Cargo Bay Fire Protection with a Fuel Tank Inerting System

William Cavage
AAR-440 Fire Safety Branch
Wm. J. Hughes Technical Center
Federal Aviation Administration

FAA

International Systems Fire Protection
Working Group
Tropicana Casino and Resort
Atlantic City, NJ
November 1-2, 2005

OBIGGS Cargo Bay Fire Protection

Outline

- Background
- Test Article / Methods
  - ASM Performance Testing
  - 747SP Cargo Bay Inerting
- Modeling Methodology
  - Time to Inerting Bay
  - Time Bay Not Inert
- Results
- Summary

OBIGGS Cargo Bay Fire Protection

Background

- FAA developed a proof of concept inerting system to inert the CWT of classic style Boeing model 747
  - FAA intends to make a rule requiring flammability control of some or all CWTs with an emphasis on inerting system technologies
- Potential for using these systems to expand fire protection needs to be explored
  - This project focuses on using the generated NEA to replace the cargo bay fire suppression make up agent

OBIGGS Cargo Bay Fire Protection

Background – Cargo Bay Fire Suppression

- Cargo bay fire suppression is done in two parts
  - First part dispenses large volume of agent rapidly to suppress fire
  - Second part dispenses a fixed amount of agent slowly, based on the aircraft type, to make up for a predetermined cargo bay leakage
- It remains to be seen how useful an OBIGGS designed to inert the CWT of an aircraft would be for this purpose
  - Sizing would probably be different
  - Different design requirements, and certification requirements (Cert requirements still not firm)

