# A Cabin Air Separator for EVA Oxygen

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**Presently, the Extra-Vehicular Activities (EVAs) conducted from the Quest Joint Airlock on the International Space Station use high pressure, high purity oxygen that is delivered to the Space Station by the Space Shuttle. When the Space Shuttle retires, a new method of delivering high pressure, high purity oxygen to the High Pressure Gas Tanks (HPGTs) is needed. One method is to use a cabin air separator to sweep oxygen from the cabin air, generate a low pressure/high purity oxygen stream, and compress the oxygen with a multistage mechanical compressor. A main advantage to this type of system is that the existing low pressure oxygen supply infrastructure can be used as the source of cabin oxygen. ISS has two water electrolysis systems that deliver low pressure oxygen to the cabin, as well as chlorate candles and compressed gas tanks on cargo vehicles. Each of these systems can feed low pressure oxygen into the cabin, and any low pressure oxygen source can be used as an on-board source of oxygen. Three different oxygen separator systems were evaluated, and a two stage Pressure Swing Adsorption system was selected for reasons of technical maturity. Two different compressor designs were subjected to long term testing, and the compressor with better life performance and more favorable oxygen safety characteristics was selected. These technologies have been used as the basis of a design for a flight system located in Equipment Lock, and taken to Preliminary Design Review level of maturity. This paper describes the Cabin Air Separator for EVA Oxygen (CASEO) concept, describes the separator and compressor technology trades, highlights key technology risks, and describes the flight hardware concept as presented at Preliminary Design Review (PDR).**

## I. Introduction

High pressure, high purity oxygen is essential to the safe conduct of an Extra Vehicular Activity (EVA). EVA's conducted from the Space Shuttle get their oxygen from cryogenic oxygen tanks on the Shuttle vehicle. Currently, EVAs conducted out of the Quest US Joint Airlock get their oxygen from the same Shuttle cryogenic tanks. The shuttle oxygen is transferred to the airlock as a gas (nominally pressure is 800 psi), and compressed to storage pressure (nominally 2400 psi) using the Oxygen Recharge Compressor Assembly (ORCA).

With the end of the shuttle program approaching, the a new method of filling the High Pressure Gas Tanks (HPGTs) must be found. The greatest user of oxygen from the HPGT is EVA. By requirement (and conservative planning assumption) each EVA draws down approximately 25 lbs of oxygen from the HPGT. By historical average, each EVA uses approximately 20 lbs of oxygen. EVA oxygen must be at a pressure of 1200 psi or greater, and it must have an oxygen purity that meets specification SE-S-0073 (oxygen purity >99.5%). In addition to EVA use, there are requirements to have stores of oxygen for emergency medical, and contingency oxygen for metabolic consumption. Small amounts of oxygen are used by the Water Processor Assembly (WPA), and Oxygen Generator Assembly (OGA). Any method of delivering high pressure high purity oxygen must meet the needs of each of these users.

CASEO takes advantage of existing methods of delivering low pressure oxygen intended for metabolic consumption. CASEO does not make oxygen, it takes a low pressure, low purity oxygen product from the cabin atmosphere, purifies it, compresses it, and transfers it into the HPGT. Once HPGT #2 is filled, a sample is taken, delivered to ground, and analyzed for purity. The CASEO traffic model is shown in Figure 1.

