4(O2)
PCO2FC
34.0 %
Auto
33.99 %
O2 Ch Average
67.34 °F
TC-20AC-9
2.09 Watts
20AC-OUT-1
75.30 °F
HVAC_SCR_ENC_T
TP-20HT-17
55.30 °F
TC-20AC-16
121.64 °F
TP-20HT-18
55.74 °F
TP-20HT-19
55.62 °F
851 RPM
RP-20BL-20
TC-20AC-10
58.53 °F
Manlock
GA-20-MLK(O2)
33.26 %
GA-20-MLK(CO2)
0.70 %
TC-20CW-105
55.46 °F
TC-20CW-106
54.52 °F
MFC-O2-322
MFC-O2-323
29.45 psig
PT-O2-312
Chamber PE O2 Supply
80.34 psig
PT-O2-212
Manlock O2 Supply
80.55 psig
PT-O2-112
HV-O2-31
HV-O2-21
HV-O2-11
SOV-O2-309
SOV-O2-209
SOV-O2-109
29.45 psig
PT-O2-306
80.43 psig
PT-O2-206
80.58 psig
PT-O2-106
PR-O2-30
PR-O2-20
PR-O2-10
PT-O2-16
864.85 psig
HV-O2-30
HV-O2-20
HV-O2-10
PT-O2-8
Low Pressure
873.20 psig
PR-O2-4
SOV-O2-1
100% Oxygen
PT-O2-28
Low Pressure
902.48 psig
PR-O2-24
SOV-O2-3
PT_SSF_102
64.84 psig
Fire Supression Water Pressure
PT_SSF_104
137.76 psig
Fire Supression Water Pressure
Chamber
Man Lock
800
640
480
320
160
0
DARS Pages
Elevation
Drain Tank Empty
4.3 Rules Disabled
8.2 Rules Enabled
Stop
0 - 11 : 22 : 39
Change Display

Timeline Implications



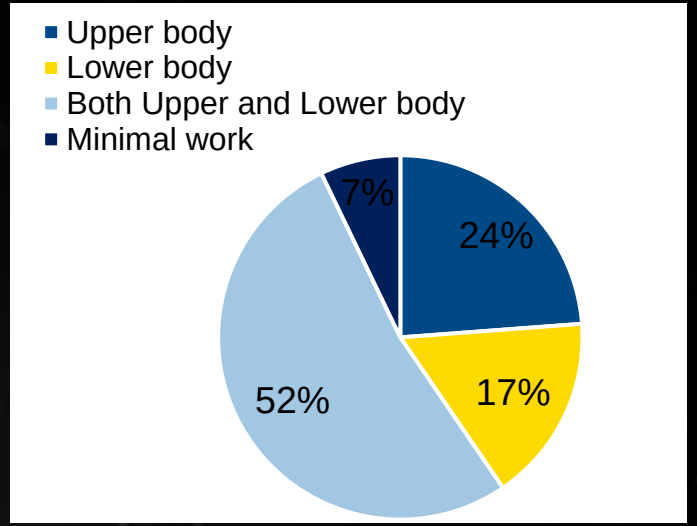
- Timelines are notional and for purposes of comparison only
- All prebreathe durations are model-based estimates [2-4]
- Detailed depress profiles being worked with CX3

Exploration conops are incompatible with multi-hour prebreathe durations

[2] Abercromby et al. *"Suited Ground Vacuum Chamber Testing Decompression Sickness Tiger Team Report"*, 2018 NASA Technical Report
[3] Abercromby, et al. *"Using the Shuttle Staged Prebreathe Atmosphere and Variable Pressure Spacesuits for Exploration Extravehicular Activity"*, 2018 AsMA.
[4] Abercromby et al. *"Modeling Oxygen Prebreathe Protocols for Exploration EVA Using Variable Pressure Suits"*, 2017 AsMA.

EVA Simulation – Rationale for Tasks

- 61 exploration EVA tasks[2] were decomposed into 126 subtasks then characterized by functional requirements of each subtask
- **Categories:**
  - **Body Positioning:** Seated, Kneeling, Standing, Mobile, etc.
  - **Muscle Groups:** Whole/Both, Upper, Lower
  - **Ambulation:** None, Walking, Walking (terrain), Walking (slopes), Crawling, Climbing
  - **Loading Bearing:** None, Carrying, Pushing/Pulling, Attached to Suit
  - **Loads:** None, Minimal (<5 lbs), Variable, Heavy (>30 lbs)
  - **Upper Body Reach (Workspace):** None, Standard, Extended
  - **Hand Usage:** None, Fine Motor Skills, Grip Strength, Vibration, Shock, Other/Combination
  - **Task Occurrence:** Rare (<10% of EVAs), Some (~30%), Many (~50%), Most (~75%), Nearly All (>90%)
  - **Task Duration (expected)**
  - **Task Frequency:** 1-2 times per EVA, Every 2 hours during EVA, Every hour during EVA, 1-30 minutes during EVA

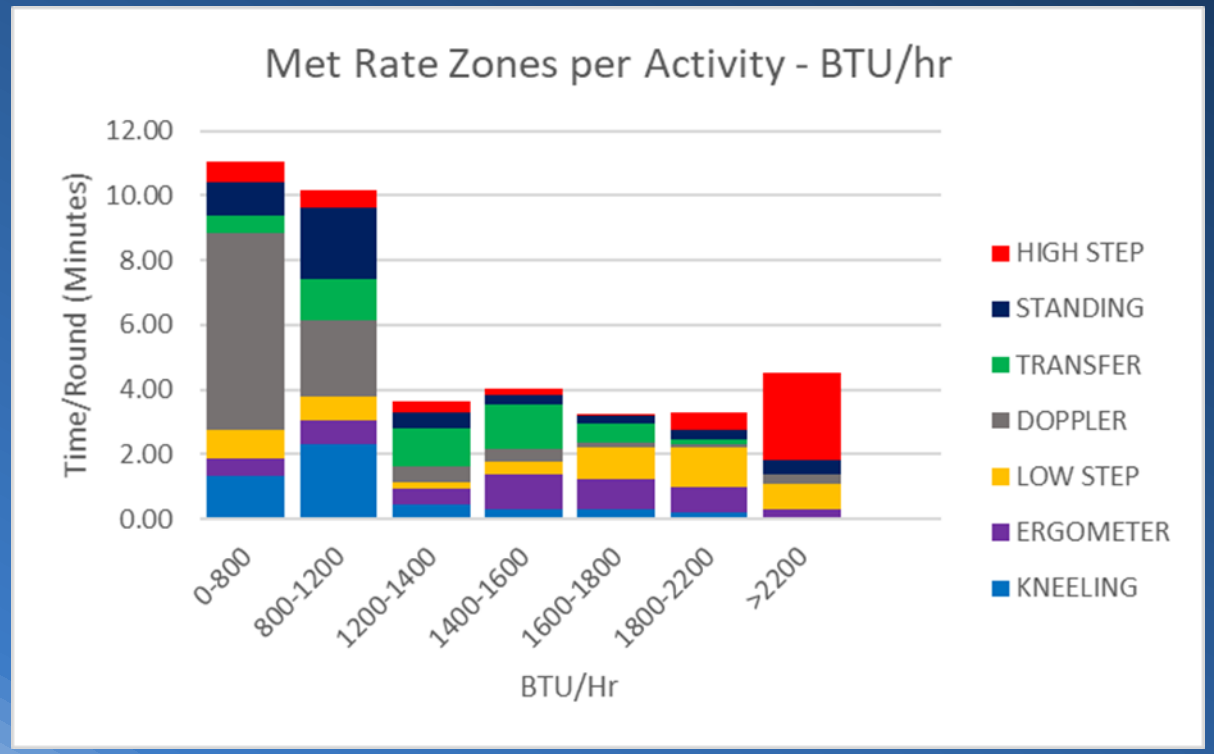


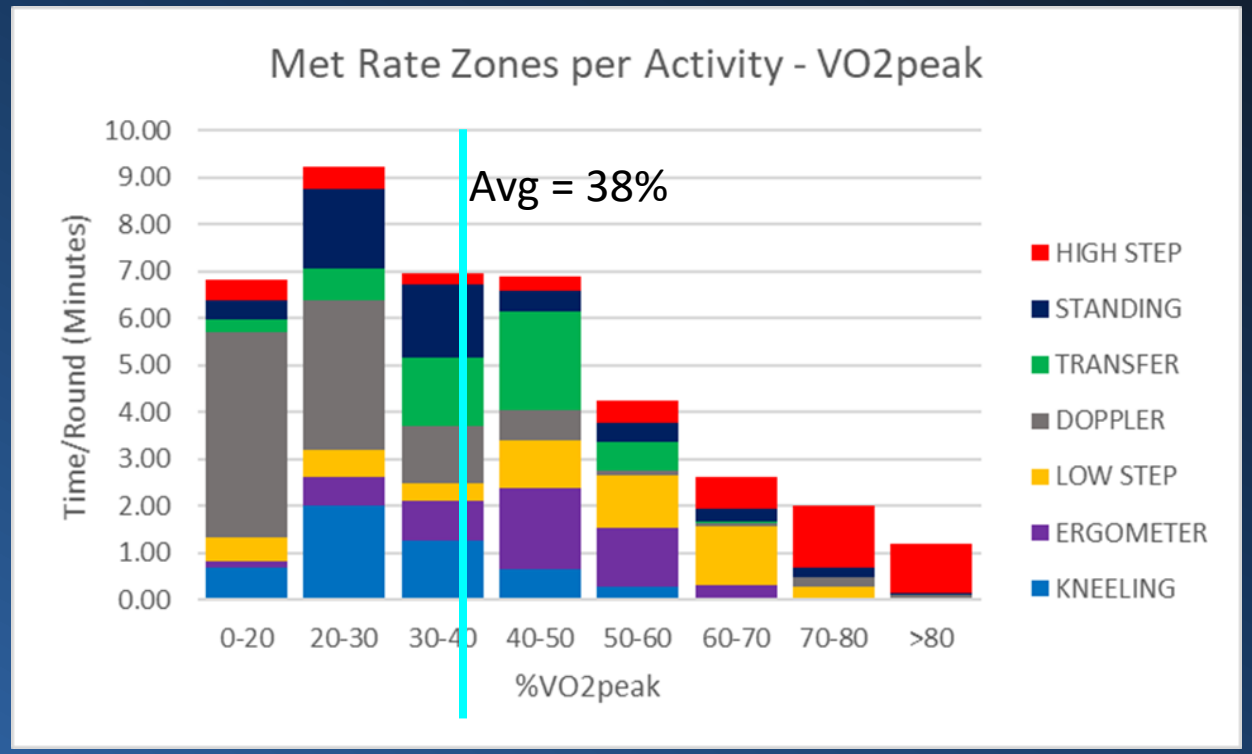
Parent Task Title	Children of the Parent Task	Load Bearing Type	Upper Body Loads	Upper Body Reach	Fine Motor / Grip	Task Occurrence	Task Duration	Task Frequency
Offload Equipment from Landers	mobile, upper and lower body work	Carrying Load	Variable Load (minimal to heavy)	Extended Workspace	Grip Strength	Rarely Occurs in any EVA (<10%)	5-15 minutes	Every 1-30 minutes during EVA
Offload Equipment from Landers	mobile, upper and lower body work	Pushing / Pulling Load	Heavy Load (> 30 lbs.)	Extended Workspace	Grip Strength	Rarely Occurs in any EVA (<10%)	5-15 minutes	Every 1-30 minutes during EVA
Load Equipment onto Rovers	mobile, upper and lower body work	Carrying Load	Variable Load (minimal to heavy)	Extended Workspace	Grip Strength	Occurs in many EVAs (~50%)	5-15 minutes	Every ~1 hr during EVA
Clean Equipment	stationary, upper body work while kneeling	No Load	No Significant Loading	Extended Workspace	Fine Motor	Occurs in some EVAs (~30%)	15-60 minutes	Total of 1-2 times during EVA
Clean Equipment	stationary, upper body work while standing	No Load	No Significant Loading	Extended Workspace	Fine Motor	Occurs in most EVAs (~75%)	15-60 minutes	Total of 1-2 times during EVA
Conduct Visual Inspection / Examine Surroundings	mobile, ambulation	No Load	No Significant Loading	None	Fine Motor	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every 1-30 minutes during EVA
Conduct Visual Inspection / Examine Surroundings	seated	No Load	No Significant Loading	None	None	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every ~1 hr during EVA
Conduct Photo Documentation	stationary, upper body work while kneeling	Other / Unknown	Minimal Load (less than 5 lbs.)	Standard Workspace	Fine Motor	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every 1-30 minutes during EVA
Conduct Photo Documentation	stationary, upper body work while standing	Other / Unknown	Minimal Load (less than 5 lbs.)	Standard Workspace	Fine Motor	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every 1-30 minutes during EVA

[2]Coan D. Exploration EVA System Concept of Operations. NASA TR, EVA-EXP-0042 RevB. 2020

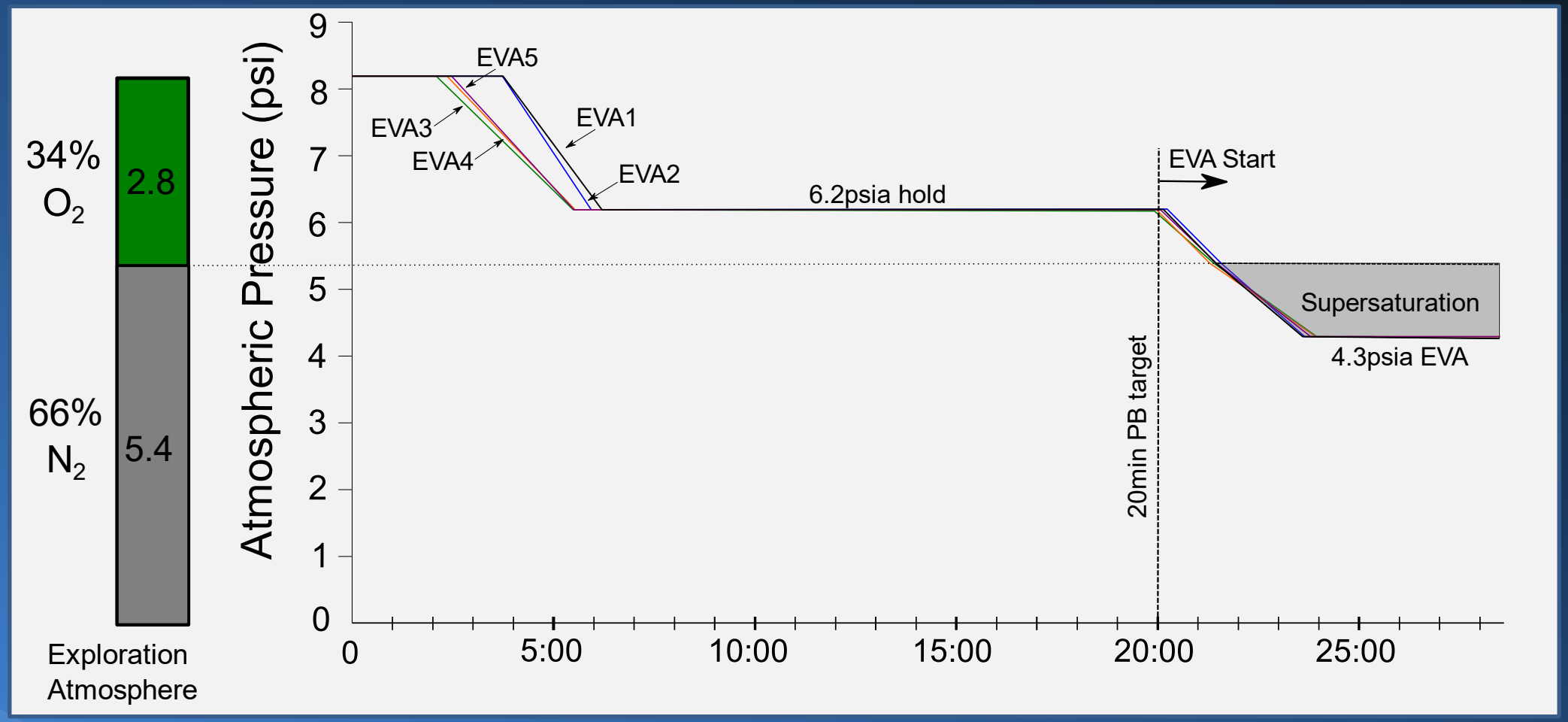
Pilot Data - Results

- The average %VO_2peak across all tasks was ~38% (1274 BTU/hr).





Was the prebreathe within parameters?



Prebreathe Times:
EVA1: 20min 14 sec
EVA2: 20min 21 sec
EVA3: 20min 01 sec
EVA4: 20min 04 sec
EVA5: 20min 10 sec

*Transition from 6.2 psi to 5.4 psi (supersaturation point) added ~80-90 sec

Modified Eftedal Brubakk Score

- Exploration Atmosphere VGE Scoring uses the Modified Eftedal Brubakk Score. Scoring is done only considering right atrium & ventricle.*

Score	Definition
0	No Visible Bubble
1	Occasional bubbles
2	At least 1 bubble every 4-heart-cycle
3	At least 1 bubble every heart cycle
4	Not more than one thirds of every image
5	Not more than two thirds of every image
6	Near whiteout; individual bubbles still discerned
7	Whiteout; individual bubbles can't be discerned

* No LVGE detected.

Eftedal O, Brubakk AO. Agreement between trained and untrained observers in grading intravascular bubble signals in ultrasonic images. Undersea Hyperb Med. 1997 Winter;24(4):293-9. PMID: 9444060.

Research Goals

Primary Research Goal

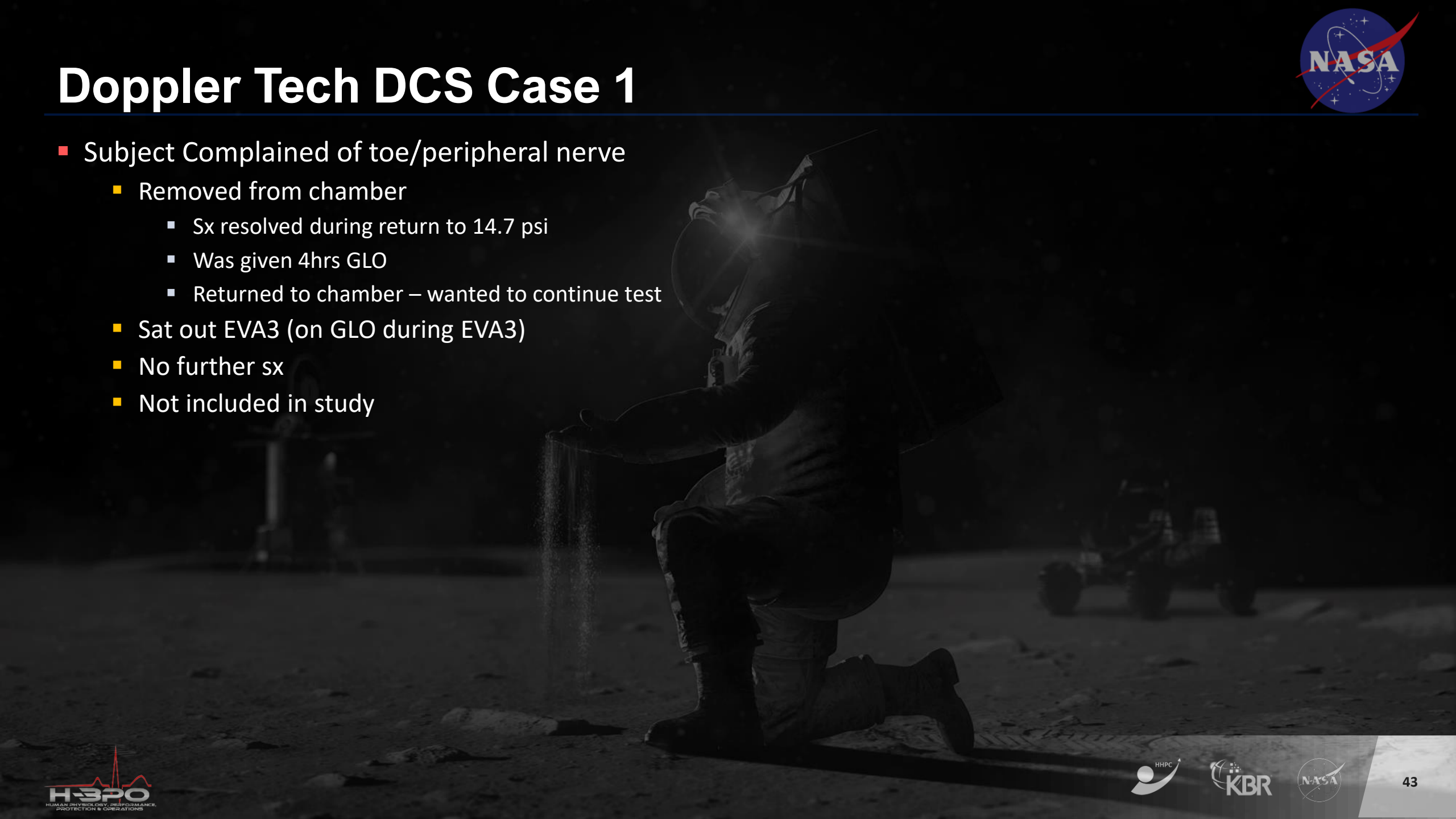
1. **Prebreathe Validation (H3PO)**

Secondary Research Goals

2. Response/Recovery from Mild Exercise (H3PO)
3. Visual Acuity and Contrast (H3PO)
4. Acute Mountain Sickness Symptoms (H3PO)
5. Performance during EVA Simulations (H3PO)
6. Physiological Reponses of Hypobaric Hyperoxic Environment (Cardiovascular and Vision Lab)
7. Hematology/Immunology/Inflammatory Response (Immunology Lab)
8. Oxidative Damage (Nutritional Biochemistry Lab)
9. Appetite and Food Intake Impacts (Space Food Systems Lab)
10. Sleep Quality and Duration Impacts (Behavioral Health and Performance Lab)
11. Neurocognitive and Functional Responses (Behavioral Health and Performance Lab)
12. Habitability Acceptability (HFEL/CDSA)

