Aero Companies

International Aircraft Fire & Cabin Safety Research Conference
24 October 2001

On-Board Ground Inerting (OBGI) Systems For Transport Category Aircraft

Presented by
Phil Jones
Shaw Aero Devices
Member - ARAC On-Board Team

Introduction

The On-Board Ground Inerting System (OBGI) is one of four main system categories studied by the 2000 ARAC FTIHWG Onboard Airplane Design Task Team. The Onboard team derived a system architecture and studied the system size for a variety of "modeled" aircraft center wing and auxiliary fuel tanks. In addition, the Team performed additional analysis, in excess of the Tasking Statement's requirements, by determining the system size for all fuel tanks. The team also defined the physical size and weight of the multitude of components needed to support OBGI. Finally, power and air consumption needs were defined.

Aero Companies

Requirements

- **Oxygen Concentration at Pushback.**
  - **All applicable fuel tank ullage volumes are to have an oxygen concentration of 10% maximum before the aircraft is pushed back from the gate. This requirement allowed a direct comparison with the ground based inerting design concept.**
- **Nitrogen as Inerting Agent.**
  - **As required by the tasking statement, the Team only considered on-board nitrogen gas inerting equipment.**
- **Equipment Location.**
  - **All equipment needed to inert the aircraft is installed on the airframe, except for diagnostic equipment.**
- **Redundancy.**
  - **The tasking statement encouraged a simple system with little or no redundancy.**

Aero Companies

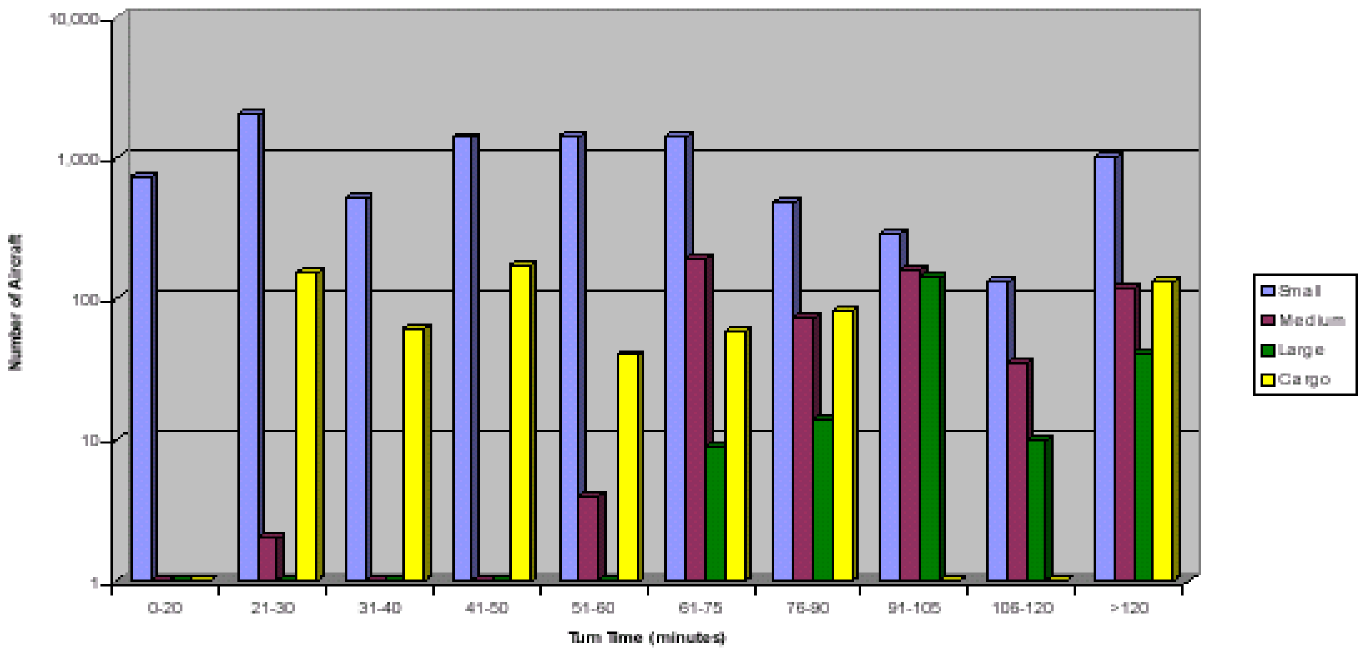
Turn Around Times

- **The mission scenarios that were used in the July 1998 ARAC Fuel Tank Harmonization Working Group Report had turn times listed for the various aircraft. The turn times can be seen summarized in Figure below:**

Generic Aircraft	Pre-flight Time (Minutes)
Turbofan	20
Turboprop	20
Business Jet	45
Small	45
Medium	60
Large	90

Turn Around Times

To ensure the turn times being used were representative of the aircraft in service today, a survey was conducted of several major airlines. They were asked to supply the times that they were currently using as part of their normal operations today. Airlines that responded to the survey were Airborne, Aloha, America West, British Airways, Continental, Delta, Northwest, Southwest, UPS, and Virgin. A summary of the data collected can be seen in Figure below:



Aero Companies

Turn Around Times

- **The Team made the decision to modify the Aircraft turn times to the values seen in the figure below. These values were used in the sizing of the components for the various OBGI systems because the working group concluded that they were representative of the in-service fleet.**

Generic Aircraft	Turn Time (Minutes)
Turbofan	15
Turboprop	15
Business Jet	60
Small	20
Medium	45
Large	60

Assumptions

- **Initial Oxygen Concentration.**
  - **The starting oxygen content in the ullage is always 20.9%.**
- **Hydraulic Power Availability.**
  - **The team assumed that hydraulic power to operate OBGI equipment was not available while the aircraft was on the ground. To use hydraulic power it would be necessary to upgrade the existing on-board systems. This would in many cases be costly and difficult.**
- **Electrical Power Available From the Aircraft Gate.**
  - **The team assumed that sufficient ground power could be made available to operate an OBGI system. This power could be made available from either a ground cart or from a connection made directly to the terminal electrical system. This would allow the on-board system to operate on the ground without either the APU or aircraft engines operating.**

SHAW
Aero Companies

Assumptions

- **Electrical Power Available From Aircraft Sources.**
  - **The team assumed for the design that sufficient aircraft power could be made available to operate an OBGI system. This would allow the on-board system to operate on the ground with either the APU or aircraft engines operating. This source of power would be used when gate power is not available.**
- **Compressed Air.**
  - **The availability of aircraft bleed air was assumed not to be available at all times because some local laws prohibit engine or APU operation at the gate. The assumption was made that an alternate source of compressed air was required.**
- **Vent Systems Modifications.**
  - **It was assumed that necessary vent system modifications will be made to prevent cross-venting during crosswind conditions.**

Aero Companies

Other Assumptions

- System must have no effect on turn time
- System must be practical with today's technology
- Equipment must fit in space available on most current aircraft
- The net change in safety parameters must be positive
- Failure of equipment must not cause a hazard which would cause loss of life or loss of an aircraft
- Equipment should not require resources (power etc.) which would cause a major system redesign on current aircraft
- Additional environmental emissions are acceptable to environmental authorities
- Single failure of a critical system component must be detectable
- System to be depot-level maintainable by the use of LRU's of manageable size

SHAW Aero Companies

Concept Development

- The main objective was to define system parameters, such as cost, weight, performance and size, for comparison purposes with OBIGGS systems and ground-based systems.
- System effectiveness was predicted using FAA-supplied flammability exposure computer models, which were also used by both the OBIGGS and ground-based teams.
- Define a system that would minimize the impact and required changes for retrofit to existing aircraft and provide optimum efficiency for new aircraft designs.
- Issues included on-board resources available to operate the system, available space, weight, cost, and necessary aircraft modifications.
- System efficiency, safety and failure protection were major considerations: addition of components to the system.

Aero Companies

Concept Development

- **The most crucial issue was the power available to run the system:**
  - **On-board power is available on aircraft in several forms**
    - **Pressurized air**
    - **Hydraulic power**
    - **Electricity.**
  - **Each of the available air separation module (ASM) technologies requires that pressurized air be supplied to the ASM.**
  - **System is required to convert the available power to airflow at an elevated pressure for delivery to the ASM and subsequent NEA delivery to the fuel tanks.**

SHAW
Aero Companies

Characteristics

- **Pressurized Air Supply**
  - **Several ASM supply sources considered. Air pressurized to the outlet pressure of APU allowing system operation when primary air source is not available. A three-to-one (3:1) pressure ratio was chosen to match the most common APU compressor ratio.**
- **Compressor and electric motor technologies:**
  - **Screw-type, positive displacement**
  - **Vane-type, positive displacement**
  - **Piston, positive displacement**
  - **Rotor dynamic (Radial, mixed flow, axial)**
  - **Free piston (diesel) engine**
  - **Three-phase induction motor**
  - **Brushless DC motors**
  - **Switched reluctance motors**

Aero Companies

Characteristics

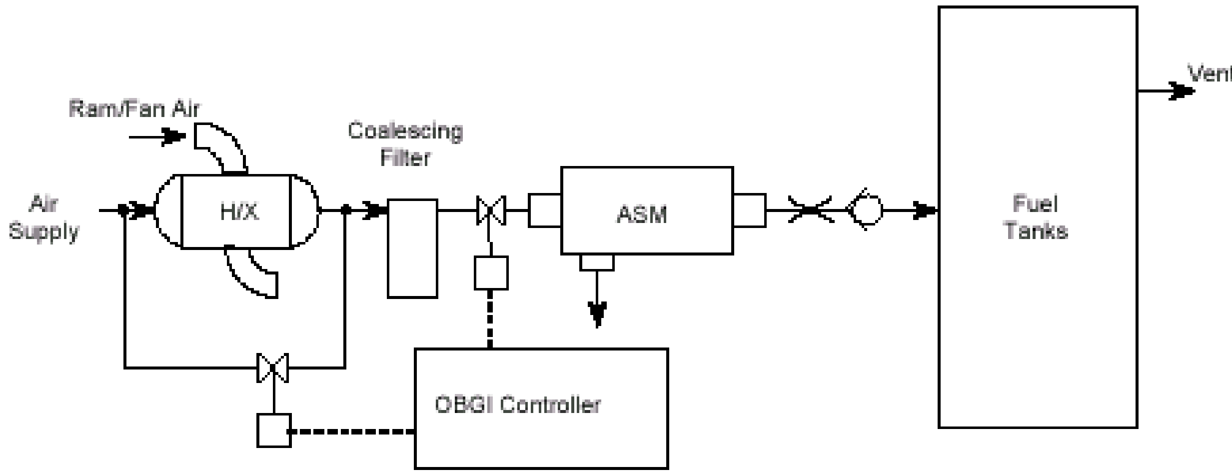
- **Preconditioning:**
  - Equipment was required to ensure that the air supplied to the ASM is cooled and filtered; includes heat exchanger with cooling fan and a coalescing filter.
- **Air Separation:**
  - Technologies: membrane, pressure swing adsorption (PSA), and cryogenic distillation - operate at differing levels of efficiency, require different amounts of pressurized air for a given condition. NEA flow defined by tank size and time available.
- **Distribution.**
  - Ensure delivery and adequate mixing - not be significantly affected by the choice of ASM technology.
- **Control.**
  - Signals to operate the compressor, cooling system, and valves - not be significantly affected by the choice of ASM technology.