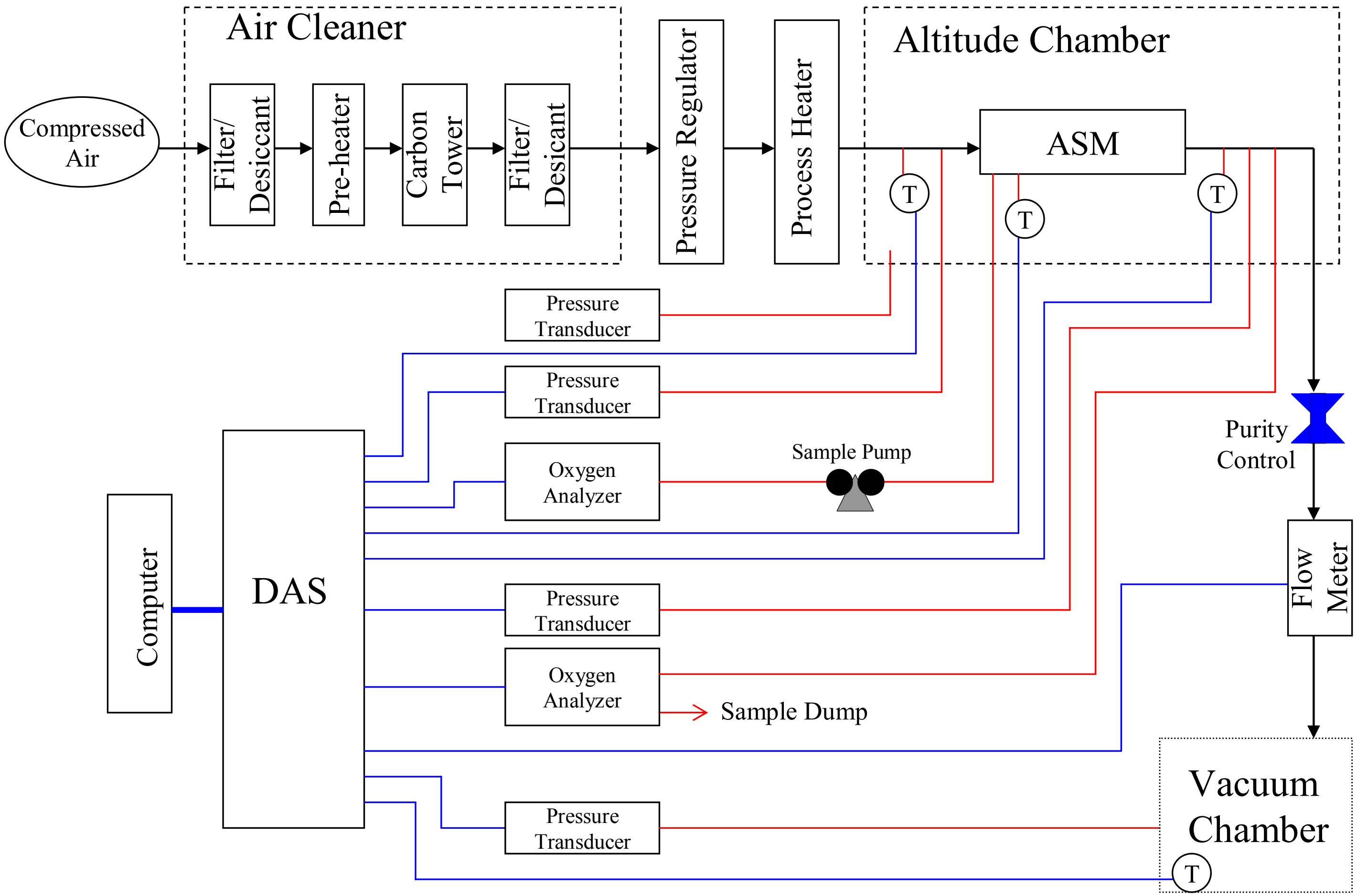
OBIGGS Cargo Bay Fire Protection

Test Article – ASM Performance Testing

- Placed single D-640 ASM in altitude chamber and measured NEA flow and purity under a variety of conditions relevant to aircraft cargo bay fire protection
  - Primary factors effecting ASM performance are ASM feed pressure, ASM permeate pressure, and purity (residual oxygen concentration) of NEA being made
  - All data presented for D-640 ASM at 180 degrees F
  - Looked at ASM performance changes due to varying deposit pressure (i.e. cargo bay pressure changes)
- Used this data as input to inerting model given the different altitudes and bleed air pressures to examine cargo bay fire suppression in terms of oxygen concentration reduction