Doppler Tech DCS Case 1

- Subject Complained of toe/peripheral nerve
  - Removed from chamber
    - Sx resolved during return to 14.7 psi
    - Was given 4hrs GLO
    - Returned to chamber – wanted to continue test
  - Sat out EVA3 (on GLO during EVA3)
  - No further sx
  - Not included in study



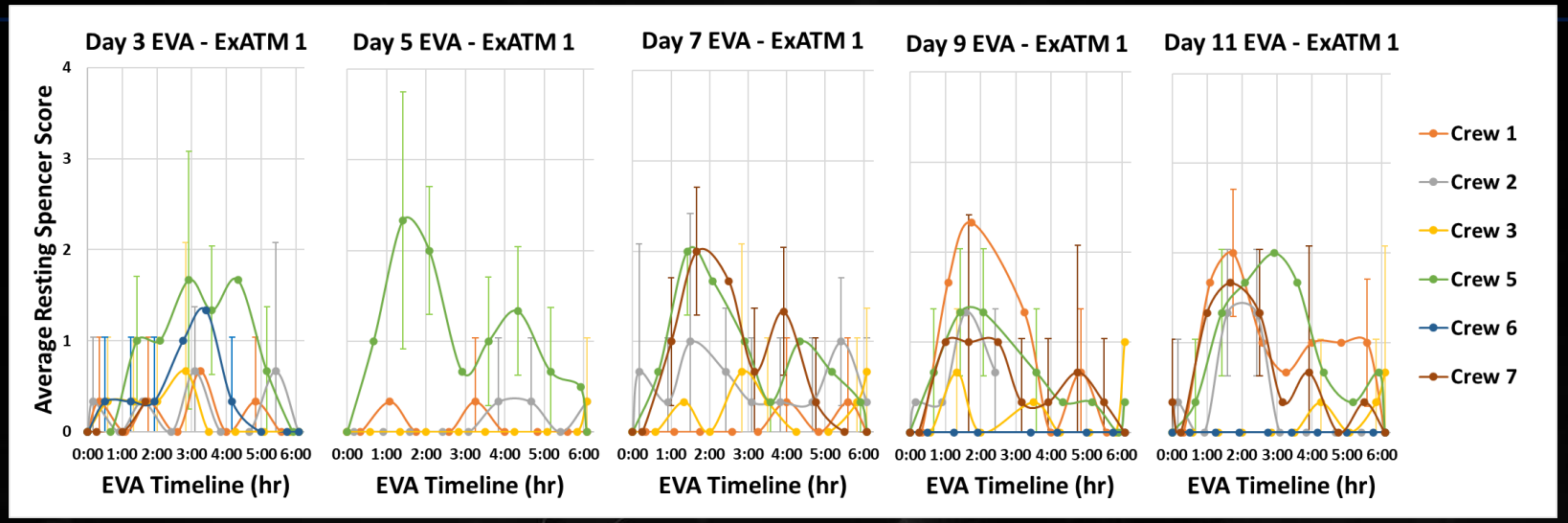
Doppler Tech DCS Case 2

- Subject Complained of L knee pain at end of EVA
  - Was ‘replacement’ Doppler Tech
    - On 4.5hr PB per NASA protocol
  - Removed from chamber at end as planned
    - Sx resolved during return to 14.7 psi
    - Refused 4hrs GLO
  - No further sx
  - Not included in study
- Ongoing review of NASA Chamber PB guidelines may disallow ‘replacement’ Doppler Techs

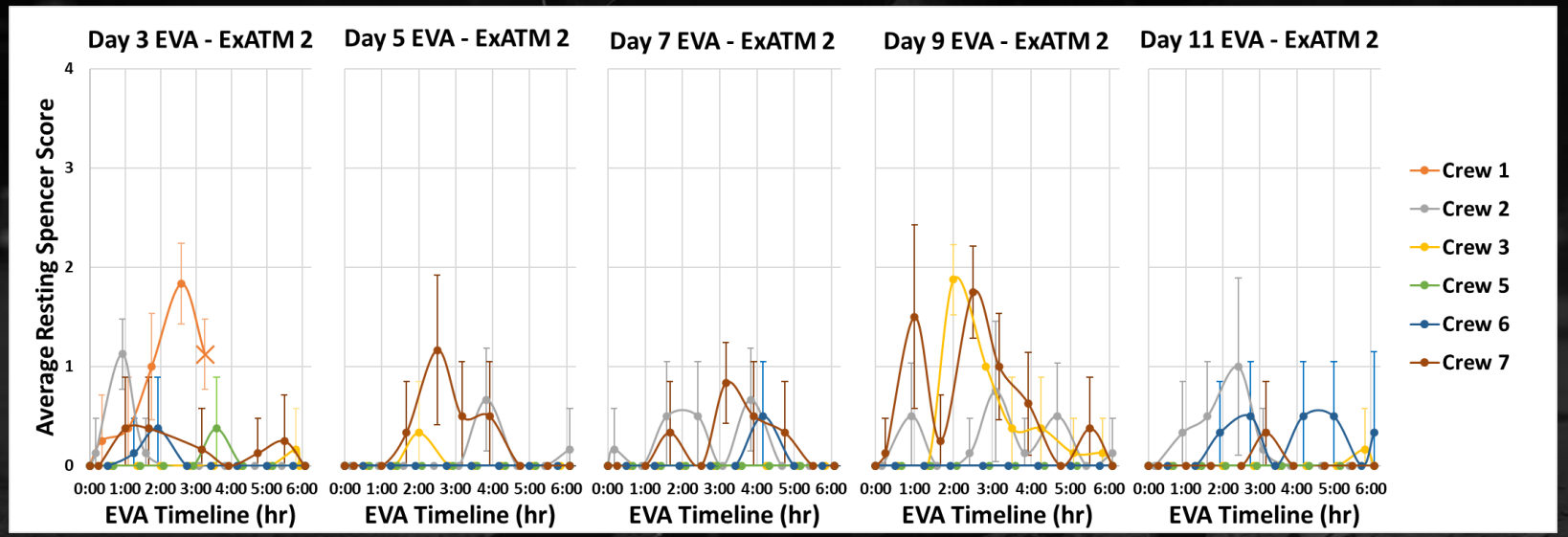
Doppler Summary

Doppler – Resting Spencer Grade

EA1

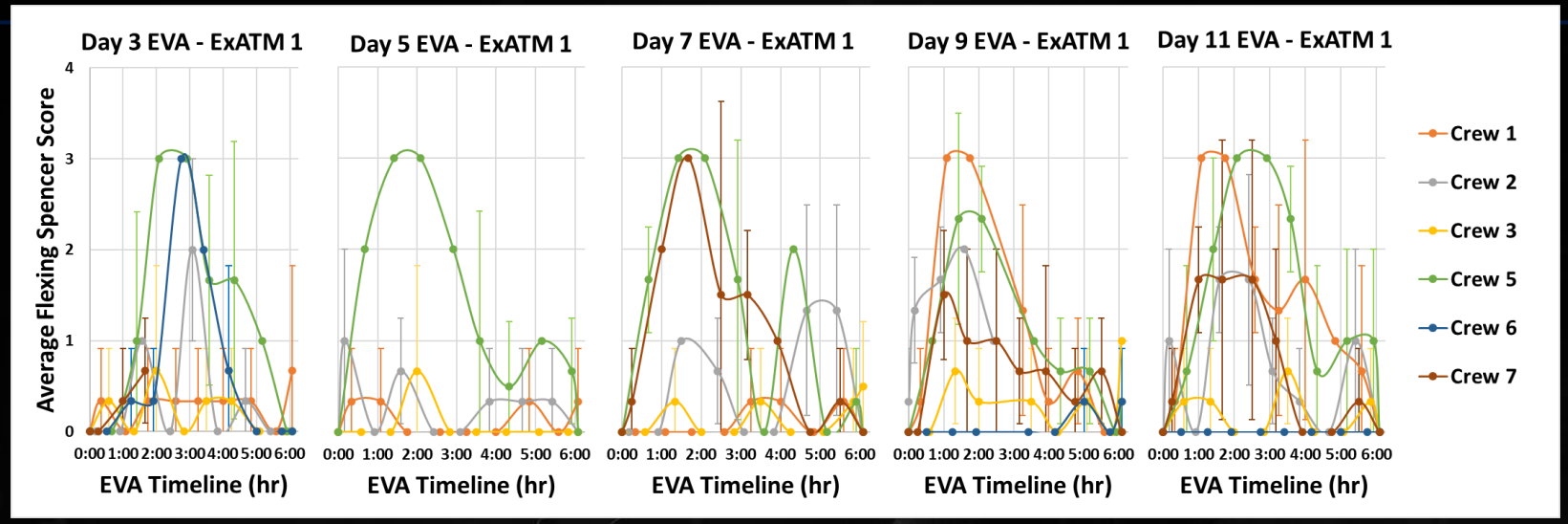


EA2

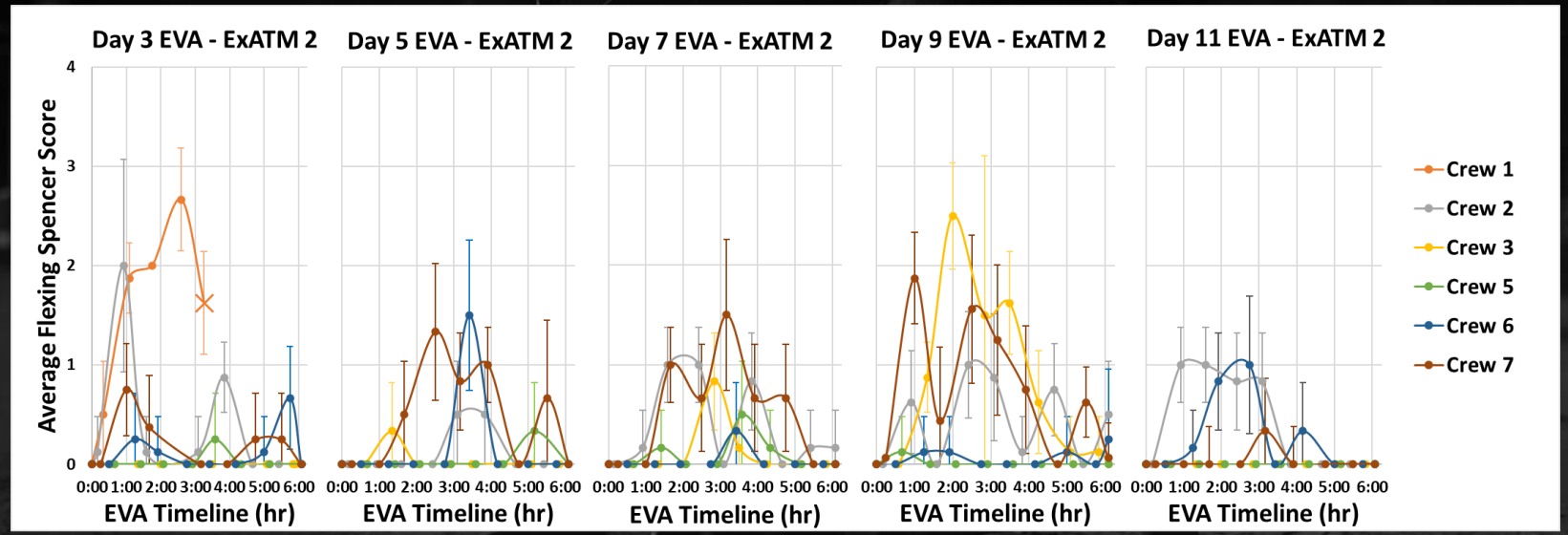


Doppler – Flexing Spencer Grade

EA1



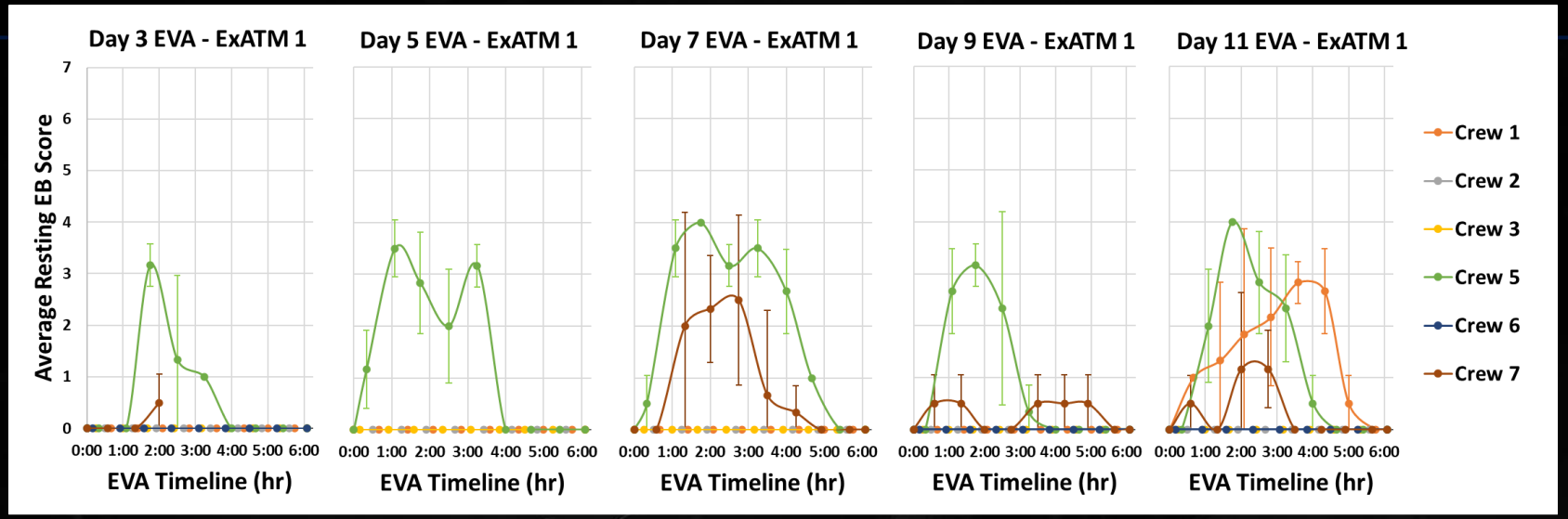
EA2



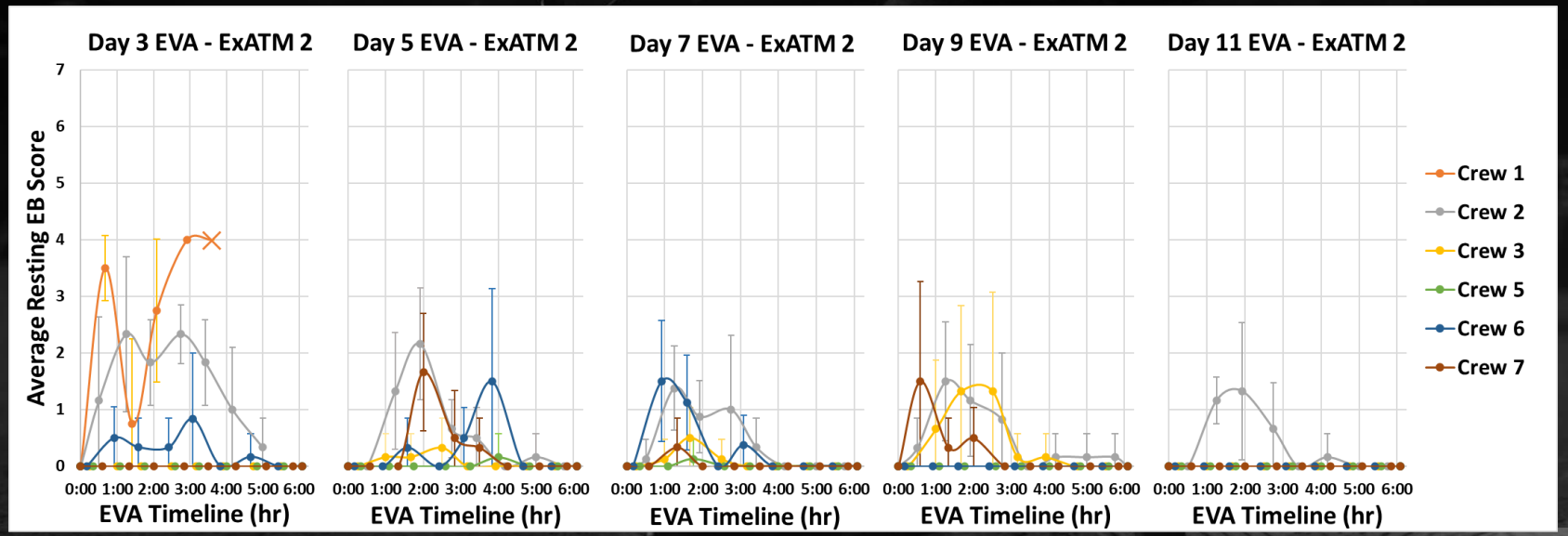
U/S Summary

Ultrasound – Resting EB Score

EA1

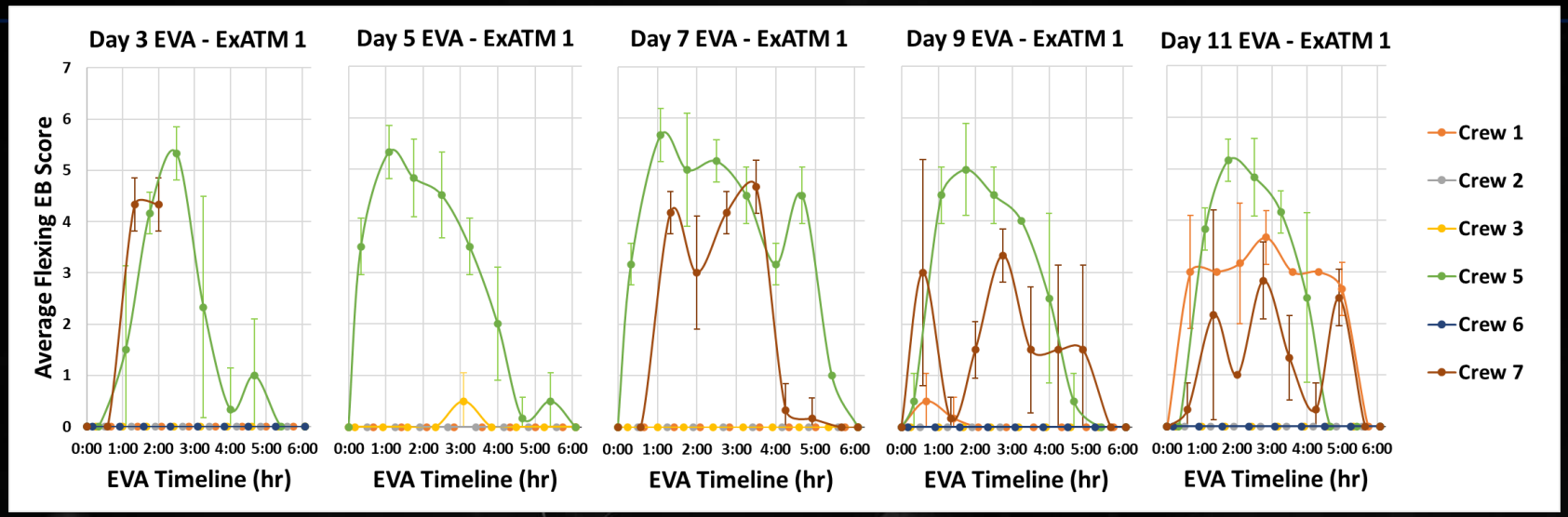


EA2

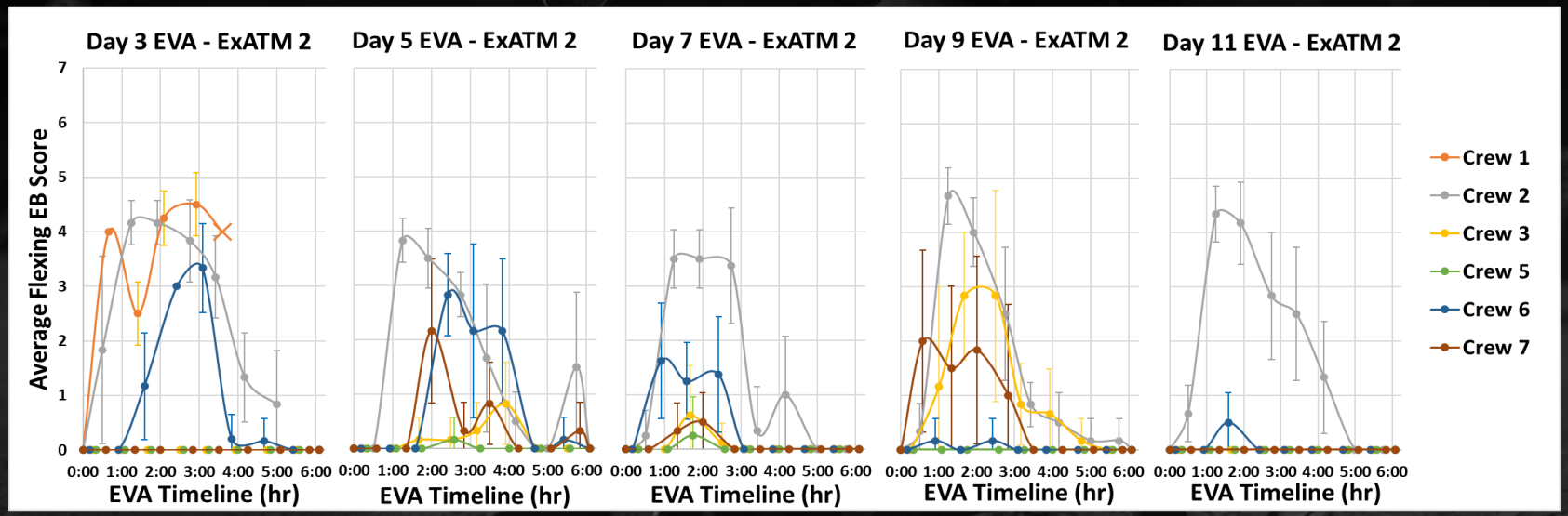


Ultrasound – Flexing EB Score

EA1



EA2



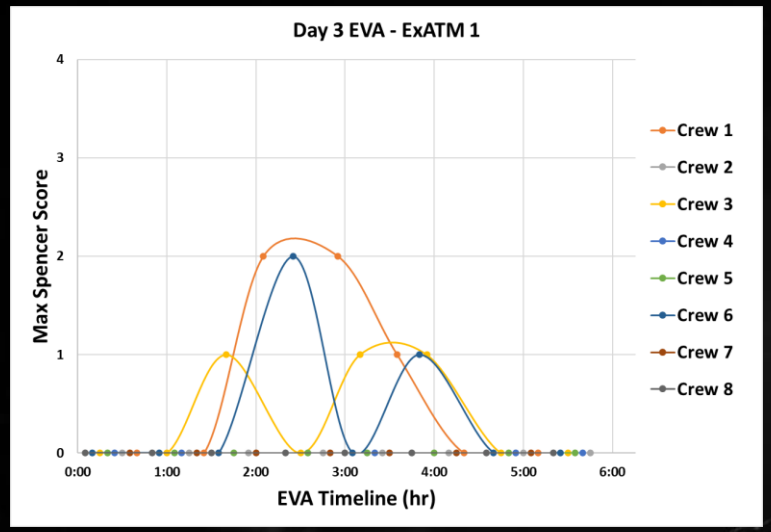
Day by Day Review

2022-03: 3-day Rehearsal

(3-day tests excluded for overall stats)