Aero Companies

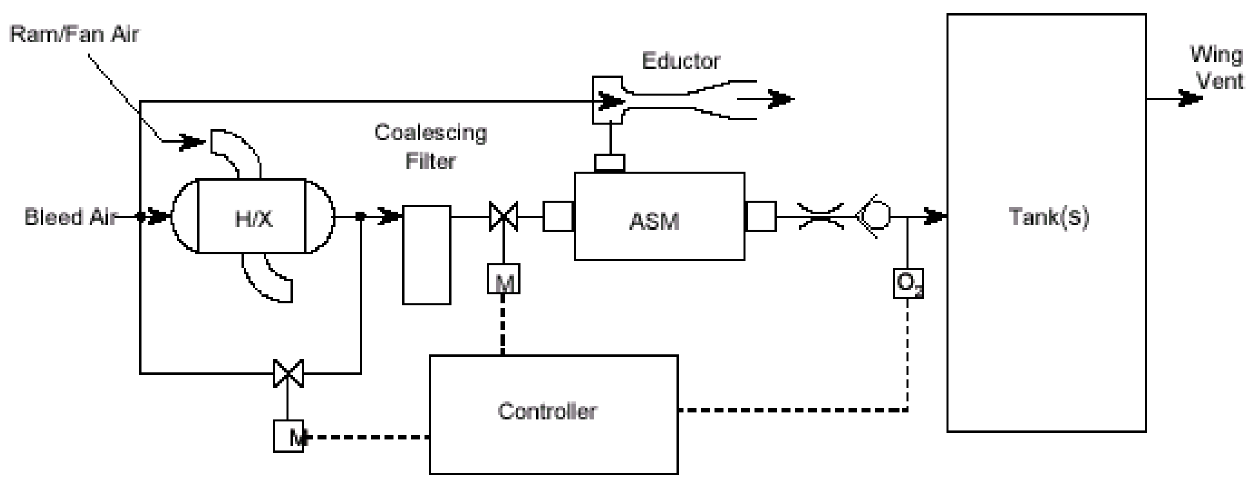
Concept Development

- **Concepts Evaluated:**
  - **Concept 1: baseline concept.**
  - **Concepts 2 through 6 are similar with variations to the bleed air source.**
  - **Concept 7: improved ASM efficiency is achieved by applying vacuum to the ASM waste port with an OEA eductor.**
  - **Concept 8: bleed air is used to assist an ullage gas recirculation system, which draws air from the tank and flows it through the ASM and back to tank.**
  - **Concept 9: similar to Concept 8 except bleed air is not used to assist the recirculated flow.**
- **All concepts require conditioning by a heat exchanger and a coalescing filter for temperature control and to remove free water. Controller regulates the air supply temperature and to the ASM for purity of NEA.**

