OBOGS Chemical Challenge Test Stand Development UPDATE

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Presented to:
2023 OSCG Annual Meeting

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DISCLAIMERS

- The opinions expressed in this brief are those of the presenter and do not represent an official position of the US Government

- I have no financial relationships to disclose

Purpose of this brief

- Provide stakeholders and other interested parties with the current state of this work effort
- Highlight technical accomplishments in the area of chemical challenge testing
- Provide the most current timeline for this work effort
- Discuss implications for future OBOGS testing against MIL-STD-3050 requirements/recommendations regarding chemical protectiveness of oxygen equipment

NAWC Aircraft Division NAVAL AIR WARFARE CENTER

NOTE: Use slide show to view this chart

email suggestions for improvement

This chart illustrates DoDI 5000.85, Major Capability Acquisition model; tailoring to individual program circumstances is essential.

Major Capabilities Acquisition (Pre-Tailoring)

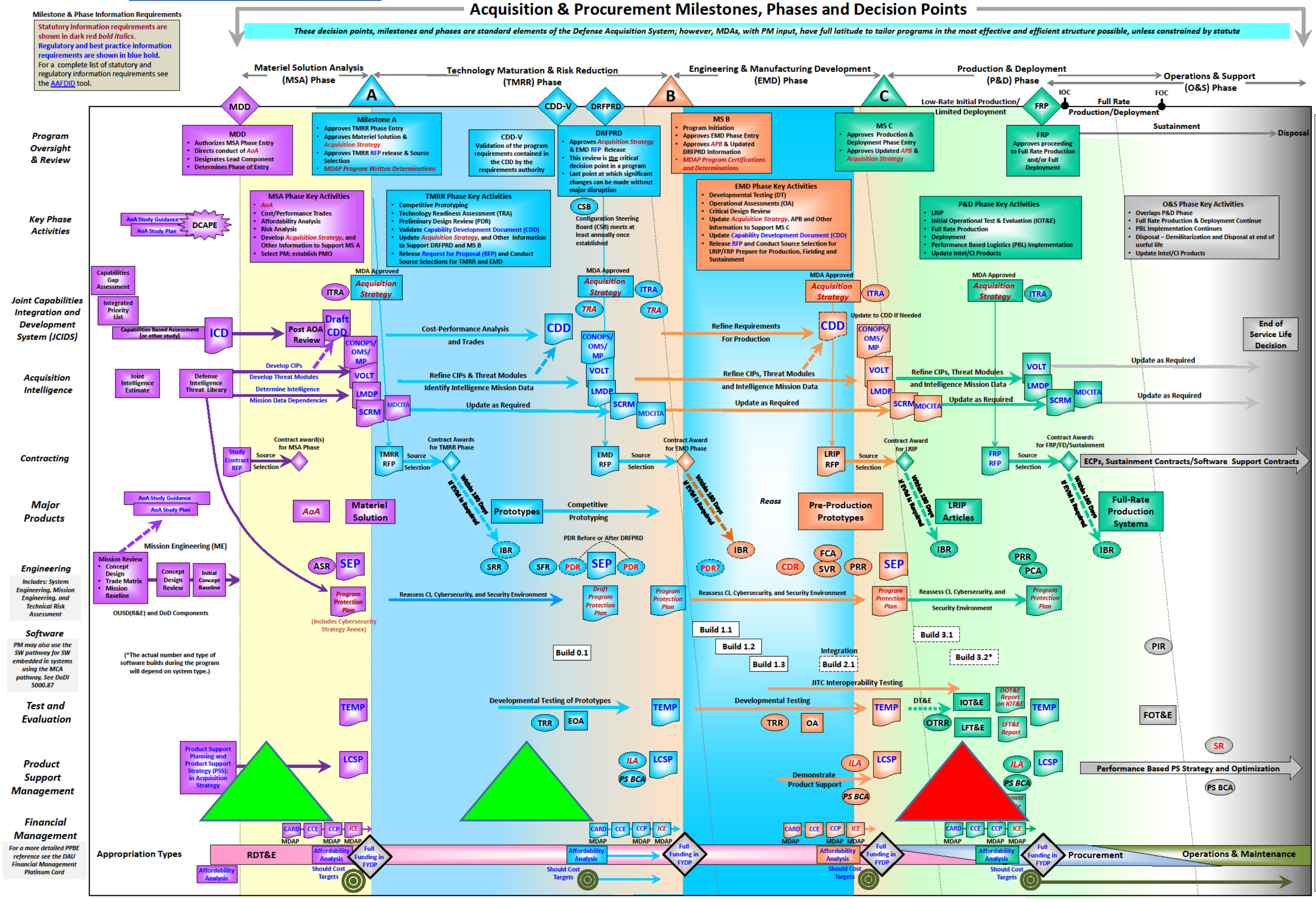
Acquisition & Procurement Milestones, Phases and Decision Points

See the Adaptive Acquisition Framework for other approaches to acquiring capability.

Ver. 2.1
October 21, 2022

Milestone & Phase Information Requirements

Statutory information requirements are shown in dark red *bold italics*.
Regulatory and best practice information requirements are shown in blue bold.
For a complete list of statutory and regulatory information requirements see the AAFDID tool.



Acronyms & Abbreviations

ACAT – Acquisition Category
AoA – Analysis of Alternatives
APB – Acquisition Program Baseline
ASR – Alternative Systems Review
CARD – Cost Analysis Requirements Description
CCE – Component Cost Estimate
CCP – Component Cost Position
CDD – Capability Development Document
CDD –V – Capability Development Document Validation
CDR – Critical Design Review
CI - Counterintelligence
CIPs – Critical Intelligence Parameters
CONOPS/OM/MSP – Concept of Operations/Operational Mode Summary/Mission Profile
CSB – Configuration Steering Board
DCAPE – Director, Cost Assessment & Program Evaluation
DRFPRD – Development Request for Proposals Release Decision
DT&E – Developmental Test & Evaluation
DoDI – Department of Defense Instruction
DOT&E – Director of Operational Test & Evaluation
ECPs – Engineering Change Proposals
EMD – Engineering & Manufacturing Development
EOA – Early Operational Assessment
EVM – Earned Value Management
FCA – Functional Configuration Audit
FD – Full Deployment
FOC – Full Operational Capability
FOT&E – Follow-on Operational Test & Evaluation
FRP – Full-Rate Production
FRP/FD – Full-Rate Production / Full Deployment Decision Review
FYDP – Future Years Defense Program
IBR – Integrated Baseline Review
ICD – Initial Capabilities Document
ICE – Independent Cost Estimate
ILA - Independent Logistics Assessment
IOC – Initial Operational Capability
IOT&E – Initial Operational Test & Evaluation
ISR – In-Service Review
ITRA - Independent Technology Risk Assessment (MDAPs Only)
JIE – Joint Intelligence Estimate
JITC – Joint Interoperability Test Command
JROC – Joint Requirements Oversight Council
LCCE – Life Cycle Cost Estimate
LCSP – Life Cycle Support Plan
LFT&E – Live Fire Test & Evaluation
LMDP – Life-Cycle Mission Data Plan
LRIP – Low-Rate Initial Production
MDA – Milestone Decision Authority
MDAP – Major Defense Acquisition Program
MDCITA - Multi-Discipline Counterintelligence Threat Assessment
MDD – Materiel Development Decision
MS – Milestone
MSA – Materiel Solution Analysis
OA – Operational Assessment
OTRR – Operational Test Readiness Review
PBL – Performance-Based Life-Cycle Product Support; Performance-Based Logistics
PCA – Physical Configuration Audit
PDR – Preliminary Design Review
PIR – Post Implementation Review
PM – Program Manager
PMO – Program Management Office
PPBE – Planning, Programming, Budgeting & Execution
PRR – Production Readiness Review
PSS – Product Support Strategy
PS BCA – PS Business Case Analysis
RDT&E – Research, Development, Test & Evaluation
RFP – Request for Proposal
SCRM – Supply Chain Risk Management
SEP – Systems Engineering Plan
SRR – System Requirements Review
SFR – System Functional Review
SVR – System Verification Review
TEMP – Test & Evaluation Master Plan
TMRR – Tech Maturation & Risk Reduction
TRA – Technology Readiness Assessment
TRR – Test Readiness Review
VOLT – Validated Online Lifecycle Threat