2022-03 (EA1): 3-Day EVA1

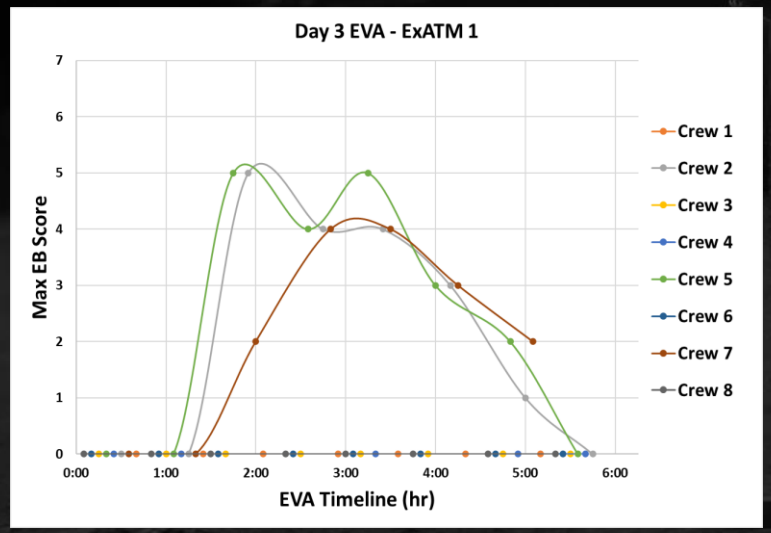
Doppler

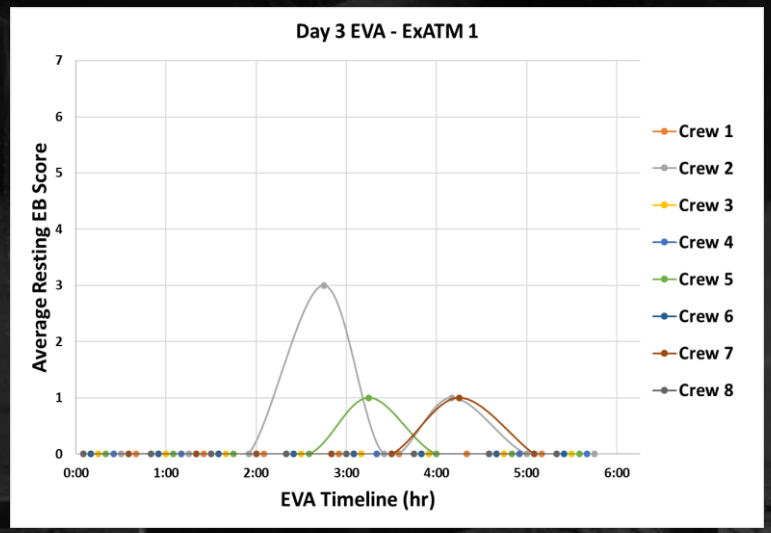


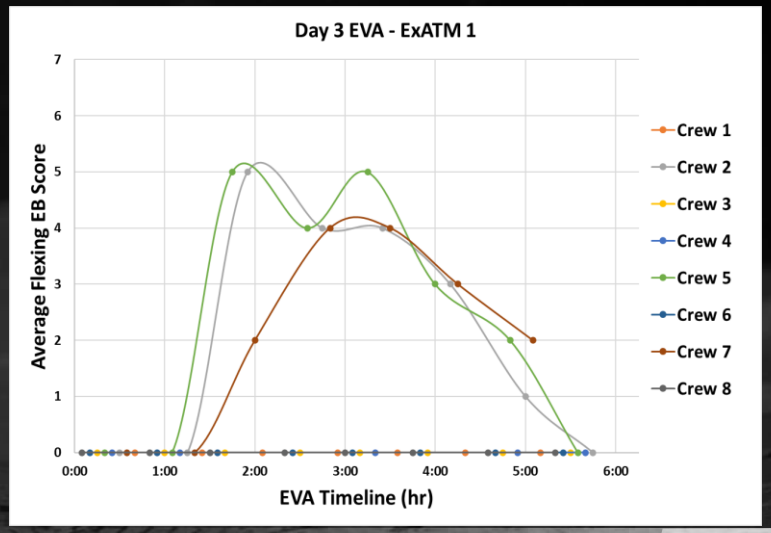
*No Standard Deviations

**Max Spencer Score is graphed since only one measurement was taken for all rests and flexes

U/S





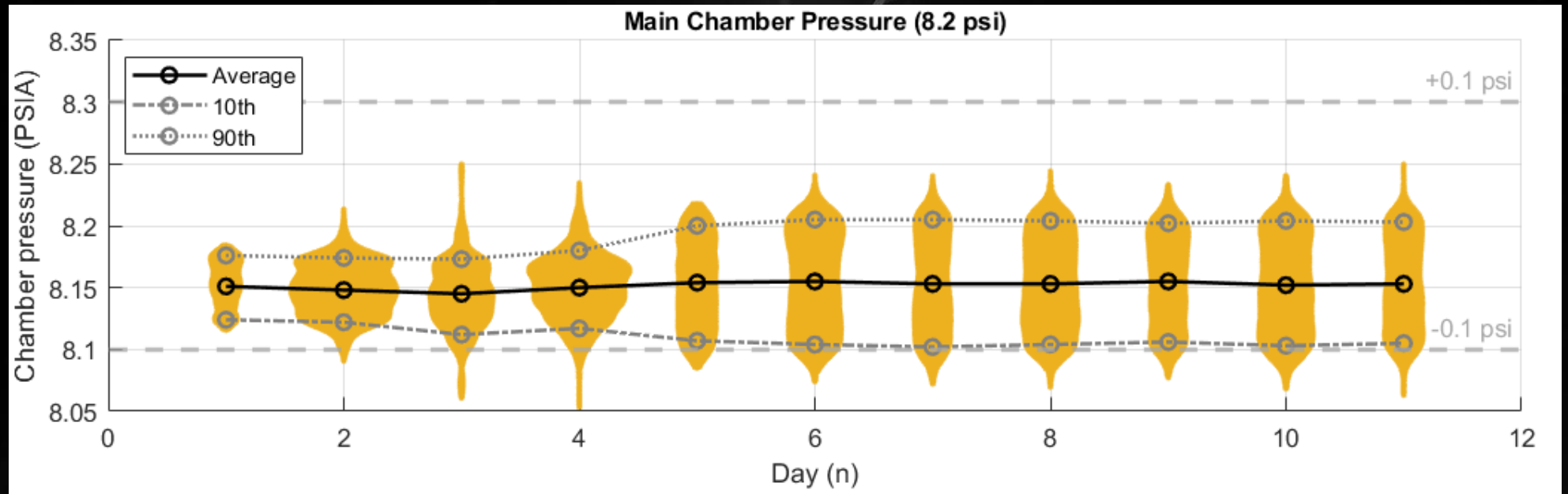


Day by Day Review

2022-06: 11-day Test

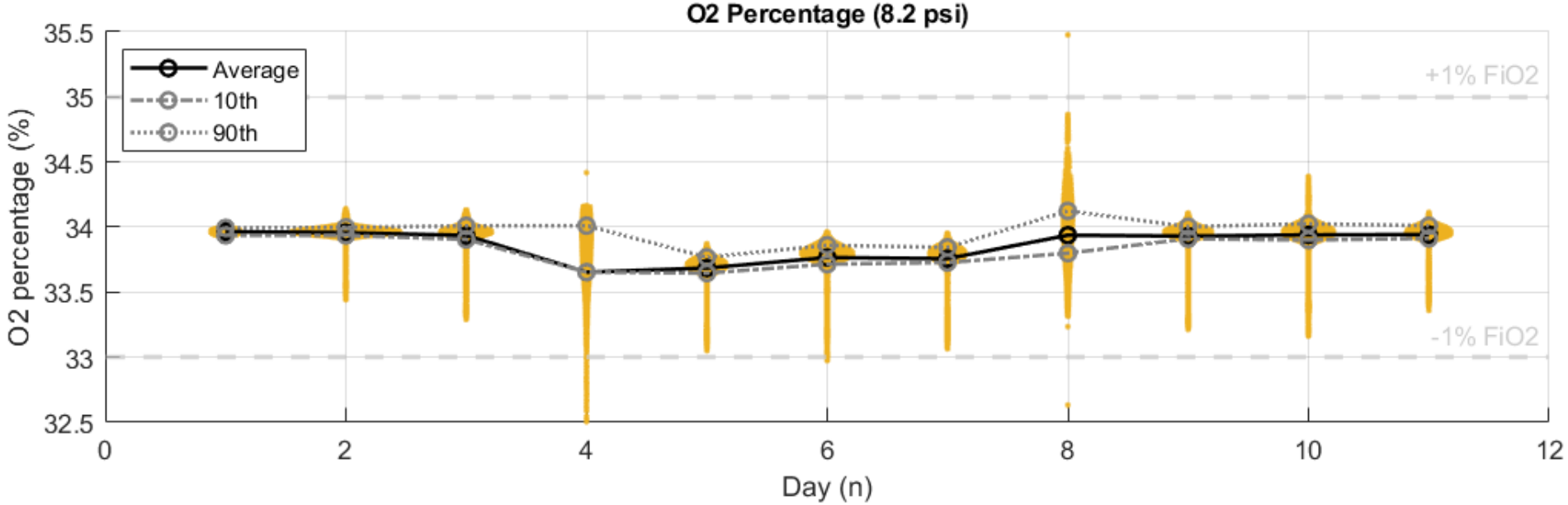
EA1

EA1 Chamber Pressure



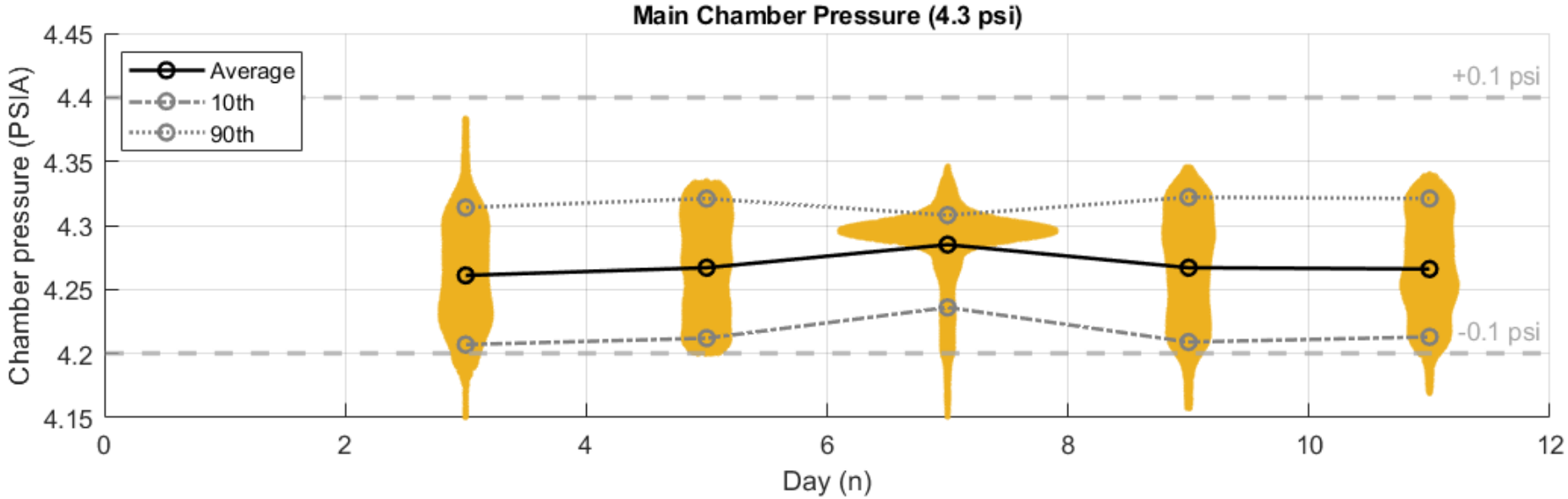
	1	2	3	4	5	6	7	8	9	10	11
Average (PSIA)	8.1510	8.1480	8.1450	8.1500	8.1540	8.1550	8.1530	8.1530	8.1550	8.1520	8.1530
10th (PSIA)	8.1240	8.1220	8.1120	8.1170	8.1070	8.1040	8.1020	8.1040	8.1060	8.1030	8.1050
90th (PSIA)	8.1760	8.1740	8.1730	8.1800	8.2000	8.2050	8.2050	8.2040	8.2020	8.2040	8.2030
Max (PSIA)	8.1900	8.2130	8.2500	8.2350	8.2180	8.2410	8.2400	8.2440	8.2330	8.2400	8.2500
Min (PSIA)	8.1090	8.0910	8.0610	8.0530	8.0850	8.0740	8.0720	8.0700	8.0770	8.0680	8.0630

EA1 Chamber Oxygen



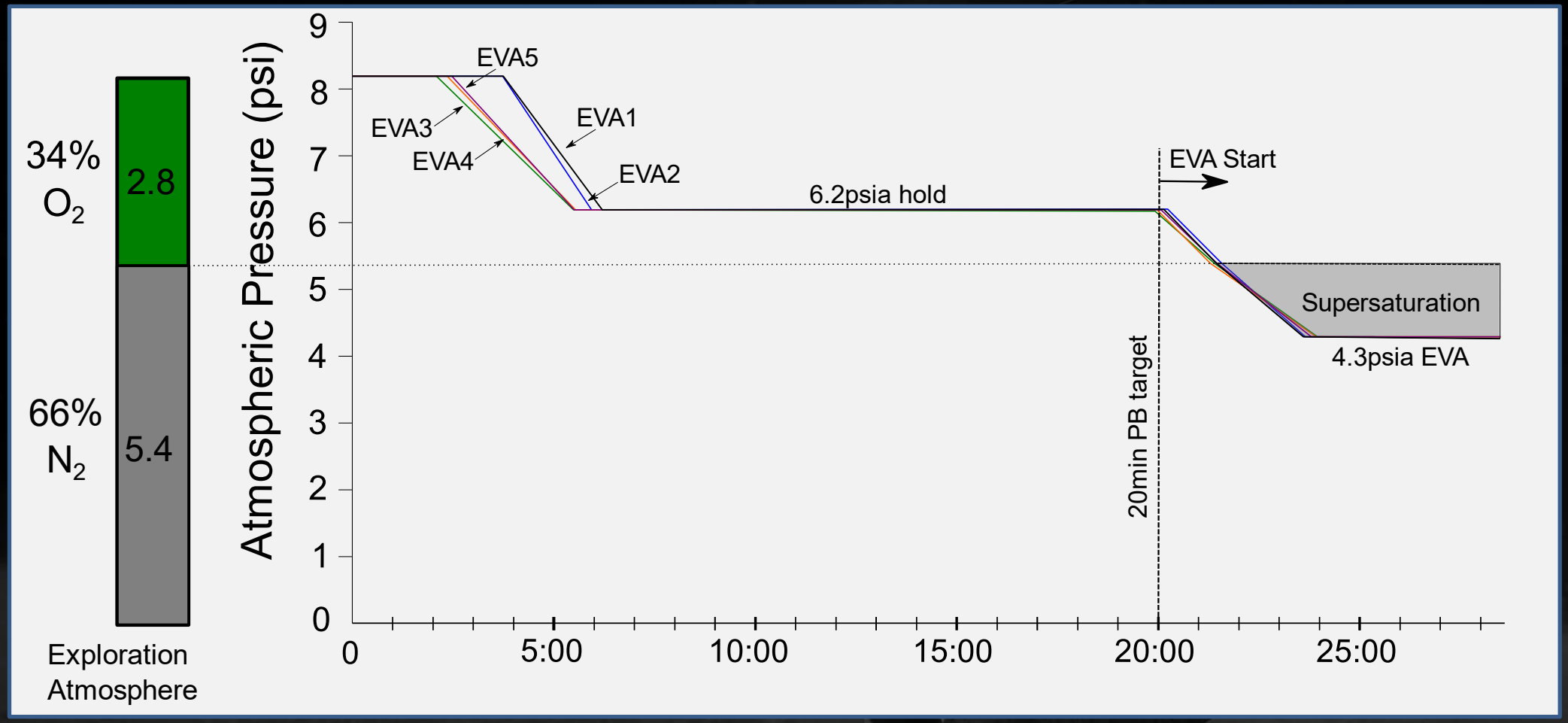
	1	2	3	4	5	6	7	8	9	10	11
Average (%)	33.9649	33.9572	33.9360	33.6538	33.6855	33.7660	33.7575	33.9376	33.9307	33.9398	33.9432
10th (%)	33.9362	33.9361	33.9054	33.6542	33.6465	33.7150	33.7276	33.7993	33.9102	33.9007	33.9128
90th (%)	33.9939	33.9978	34.0093	34.0111	33.7680	33.8603	33.8438	34.1242	34.0031	34.0254	34.0108
Max (%)	34.0409	34.1430	34.1314	36.0516	33.8733	33.9640	33.9540	47.6383	34.1085	34.3898	34.1133
Min (%)	33.8884	33.4401	33.2897	24.1942	33.0508	32.9748	31.4106	22.0968	33.2129	33.1615	33.3588

EA1 EVA Pressure



	3	5	7	9	11
Average (PSIA)	4.2610	4.2670	4.2850	4.2670	4.2660
10th (PSIA)	4.2070	4.2120	4.2360	4.2090	4.2130
90th (PSIA)	4.3140	4.3210	4.3080	4.3220	4.3210
Max (PSIA)	4.3830	4.3350	4.3460	4.3460	4.3400
Min (PSIA)	4.1470	4.1990	4.1280	4.1570	4.1690

EA1 Prebreathe Timelines

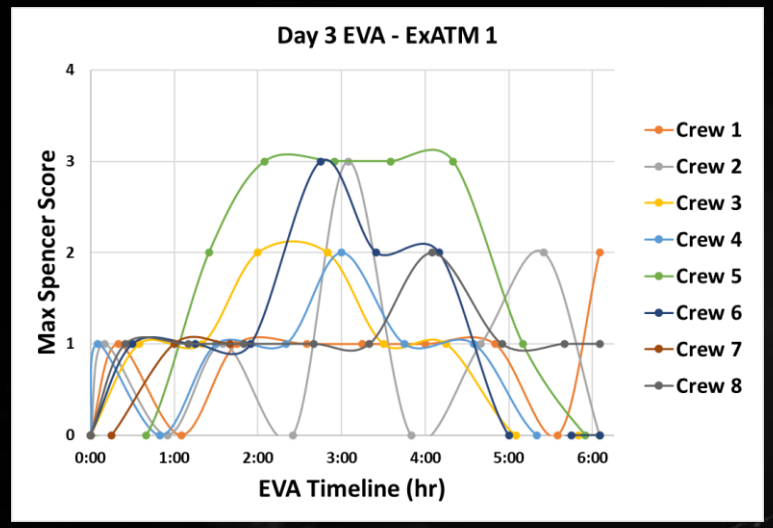


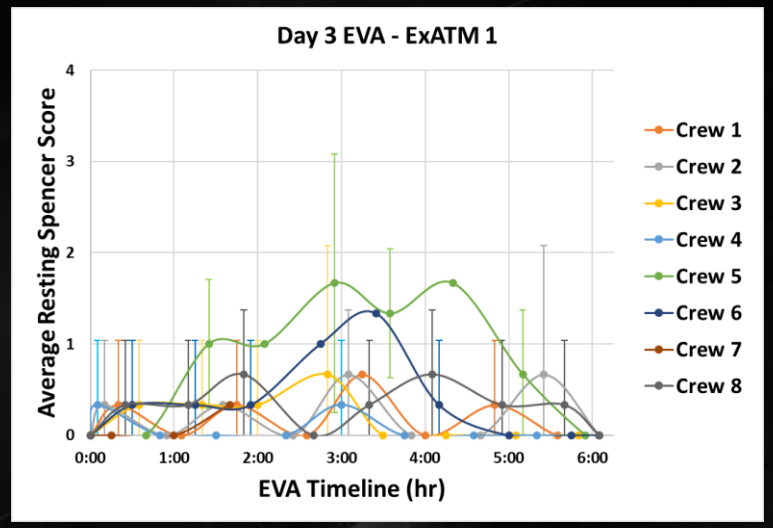
Prebreathe Times:
EVA1: 20min 14 sec
EVA2: 20min 21 sec
EVA3: 20min 01 sec
EVA4: 20min 04 sec
EVA5: 20min 10 sec

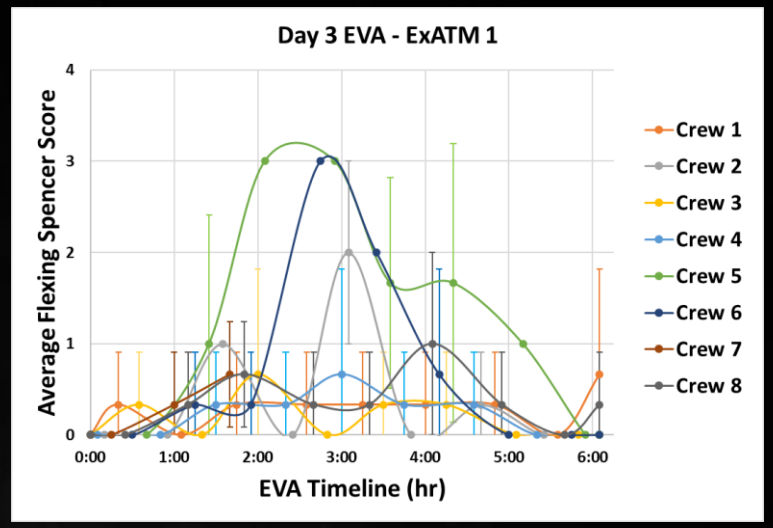
*Transition from 6.2 psi to 5.4 psi (supersaturation point) added ~80-90 sec