Concept Development



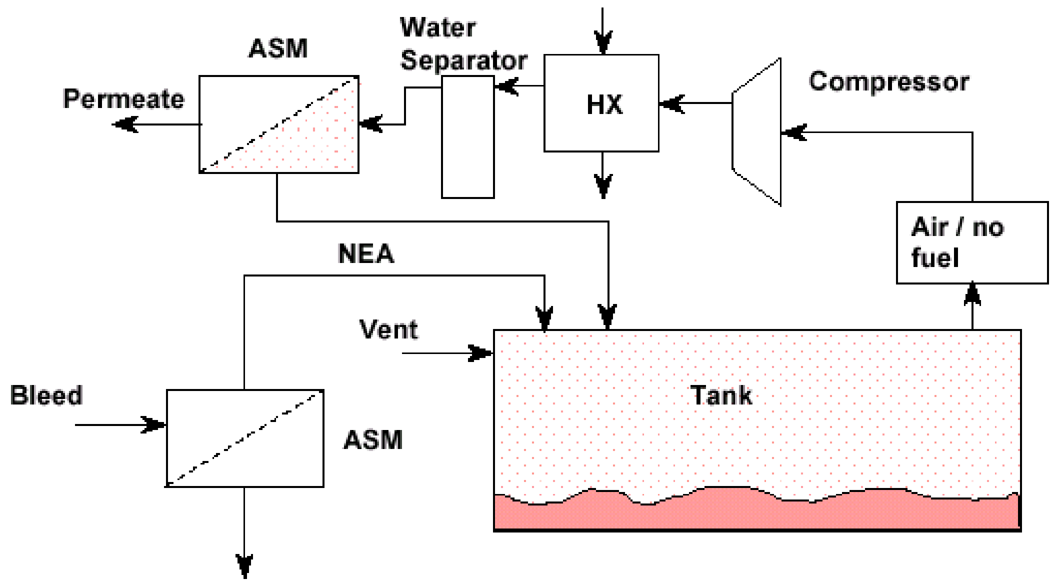
Concepts 1 - 6



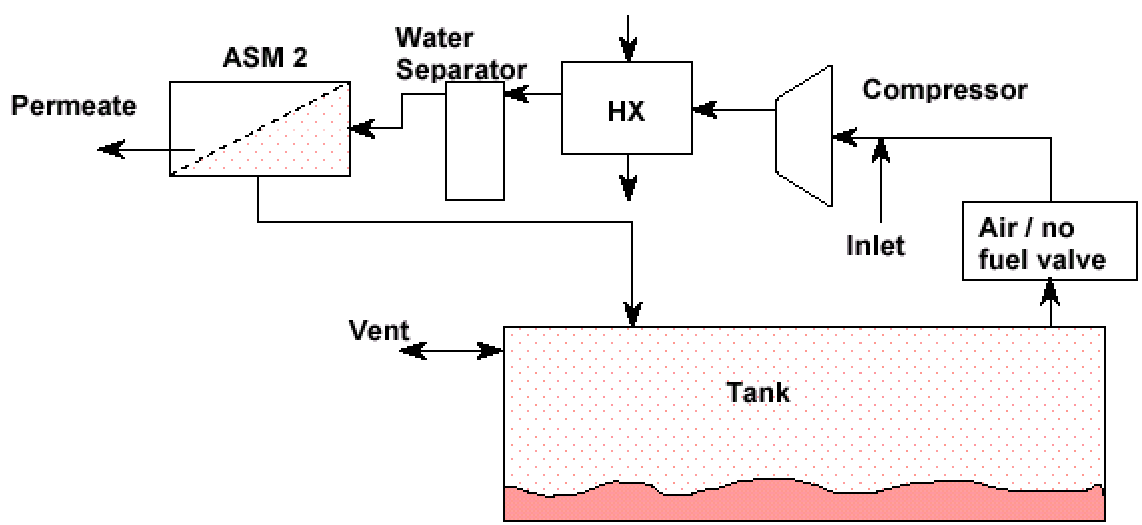
Concept 7

Aero Companies

Concept Development



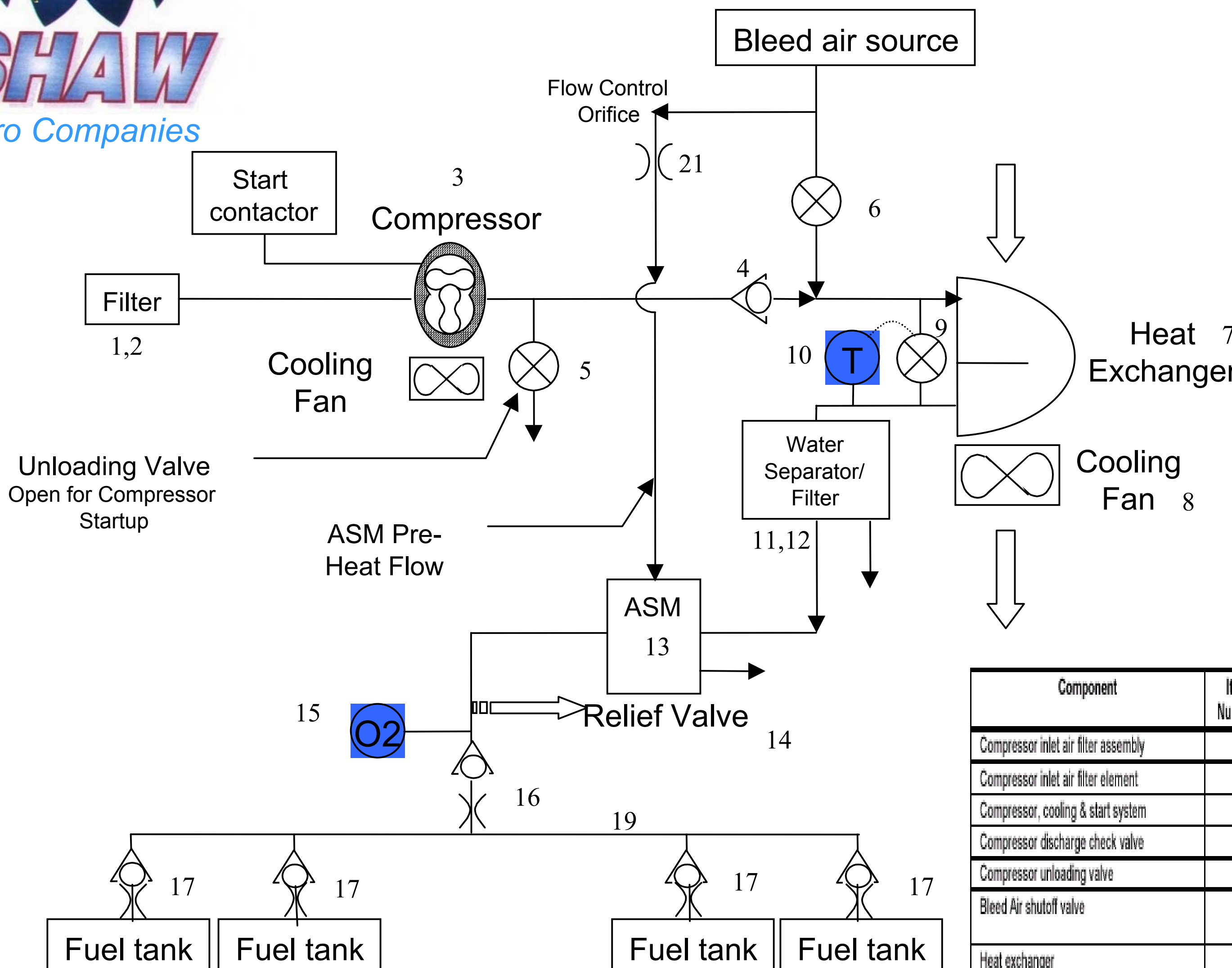
Concept 8



Concept 9

SHAW
Aero Companies

Concept No.	Title (Fig. Ref.)	Analysis	Conclusion
		System Concepts	
1	Engine Bleed Only (1.4.2-2)	• Works only when main engines on. Small part of the on -ground time. • Implies a larger system. • Can tap off the bleed air gallery. • Expected to result in a large ASM – superseded by 4 & 6	Rejected
2	APU Only (1.4.2-2)	• Operational restrictions to use of APU. Ground use of APU not allowed by some airport authorities. APU has no spare flow capacity on hot days on retrofit aircraft. • Larger system because of limited flow / pressure. • Superseded by 4 & 6	Rejected
3	Air Cart Only (1.4.2-2)	• Only available at the gate. Not universally available. Additional ground equipment investment. Labor cost of connection. • Superseded by 6	Rejected
4 Retrofit	Engine APU & Ground Cart (1.4.2-2)	• Restricted by availability unless ECS (Cabin Cooling) degraded, as protection needed most on hot days: needs an excess of air to ECS packs. • Superseded by 6	Rejected
4 New	Engine APU & Ground Cart (1.4.2-2)	• Can design for required bleed capacity BUT still restricted by availability.	Consider
5	Compressor. Electrically, hydraulic or bleed-air driven from the aircraft power sources (1.4.2-2)	• Easier installation. Power may be restricted at gate. Increases size and weight. Less impact on ECS. • Spare Power is 10kW per engine, may be restricted on ground. • Not available on ground. • Only useful to boost low pressure/high flow bleed air.	Rejected
5a	Compressor (1.4.2-2)	• Electrically driven from a ground power supply. If power requirements are within the rating of existing supplies provided at the gate, expected to be viable.	Consider
6	Integrated Air supply (1.4.2-2)	• Combines the electric compressor with bleed air as an alternative source. Gives the operator some flexibility in the event that a compressor fails as either an engine or APU can be run if ambient conditions are such that the flammability risk is high.	Preferred
7	ASM with eductor or suction pump (1.4.2-3)	• An optimization of ASM (membrane & PSA) • Eductor requires additional bleed air. • Suction Pump requires integration with compressor.	Consider
8	Closed Loop. Bleed air assisted (1.4.2-4)	• Smaller, reduced hydrocarbon emissions. • Only works with additional compressor. ASM has to be hydrocarbon compatible. Risk of contamination. Compressing fuel vapor air mix considered a safety hazard. Unproven technology. Dependent on Bleed Air supply	Rejected
9	Closed Loop (1.4.2-5)	• Smaller, reduced hydrocarbon emissions. • Only works with additional compressor. ASM has to be hydrocarbon compatible. Risk of contamination. Compressing fuel vapor air mix considered a safety hazard. Unproven technology.	Rejected
		ASM Technologies	
	Cryogenic	Viable ASM technology	Consider
	Membrane	Viable ASM technology	Consider
	PSA	Viable ASM technology.	Consider



Final System Configuration

Component	Item Number	Component	Item Number
Compressor inlet air filter assembly	1	Water separator/filter assembly	11
Compressor inlet air filter element	2	Water separator/filter element	12
Compressor, cooling & start system	3	Air separation module	13
Compressor discharge check valve	4	Relief valve	14
Compressor unloading valve	5	Oxygen sensor	15
Bleed Air shutoff valve	6	ASM check valve & restrictor assembly	16
Heat exchanger	7	Fuel tank check valve	17
Cooling fan & ram ducts assembly	8	Controller / control card	18
Heat Exchanger bypass valve	9	Ducting	19
Temperature sensor & controller	10	Wiring	20
		Bleed Orifice & duct	21

Aero Companies

System Sizing & Performance

- **The ullage was required to be inert to 10% O_2 at pushback from the gate, for comparison with the ground-based system. Parameters such as ASM efficiency and fuel tank volumes were primary factors. The ASM performance determines the amount of feed air needed to make the required amount of NEA. Feed air quantity and temperature size the compressor and the feed air heat exchanger.**
- **Primary tool used for determining the system performance was the FAA inerting computer model. This analysis tool determines flammability exposure of the fuel tank ullage.**
- **Key parameters to optimize the OBGI System components: effect of feed pressure, NEA oxygen content, feed air temperature, and turn-time.**

Aero Companies

Key Sizing Parameters

- **The OBGI system NEA flow rate (therefore the system size, cost, & weight) is directly proportional to the minimum aircraft turn-time - dictates the time to operate the system.**
- **Another key parameter is the ASM feed pressure. Because the system can operate on engine or APU bleed air, it was sized using the minimum pressure available from existing aircraft. This had an effect on the size and weight of the ASM selected.**
- **System heat exchangers use ambient air to cool the hot ASM feed air to the temperature that the ASM can tolerate. 111°F ambient air temperature used as the worst-case ambient air heat sink. PSA ASM feed air had to be cooled to 125°F. Membrane ASMs operate efficiently at 180°F and were sized accordingly. Operating the membrane ASMs at this temperature requires more feed air than operating at cooler temperatures.**

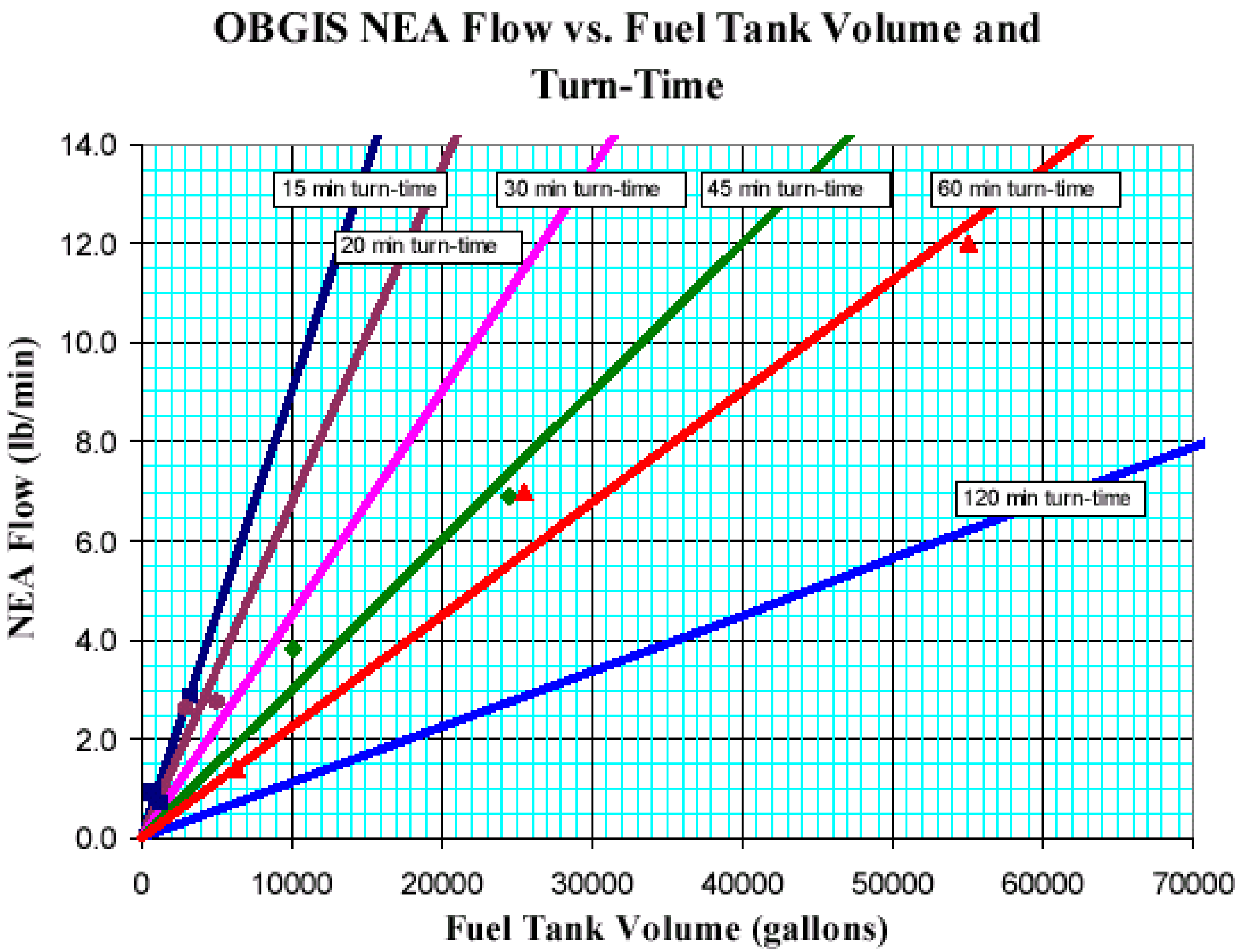
Aero Companies

Key Sizing Parameters

- The NEA flow rate required to inert the tank is a function of the NEA purity generated by the system. The OBGI system weight, volume, power consumption and cost results are based on membrane NEA purity of 6.76% oxygen and PSA purity of 7.4% oxygen.
- Analysis was done to ensure there was not a high dependency of system weight and size on NEA concentration.
  - Performed several sizing iterations using the inerting model and only varying the NEA concentration. Through the entire range of purity, the weight of the system changed only 5%.
  - Savings minimal and overall the fleet-wide savings considered negligible.