https://www.dau.mil/tools/t/DAU-Glossary

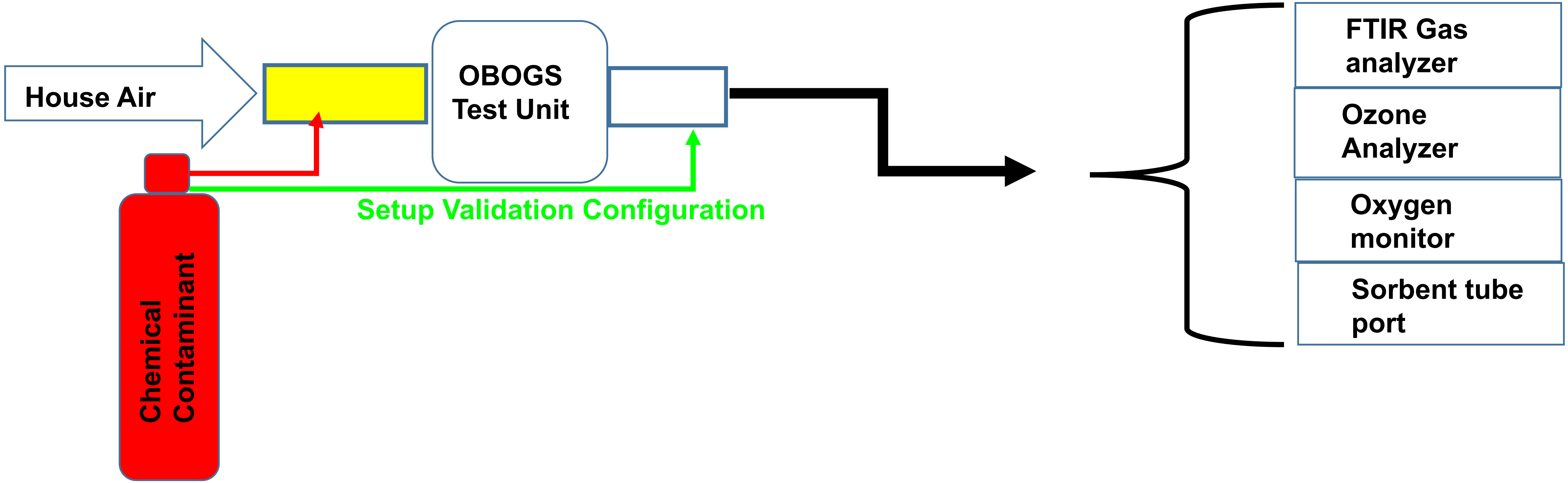
Target Chemicals for Test Stand

MIL-STD-3050A Table IV	INLET AIR CONTAMINANT	OUTLET AIR CONTAMINANT	Room Temp. State	Representative compound(s)	Comments
Acrolein	0.1 ppmv	0.05 ppmv	liquid	acetone, acrolein	
Aldehydes	1 ppmv	0.2 ppmv	liquid or gas	acetalydehyde, propanal	
Aromatics	10 ppmv	0.1 ppmv	liquid	toluene, xylenes	
Carbon Dioxide	5000 ppmv	500 ppmv	gas	carbon dioxide	
Carbon Monoxide	50 ppmv/250 ppmv (Navy)	10 ppmv	gas	carbon monoxide	
Cobalt	0.1 mg/m^3	0.025 mg/m^3	solid	N/A	
Ethanol	1000 ppmv	500 ppmv	liquid	ethanol	
Fluorine (as HF)	0.1 ppmv	0.05 ppmv	liquid	HF	recommend separate filter testing
Halogenated Solvents	2 ppmv	0.2 ppmv	liquid or gas	dichloromethane, trichloroethylene	
Hydrogen Peroxide	1 ppmv	0.5 ppmv	liquid solution	hydrogen peroxide	material incompatible with zeolites
Methyl Alcohol	200 ppmv	100 ppmv	liquid	methyl alcohol	
Methyl Bromide	20 ppmv	1 ppmv	gas	methyl bromide	
Nickel	0.5 mg/m^3	0.125 mg/m^3	solid	N/A	
Nitrogen Oxides	5 ppmv	0.1 ppmv	gas	nitrogen dioxide	
Oil Breakdown Products	1 ppmv	0.1 ppmv	particles	N/A	
Oil and Particulate Matter	2 mg/m^3	0.2 mg/m^3	particles	N/A	
Ozone	0.1 ppmv	0.05 ppmv	gas	ozone	
Sub-micron particles	0.5 mg/m^3	0.05 mg/m^3	particles	N/A	
Total hydrocarbons	250 ppmv	25 ppmv	liquid or gas	n-heptane, n-octane	
Unsaturated hydrocarbons (alkenes, alkynes)	2 ppmv	0.2 ppmv	liquid or gas	ethylene, propyne	
Vapor Phase Water	≤ 95% non-condensing	-4^{o} F dew point	liquid	N/A	

Challenges to Address

- Low target concentrations
  - Difficult to hold consistent vapor concentration
  - Signal-to-noise ratios in detection equipment
- Low vapor pressures in some target chemicals
  - COTS vapor generation insufficient
  - Maintain vapors at room temperature to avoid condensation during testing
- High oxygen concentrations can reduce sensitivity of industrial gas analyzers
  - Raises the LOD during testing with running OBOGS
- Pressure pulses from running OBOGS
  - Less stable baselines
  - Reduced signal-to-noise ratio

Test Rig Capability Overview



- High-flow vapor generation system
- Low-flow vapor generation system
- Ozone generation system
- Gas cylinder dilution system

- Fourier-Transform Infrared Spectrometer (FTIR) detector/analyzer
- Ozone analyzer
- Sorbent tube port