2022-06: EA1 EVA1

Doppler







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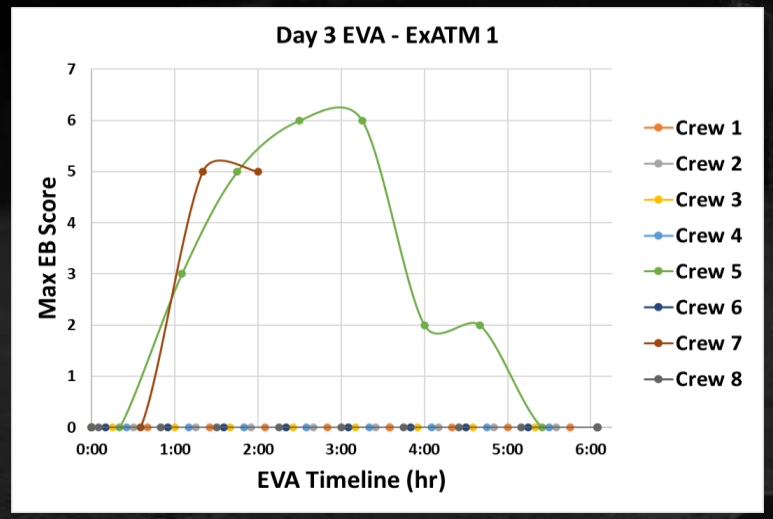
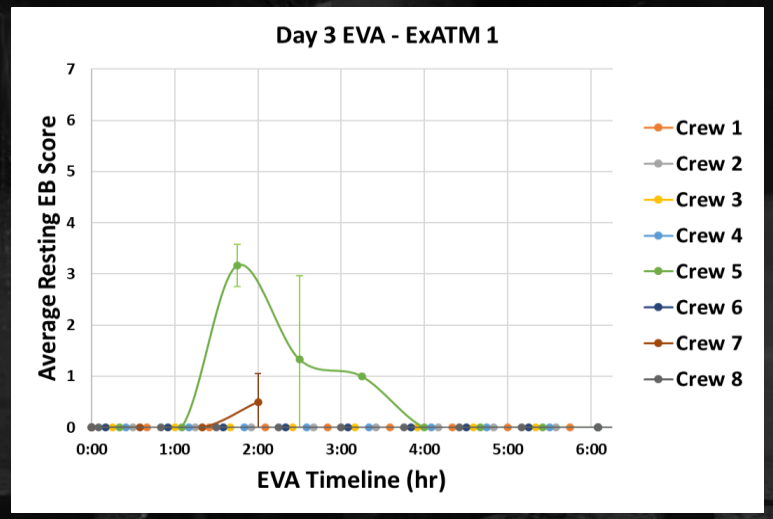
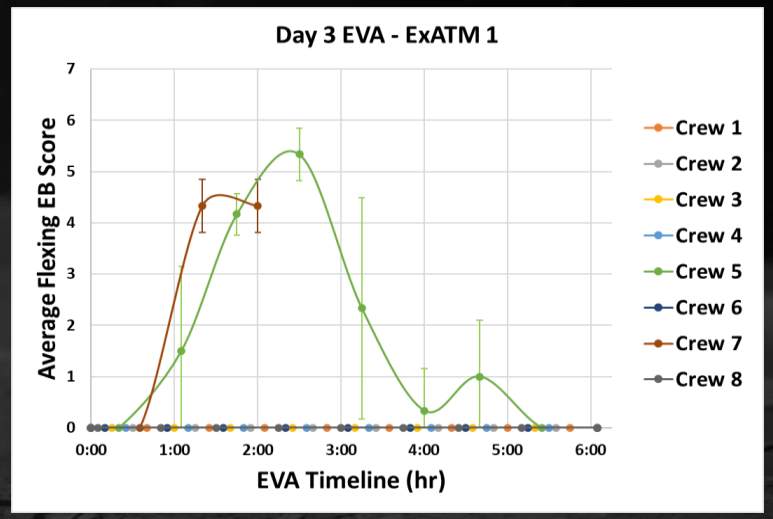
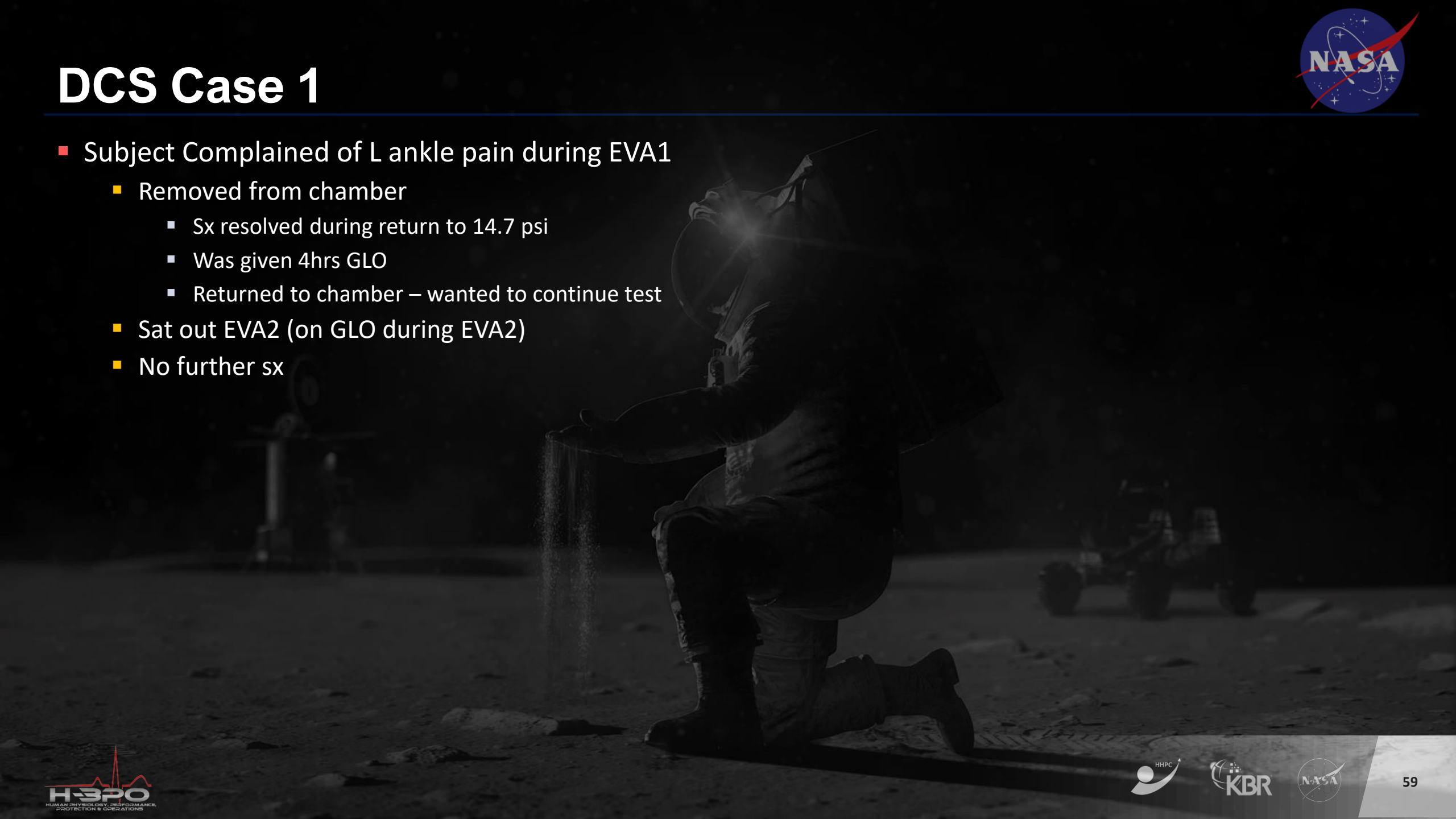






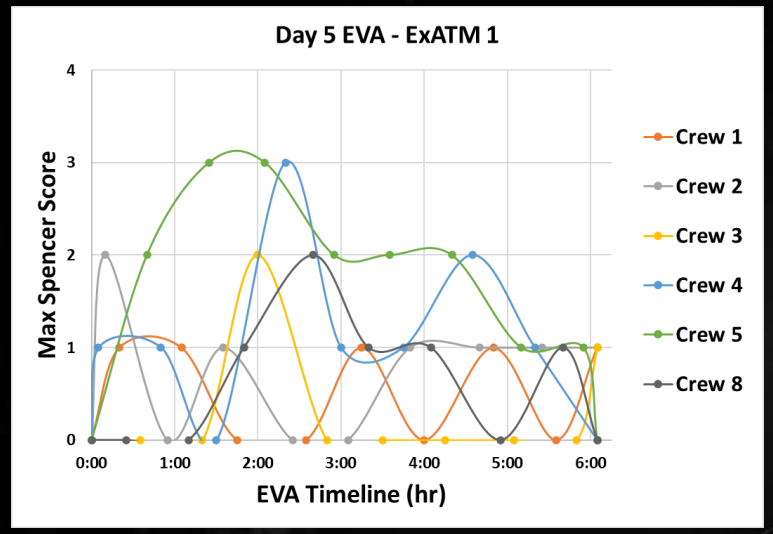
DCS Case 1

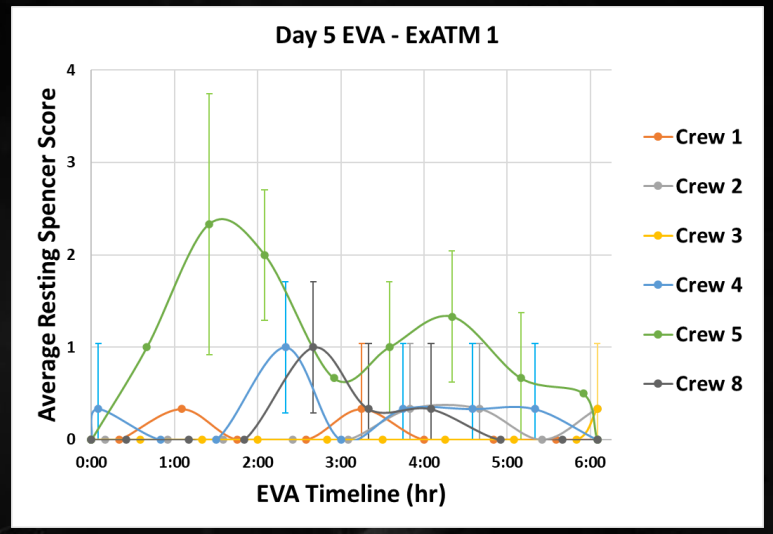
- Subject Complained of L ankle pain during EVA1
  - Removed from chamber
    - Sx resolved during return to 14.7 psi
    - Was given 4hrs GLO
    - Returned to chamber – wanted to continue test
  - Sat out EVA2 (on GLO during EVA2)
  - No further sx

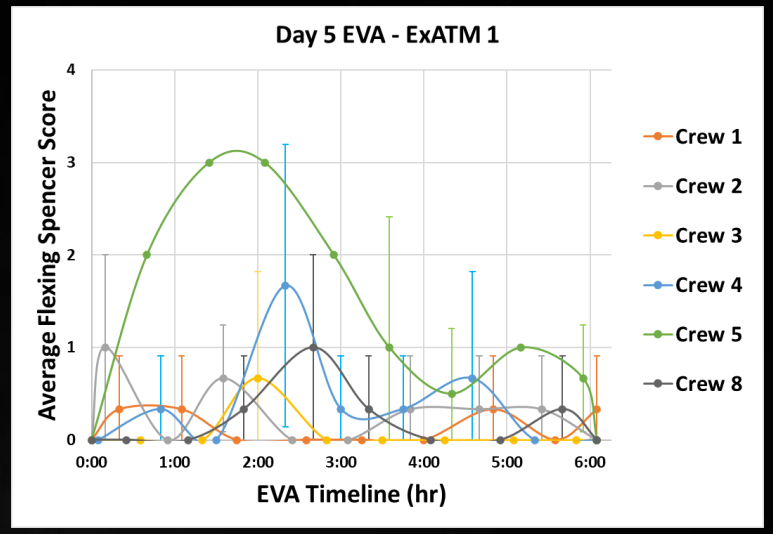


2022-06: EA1 EVA2

Doppler







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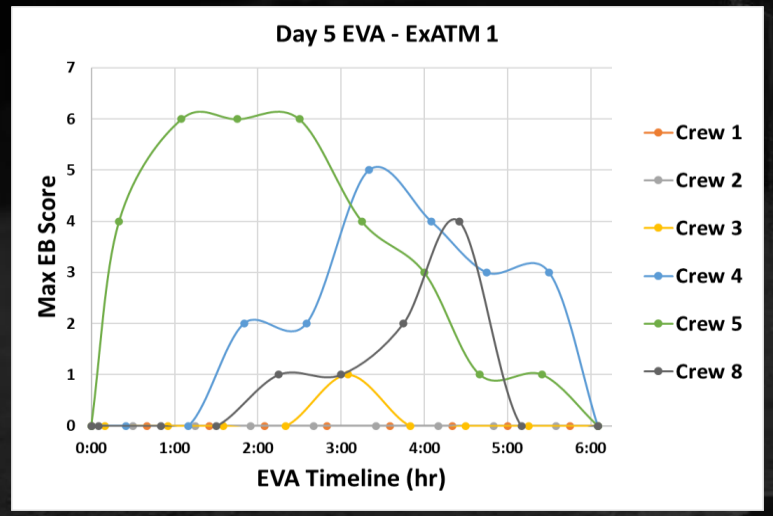
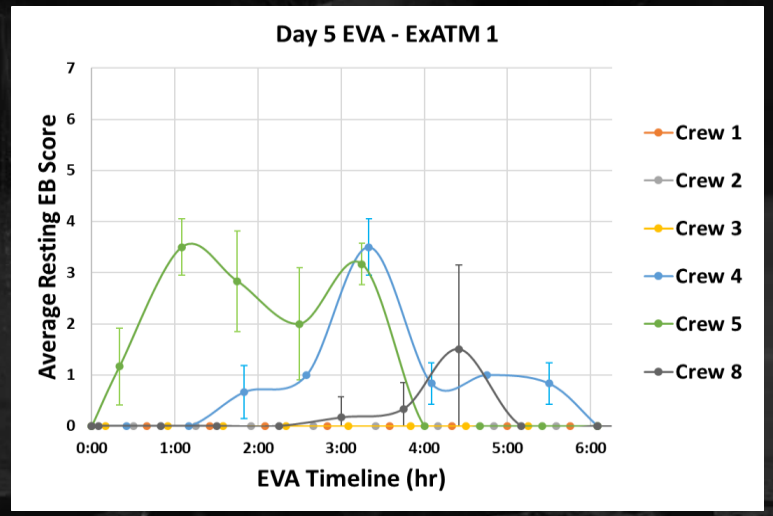
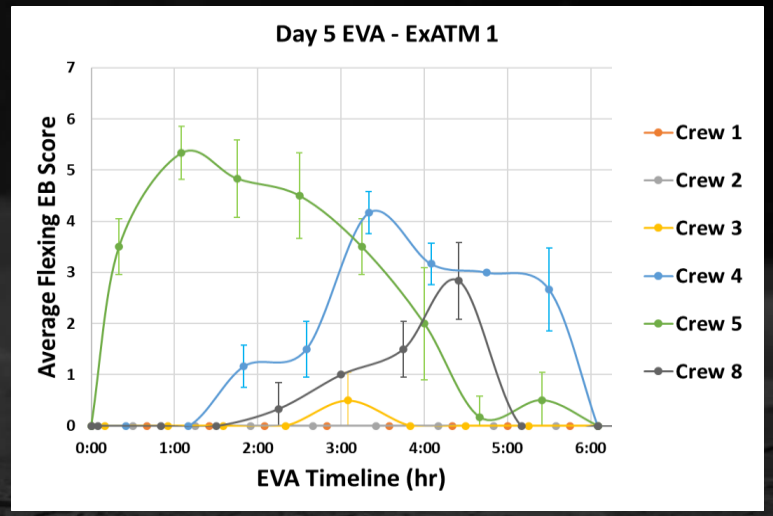
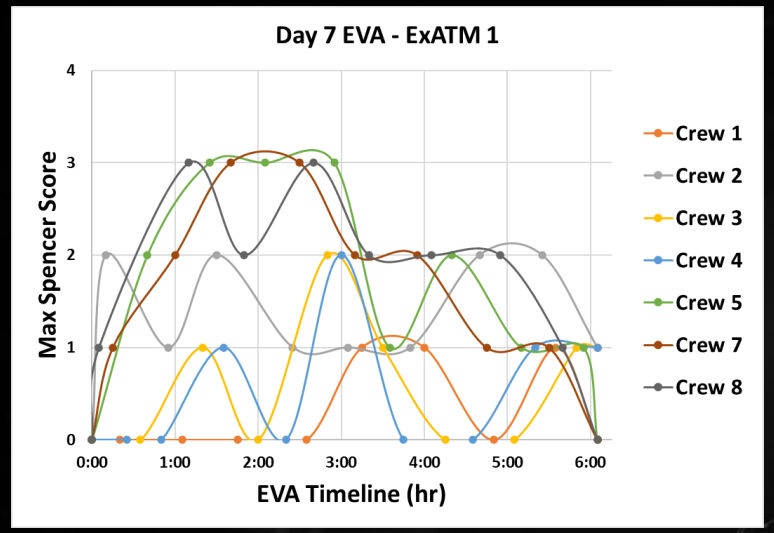