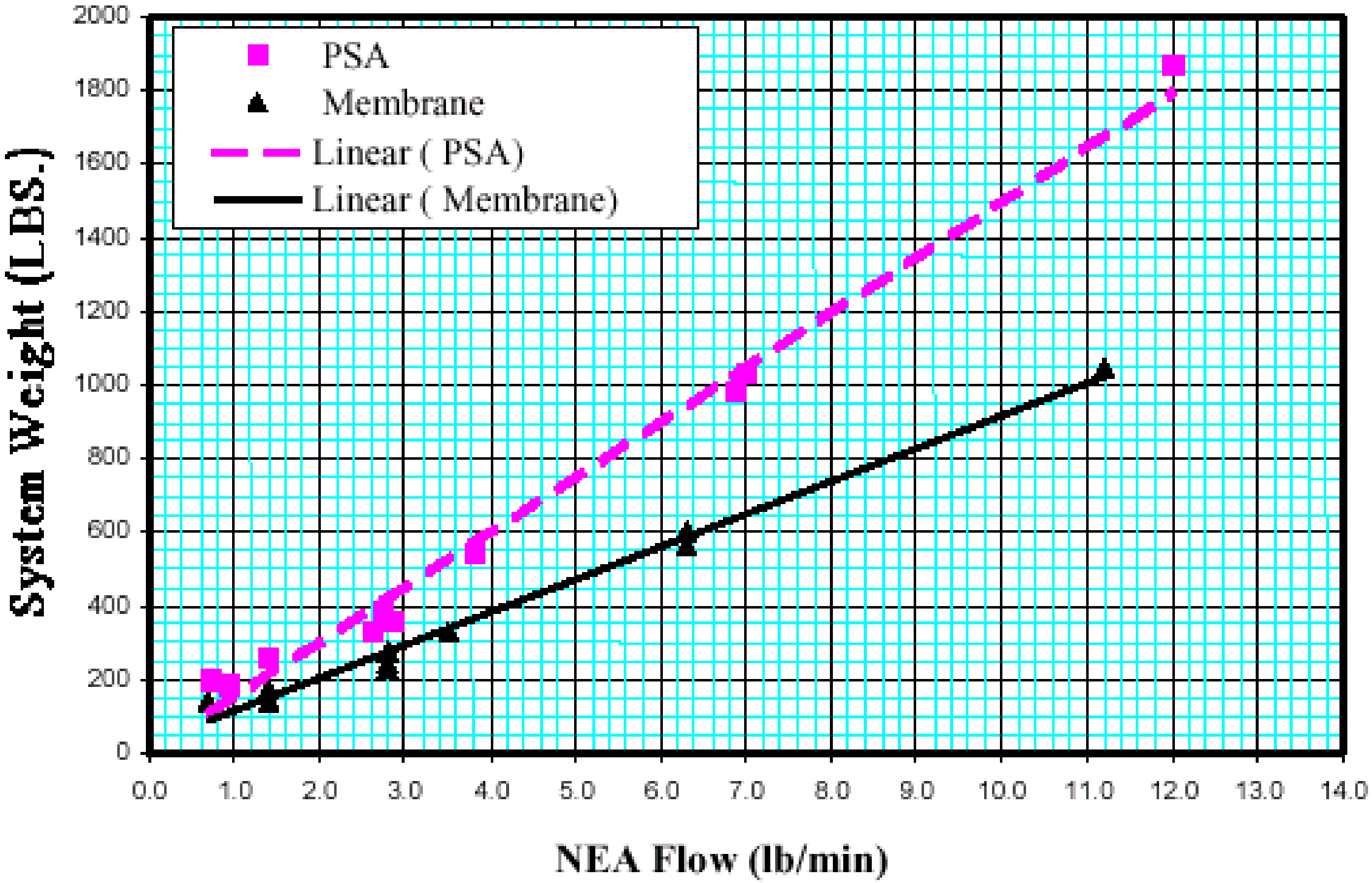
Aero Companies

Parametric Sizing



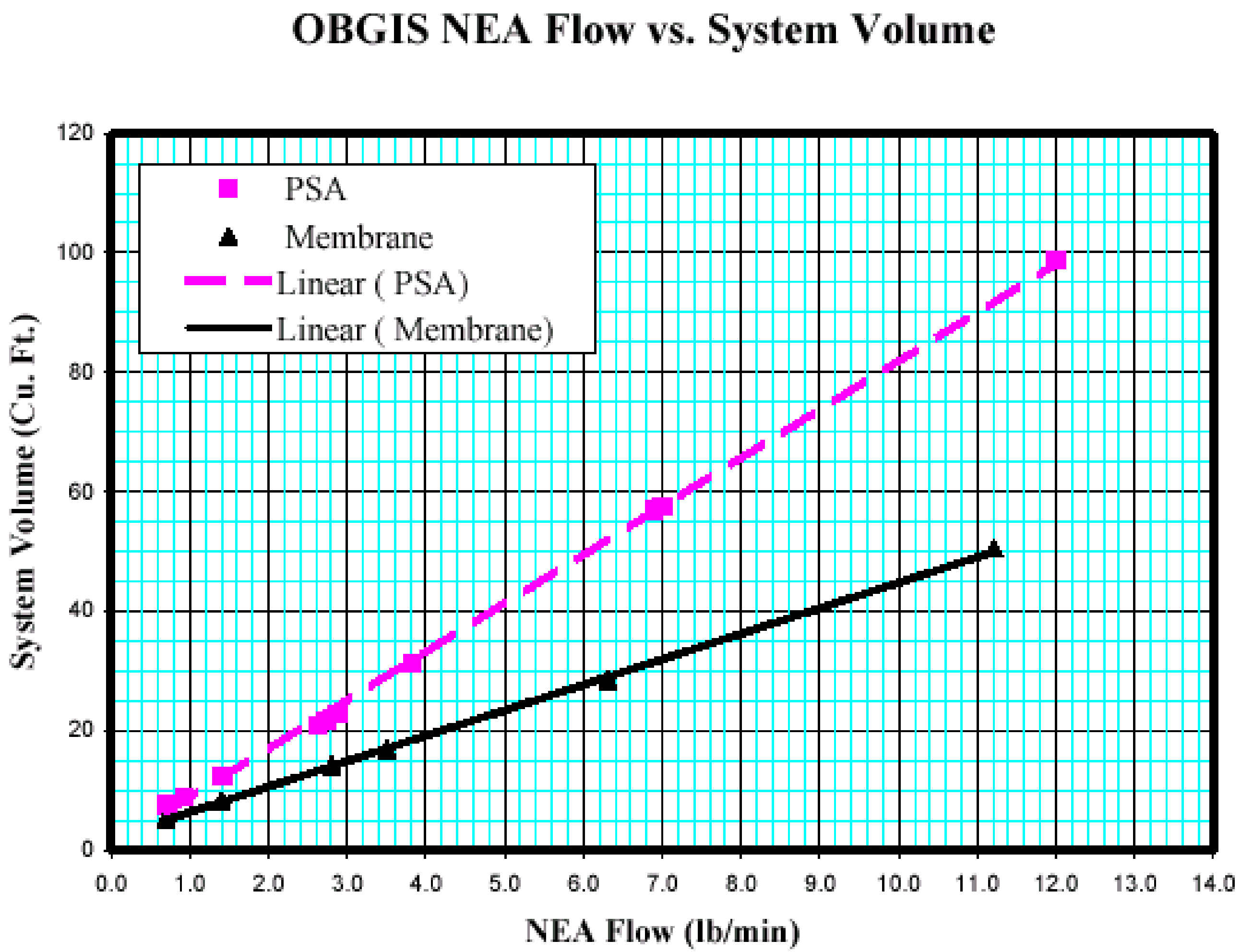
Aero Companies

Parametric Sizing

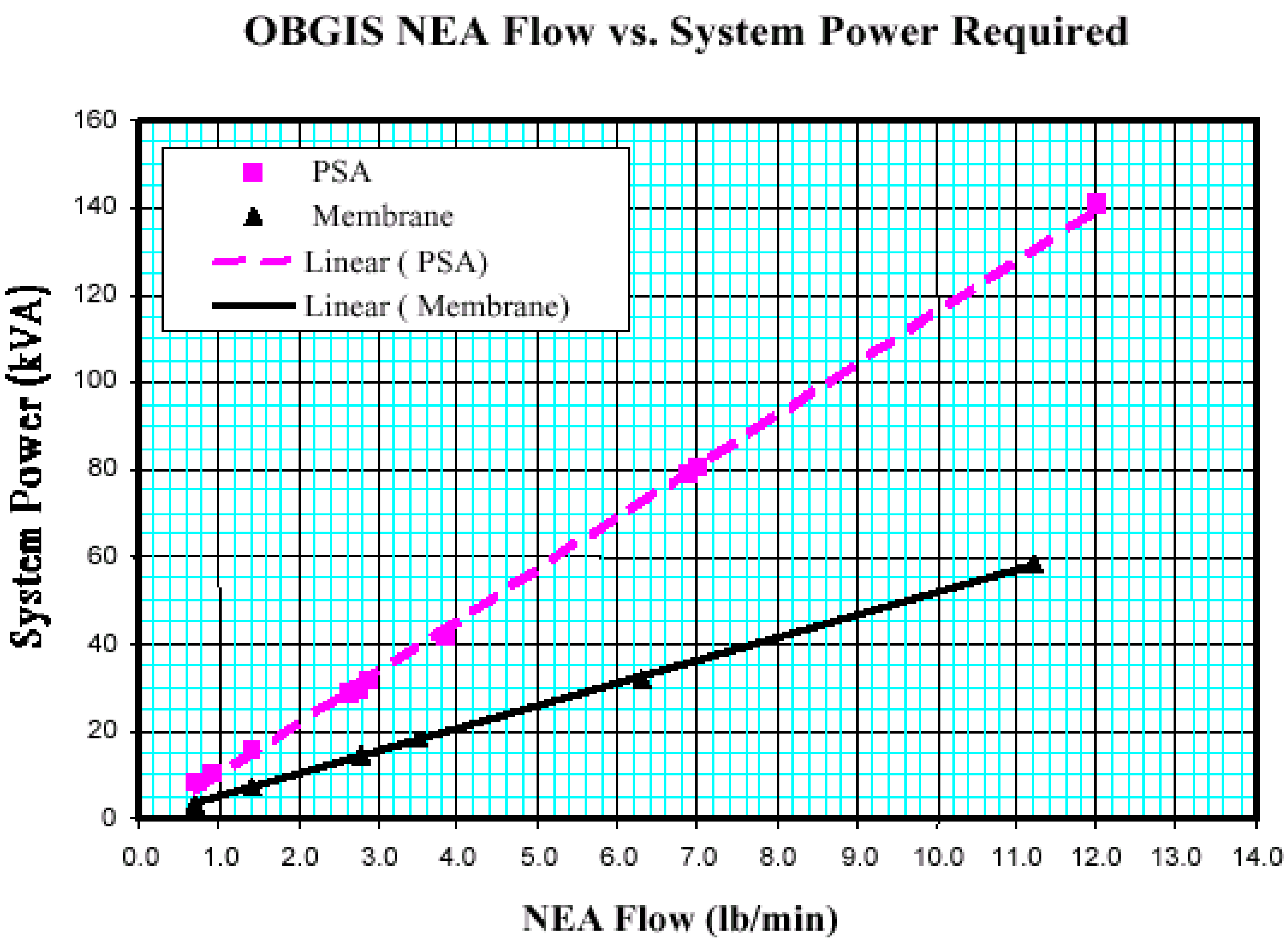


Parametric Sizing

Aero Companies



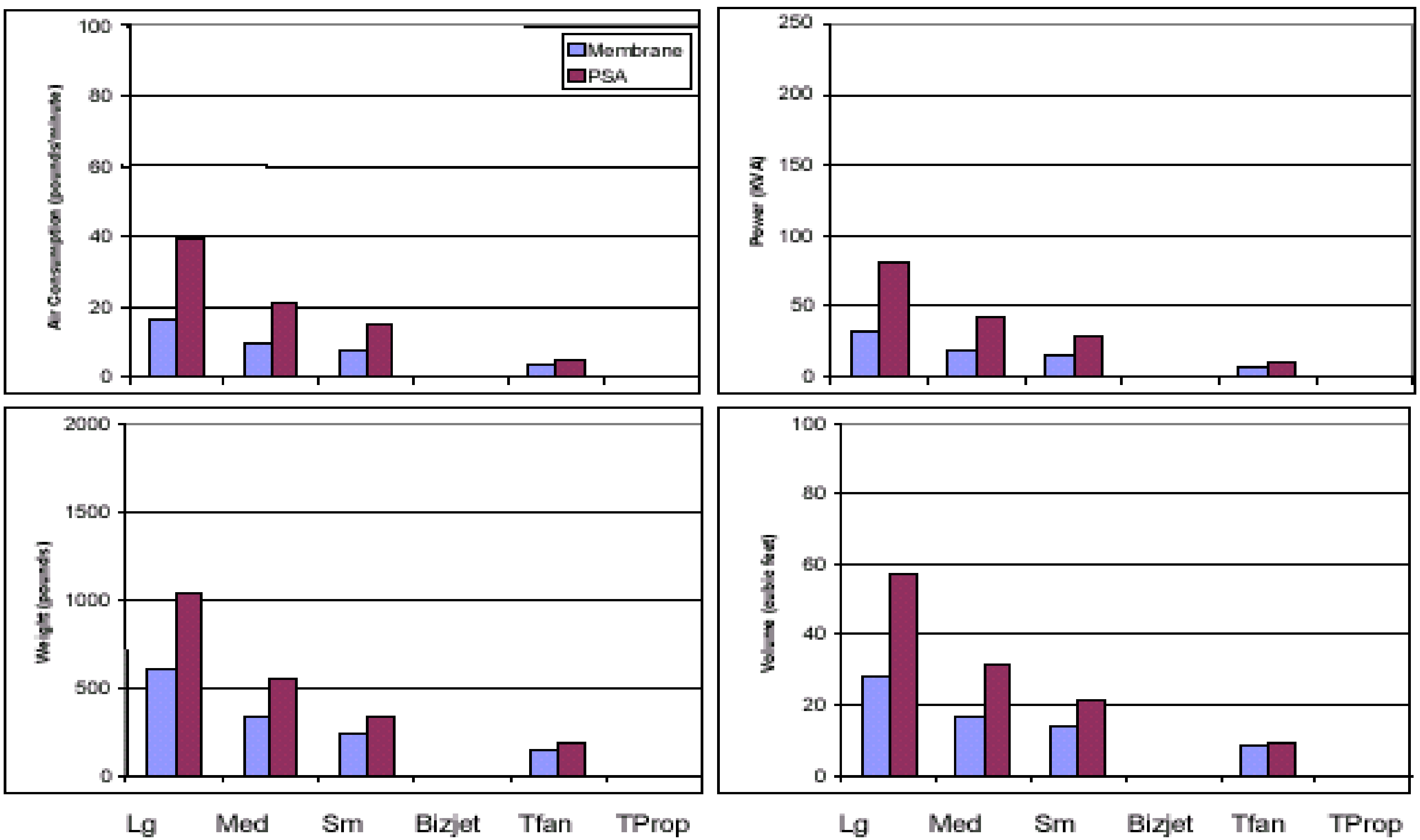
Parametric Sizing



SHAW
Aero Companies

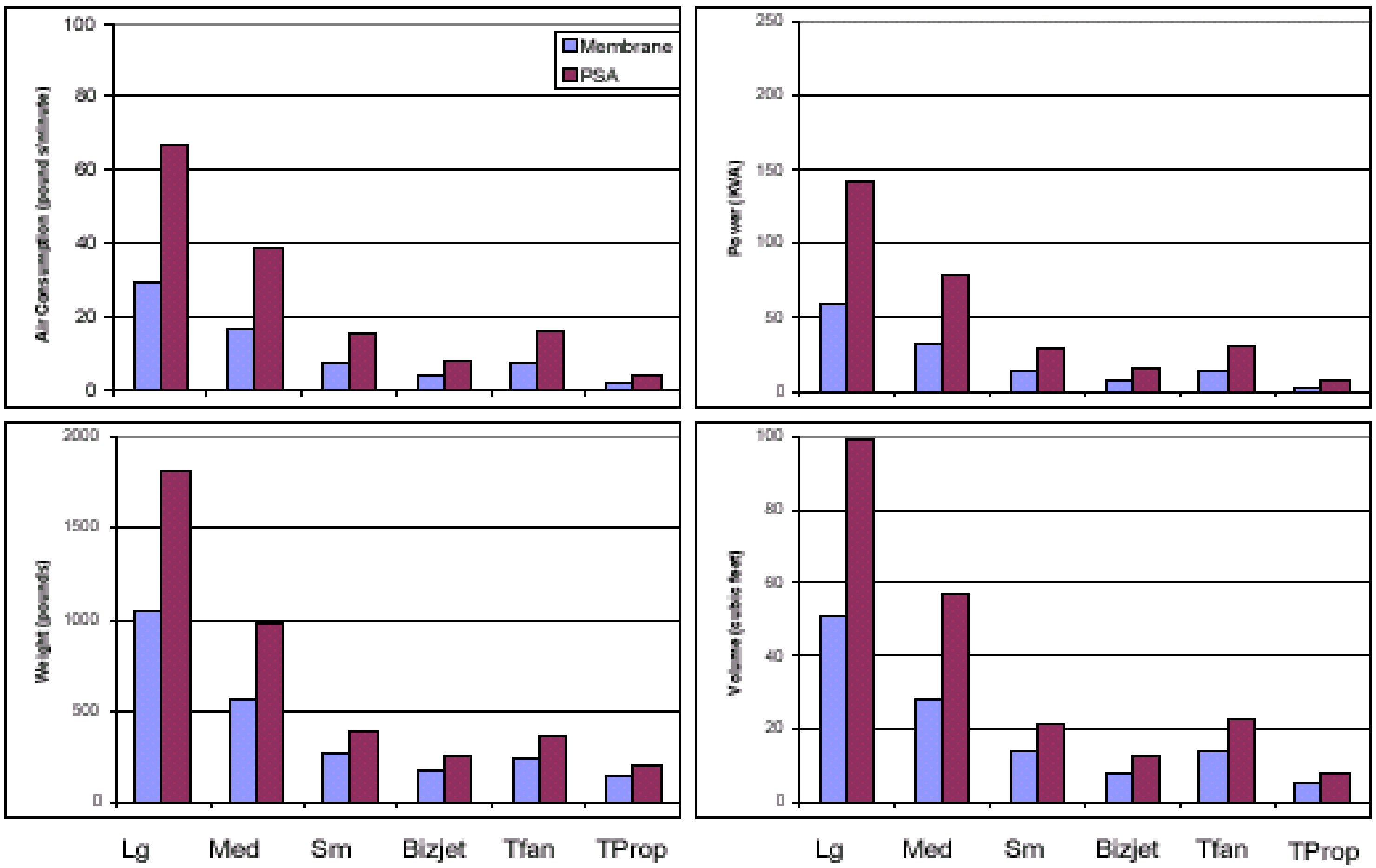
Results

OBGI - Center Wing Tank



Results

OBGI - All Tanks



Aero Companies

Results

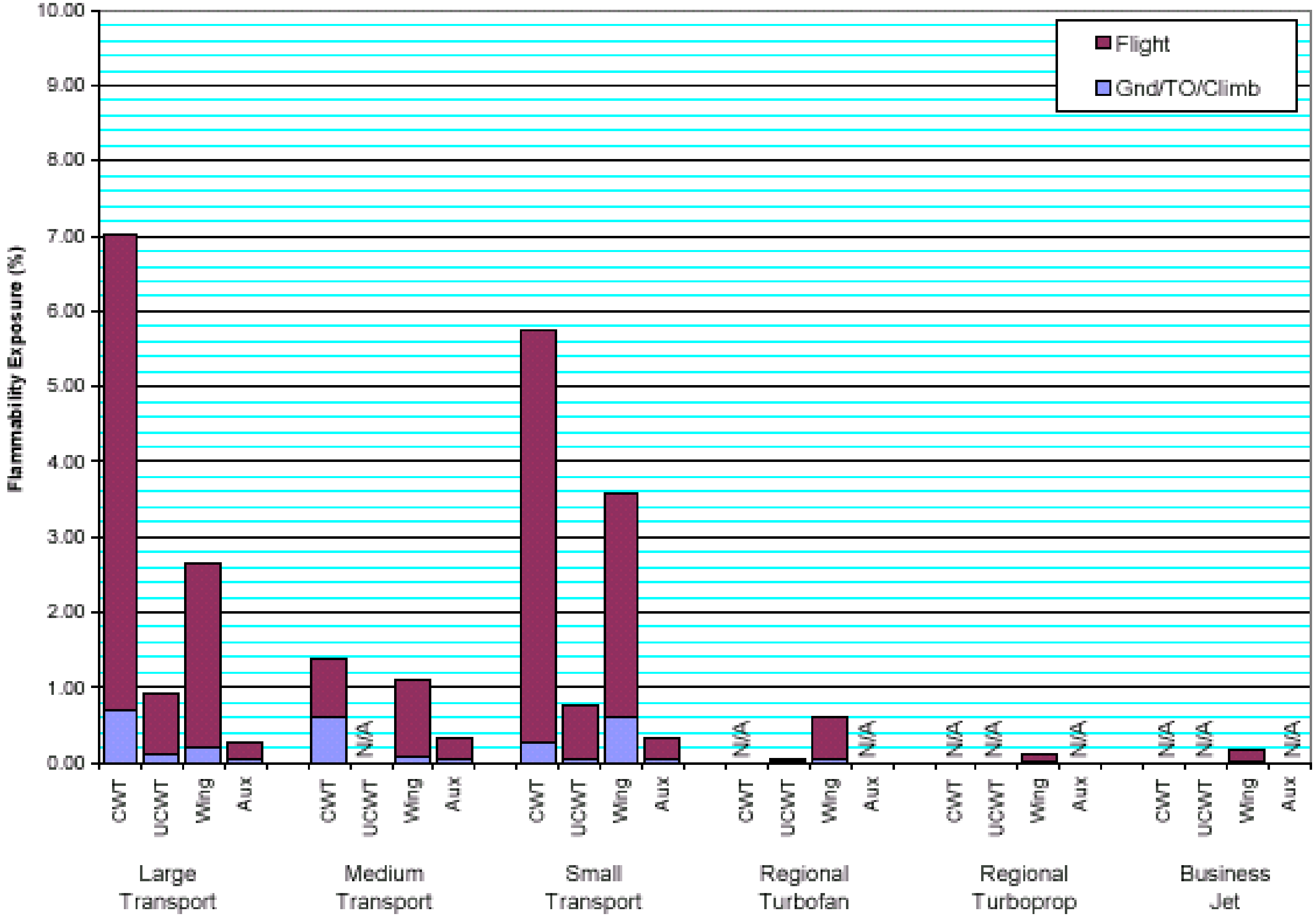
- **Flammability Exposure**
  - **Flammability exposure for each of the generic aircraft types was determined for each fuel tank type by simulating 5,000 random flights. Both the PSA and membrane ASM systems were evaluated based on the system sizing that ensured tanks were inert at pushback from the gate for all ground scenarios.**
  - **Flammability exposure results for the OBGI systems are shown in The following Figures.**

Aero Companies

Results

- **Flammability Exposure**
  - **Total flammability exposure represents the total flight and ground time spent flammable and not inert as a percentage of the total flight and ground time.**
  - **The portion of the total flammability exposure corresponding to gate time, taxi out, takeoff and climb segments were separately summed, to allow for direct comparisons of each inerting option in the portion of the mission where the risk of an explosion was higher. The FAA flammability model conservatively uses sea level criteria at altitude; total exposure is not necessarily the best measure for comparing overall performance between inerting system types.**