Theoretical Capability of FTIR vs MILSTD3050A

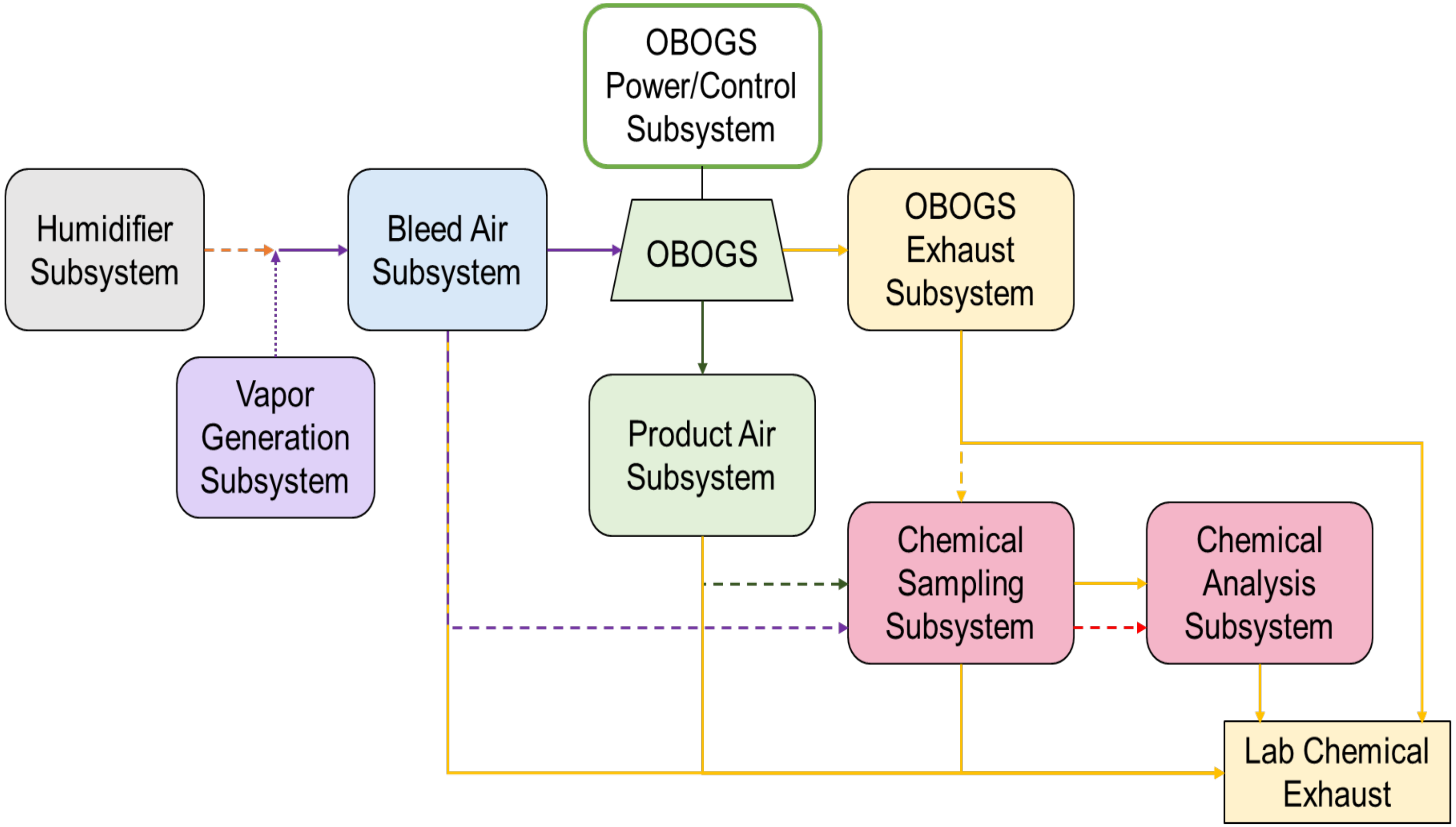
Chemical	Wavelength (cm^{-1})	Absorption cross section (cm^2/molecule)	MIL-STD Max Outlet concentration (ppmv)	LoD from averaging 100 scans (ppmv)	Factor above MILSTD
Acrolein	1730	9.33E-19	0.05	0.044	1.1
Carbon Dioxide	2361	1.48E-17	500	0.003	181000
Carbon Monoxide	2173	2.04E-18	10	0.020	500
Ethanol	1066	3.03E-19	500	0.135	3711
Hydrogen Peroxide	1250	3.74E-19 [13]	0.5	0.109	4.6
Methanol	1033	1.05E-18	100	0.039	2568
Methyl Bromide	1450	4.57E-19	1	0.089	11
Ozone	N/A	N/A	N/A	N/A	N/A
Acetaldehyde	1761	4.56E-19	0.2	0.089	2.2
Propanal	1754	4.76E-19	0.2	0.086	2.3
Toluene	829	9.25E-19	0.1	0.044	2.3
m-Xylene	769	7.18E-19	0.1	0.057	1.8
Dichloromethane	750	7.76E-19	0.2	0.053	3.8
Trichloroethylene	849	8.19E-19	0.2	0.050	4.0
Nitrogen Dioxide	1603	2.63E-18	0.1	0.016	6.4
Nitric Oxide	1900	6.47E-19	0.1	0.063	1.6
n-heptane	2936	1.02E-18	25	0.040	623.7
n-Octane	2933	1.33E-18	25	0.031	813.0
Ethylene	949	1.88E-18	0.2	0.022	9.2
Propyne	635	1.53E-18	0.2	0.027	7.5

From first principles, FTIR spectroscopy can reasonably detect MILSTD chemicals of interest at required concentrations

FY22-23:

- Develop new capability to generate MIL-STD-3050 chemical vapors at required pressures, flow rates, and controlled concentrations to introduce into an operating OBOGS.
- Verify vapor generation methods with multiple chemicals at a range of experimental conditions.
- Build a test stand that is capable of evaluating the chemical filtration performance of an OBOGS to ensure it meets MIL-STD-3050 requirements.

OBOGS Test Stand System Overview



Some RDTE Focus Chemicals

- Acrolein (Acetone proxy)
- Acetaldehyde
- Octane
- Ozone

- Lowest target outlet concentration; low detection factor above need based on absorption cross-section
- Fairly polar; test gas-dilution system
- Higher concentrations to test; testing high-flow vapor generator developed by JHU/APL
- Test ozone generator and detector