OBIGGS Cargo Bay Fire Protection

Block Diagram of ASM Performance Test Apparatus



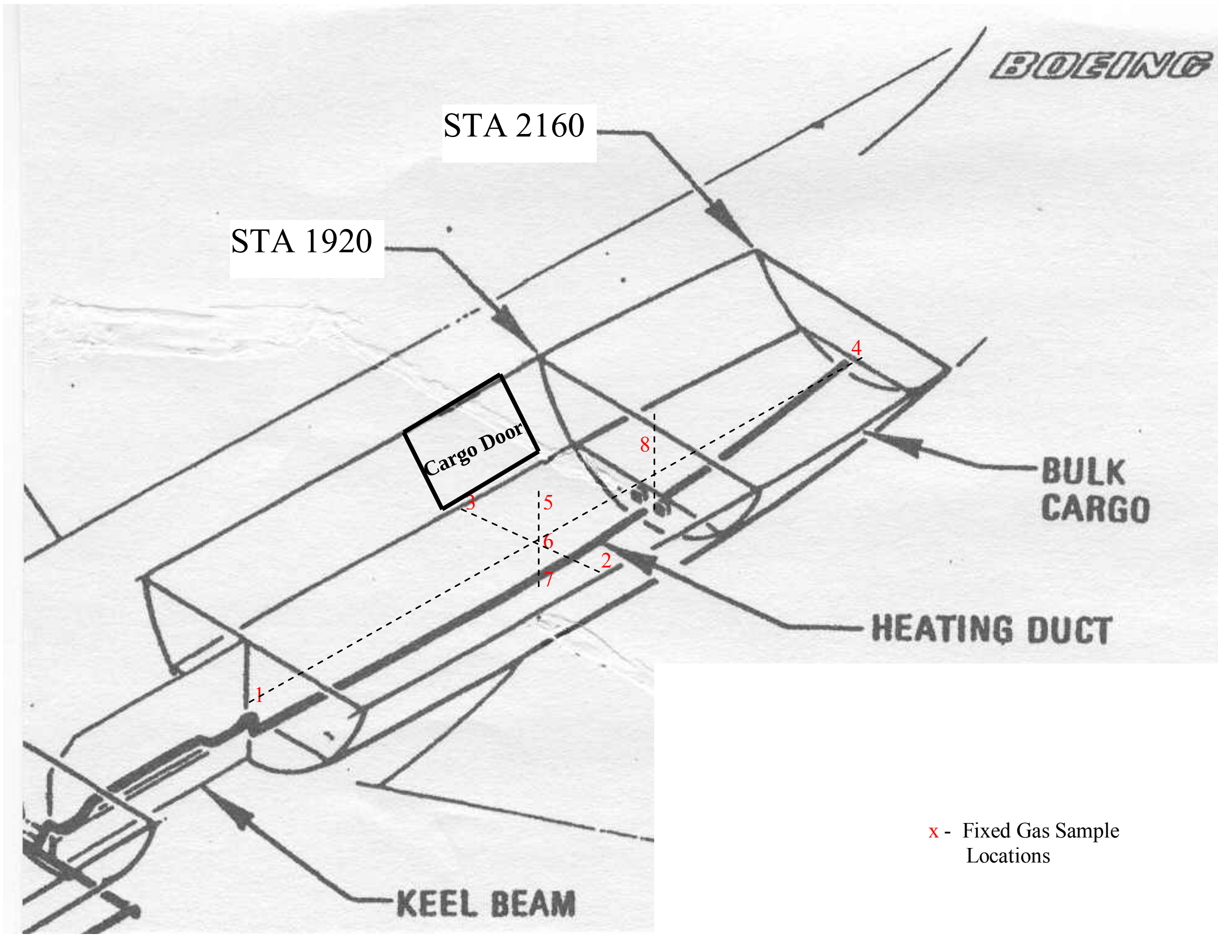
OBIGGS Cargo Bay Fire Protection

Test Article - 747SP Cargo Bay

- Used existing 747SP ground test article, with OBIGGS installed, to study the issues associated with cargo bay inerting on ground
  - Plumbed the OBIGGS to allow for inerting the aft cargo bay with a simple deposit system
  - Can deposit 1-6 ASMs amount of NEA of varying purity in bay
  - Eight gas sample locations in cargo bay used to continually measure oxygen concentration during testing
  - Also can measure flow and purity of NEA being deposited
  - Multiple temperatures and pressure in aircraft available
- Using the ground tests to validate the model that is being used to determine the effectiveness of a CWT inerting system as to cargo bay fire protection

OBIGGS Cargo Bay Fire Protection

Rendering of Cargo Bay with Gas Sample Locations



OBIGGS Cargo Bay Fire Protection

Modeling Methods

- Modified existing single bay fuel tank inerting model to allow for a constant air leakage in addition to deposited NEA
  - Model calculates moles of air in / out of the tank due to depositing inert gas, changing cargo bay pressure altitude, and a fixed air leak rate in
  - All modeling work was for an OBIGGS using six D-640 ASMs
    - Extensive amount of ASM performance data acquired in lab first
  - This allowed for calculation of time to inert for constant conditions to determine the amount of time to reach the inerting oxygen concentration (12 and 15%) in a 2600 ft^3 cargo bay with no **net** leakage using OBIGGS
    - Model assumes NEA flow "holds back" the leakage
- Added routine to calculate Halon concentration
  - Used this model to determine time not inert for previously studied OBIGGS/aircraft conditions using a 5% Halon discharge in a 2600 cubic ft bay with 50 SCFM leakage (assume 3% Halon inerting conc.)