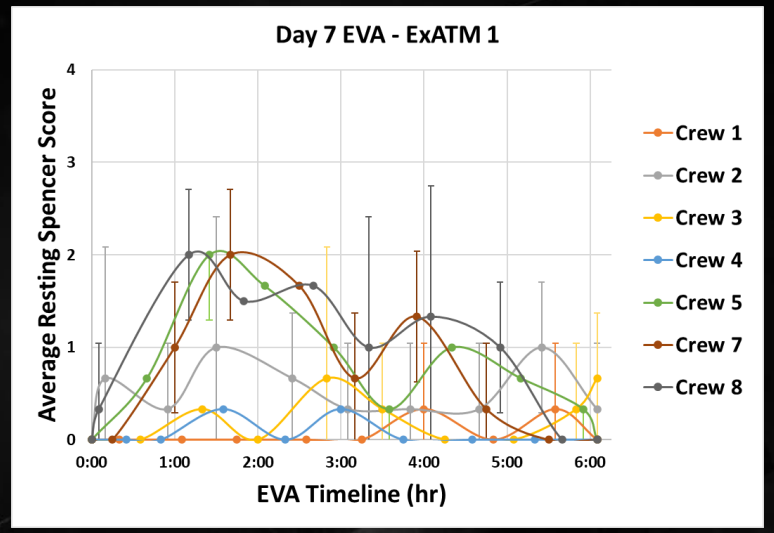


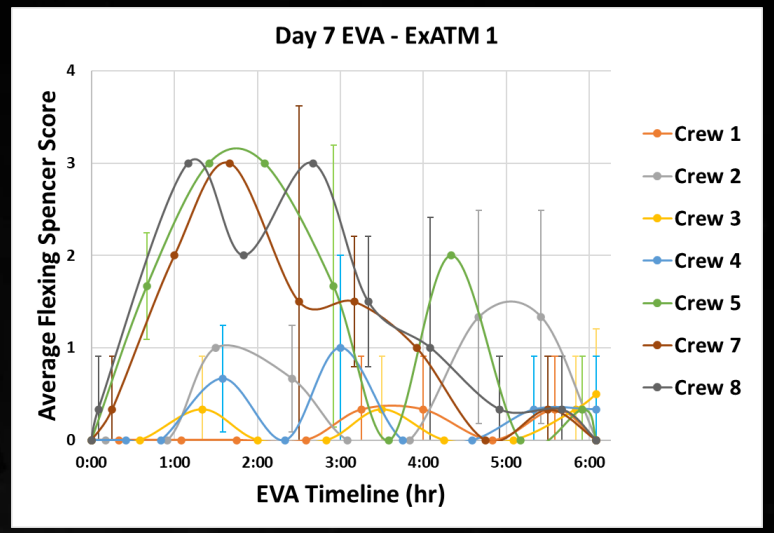


2022-06: EA1 EVA3

Doppler







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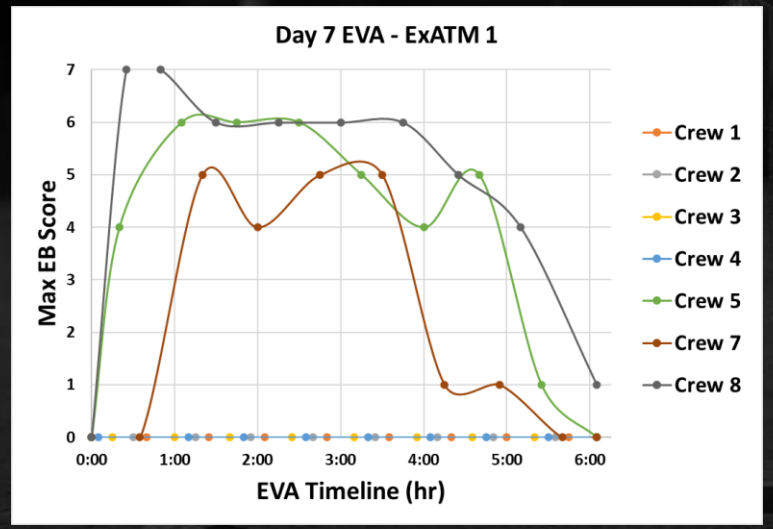
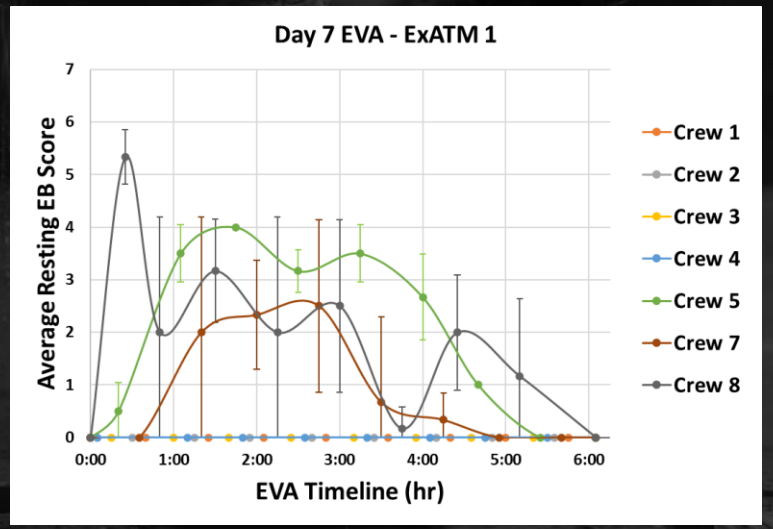
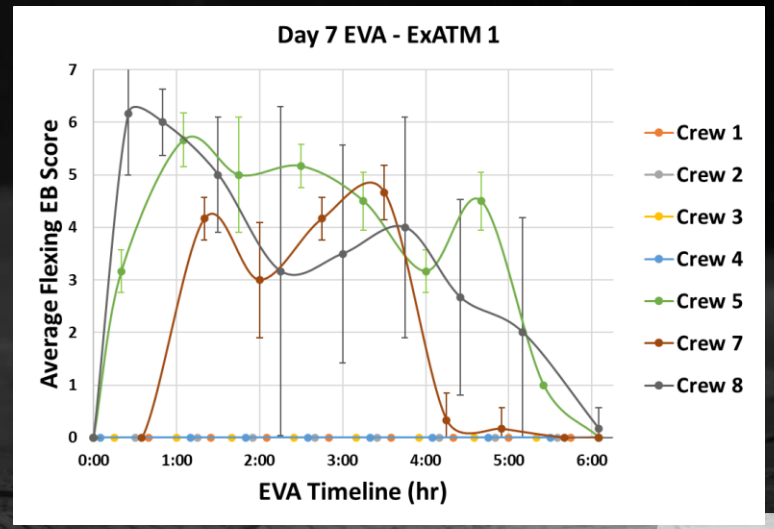
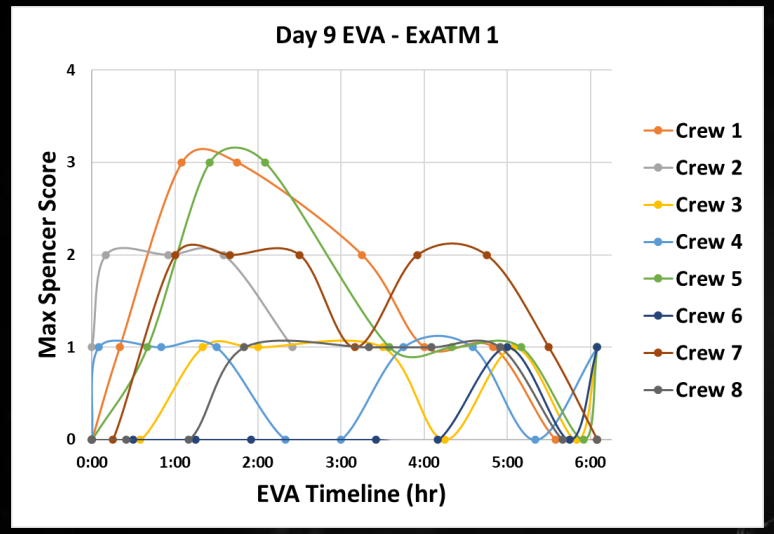


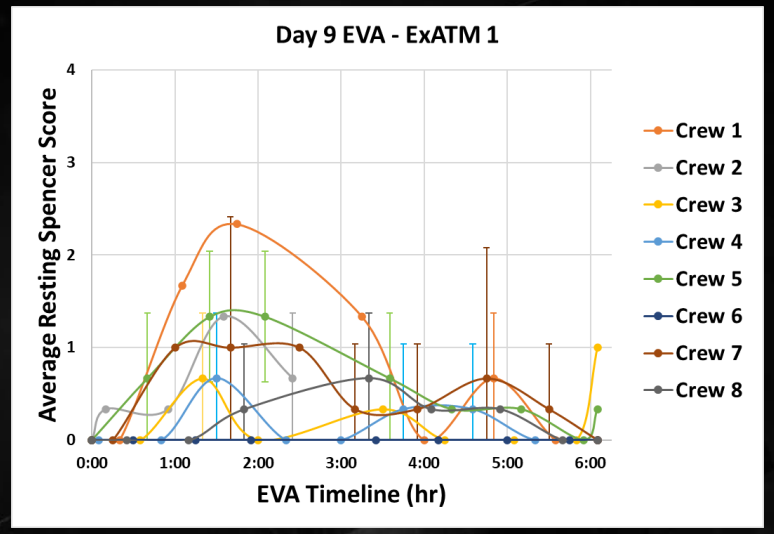


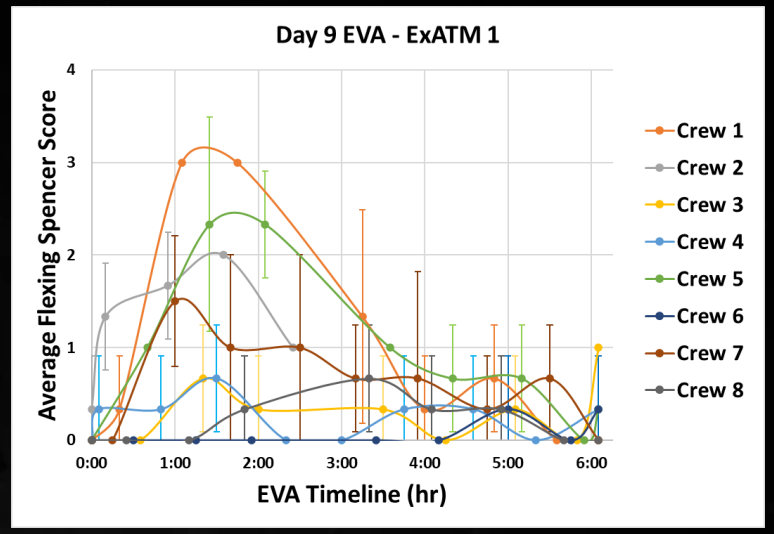


2022-06: EA1 EVA4

Doppler







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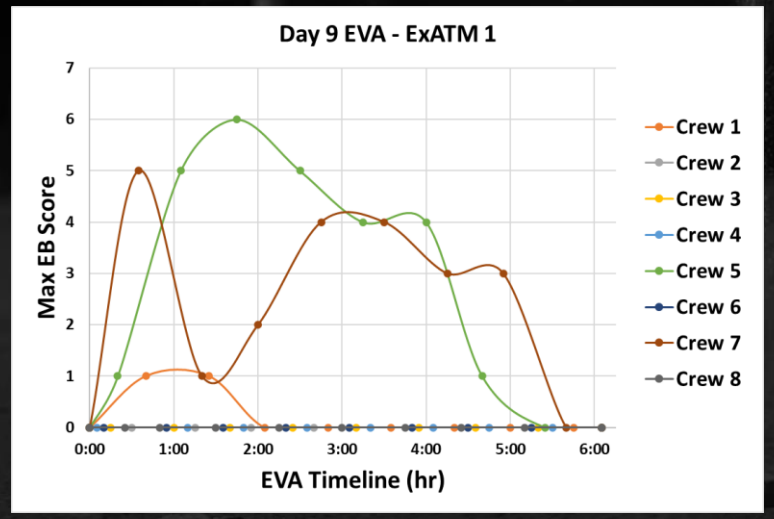
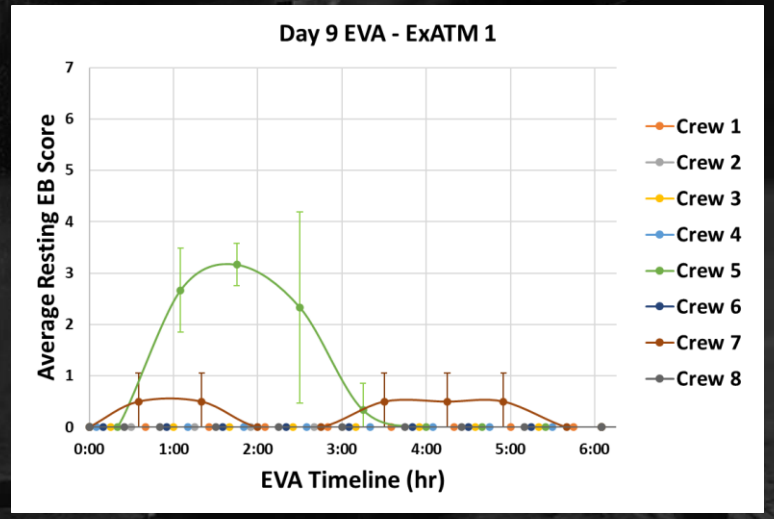
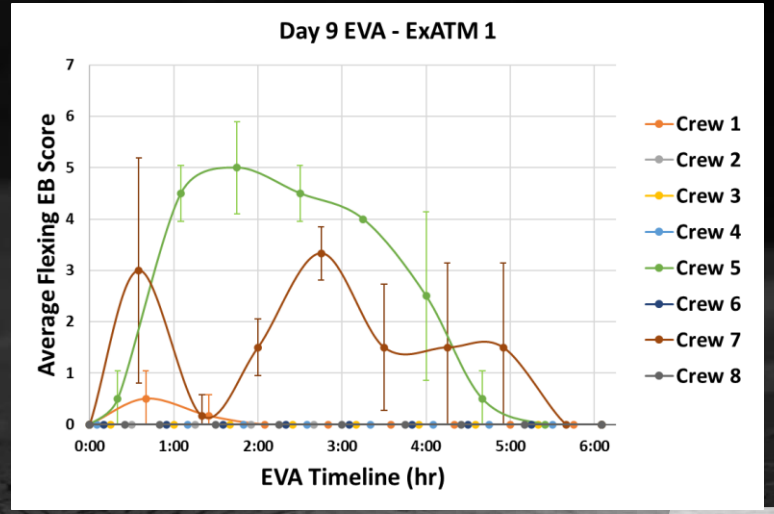
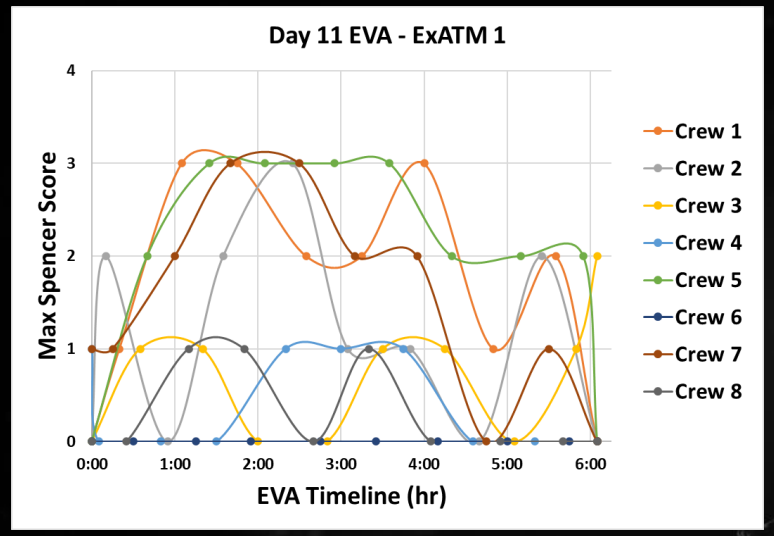


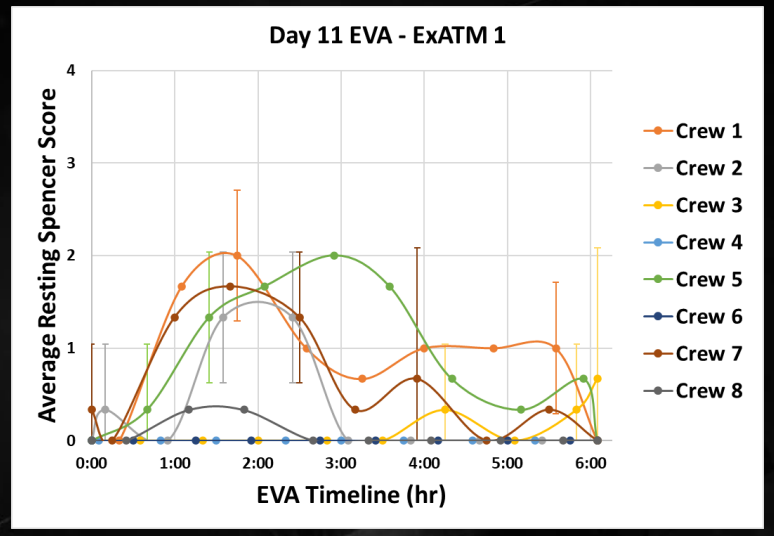


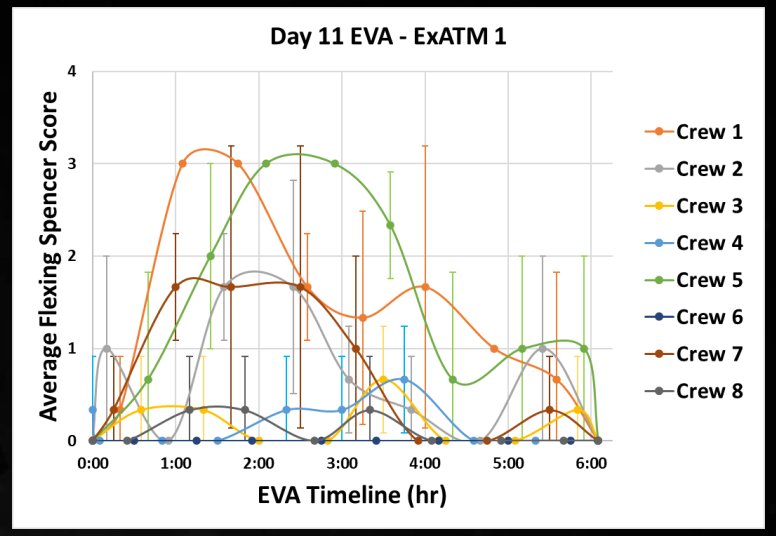


2022-06: EA1 EVA5

Doppler







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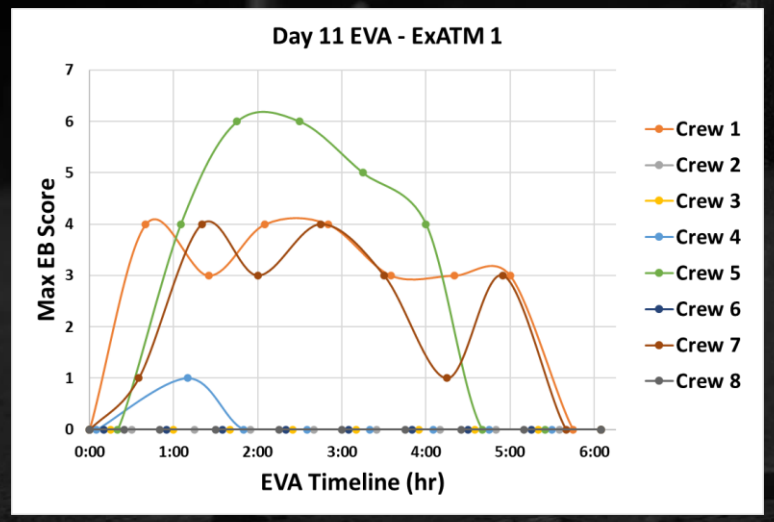
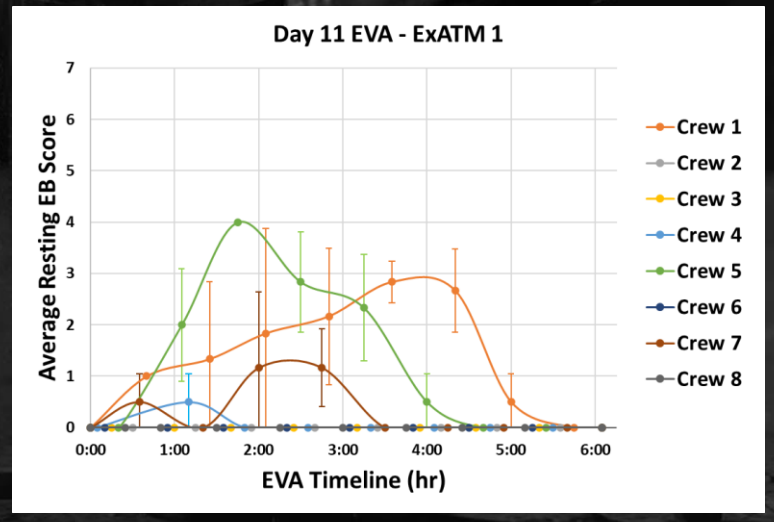
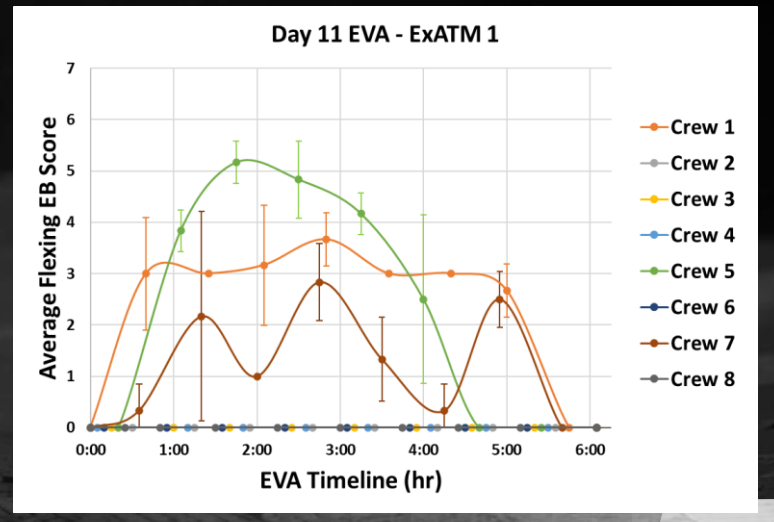






DCS Case 2

- Subject Complained of bilateral hip/knee pain
  - Pt reported sx 36hrs post chamber test/last EVA
    - Presented to local ER (backup HBOT site, familiar with test)
    - Underwent TT5
    - Sx resolved
  - No further sx
    - Extended HBOT on duty times
    - Briefed future subjects about delayed presentation vs delayed reporting

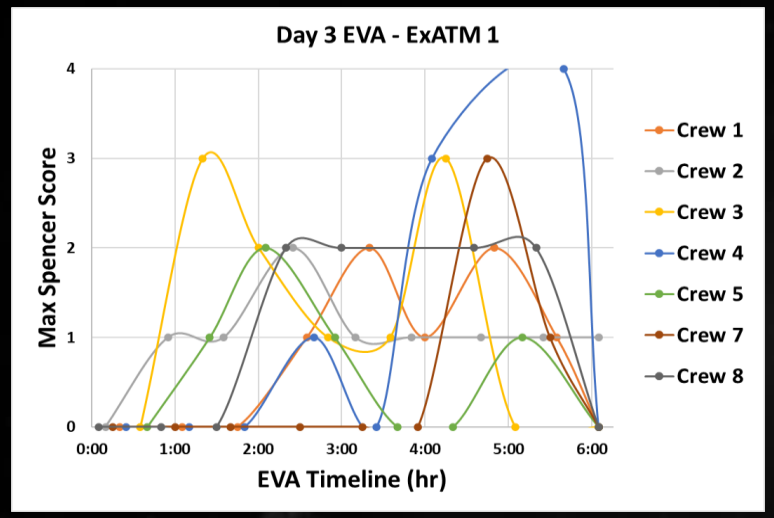
Day by Day Review

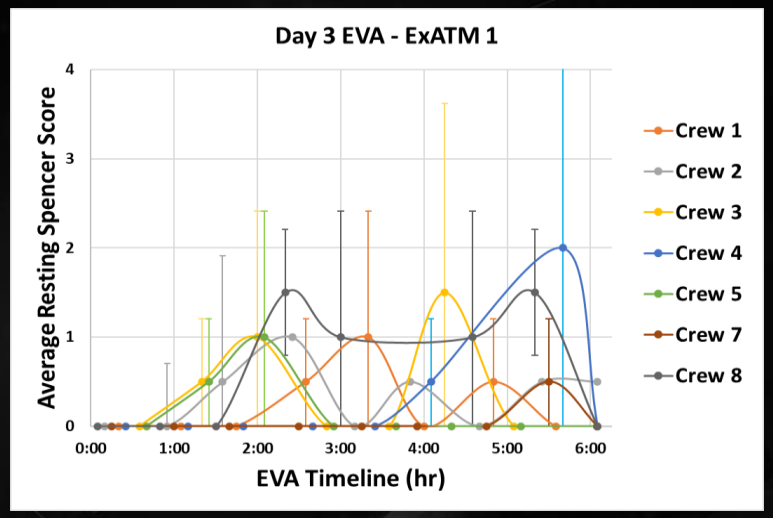
2023-03: 3-day Rehearsal

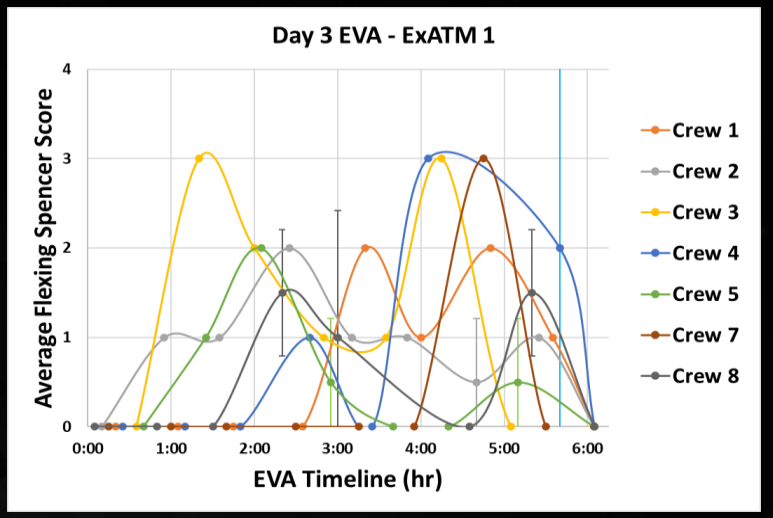
(3-day tests excluded for overall stats)