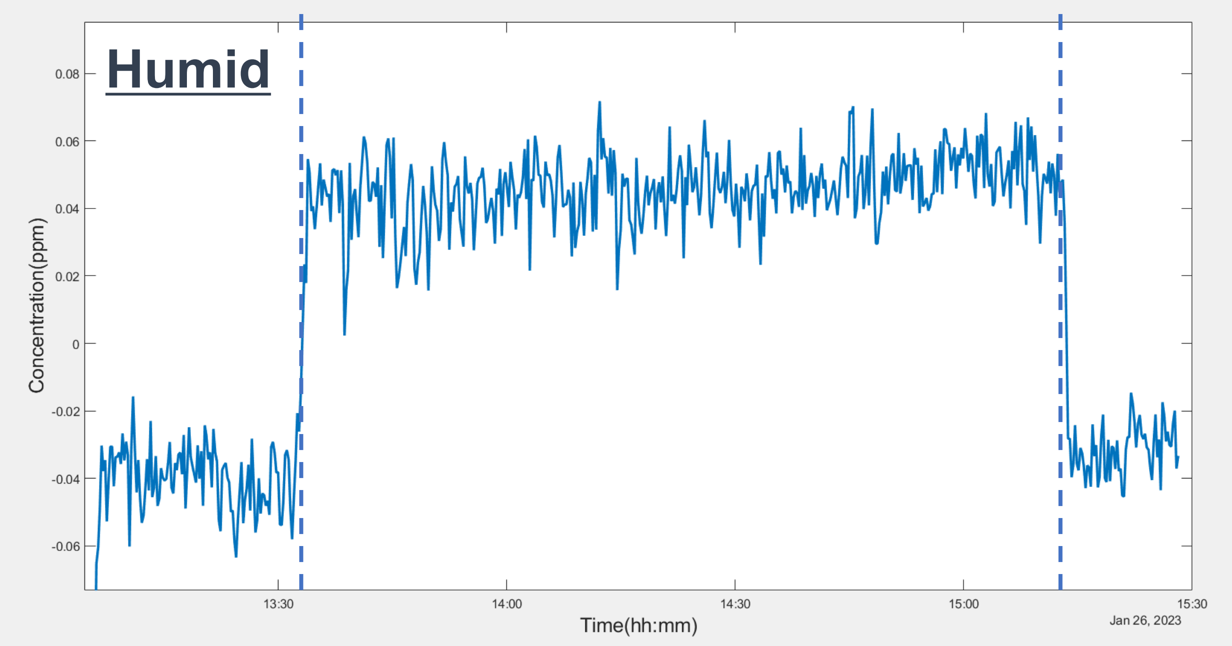
Acrolein vs Acetone in RDTE Testing

Chemical classification	Chemical	Polarity	Dipole moment (d)	Density (g/mL)	Surface Tension (mN/m)	MW (g/mol)	Viscosity (mPa-s)	Boiling Point (1 atm)
Aromatics	Benzene	nonpolar	0	0.879	28.22 at 25 °C	78.11	0.604 at 25 °C	176.2 °F
Aromatics	Toluene	nonpolar	0.375	0.867	27.73 at 25 °C	92.14	0.560 at 25 °C	231.1 °F
Alcohols	Ethanol	polar	1.66	0.79	21.97 at 25 °C	46.07	1.074 at 25 °C	173.3 °F
Alcohols	Methyl Alcohol	polar	1.7	0.792	22.07 at 25 °C	32.04	0.544 at 25 °C	148.3 °F
Alkane	Decane	nonpolar	0.07	0.73	23.37 at 25 °C	142.28	0.838 at 25 °C	345.4 °F
Halogenated Solvents	Dichloroethene	polar	1.9	1.21	24 at 20 °C	96.94		118 to 140 °F
Organobromine	Methyl Bromide	polar	1.83	1.73	24.5 at 15 °C	94.94	0.397 at 0 °C	38.4 °F
Aldehyde	Acrolein	polar	3.11	0.838	24 at 20 °C	56.06	0.35 at 20 °C	126 °F
	Water	polar	1.8546	1	71.97 at 25 °C	18.015	0.8949 at 25 °C	212 °F
Carboxylate ester	Ethyl Acetate	polar	1.78	0.902	24 at 20 °C	88.11	0.423 at 25 °C	171 °F
Ketone	Acetone	polar	2.88	0.791	23.7 at 20 °C	58.08	0.32 at 20 °C	133 °F
Ether	Diethyl ether	nonpolar	1.15	0.714	17.06 at 20 °C	74.12	0.2448 at 20 °C	94.3 °F
Nitrile	Acetonitrile	polar	3.92	0.787	29.04 at 20 °C	41.05	0.35 at 20 °C	178.9 °F
Ketone	2-pentanone	nonpolar	2.7	0.809	25.09	86.13	0.473 at 25 °C	212 to 214 °F
Ketone	cyclohexanone	nonpolar	2.9	0.945	35.05 at 20 °C	98.14	2.2 at 25 °C	312.1 °F
Alcohols	Glycerol	polar	2.56	1.261	63.4 at 20°C	92.09	954 at 25 °C	554 °F

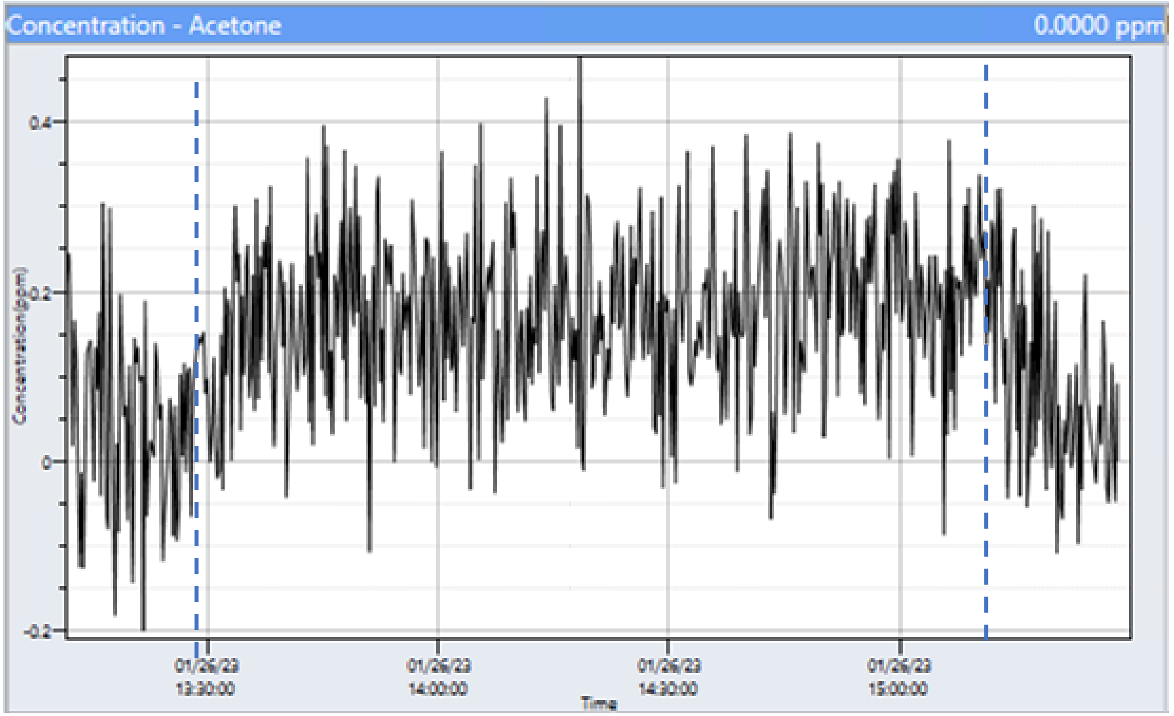
- Acrolein NIOSH TWA REL 0.1 ppm; 15 min REL 0.3 ppm; IDLH 2 ppm
- Acetone NIOSH TWA REL 250 ppm; IDLH 2500 ppm

100 ppb acetone in humid conditions – APL FTIR analysis compared to commercial analysis