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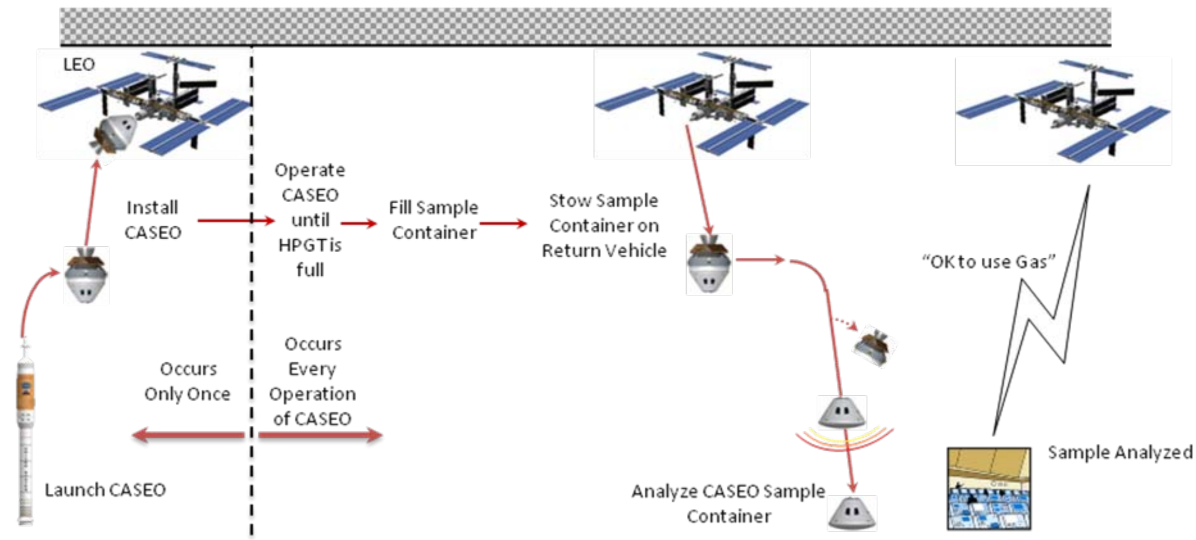



Figure 1: CASEO Traffic Model

## A. The CASEO Concept

The CASEO flight concept consists of three major elements: a separator module, an electronics module, and a compressor module. These three modules are launched separately, connected on orbit, and attached to a seat track in the airlock, in a location similar to the current location of the ORCA. After shuttle retirement, the ORCA will have no gaseous oxygen to compress, so the ORCA will no longer be used. ORCA cannot be used for CASEO because ORCA requires 800 psig inlet pressure, and the CASEO separator module produces oxygen with a pressure of less than 30 psig.

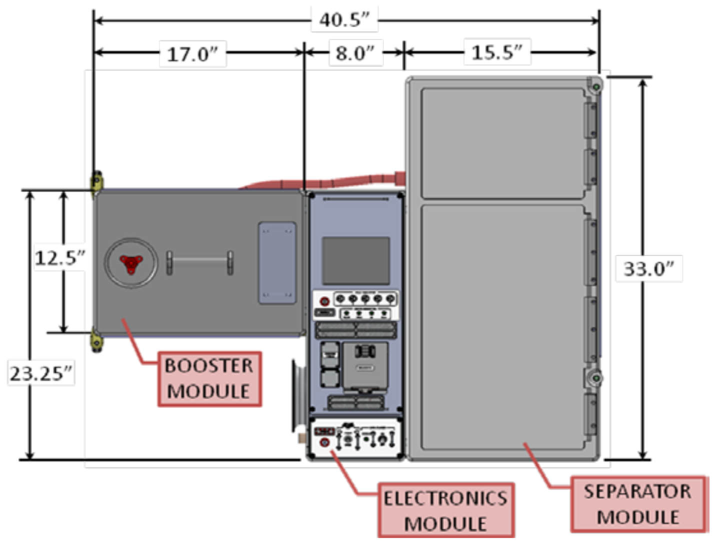



Figure 2: CASEO Component Layout

## B. Description of Booster Module

The Booster Module is a modified form of a three stage mechanical piston compressor supplied by Cobham Inc. It was originally designed for military medical oxygen applications. The major modifications are to use a DC powered flight compatible motor, and to add a return spring on the first stage inlet so the pump can receive oxygen product at low pressures. Without the spring modification, the inlet oxygen needs to have pressure of 15 psig or greater. Supplying oxygen at >15psig causes separator performance to suffer.