2023-03 (EA2): 3-Day EVA1

Doppler







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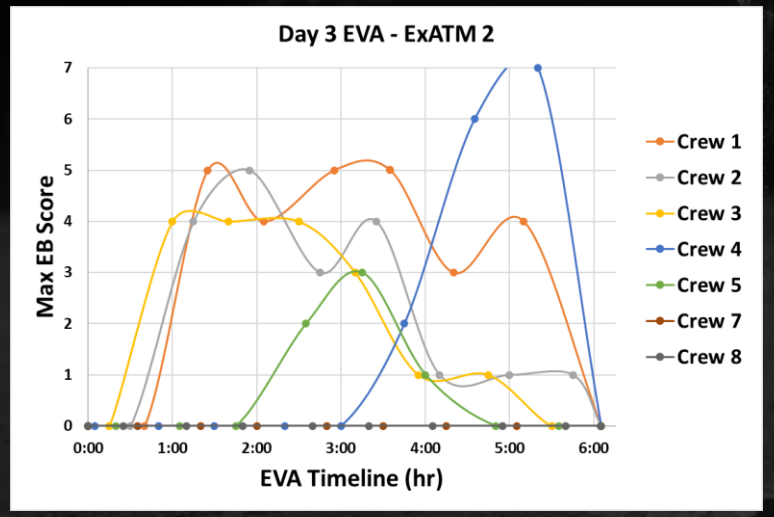
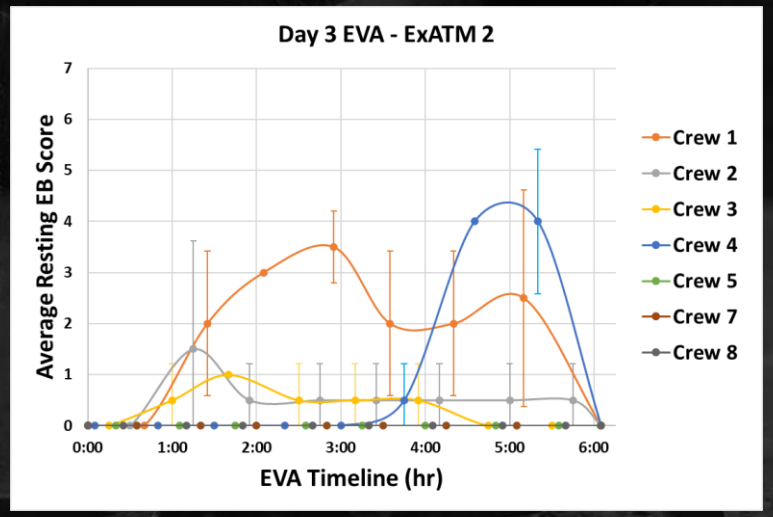
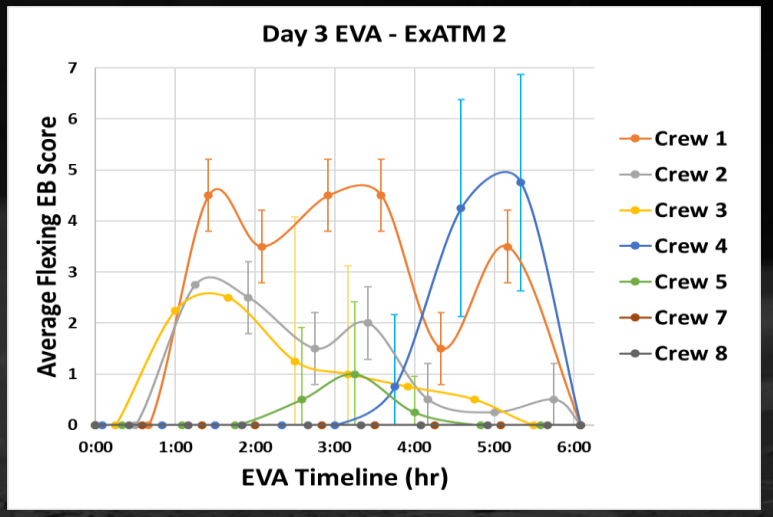




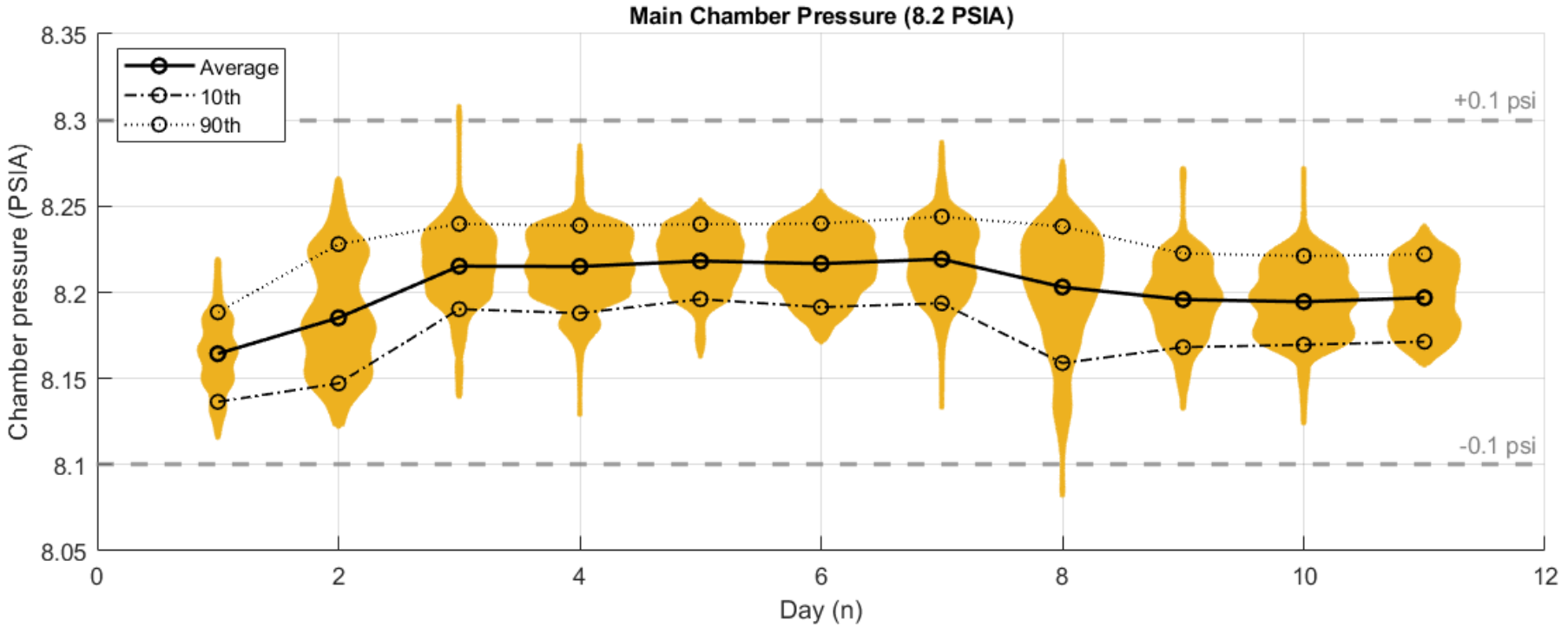


Day by Day Review

2023-06: 11-day Test

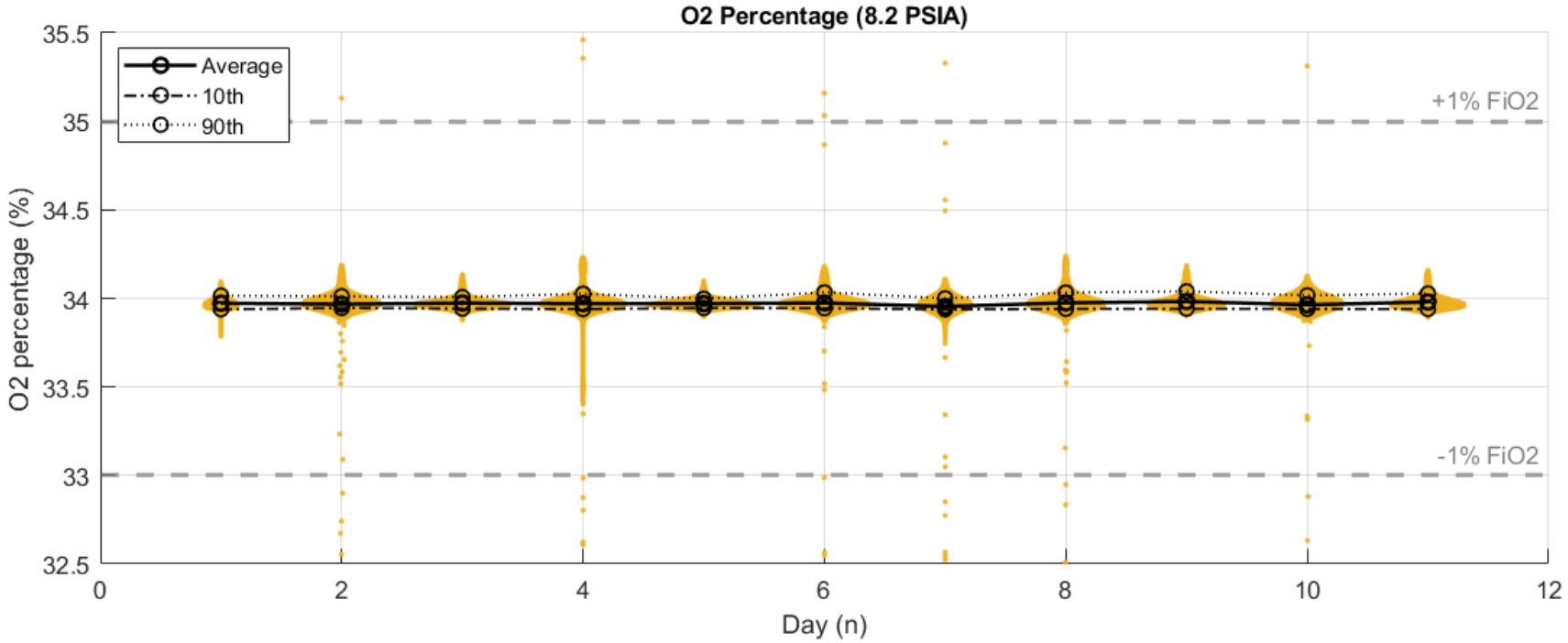
EA2

EA2 Chamber Pressure



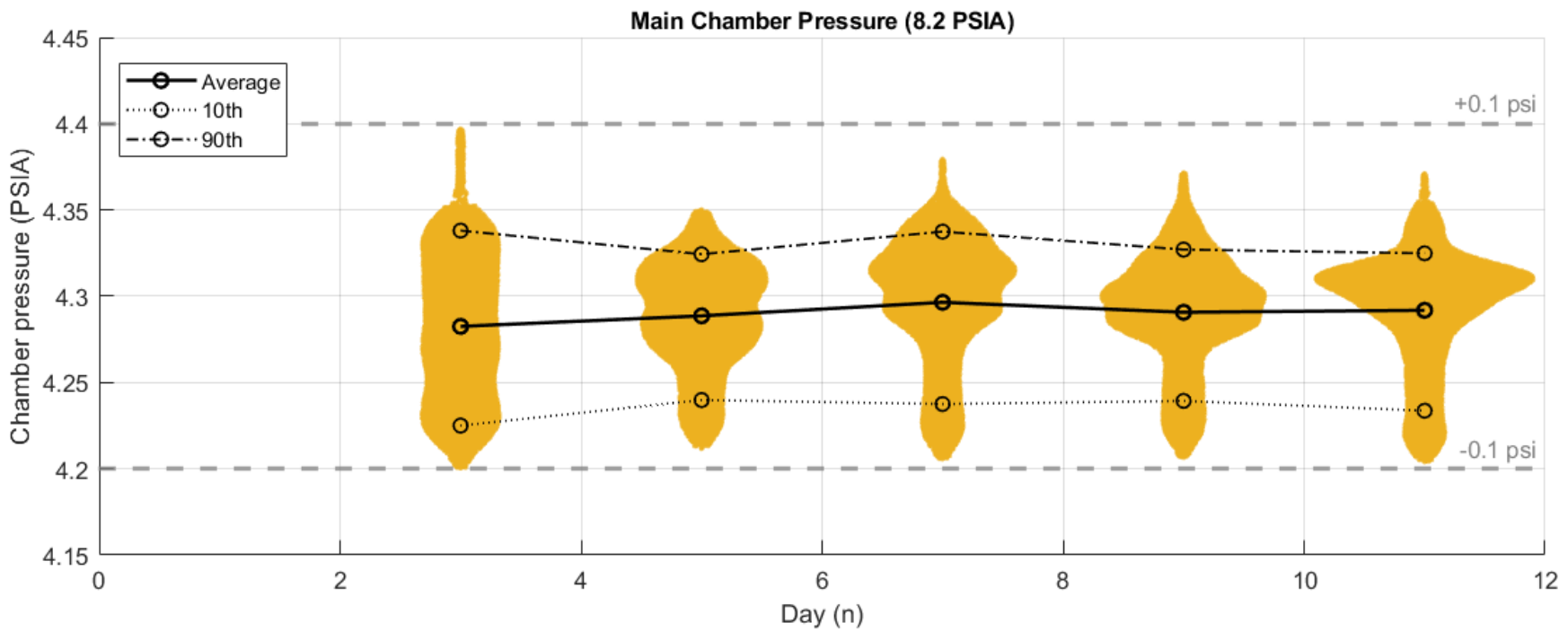
	1	2	3	4	5	6	7	8	9	10	11
Average (PSIA)	8.1644	8.1852	8.2152	8.2150	8.2182	8.2167	8.2193	8.2031	8.1958	8.1946	8.1969
10th (PSIA)	8.1365	8.1472	8.1903	8.1879	8.1960	8.1914	8.1937	8.1590	8.1682	8.1696	8.1714
90th (PSIA)	8.1884	8.2280	8.2397	8.2388	8.2395	8.2400	8.2439	8.2382	8.2226	8.2211	8.2221
Max (PSIA)	8.2192	8.2659	8.3079	8.2850	8.2535	8.2587	8.2870	8.2761	8.2718	8.2718	8.2385
Min (PSIA)	8.1159	8.1223	8.1397	8.1292	8.1629	8.1712	8.1334	8.0824	8.1328	8.1241	8.1577

EA2 Chamber Oxygen



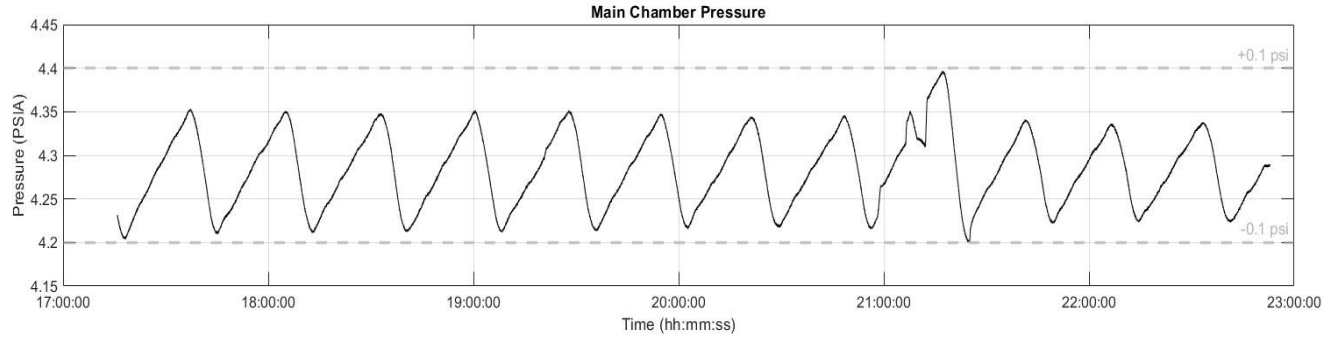
	1	2	3	4	5	6	7	8	9	10	11
Average (%)	33.9723	33.9672	33.9734	33.9700	33.9704	33.9738	33.9544	33.9746	33.9825	33.9637	33.9797
10th (%)	33.9384	33.9456	33.9422	33.9399	33.9453	33.9442	33.9382	33.9410	33.9415	33.9407	33.9400
90th (%)	34.0157	34.0117	34.0072	34.0264	33.9980	34.0340	34.0004	34.0327	34.0402	34.0169	34.0274
Max (%)	34.0939	35.1307	34.1333	36.0233	34.0982	36.4311	35.9367	36.4995	34.1848	35.6476	34.1587
Min (%)	33.7869	27.8089	33.8785	29.4371	33.8956	28.3905	30.1374	31.6183	33.9026	29.9923	33.8936

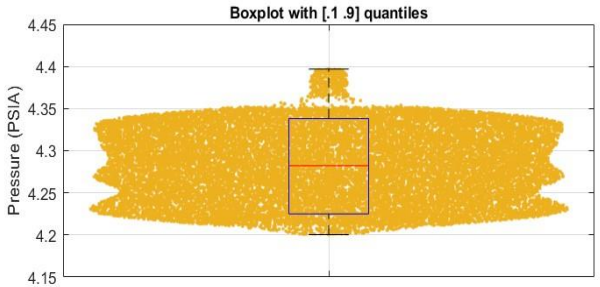
EA2 EVA Pressure



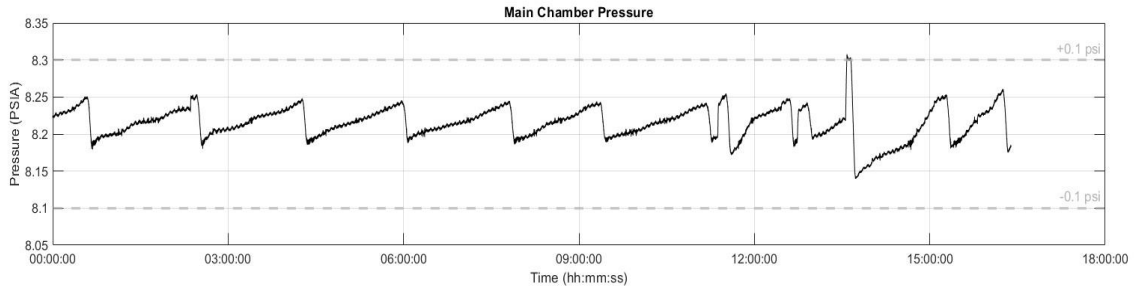
	3	5	7	9	11
Average (PSIA)	4.2825	4.2886	4.2965	4.2907	4.2919
10th (PSIA)	4.2250	4.2398	4.2375	4.2393	4.2337
90th (PSIA)	4.3381	4.3244	4.3375	4.3271	4.3249
Max (PSIA)	4.3969	4.3501	4.3793	4.3715	4.3710
Min (PSIA)	4.2004	4.2118	4.2058	4.2067	4.2042

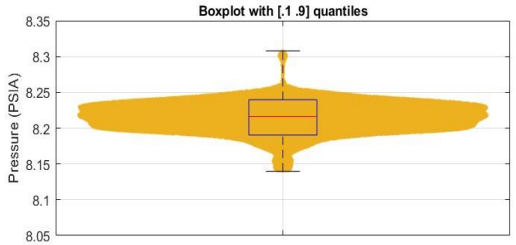
EA2 EVA1 – Chamber Pressure





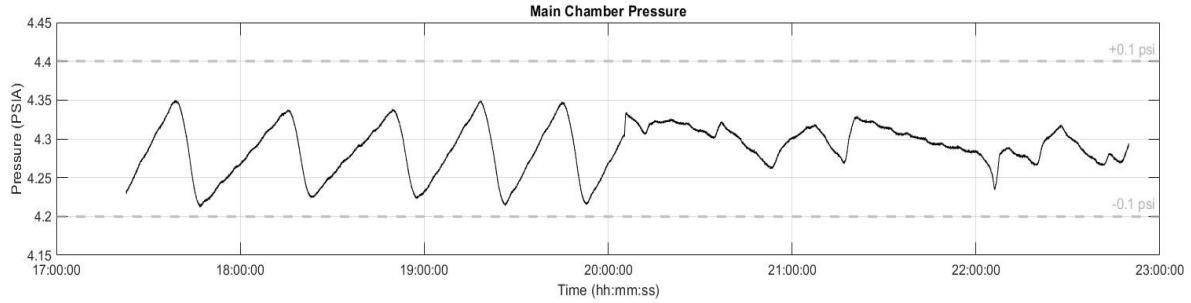
	output
Day	3
Pressure level (PSIA)	4.3000
Average (PSIA)	4.2825
10th (PSIA)	4.2250
90th (PSIA)	4.3381
Max (PSIA)	4.3969
Min (PSIA)	4.2004

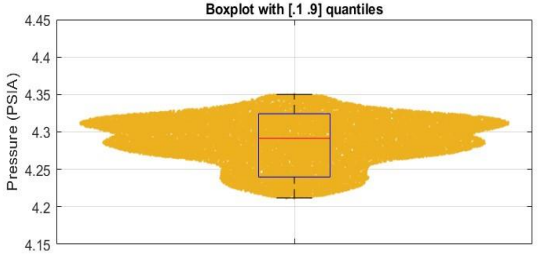




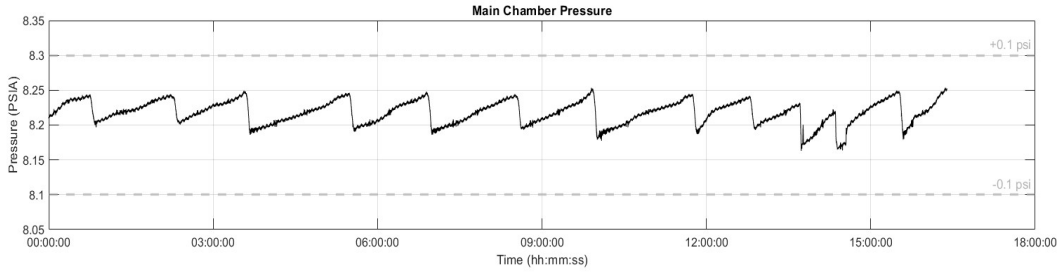
	output
Day	3
Pressure level (PSIA)	8.2000
Average (PSIA)	8.2152
10th (PSIA)	8.1903
90th (PSIA)	8.2397
Max (PSIA)	8.3079
Min (PSIA)	8.1397
Violation Events (n)	3
Total violation time (s)	231
Longest individual violation time (s)	101