APL FTIR Analysis

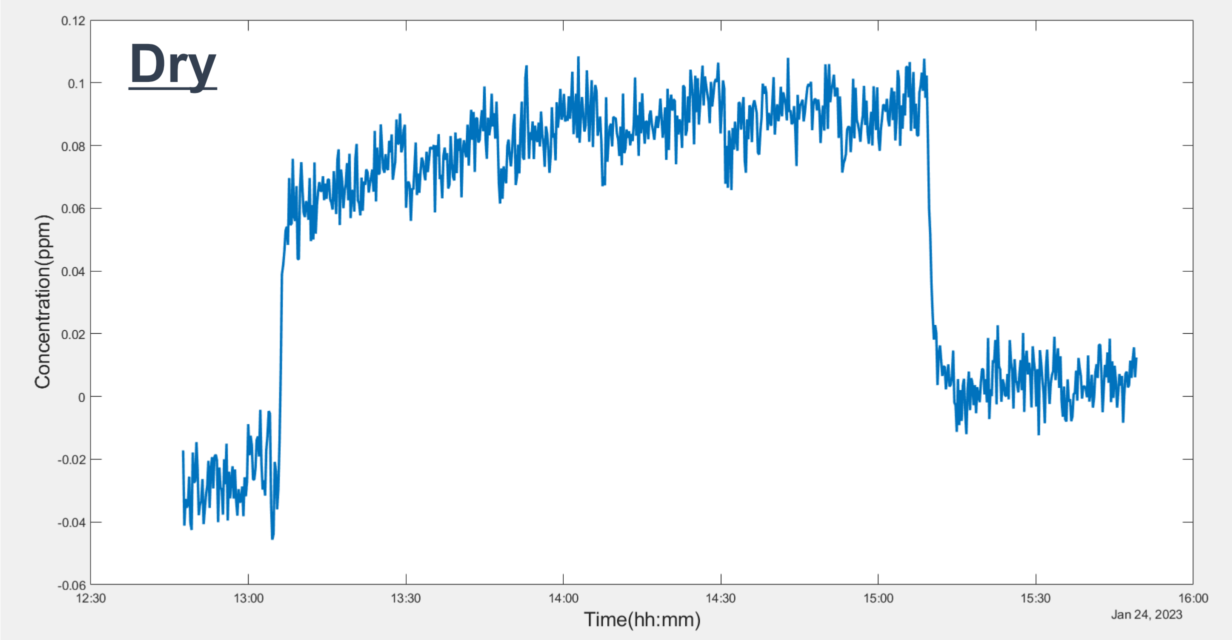


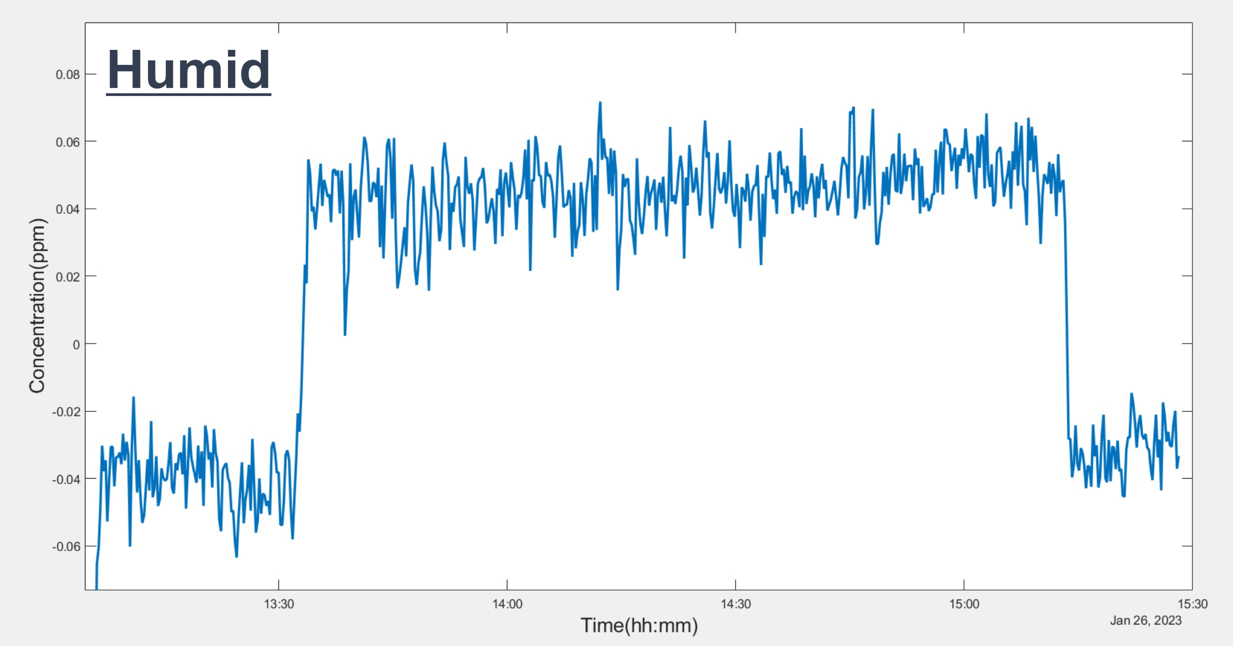
Commercial software analysis



- **Plots show analysis from same experimental data set using APL developed method (left) versus software (right) INJECTION LOCATION DOWNSTREAM OF RUNNING OBOGS**
- **Blue dashed lines indicate when chemical was introduced to bleed air and shut off.**
- **Obtaining much higher signal to noise using APL analysis compared to COTS software**