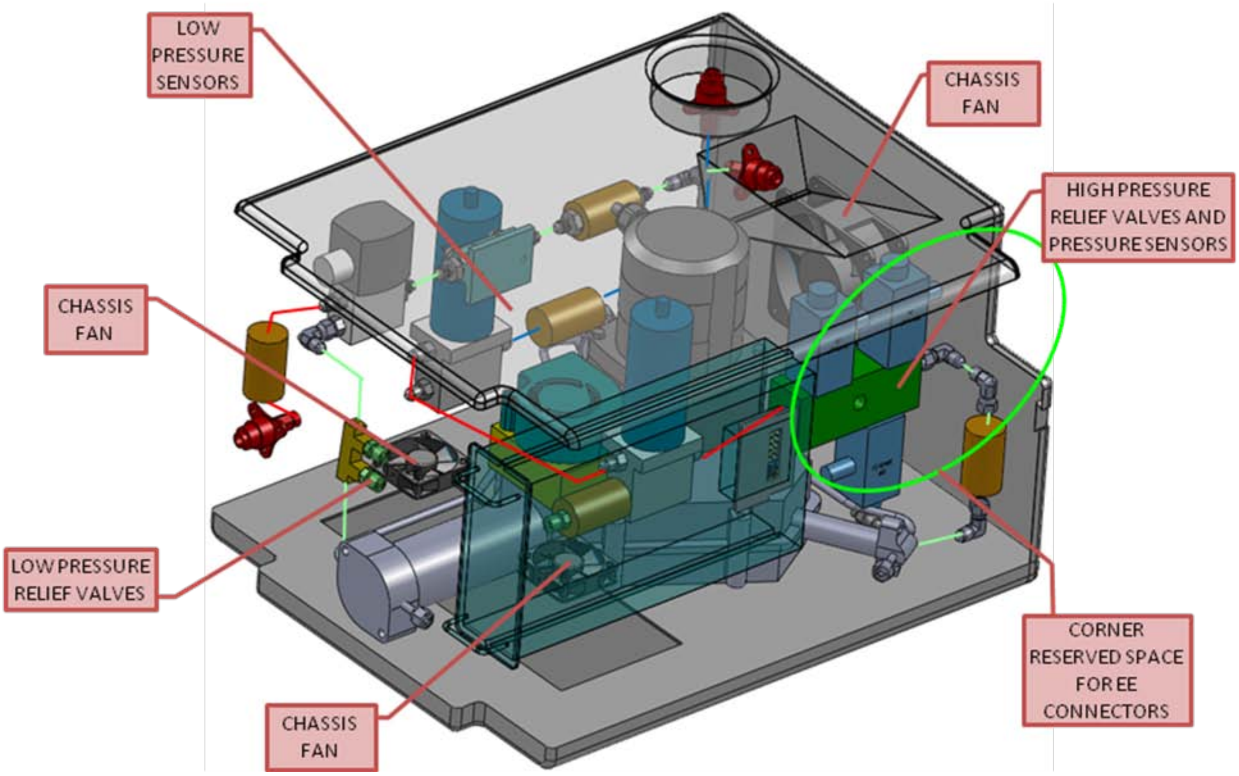



Figure 3 Layout of the Compressor Module

An earlier prototype of the Cobham compressor was tested with oxygen, 15 psi inlet pressure and outlet pressure that varied from 1000 psi to 3000 psi at a rate that matched HPGT tank fill conditions. The test was stopped at 5000 hours, and the unit was disassembled and inspected. The inspection indicated the compressor was capable of operating for a longer duration.

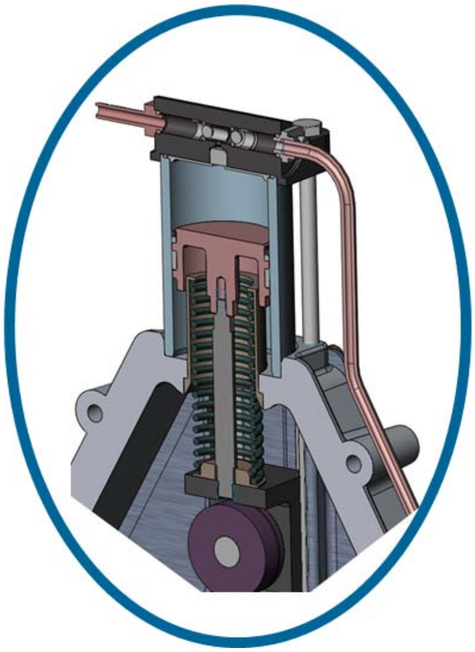


Figure 4  Detail of Modification to Add the 1st Stage Spring

Figure 4

**C.  Description of the Electronics Module**

The electronics module consists of 4 sub modules, and a cooling, data, power, and oxygen pass through.  The components are selected for radiation hardness when possible.  The CPU is modified to include an external circuit to make it fault tolerant for single event upsets.  The circuit protection is done at low voltages to allow for smaller gauge wires to be safely used.  The circuit protection is done with fast reacting devices.  The CASEO circuit protection has a faster response time than the ISS vehicle power supply interface.  All circuits are designed to withstand power spikes for a duration of 10 times longer than the response time of the circuit breaking devices.