  - **As an example, a one-percent reduction in flammability exposure during cruise does not represent the same benefit as a one-percent reduction on the ground.**

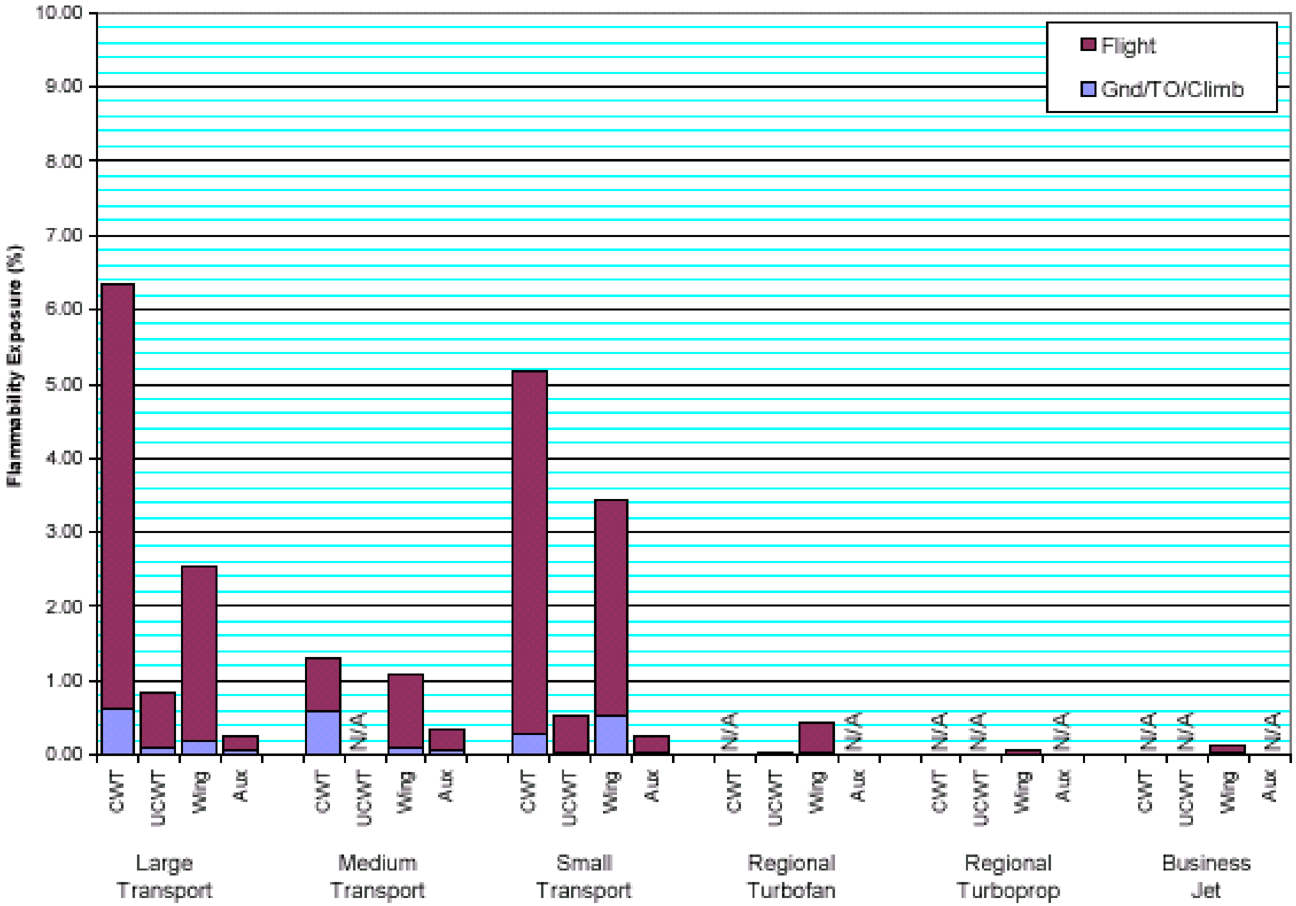
Results
Flammability Exposure



Flammability Exposure Results for the OBGI Systems PSA ASM

Aero Companies

Results
Flammability Exposure



Flammability exposure Results for the OBGI Systems Membrane ASM

Aero Companies

Application Considerations

- **Weight**
  - **The weight of the major components was derived empirically, and by detail design:**
    - **ASM's**
    - **Compressor assembly**
    - **Heat exchanger & cooling fan.**
  - **Other components weights supplied by component suppliers:**
    - **Filters**
    - **Valves**
    - **Ducting**
    - **Wiring**
    - **Installation hardware**

SHAW Aero Companies

Application Considerations

- **Volume**
  - **The volume of each component in the system derived from performance requirements**
    - **Flow**
    - **Pressure**
    - **Heat load**
    - **Purity**
  - **System volume used to determine whether it is practical to fit equipment on board an aircraft.**
    - **Determines space required for new aircraft design**
    - **Determines whether space available and environment is acceptable to mount the equipment onto an existing aircraft.**