Acetone at 100 ppb in dry/humid conditions

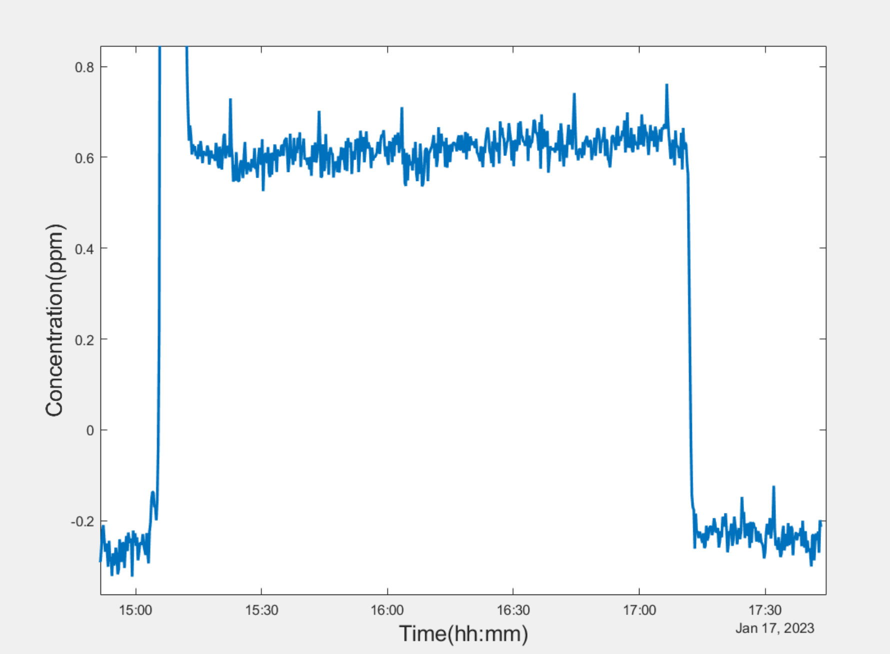




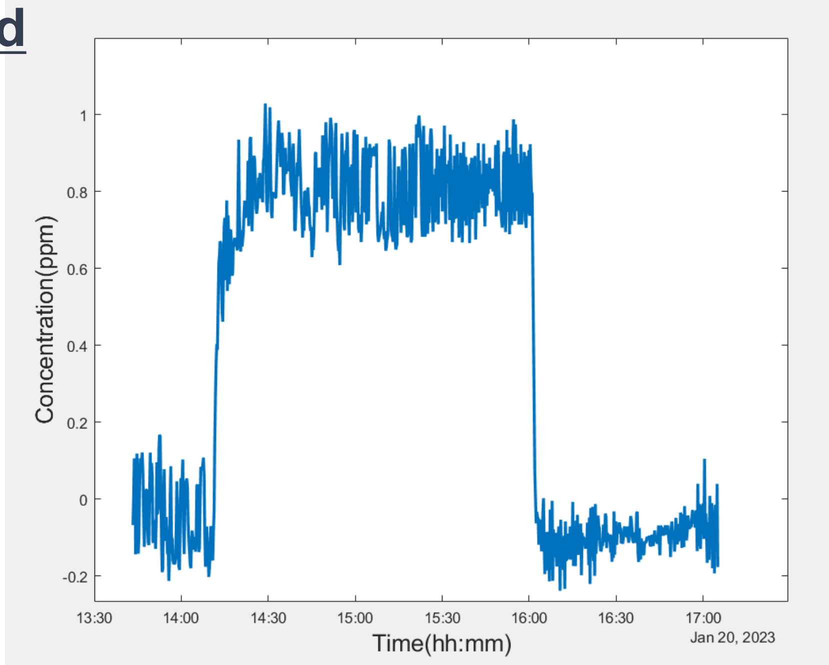
- FTIR instrument and APL analysis able to detect 100 ppb of acetone in dry and humid bleed air
- There is a zero baseline offset for acetone that needs to be taken into consideration.
- After accounting for baseline and cross calibrating, concentrations generated are 113 and 99.7 ppb in dry and humid conditions, respectively.
- Note the standard deviation in the measurement for humid conditions was observed (strongest acetone IR features overlap with water vapor)

Acetaldehyde at 1 ppm in dry/humid conditions

Dry



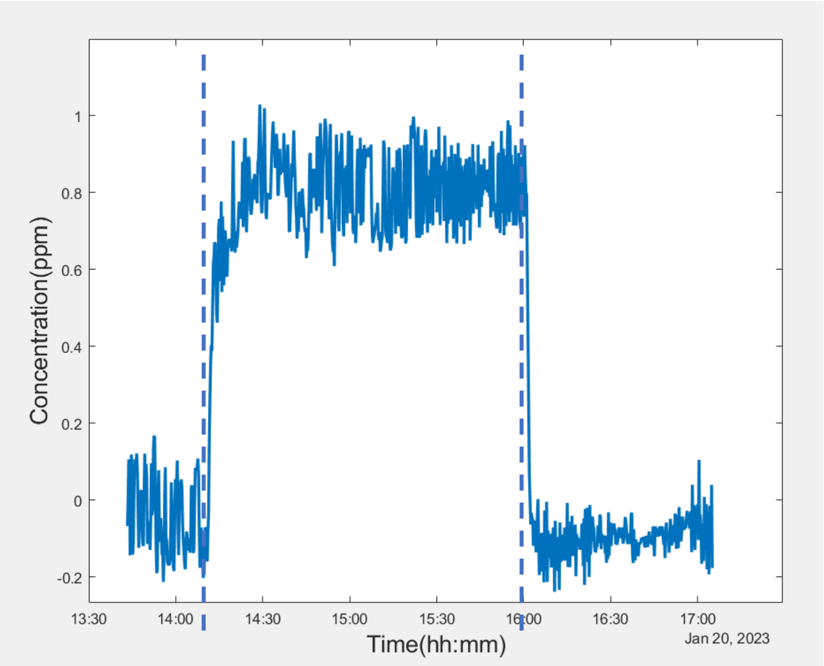
Humid



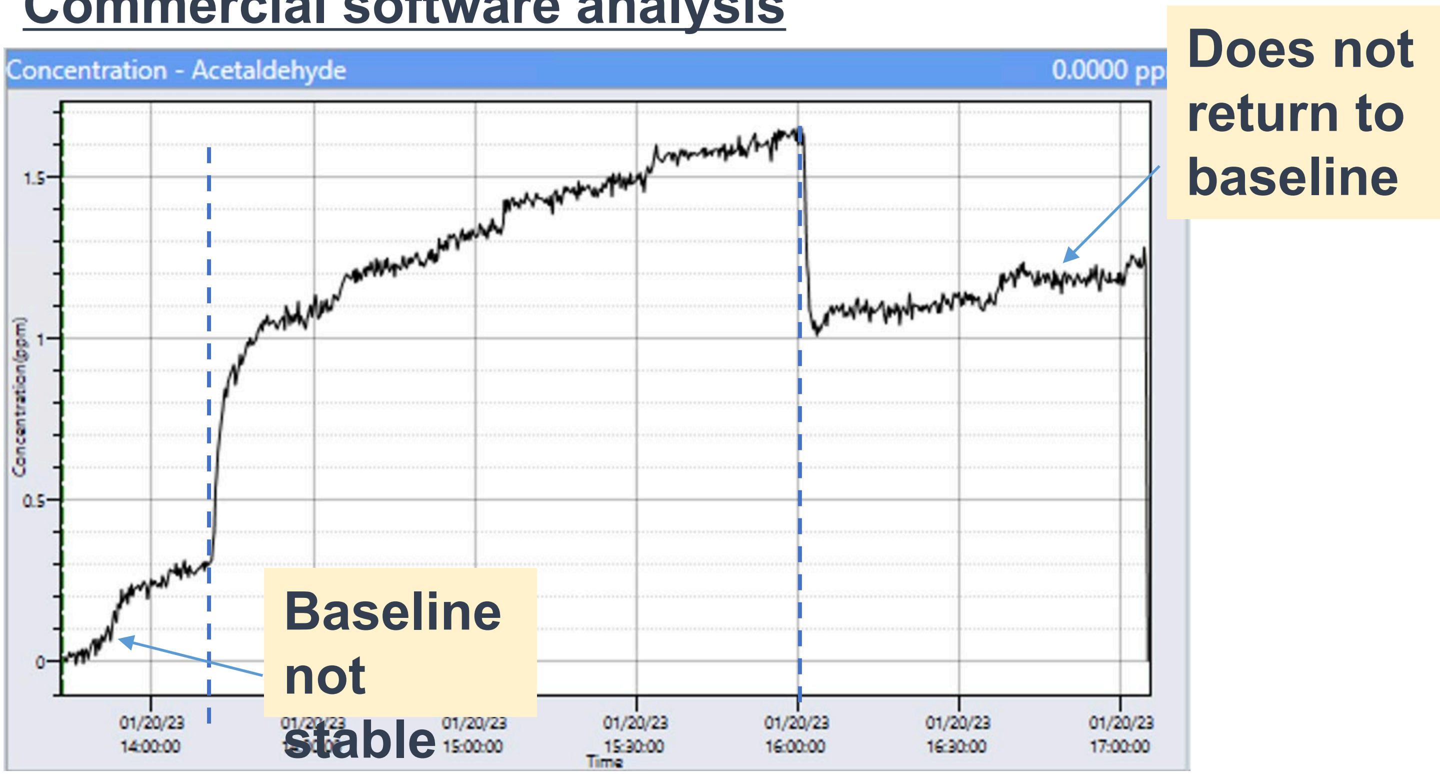
- There is a zero baseline offset (~0.1-0.25 ppm).
- After accounting for baseline and using calibration curve from previous collected data, concentrations generated are 1.03 ppm and 1.04 ppm in dry/humid conditions, respectively.
- Note there was a larger standard deviation in the measurement for humid conditions (strongest acetaldehyde IR features overlap with water vapor)