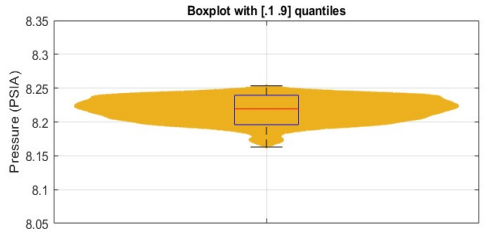
EA2 EVA2 – Chamber Pressure





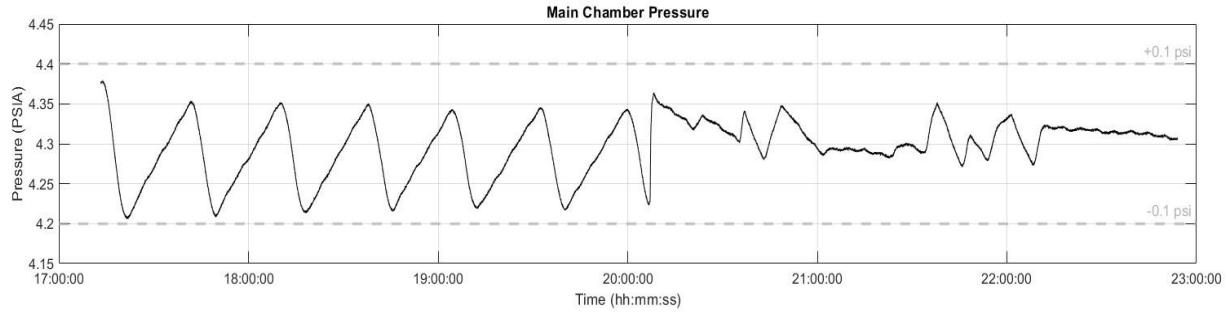
	output
Day	5
Pressure level (PSIA)	4.3000
Average (PSIA)	4.2886
10th (PSIA)	4.2398
90th (PSIA)	4.3244
Max (PSIA)	4.3501
Min (PSIA)	4.2118
Violation Events (n)	0
Total violation time (s)	
Longest individual violation time (s)	

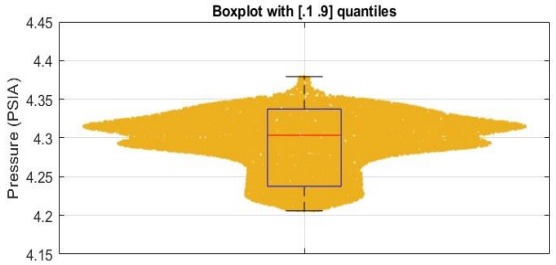




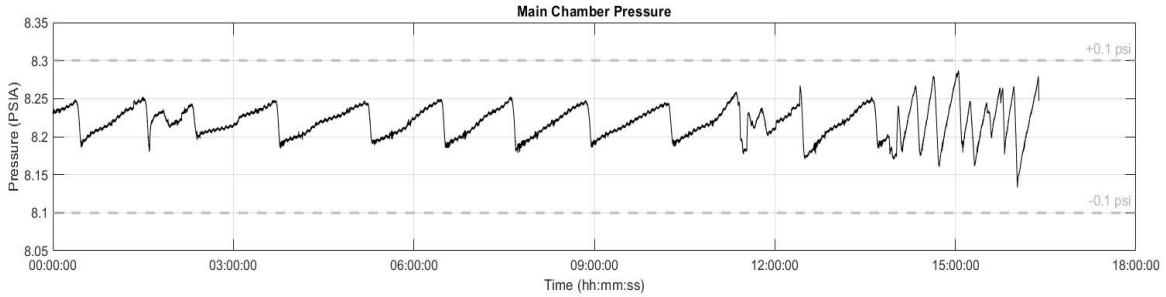
	output
Day	5
Pressure level (PSIA)	8.2000
Average (PSIA)	8.2182
10th (PSIA)	8.1960
90th (PSIA)	8.2395
Max (PSIA)	8.2535
Min (PSIA)	8.1629
Violation Events (n)	0
Total violation time (s)	0
Longest individual violation time (s)	0

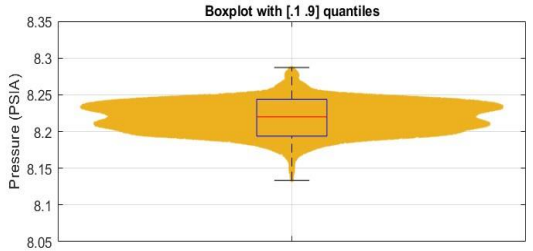
EA2 EVA3– Chamber Pressure





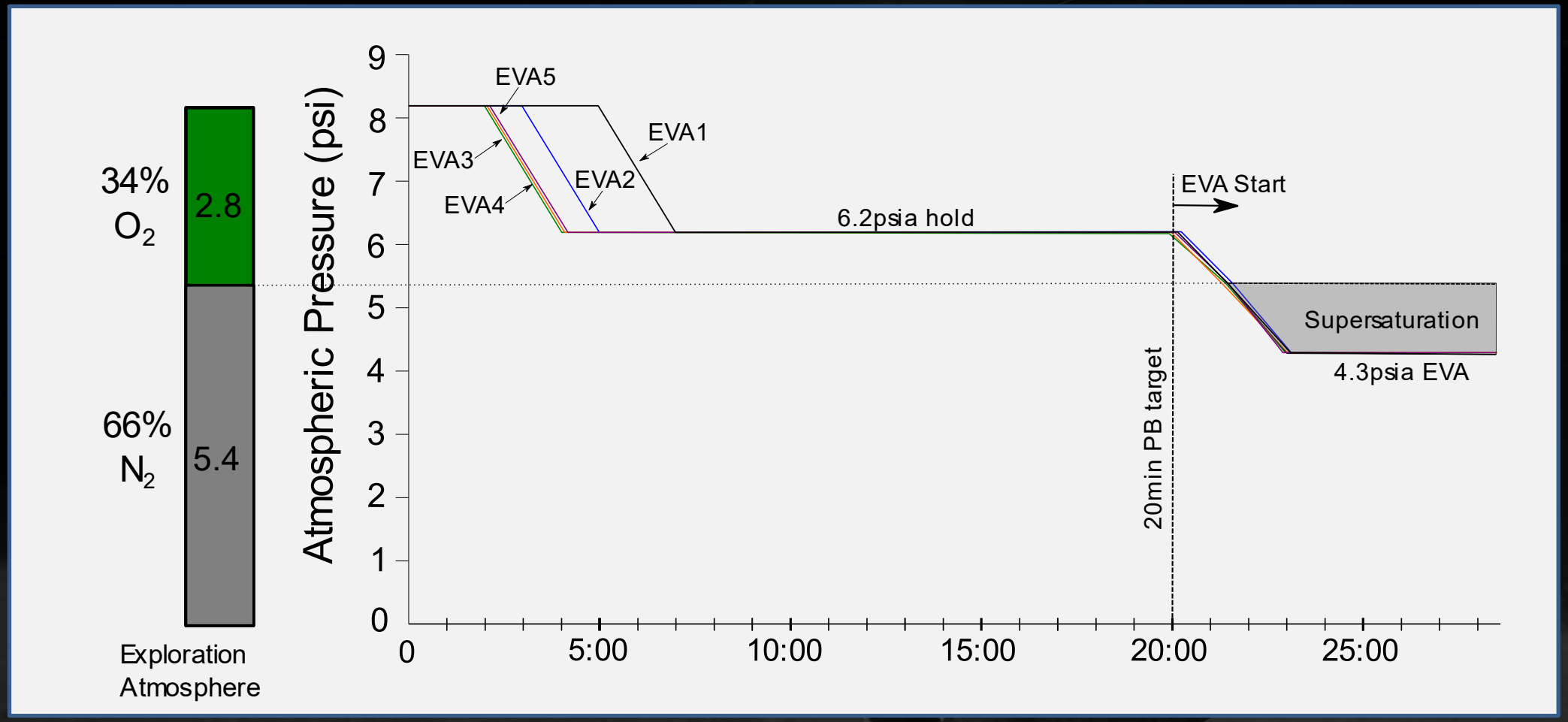
	output
Day	7
Pressure level (PSIA)	4.3000
Average (PSIA)	4.2965
10th (PSIA)	4.2375
90th (PSIA)	4.3375
Max (PSIA)	4.3793
Min (PSIA)	4.2068
Viol	
Total	
Longest indi	





	output
Day	7
Pressure level (PSIA)	8.2000
Average (PSIA)	8.2193
10th (PSIA)	8.1937
90th (PSIA)	8.2439
Max (PSIA)	8.2870
Min (PSIA)	8.1334
Violation Events (n)	0
Total violation time (s)	0
Longest individual violation time (s)	0

EA2 Prebreathe Timelines



Prebreathe Times:
EVA1: 19min 56 sec
EVA2: 20min 01 sec
EVA3: 20min 00 sec
EVA4: 20min 01 sec
EVA5: 20min

*Transition from 6.2 psi to 5.4 psi (supersaturation point) added ~80-90 sec

2023-06: EA2 EVA1

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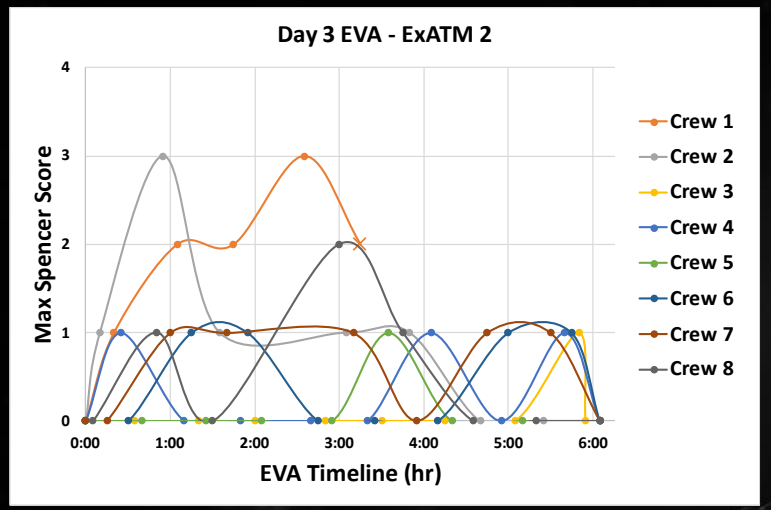

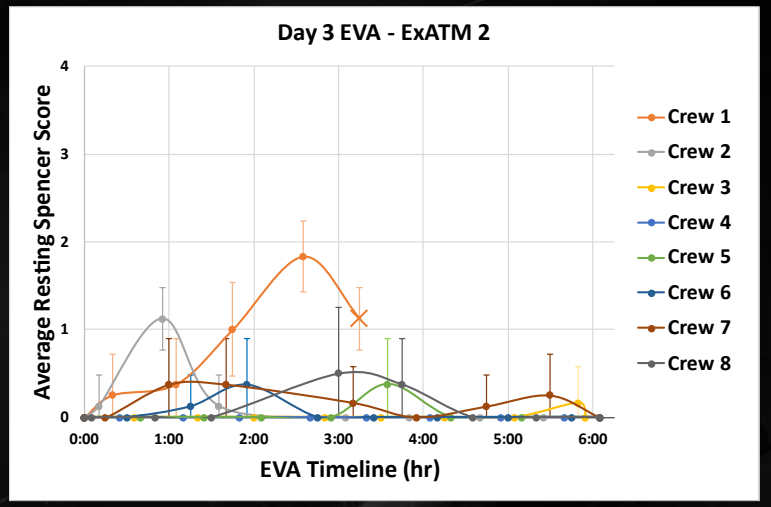

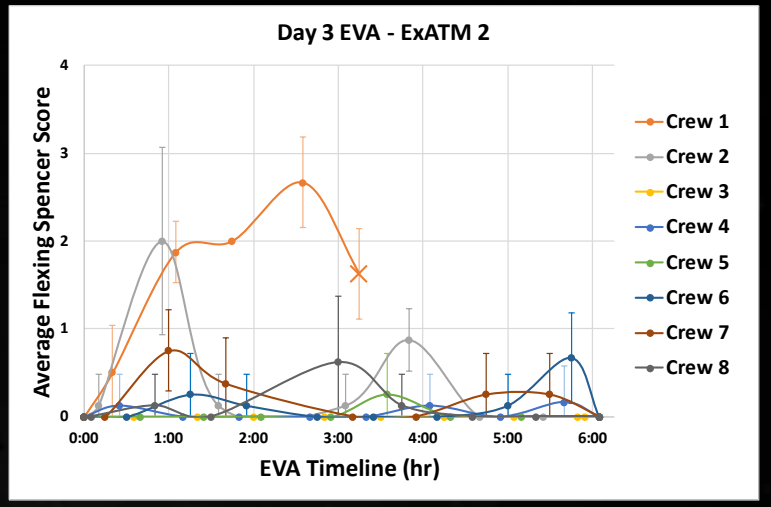

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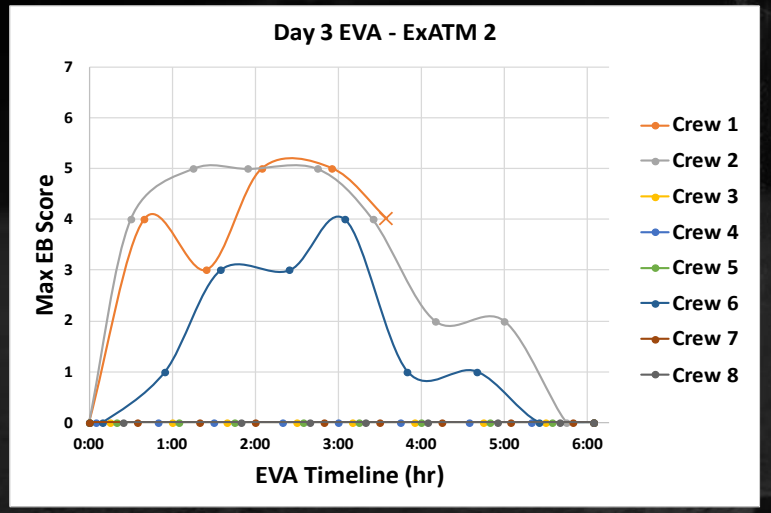
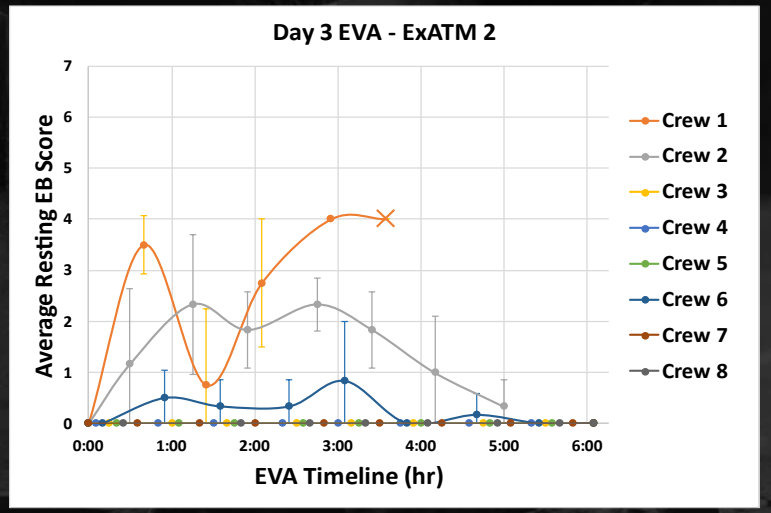
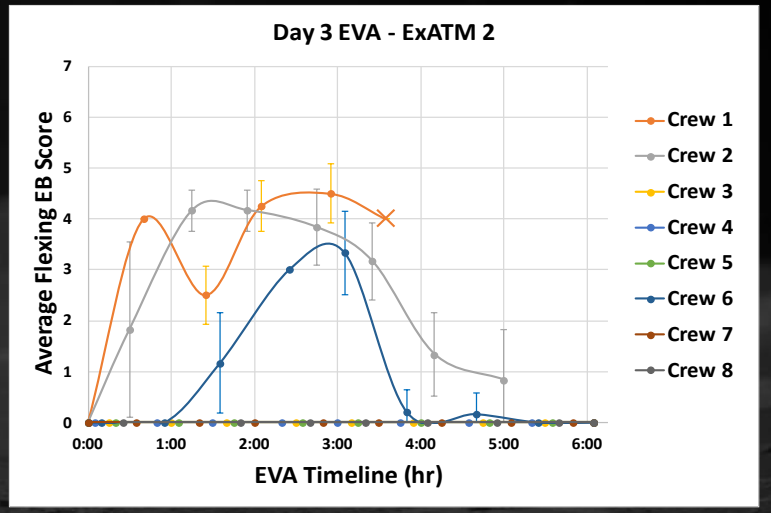
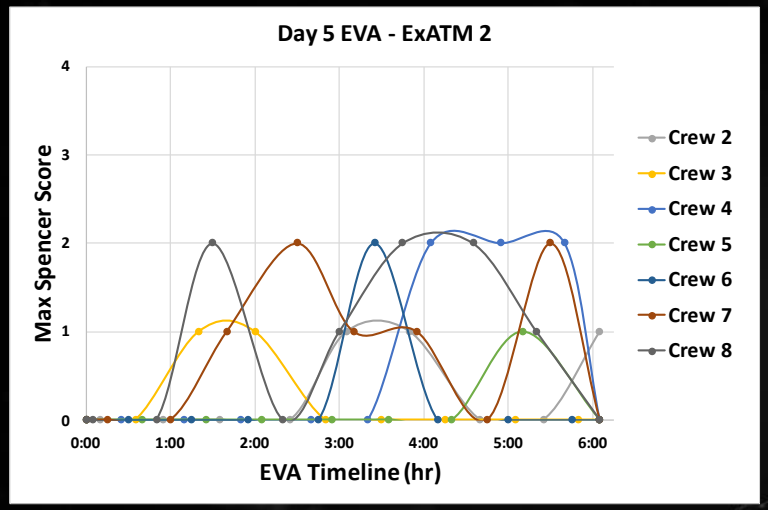