    - **Evaluates whether the existing fleet may be retrofitted with current practical considerations**

Aero Companies

Application Considerations

- **Power requirements**
  - **Determine power needs of compressor, cooling fans and other electrically powered equipment**
  - **Determine air power requirements for system operating in back-up mode using APU or engine bleed air.**
  - **Assess capability of existing aircraft equipment to accommodate power, including wire size, electrical connection power capacity**
  - **Allows evaluation of capacity of existing gate power to operate the system.**

Aero Companies

Application Considerations

- **Reliability**
  - **Component reliability determined using similarity data from existing equipment.**
- **Cost Data**
  - **Acquisition**
    - **Assumptions**
  - **Design and certification**
  - **Installation**
  - **Operating**
  - **Maintenance**

Aero Companies

Application Considerations

- System Safety
  - OEA - rich waste gas
  - NEA concentration at vent outlet
  - Additional electrical wiring
  - Potential increased fuel tank pressure during refuel failure condition.
  - High component temperatures
  - Potential system leaks
    - High temperature compressor discharge
    - NEA leaks in confined space
    - OEA leaks in confined space
    - Fuel vapor back-flow through ASM
  - Component failure

Aero Companies

Application Considerations

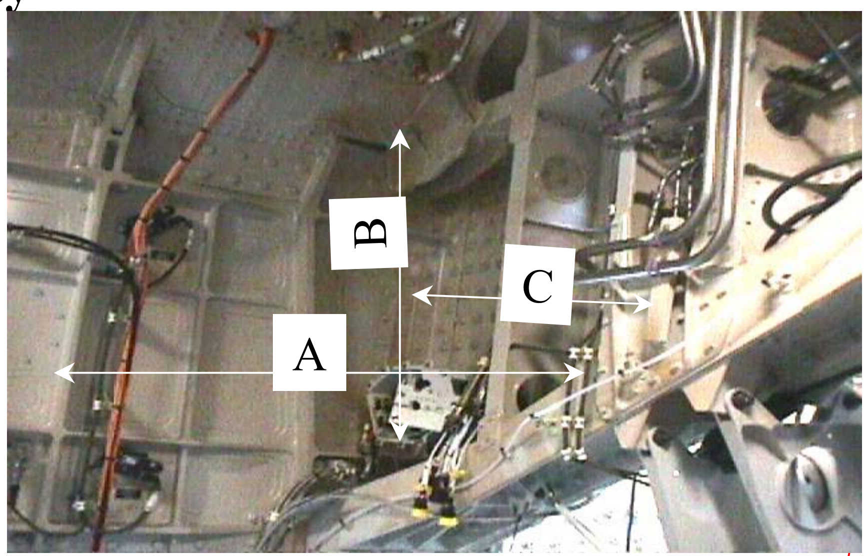
- **Installation**

Application types:

- **New aircraft design**
- **Frozen aircraft design - not yet in production**
- **In production aircraft**
- **Out of production aircraft**

Application Considerations

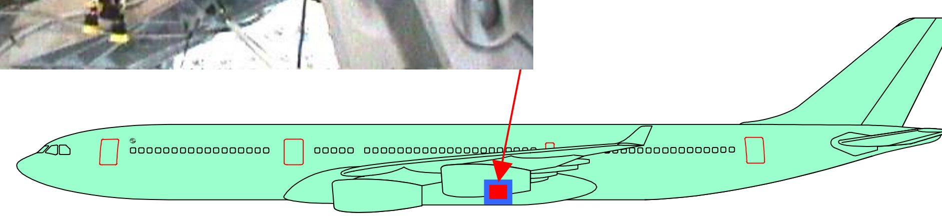
- **Unpressurized areas**
  - **AC pack bay**
  - **Wing root**
  - **Wheel well**



⌧Main landing gear bay

⌧Aerated zone

⌧Not pressurized area



☎A~0,7m

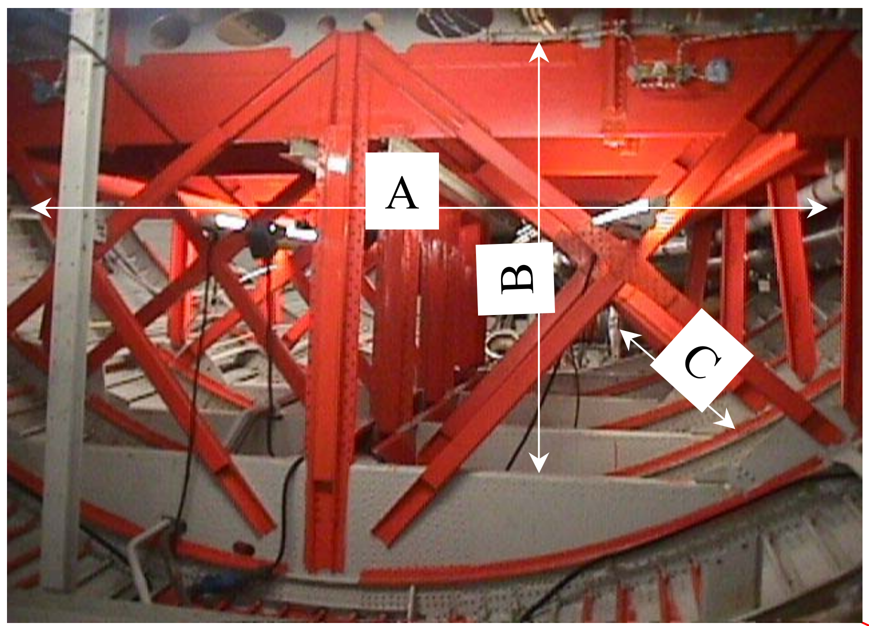
☎B~0,6m

☎C~0,5m

SHAW Aero Companies

Application Considerations

- **Pressurized areas**
  - **Forward of aft bulkhead**
  - **Cargo bay**

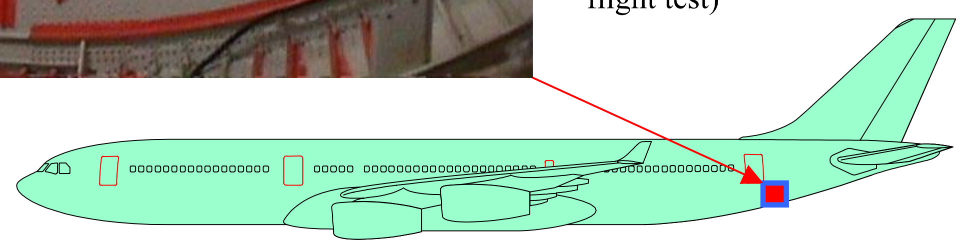


⌧Zone between bulk cargo compartment and bulkhead

⌧Pressurized area

⌧No dedicated ventilation

⌧(red structure removed after flight test)



☎A~4m

☎B~1,5m

☎C~2m

SHAW
Aero Companies

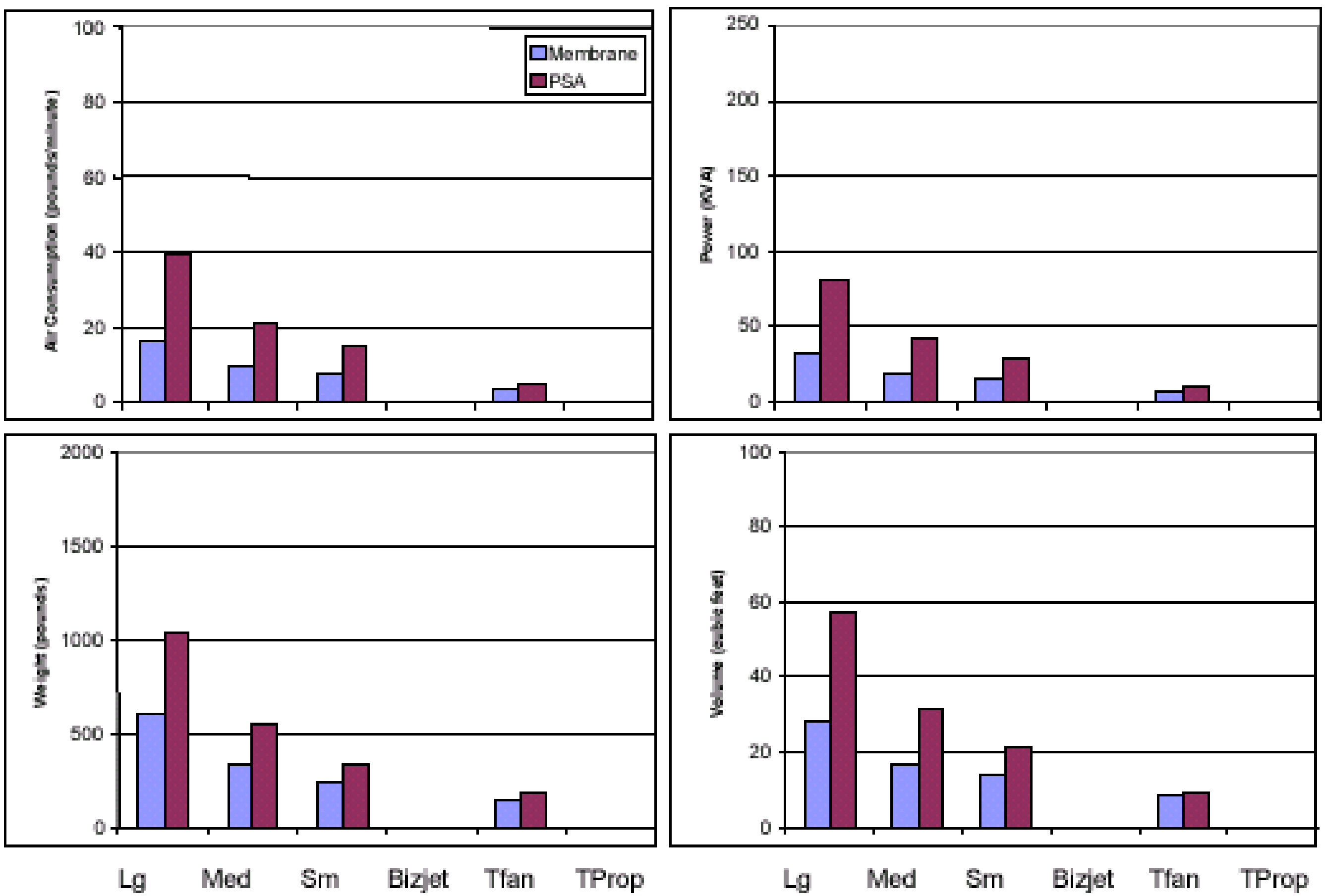
Hybrid OBGI System

The hybrid On-Board Ground Inerting System (OBGIS) is one of four main system categories studied by the 2000 ARAC FTIHWG Onboard Airplane Design Task Team. The term 'hybrid', as used here, refers to a potentially smaller system that leverages additional ground time available to operate the system. The Onboard team considered a similar system architecture to that of the baseline OBGI, and studied the system size for a variety of "modeled" aircraft center wing and auxiliary fuel tanks. The team also defined the physical size and weight of the multitude of components needed to support the hybrid OBGI. Finally, power and air consumption needs were defined.