1 ppm acetaldehyde in humid conditions – APL FTIR analysis compared to commercial software analysis

APL FTIR Analysis



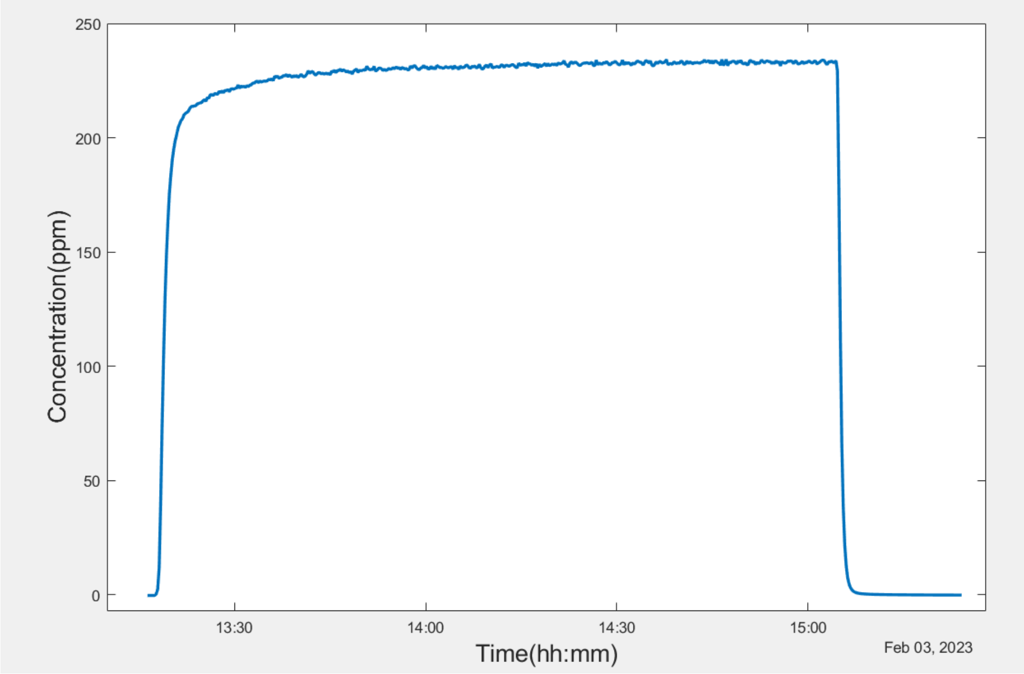
Commercial software analysis



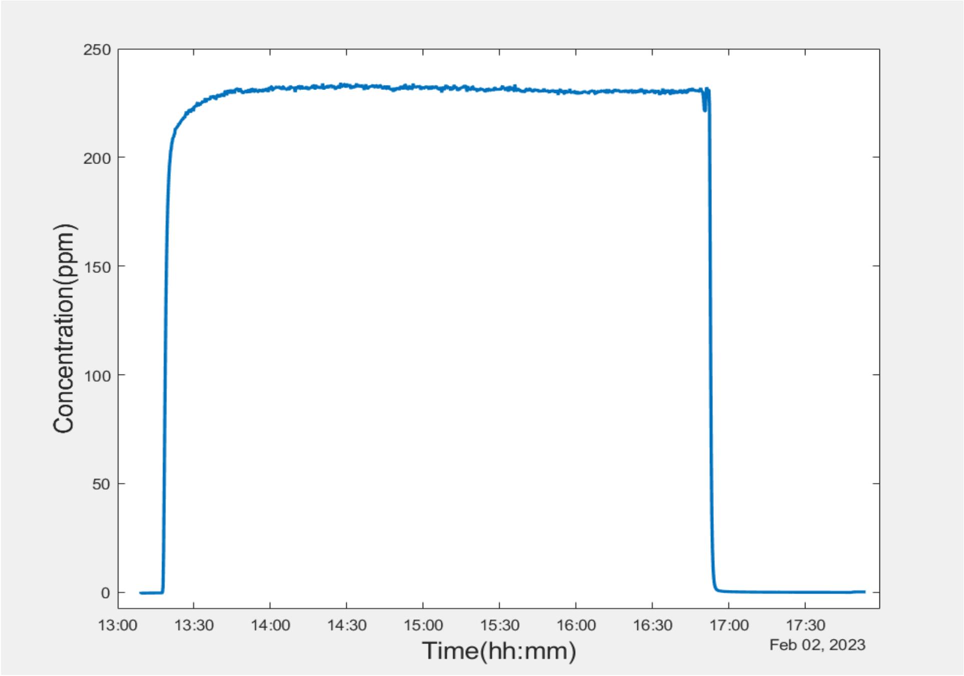
- Plots show analysis from same experimental data set using APL developed method (left) versus commercial software (right)
- Orange dashed lines indicate when chemical was introduced to bleed air and shut off.
- Commercial software real time analysis is not adequate for certain chemicals

HFVG of octane at 250 ppm in dry/humid conditions

Dry



Humid



- Irrespective of humidity, FTIR analysis showed concentration generated was reproducible (within 5 ppm between dry and humid conditions) and was within 8% of target concentration
  - FTIR analysis reading is ~232 ppm in both dry and humid conditions
- Humidity appeared to have little or no impact on vapor generator response time