OBIGGS Cargo Bay Fire Protection

Modeling Method – Altitude Calculation Model

– Basic equation governing oxygen concentration calculation

$$m_{O_2}(t) = m_{O_2}(t-1) + \dot{m} * \Delta t * IGOF - \dot{m} * \Delta t * UGOF\,(t-1)$$
$$- (\Delta\rho * V_{Tank}) * UGOF\,(t-1) + (\Delta\rho * V_{Tank}) * .21 + \dot{m}_{Leak} * \Delta t * .21$$

With:

$m_{O_2}(t)$	=	Mass of oxygen in tank at time t
$\dot{m}$	=	Mass flow rate of inerting gas (in terms of t)
$IGOF$	=	Fraction of oxygen in inerting gas
$\Delta\rho$	=	Change in Ullage Density due to Altitude Change
V_{Tank}	=	Volume of Tank Ullage
m_{Tank}	=	Mass of Gas in Tank
m_{Leak}	=	Mass of air entering tank

Ullage Gas Oxygen Fraction (UGOF) is given as: $UGOF(t-1) = m_{O_2}(t-1) / m(t-1)_{Tank}$

– Calculate Halon concentration similarly

$$M_{\text{Halon}_{Bay}}(t) = M_{\text{Halon}_{Bay}}(t-1) + \Delta M_{\text{Halon}_{Bay}}$$