SHAW
Aero Companies

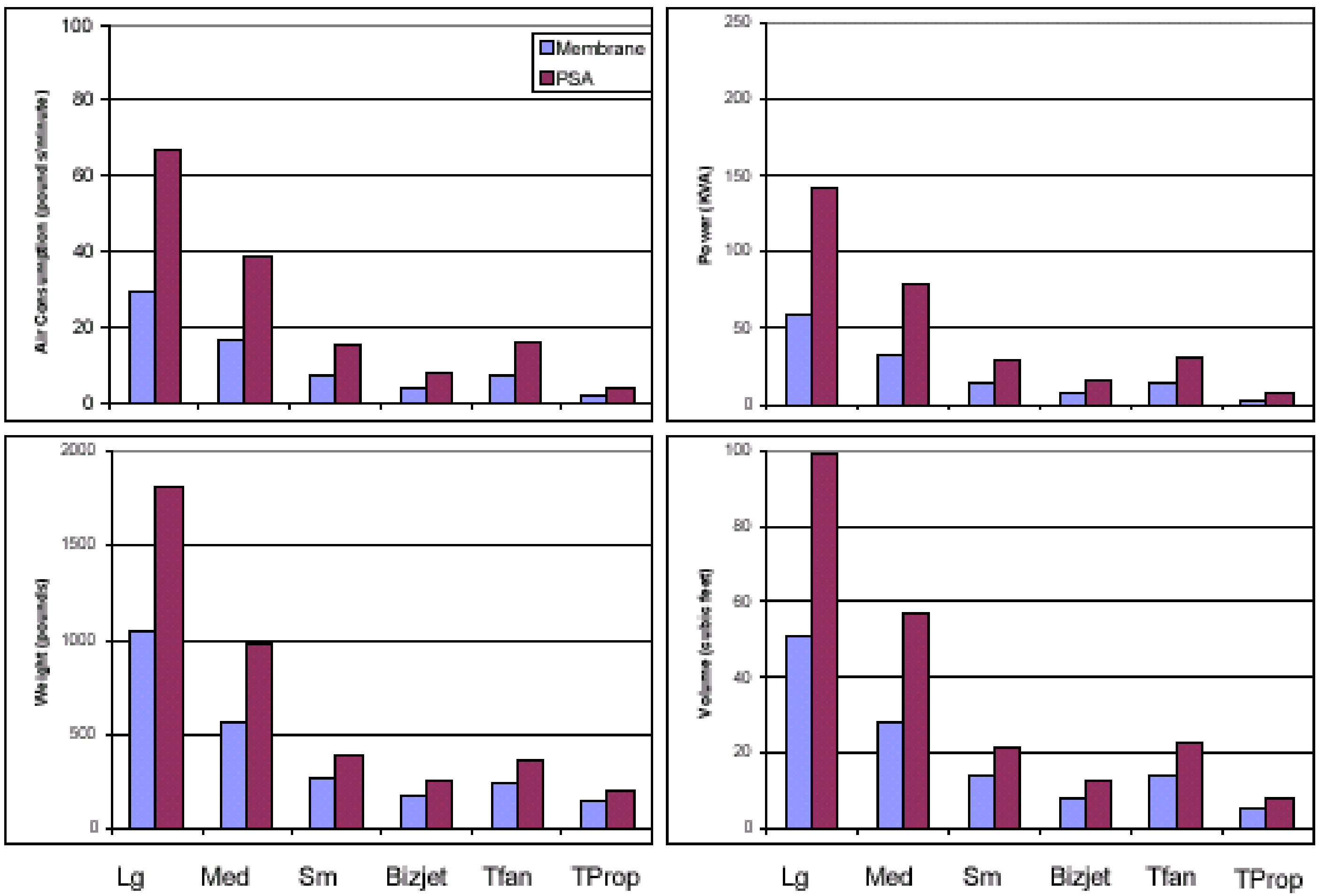
Results

OBGI - Center Wing Tank



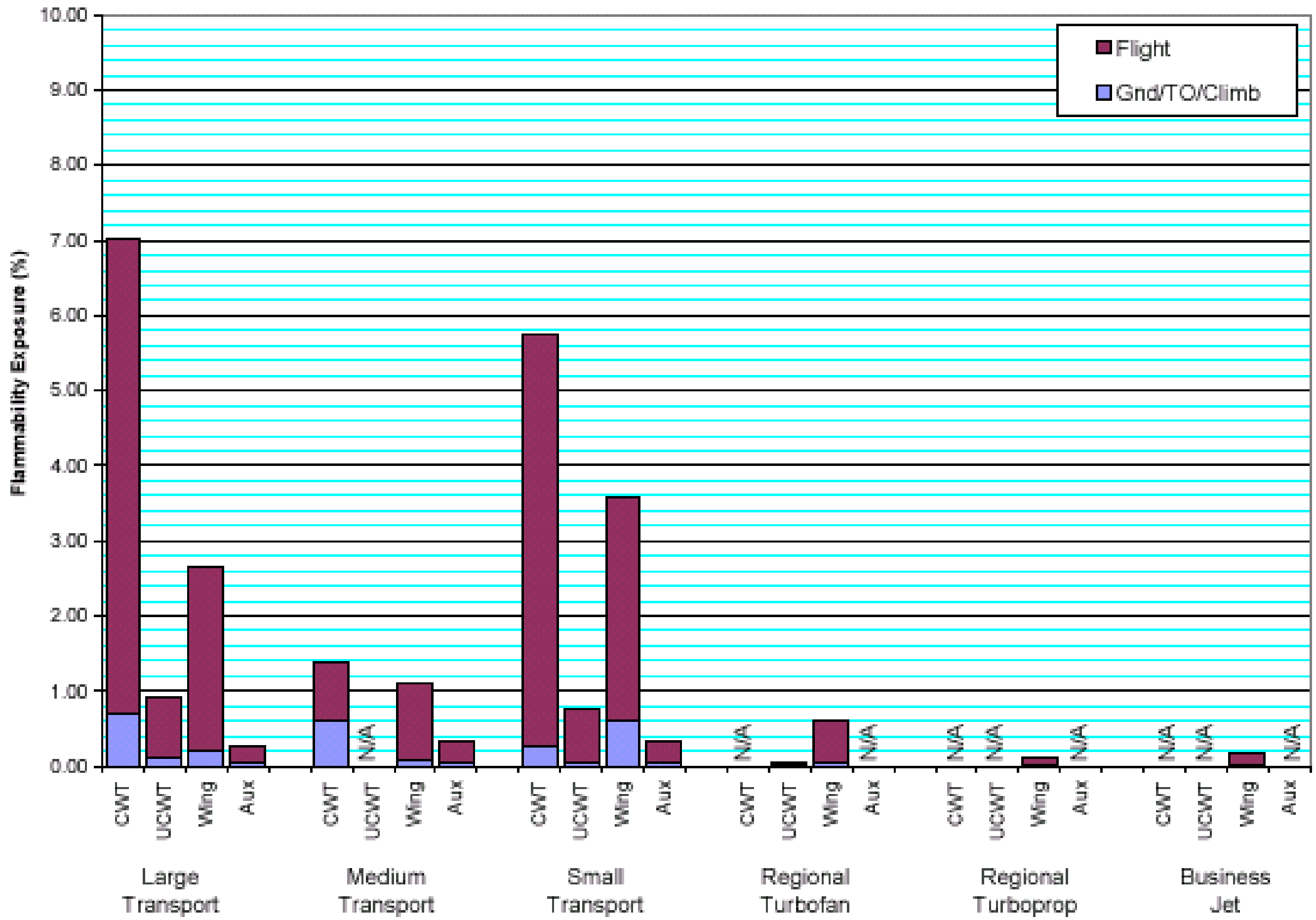
Results

OBGI - All Tanks



Results
Flammability Exposure

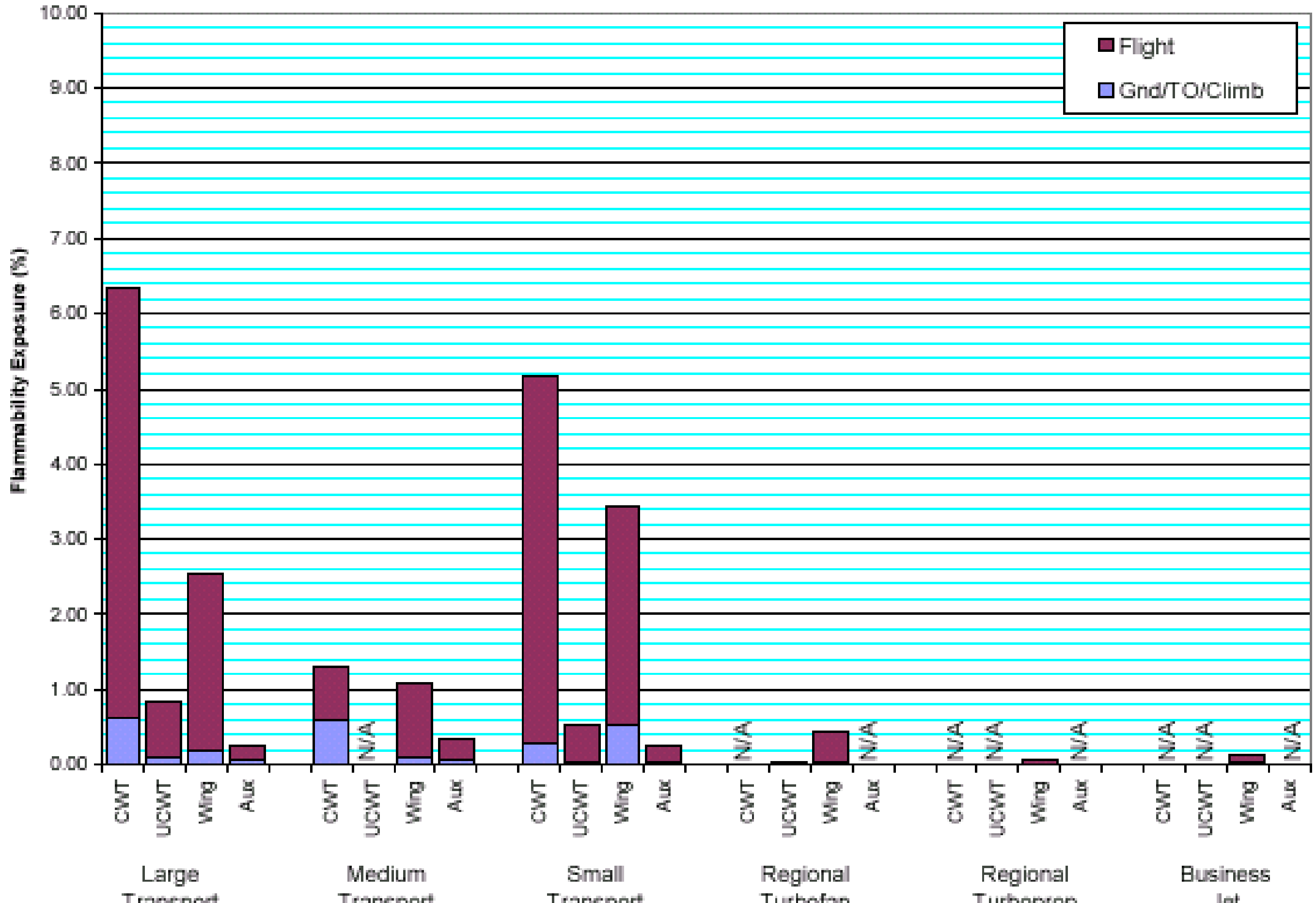
Aero Companies



Flammability Exposure Results for the OBGI Systems PSA ASM

Aero Companies

Results
Flammability Exposure



Flammability Exposure Results for the OBGI Systems Membrane ASM

Aero Companies

Conclusions

- The Team defined a practical system for both OBGI and a hybrid OBGI, featuring available technology and components.
- Available power / sources and aircraft turn-around times were the main factors in system definition.
- System sizing for the 6 aircraft sizes / types considered, concluded with performance data for those aircraft.
- Parametric data was provided to allow scaling to other aircraft sizes / parameters
- Flammability exposure performance charts were developed for comparison with other methods of fuel tank explosion protection.
- Flammability exposure for the systems showed a significant reduction, compared to heated center fuel tanks.
- The hybrid system showed a marginal performance improvement compared to the baseline system.