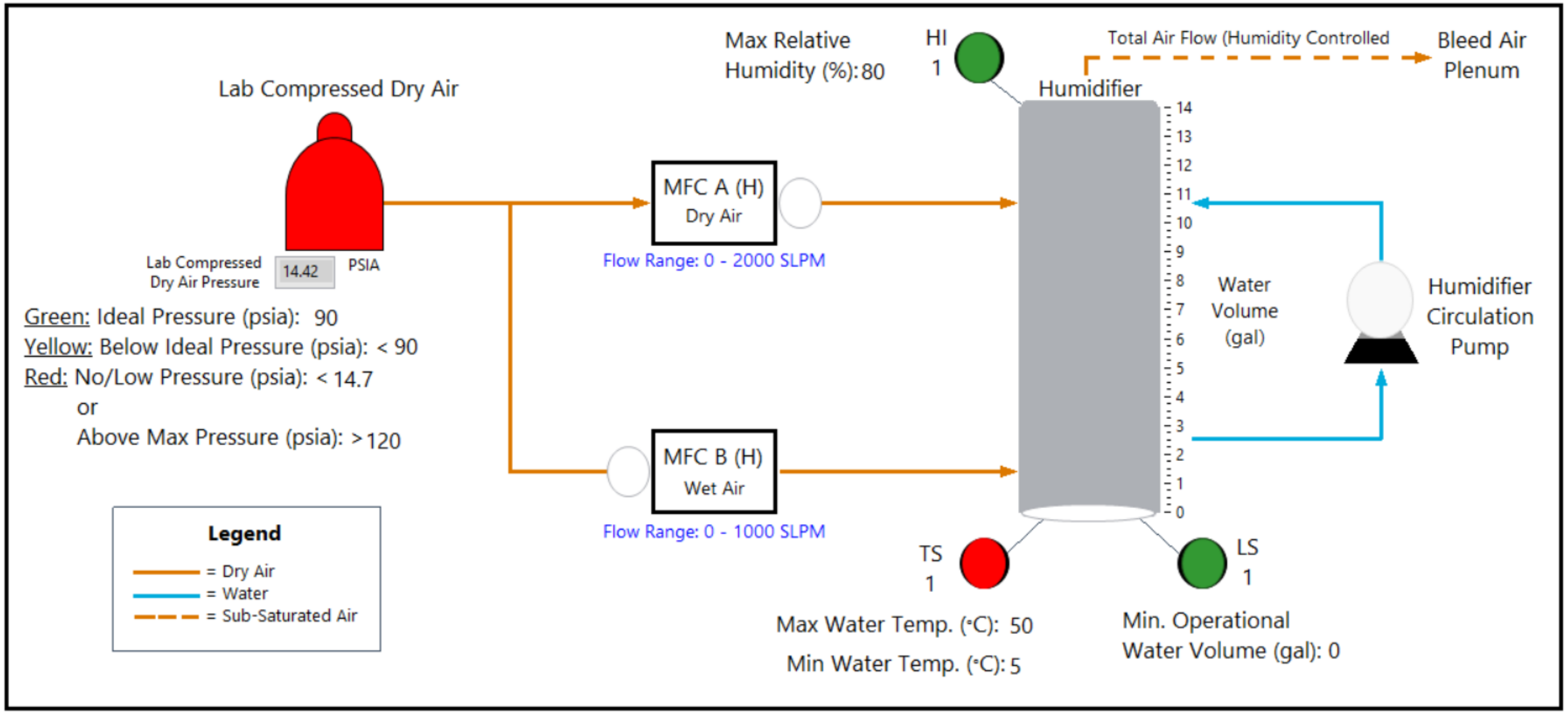
A Look at the Control Software Design and Graphical User Interface (GUI)

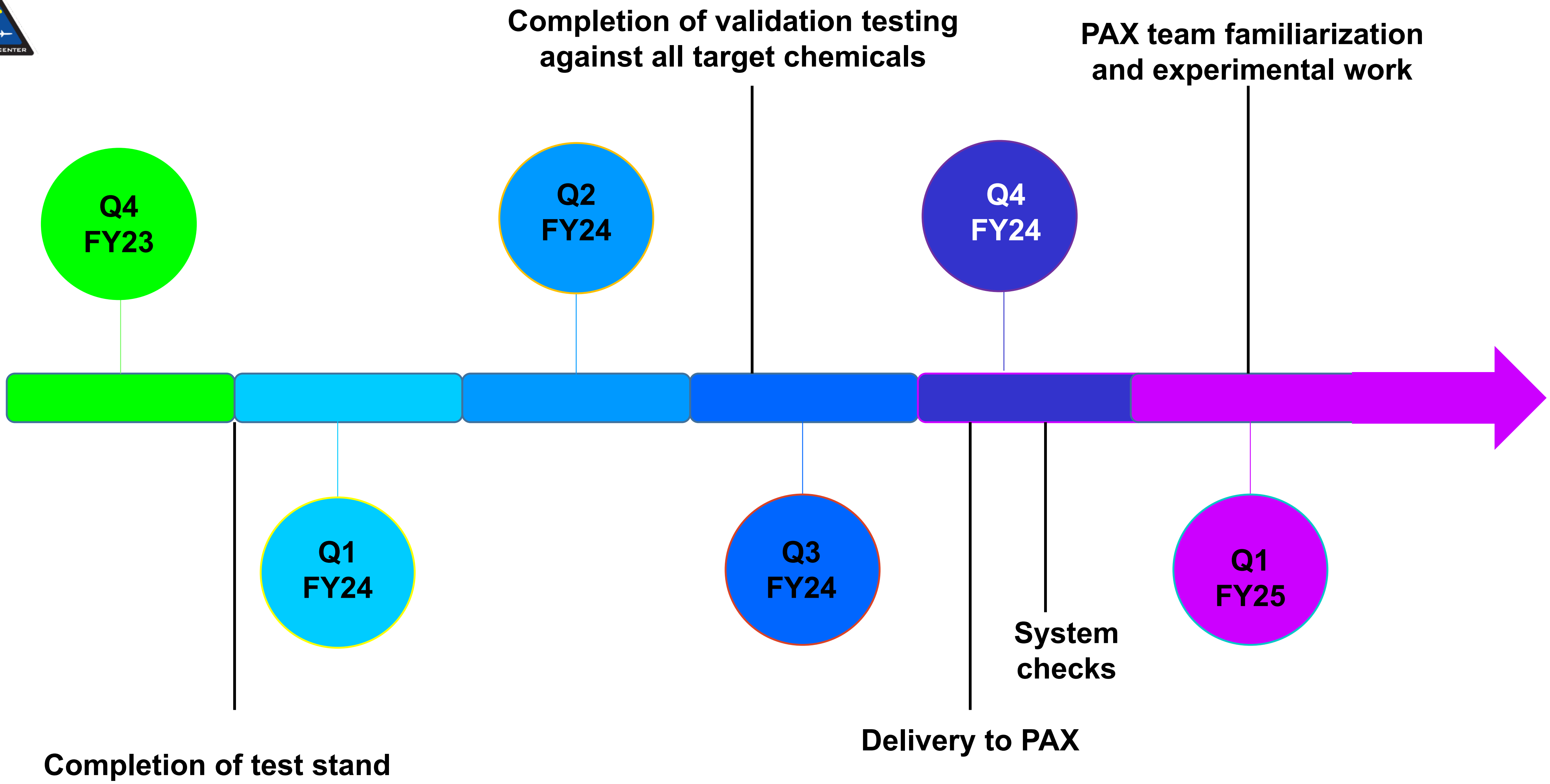
Notifications Tab on GUI

Humidifier

- MFC Mass Flow
- Water Level
- Water Temperature
- Relative Humidity
- Lab Compressed Air

Humidifier subsystem page




Completion of validation testing against all target chemicals
PAX team familiarization and experimental work
Q4 FY23
Q2 FY24
Q4 FY24
Q1 FY24
Q3 FY24
Q1 FY25
System checks
Delivery to PAX
Completion of test stand

Bottom Line In Back (BLIB)

- All components of the test stand are in-hand and initially tested against a subset of target chemicals to address the hardest challenges
  - Low-flow vapor generator
  - High-flow vapor generator
  - Gas-dilution system
  - Ozone generator
  - FTIR gas analyzer
  - Ozone analyzer
- Final completed test stand assembled and functioning by end of fiscal year
  - Software interface
  - Power
  - Control software, etc.
- FY24 goals:
  - Complete all validation testing
  - Deliver test stand to PAX
- FY 25 and beyond: Utilize the test stand for acquisition testing, developmental testing, engineering investigations as needed

Our most sincere thanks to

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- NAWCAD Life Support and Aeromedical Division
- Naval Undergraduate Flight Training Systems Program Office
- NAWCAD HSE Department

- OSCG 2023 attendees

Questions?

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