$$F_{Halon_{Bay}}(t) = M_{Halon_{Bay}}(t) \Big/ M_{Bay}(t)$$

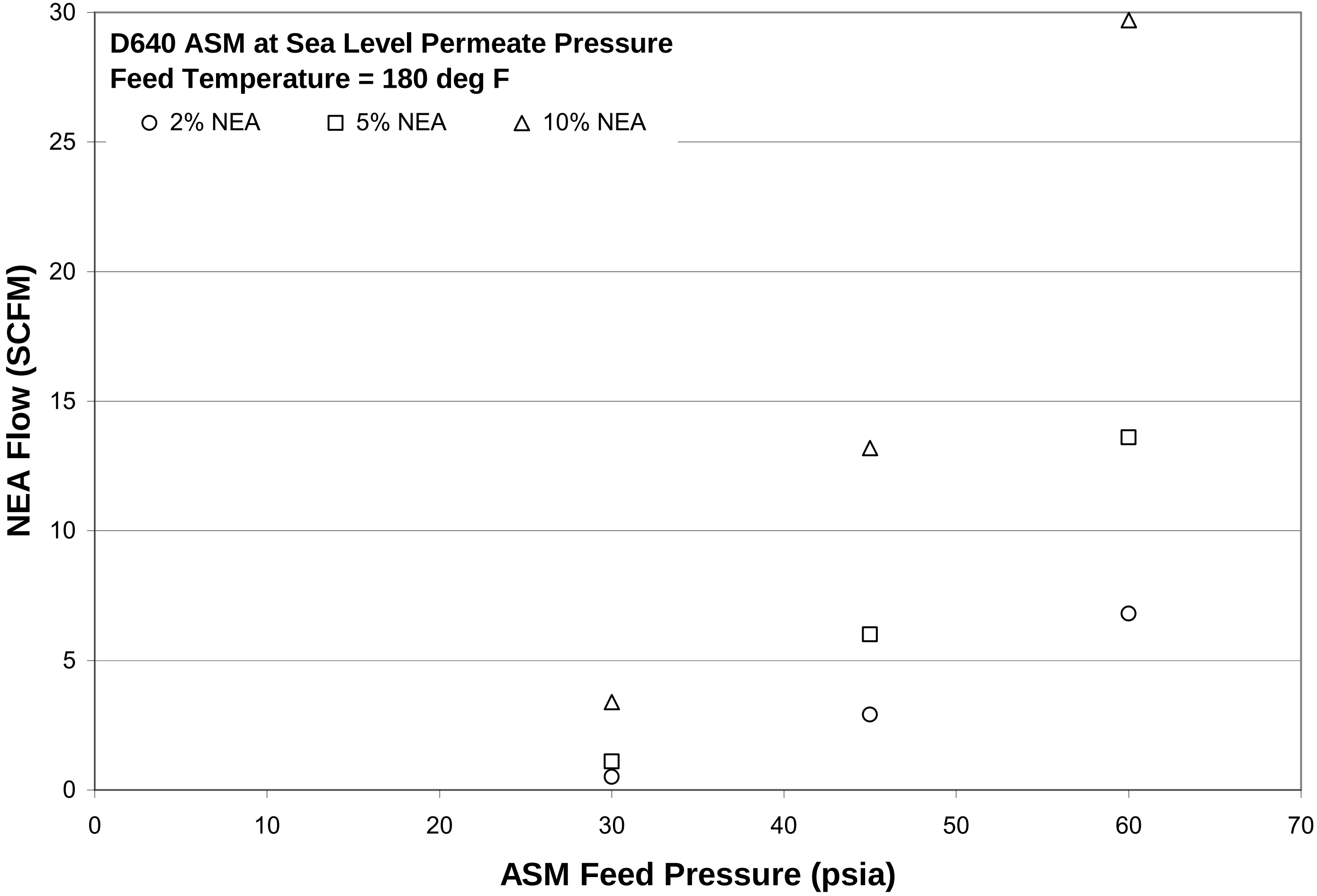
OBIGGS Cargo Bay Fire Protection

Results – ASM Performance Data

- Tests illustrate that the NEA flow for all conditions is very sensitive to the ASM feed pressure
  - Increasing the pressure by 50% (30-45 psia) gives nearly 6 times the flow of NEA
  - Permeate pressure (altitude) also has a big effect on the NEA flow of a given purity, particularly at low feed pressure where the ASM make 2-3 times as much 5% NEA at 20,000 feet than it does at sea level depending on the feed pressure
  - Validated that ASM performance is independent of cargo bay (deposit) pressure
    - Doesn't mean all points acquired at reduce pressure can be obtained at sea level
- These numbers were used in the cargo bay model to give the results of time to inert and time not inert