CASEO can safely operate as a stand alone device.  It needs no command from ISS, and it does not need any data from the vehicle.  It has two methods of transferring data to the ground: one through a wired Ethernet and one through a portable USB device

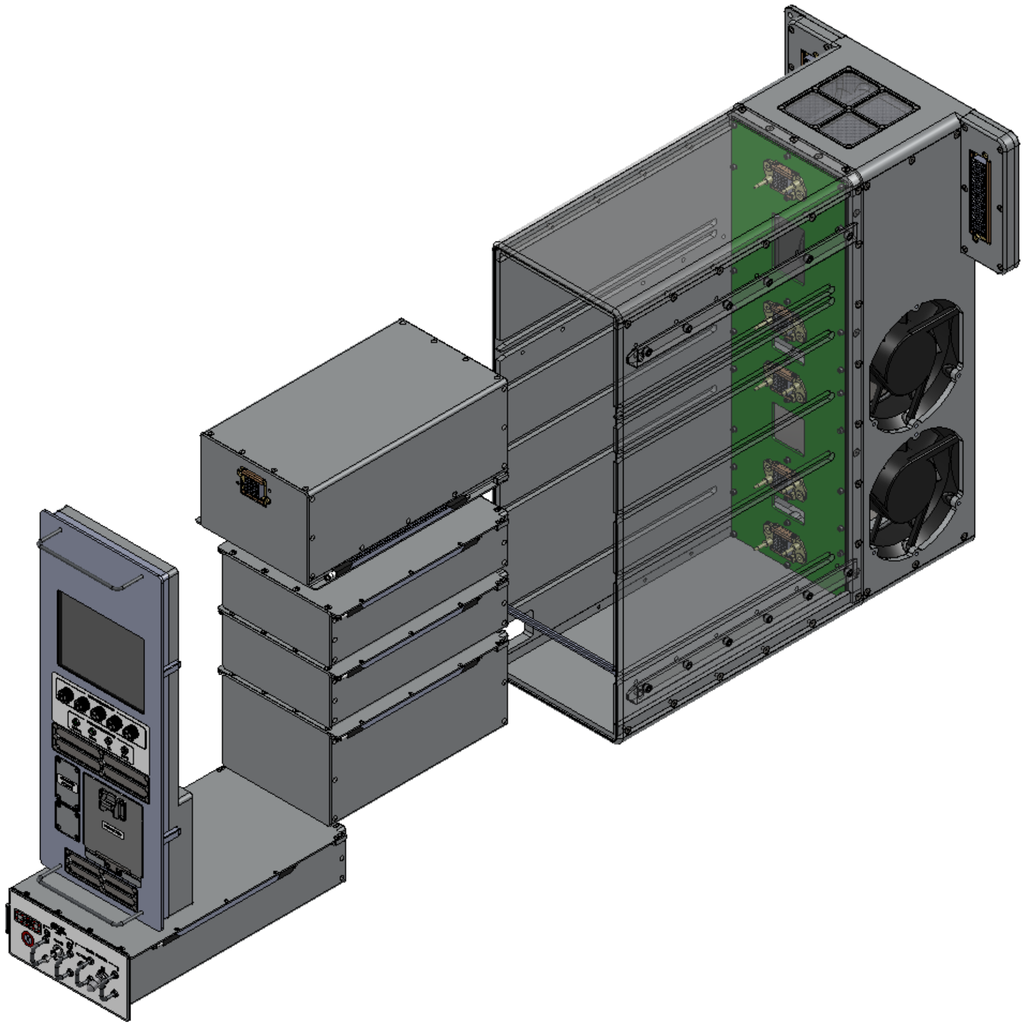


Figure5: Electronics Module Configuration

**D. Description of the Separator Module**

The oxygen separator is a two stage device that uses pressure swing adsorption as the method of oxygen separation. The separator module uses a compressor to compress cabin air to a pressure of 100psi. When compressed, two different humidity control devices dry the air to -50 degree F dewpoint conditions. The first dryer is a membrane dryer, the second drier is a pressure swing adsorption drier that uses silica gel and type 13X zeolite.

The first stage of the separator removes nitrogen from cabin air, and delivers a product that is nominally 95.5% oxygen, 4.3% argon, and 0.2% nitrogen.