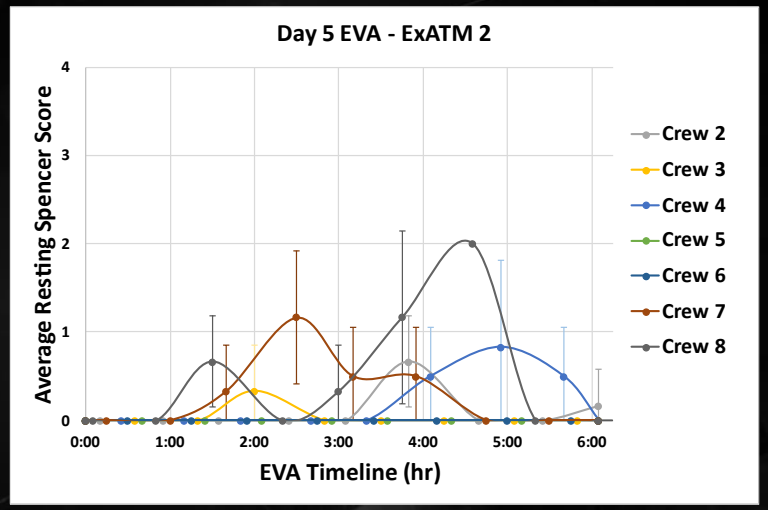


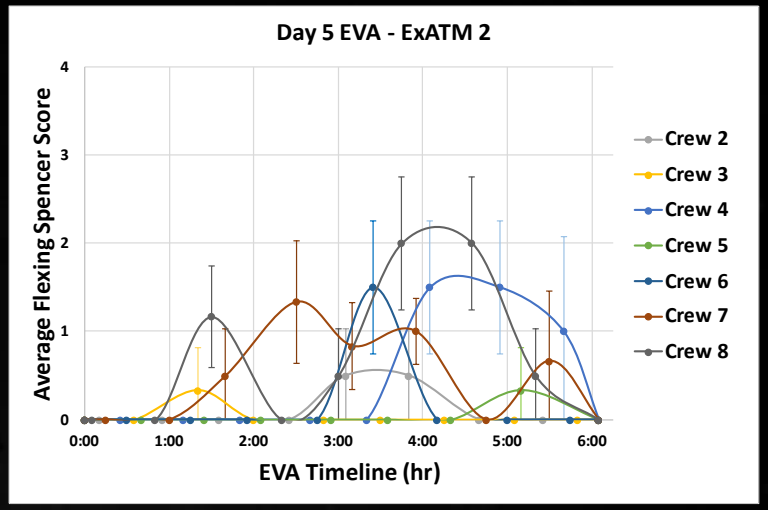


2023-06: EA2 EVA2

Doppler







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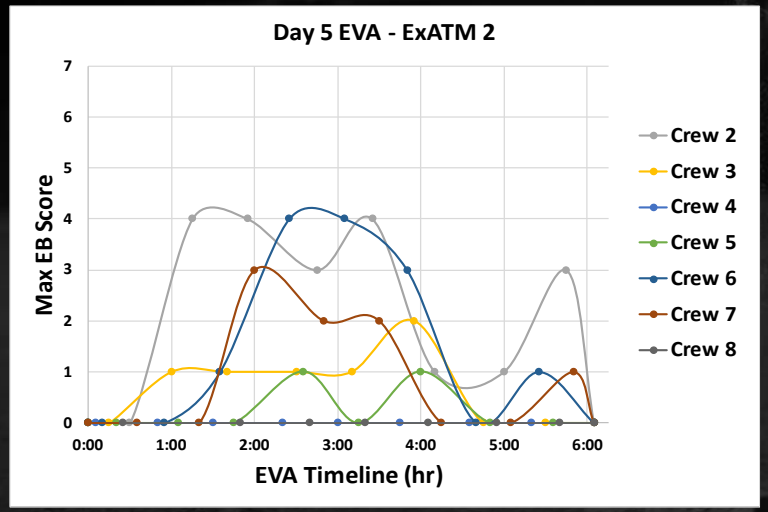
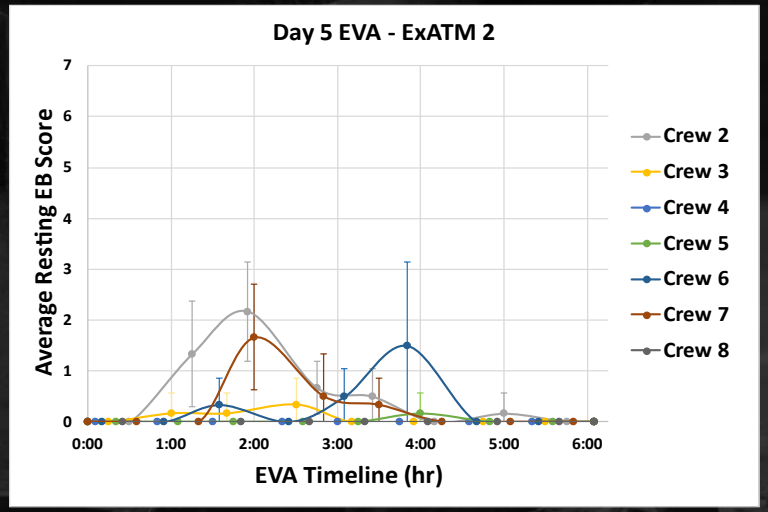
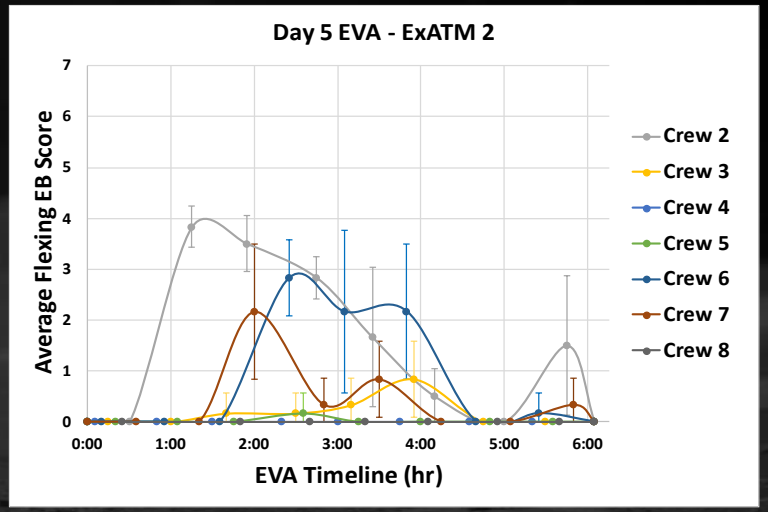
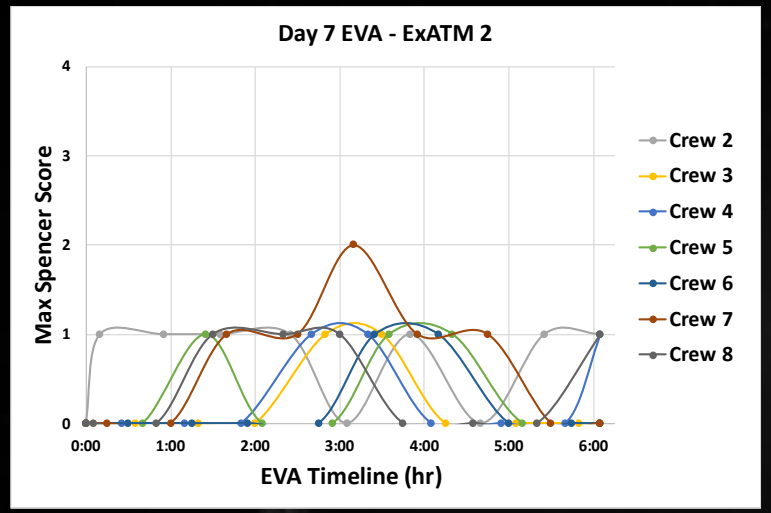


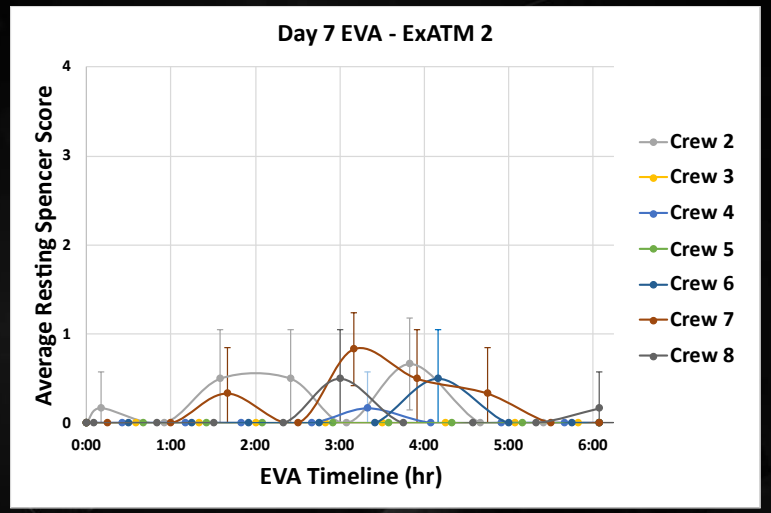


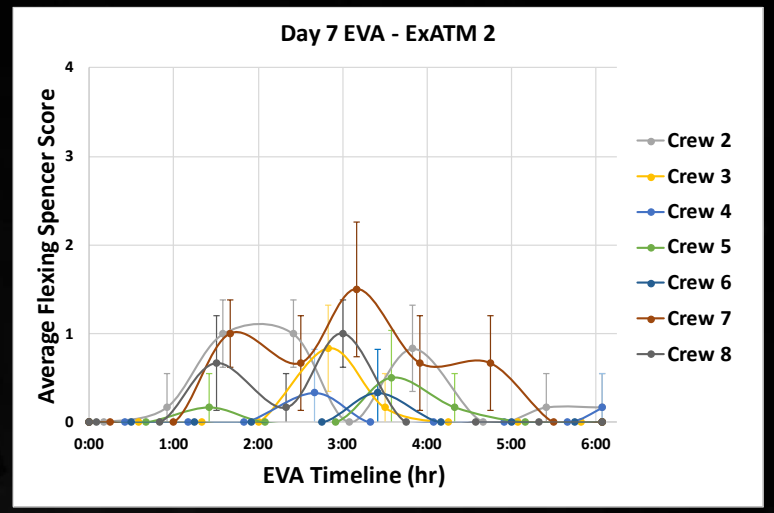


2023-06: EA2 EVA3

Doppler







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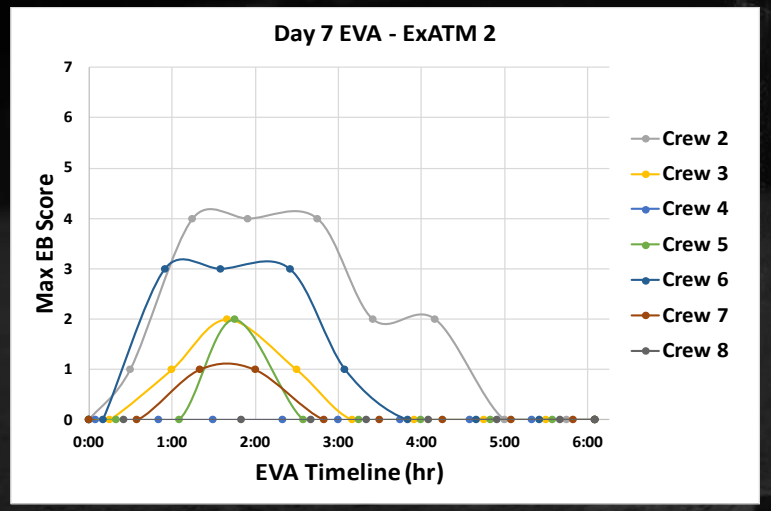

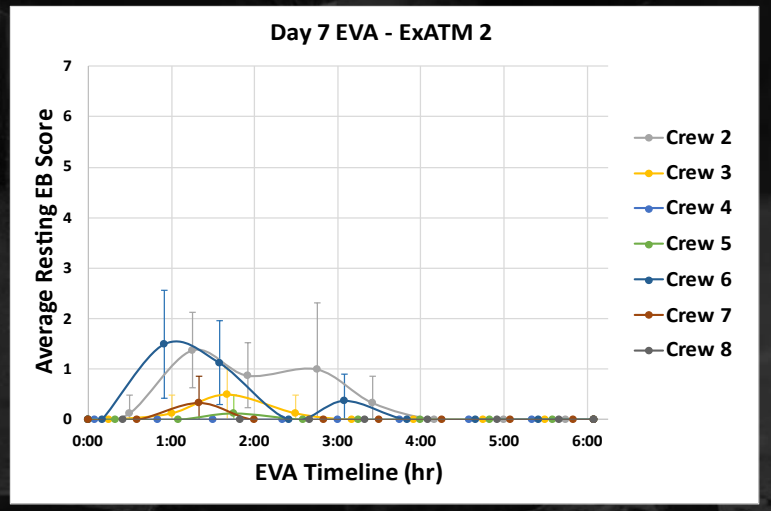

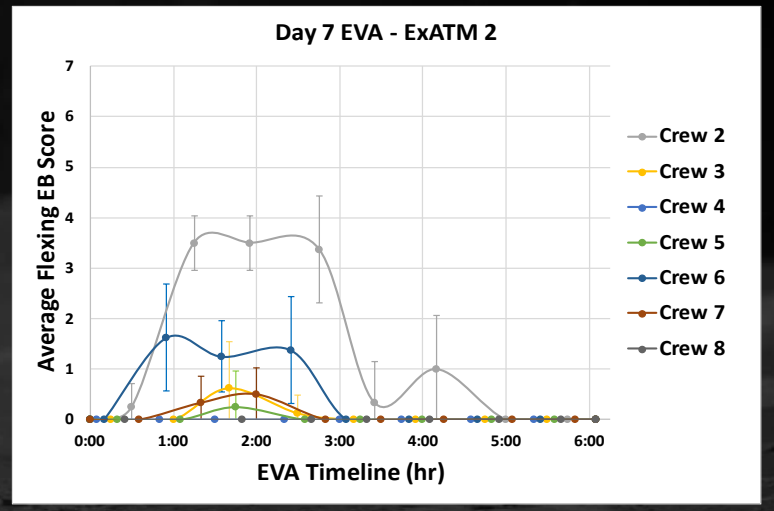

2023-06: EA2 EVA4

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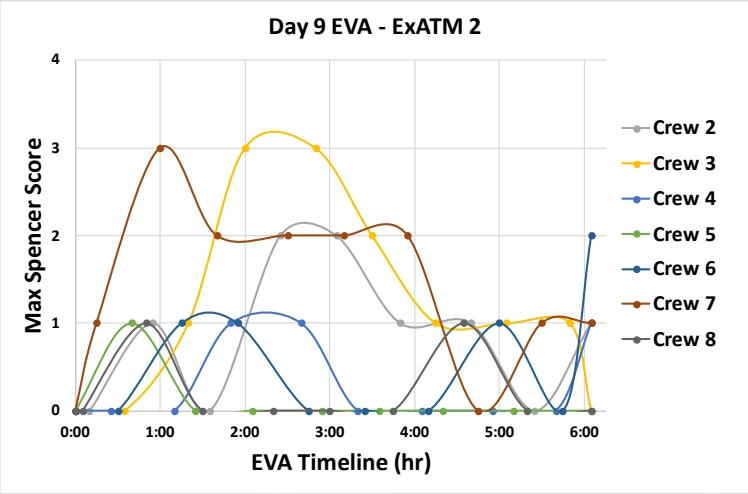

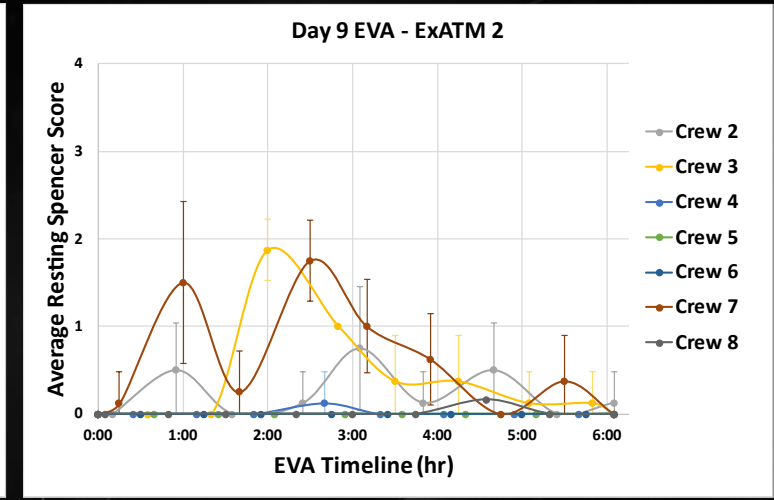

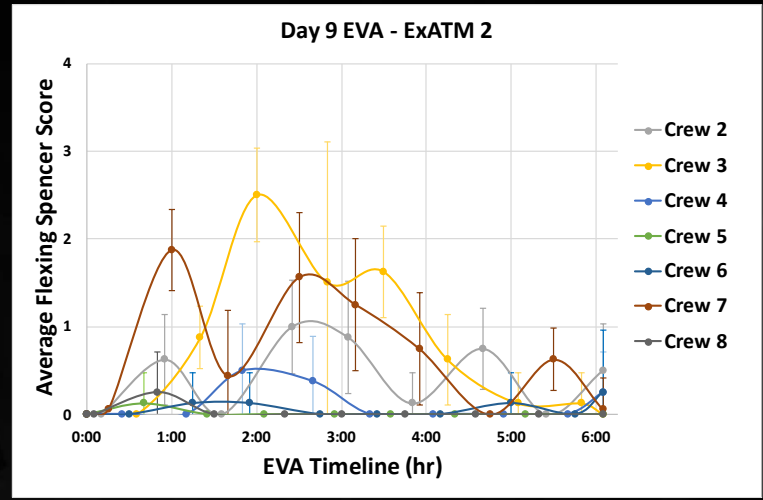

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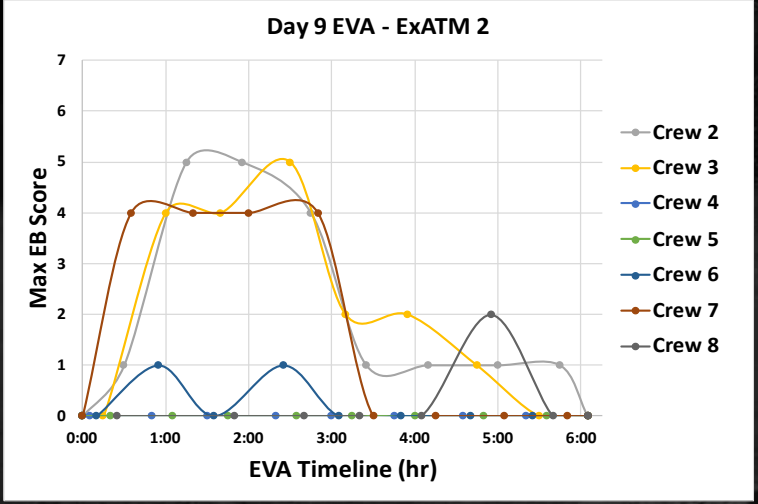

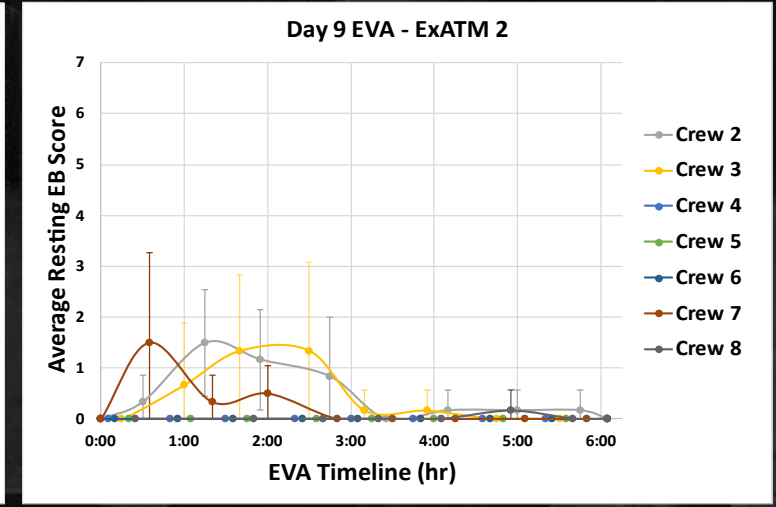

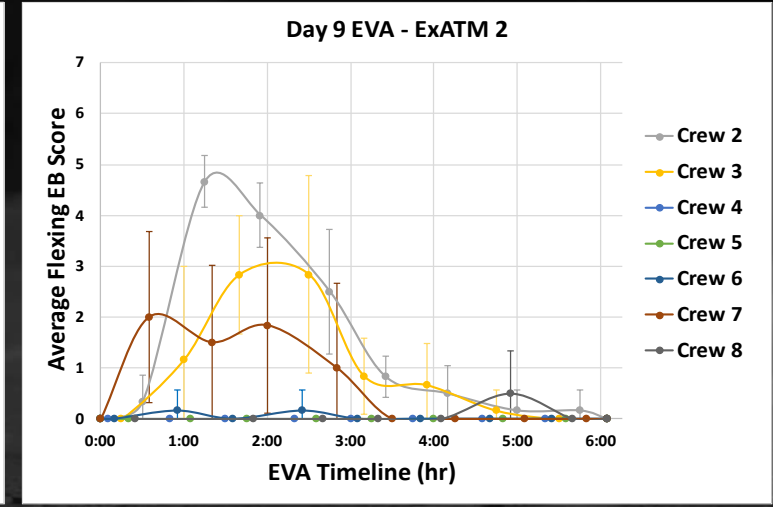

2023-06: EA2 EVA5

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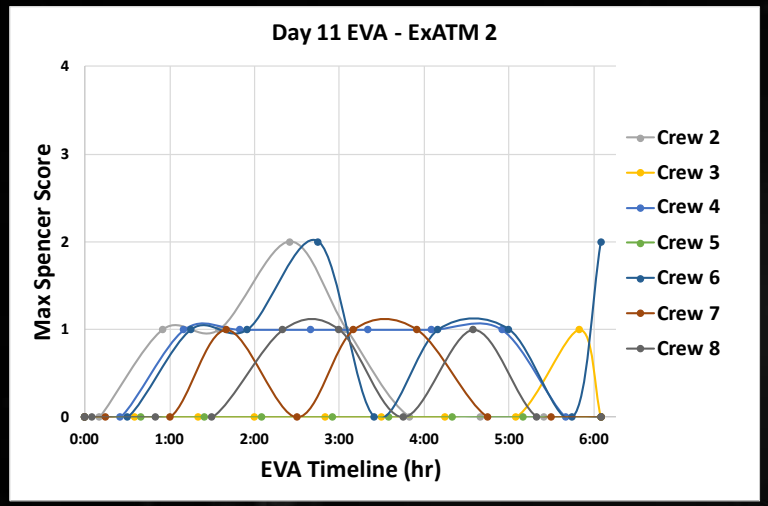

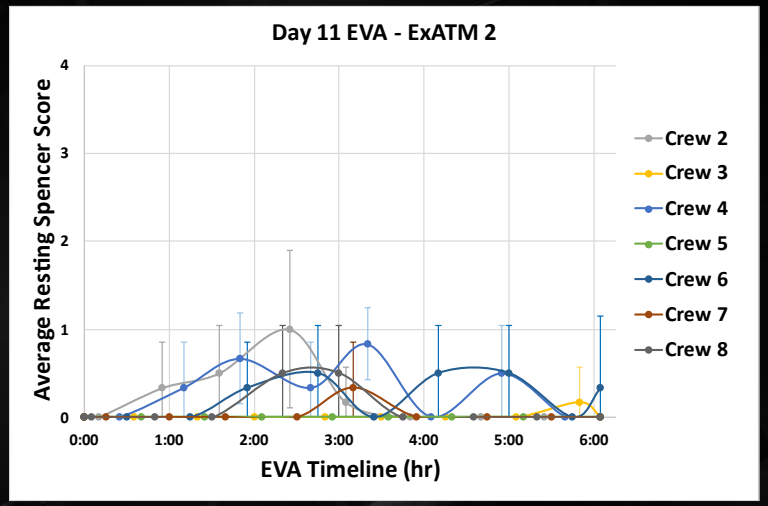

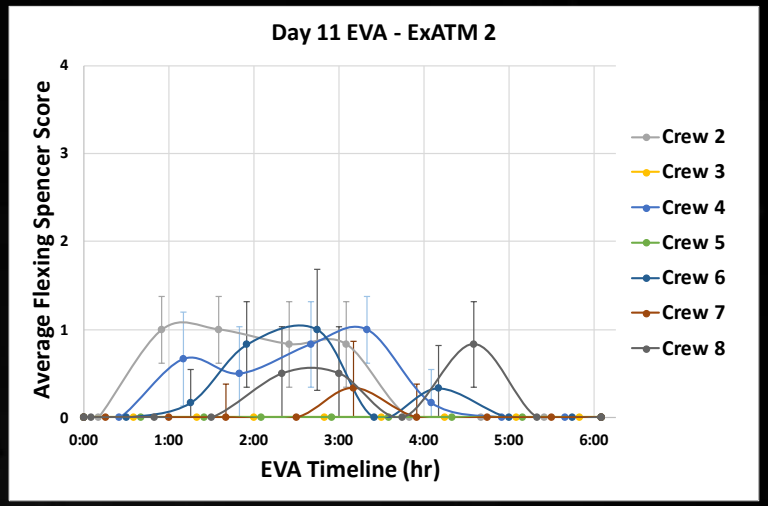

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