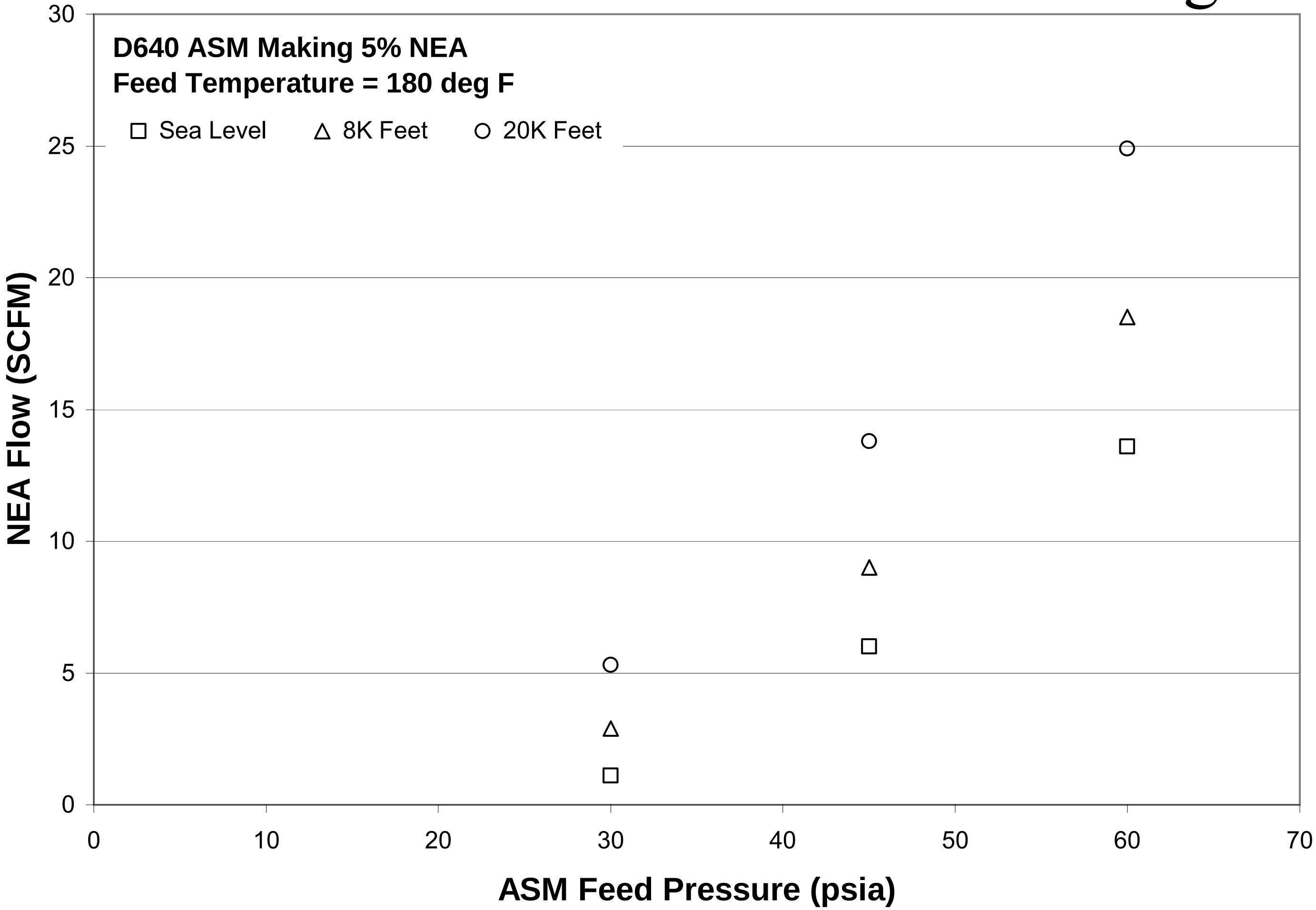
OBIGGS Cargo Bay Fire Protection

Results of ASM Performance Testing



OBIGGS Cargo Bay Fire Protection

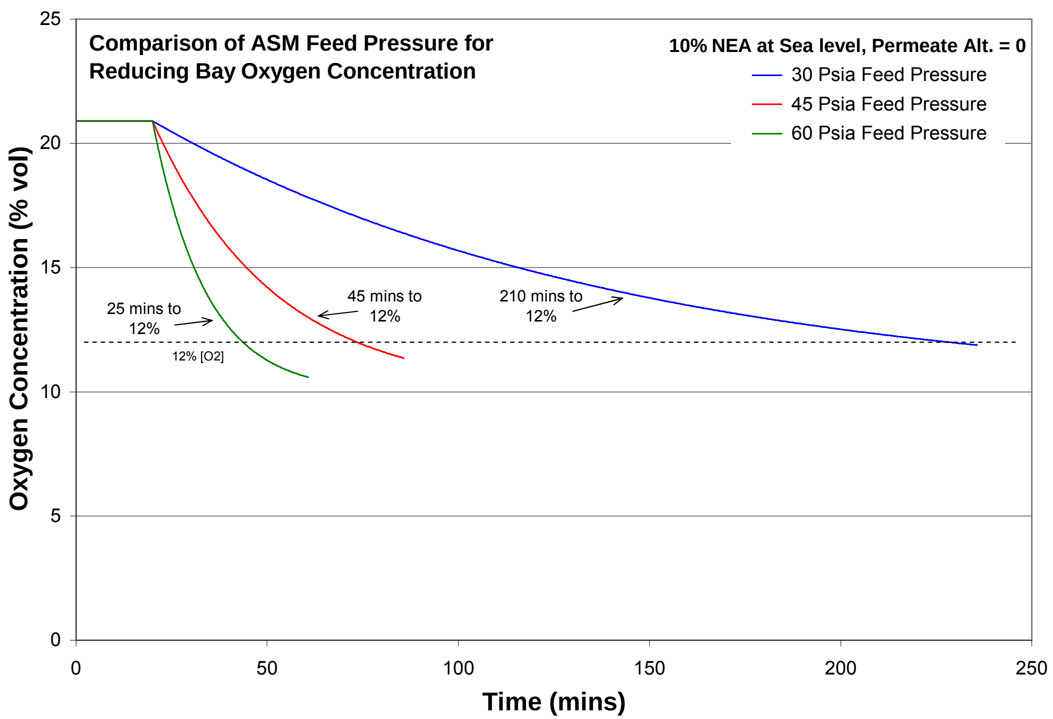
Results of ASM Performance Testing



OBIGGS Cargo Bay Fire Protection

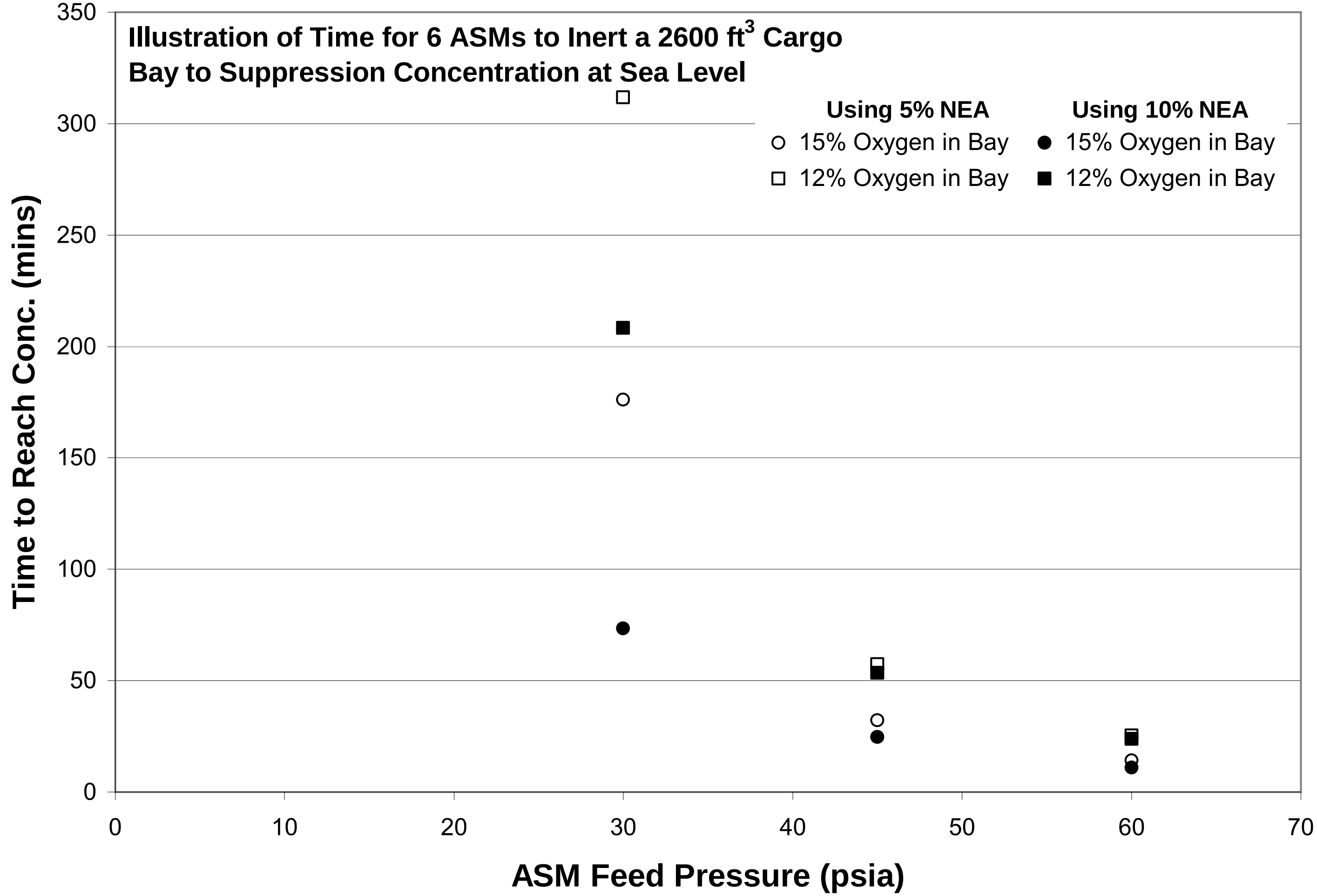
Results – Time to Inert

- Used the model to calculate oxygen concentration time traces given different ASM and cargo bay conditions for an empty 2600 cubic ft bay with no net leakage
- Results show expected trends
  - Very sensitive to ASM feed pressure
  - Permeate alt. is also important
  - Decreasing cargo bay pressure gives smaller time to inert values