The second stage of the separator uses carbon molecular sieve material to remove the argon from the first stage product. This separation step uses kinetic separation processes described in detail in references 1, 2, 3, and 4. The expected recovery efficiency is approximately 7%, amounting to a 0.5 liter per minute delivery rate. The nominal composition of the product gas is 99.6% oxygen, 0.2% argon, and 0.2% nitrogen.

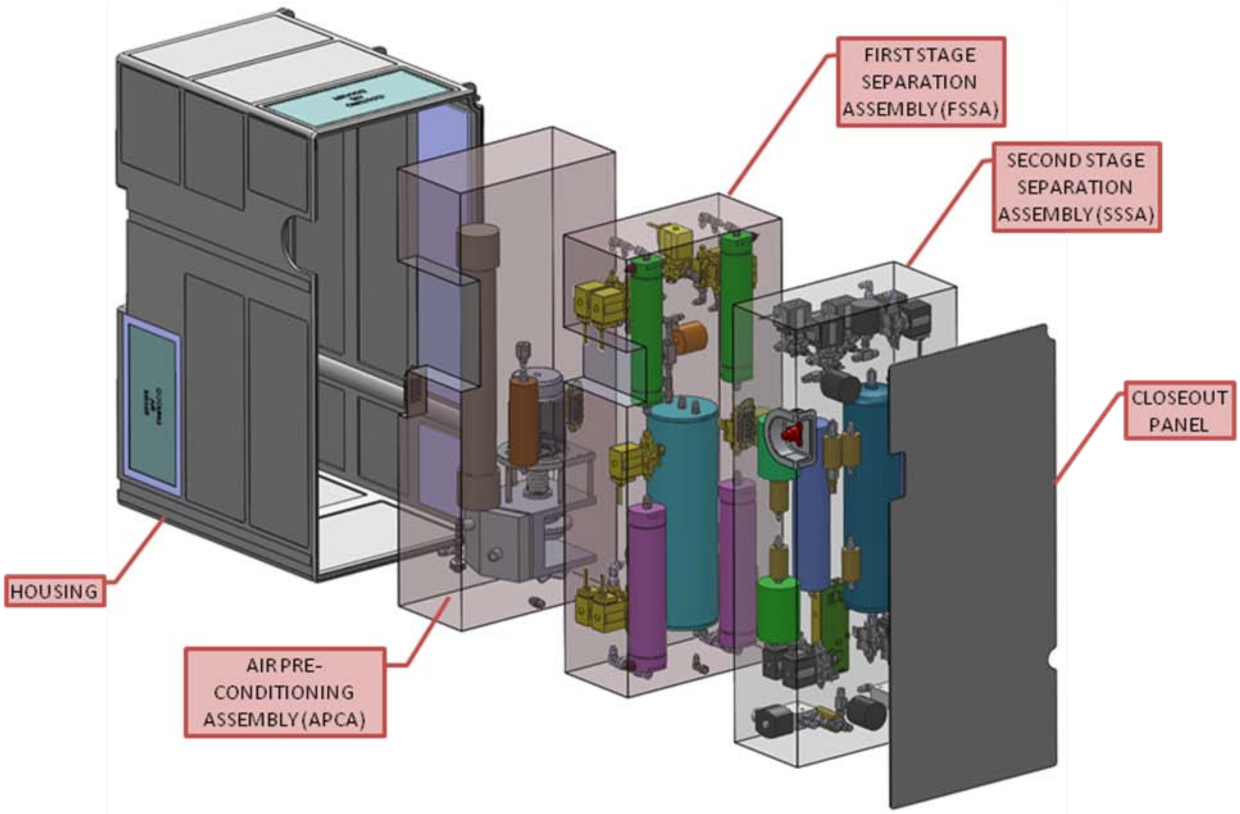



Figure6: Packaging Concept of the Separator Module

## II. Significant CASEO Development Issues

### A. Oxygen Purity

Oxygen Purity varies as a function of temperature, pressure, delivery rate, argon content in the ISS cabin air, oxygen content in the cabin air, and gas velocity in the separator beds. Current testing indicates that 99.5% oxygen purity is possible if delivery rate is 0.5 liters per minute or less. The key to oxygen purity is the design of the second stage. The second stage configuration is shown in the figure below:

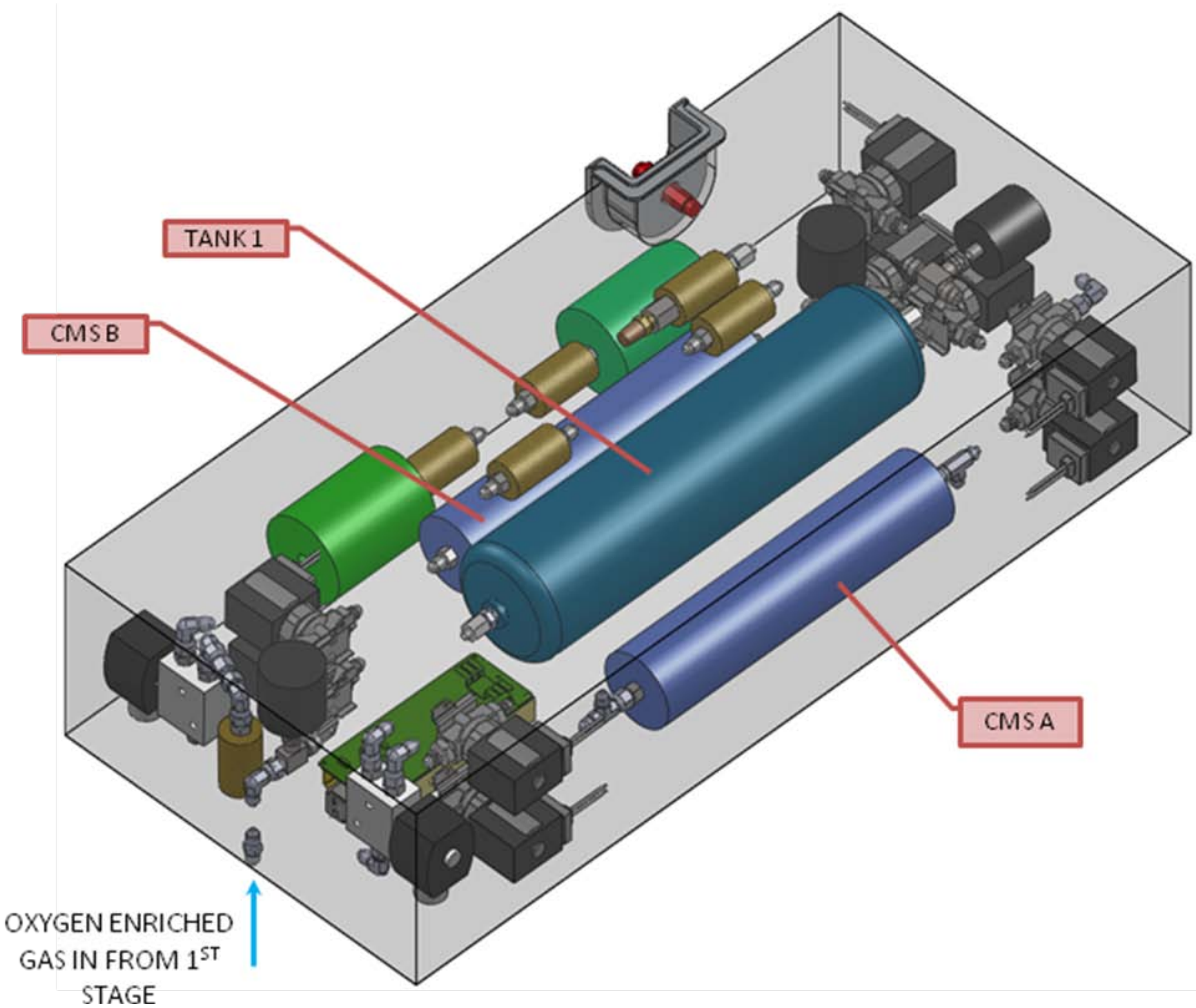
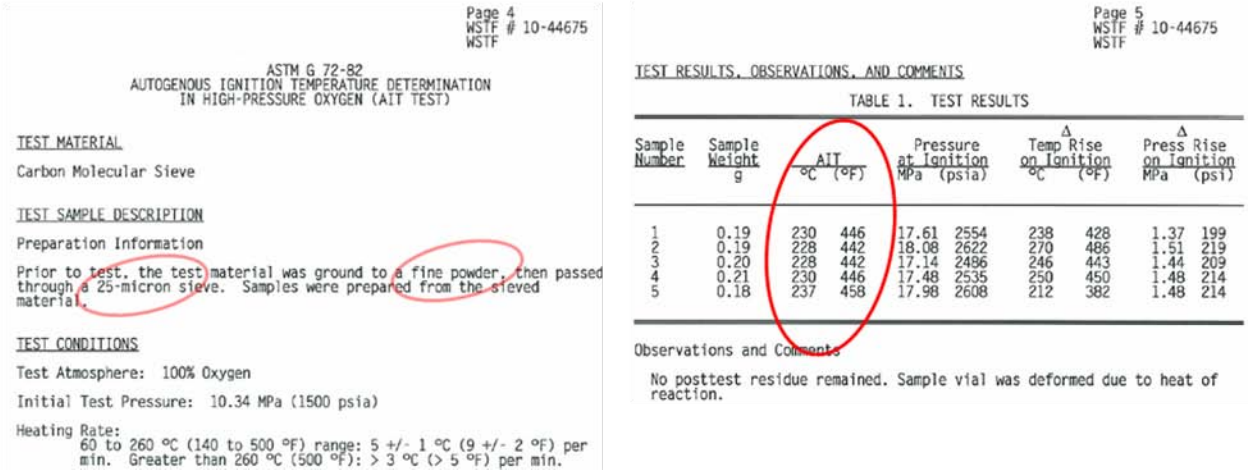


Figure7:  Second Stage Configuration

### B.  Generation of Flammable Dust

The second stage of the separator uses Carbon Molecular Sieve material.  Flammability properties were measured at WSTF.  They are shown in the figure below:



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WSTF # 10-44675
WSTF

ASTM G 72-82
AUTOGENOUS IGNITION TEMPERATURE DETERMINATION
IN HIGH-PRESSURE OXYGEN (AIT TEST)

TEST MATERIAL

Carbon Molecular Sieve

TEST SAMPLE DESCRIPTION

Preparation Information

Prior to test, the test material was ground to a fine powder, then passed through a 25-micron sieve. Samples were prepared from the sieved material.

TEST CONDITIONS

Test Atmosphere: 100% Oxygen

Initial Test Pressure: 10.34 MPa (1500 psia)

Heating Rate:
60 to 260 °C (140 to 500 °F) range: 5 +/- 1 °C (9 +/- 2 °F) per min. Greater than 260 °C (500 °F): > 3 °C (> 5 °F) per min.

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WSTF

TEST RESULTS, OBSERVATIONS, AND COMMENTS

TABLE 1. TEST RESULTS

| Sample Number | Sample Weight g | AIT °C | AIT (°F) | Pressure at Ignition MPa | Pressure at Ignition (psia) | Δ Temp Rise on Ignition °C | Δ Temp Rise on Ignition (°F) | Δ Press Rise on Ignition MPa | Δ Press Rise on Ignition (psi) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.19 | 230 | 446 | 17.61 | 2554 | 238 | 428 | 1.37 | 199 |
| 2 | 0.19 | 228 | 442 | 18.08 | 2622 | 270 | 486 | 1.51 | 219 |
| 3 | 0.20 | 228 | 442 | 17.14 | 2486 | 246 | 443 | 1.44 | 209 |
| 4 | 0.21 | 230 | 446 | 17.48 | 2535 | 250 | 450 | 1.48 | 214 |
| 5 | 0.18 | 237 | 458 | 17.98 | 2608 | 212 | 382 | 1.48 | 214 |

Observations and Comments

No posttest residue remained. Sample vial was deformed due to heat of reaction.

Figure 8: CMS Compatibility Assessment Results

The key to dust control is proper filtration. The filtration diagram below demonstrates that the CMS fines are filtered from the rest of the system, and from downstream oxygen systems:

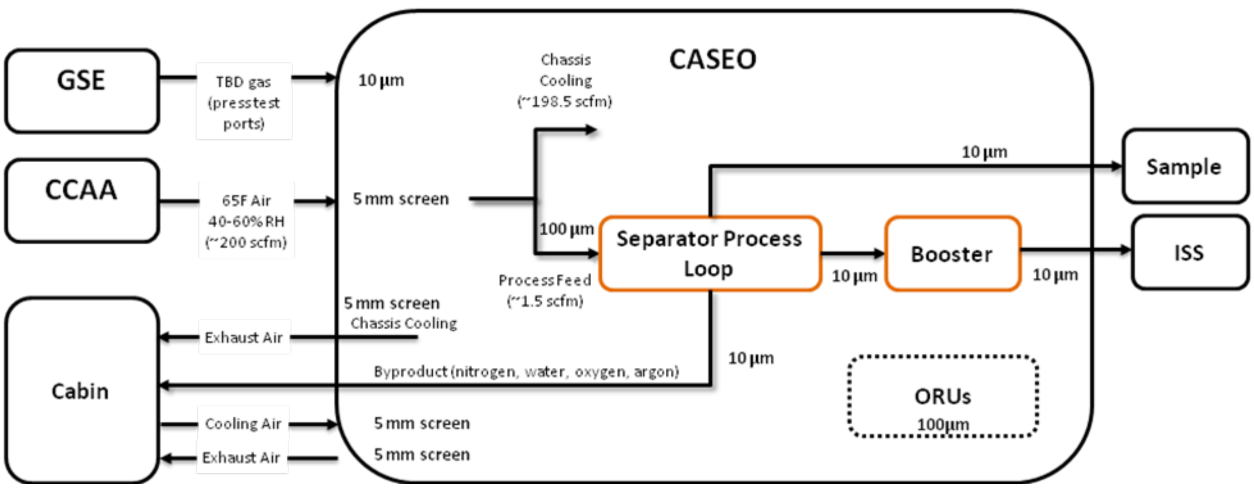


Figure 9: Filtering Diagram

### C. Noise Generation

The use of two compressors, one to compress the oxygen and one to energize the oxygen separator unit, leads to significant noise generation issues. The compressor requirements are such that every available technology produces noise. This is not an issue that can be avoided. It can be mitigated through the use of vibration isolation devices, acoustic shroud material, mufflers, and gas inlet noise exclusion devices. Of all of the acoustic treatments, the inlet noise exclusion device is the most effective and the most significant.

A figure of one candidate inlet noise exclusion device is shown.

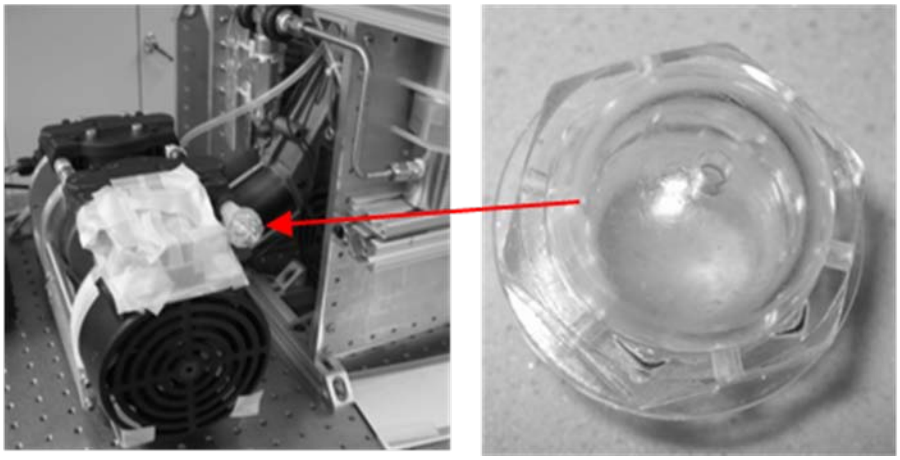

Figure10:  One Candidate Noise Exclusion Device

## III.   Conclusion

The CASEO project team has completed a PDR level design using a two stage pressure swing adsorber, a modular flight system with three main components, and a three stage mechanical piston compressor.  The project team will continue flight hardware development, with a goal of delivering the first flight system in January 2013.

## References


[1]Lee, S.J.; Jung, J.H.; Moon, J.H.; Jee, J.G.; Lee, C.H.  Parametric study of the three pressure-vacuum swing adsorption process for high purity O2 generation from ambient air.  *Ind. Eng. Chem, Res.*, 46, 3720, 2007.

[2]Knaebel K.S.; Kandybin A. Pressure swing adsorption system to purify oxygen.  U.S. Patent 5,226,933, 1993.

[3]Hayashi, S.; Kawai, M.; Kaneko, T. Dynamics of high purity oxygen PSA.  *Gas Sep. Purif*., 10, 19, 1996.

[4]Rege, S.U.; Yang, R.T. Kinetic separation of oxygen and argon using molecular sieve carbon.  *Adsorption,* 6,15,2000.