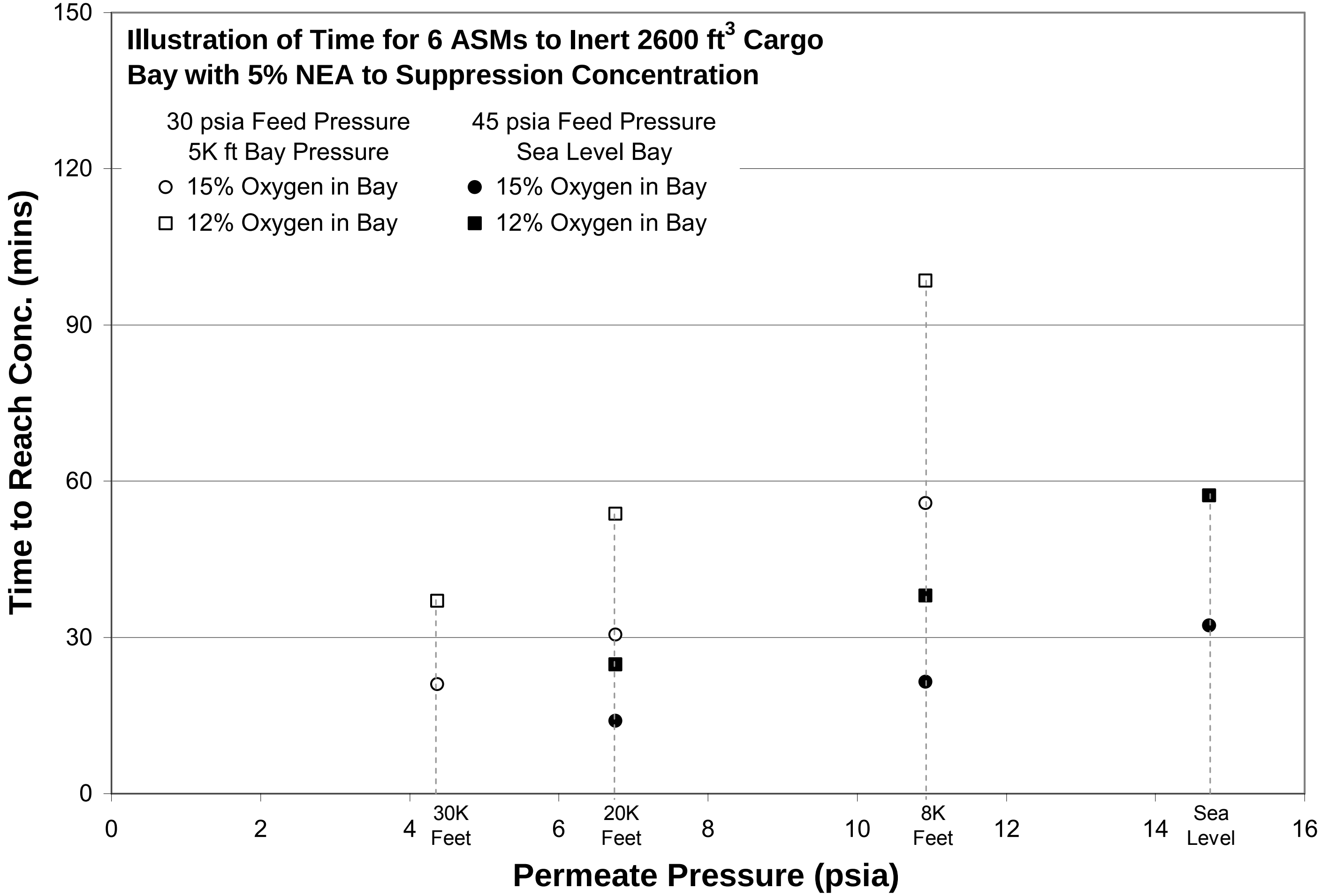
OBIGGS Cargo Bay Fire Protection

Results of Time to Inert Calculations



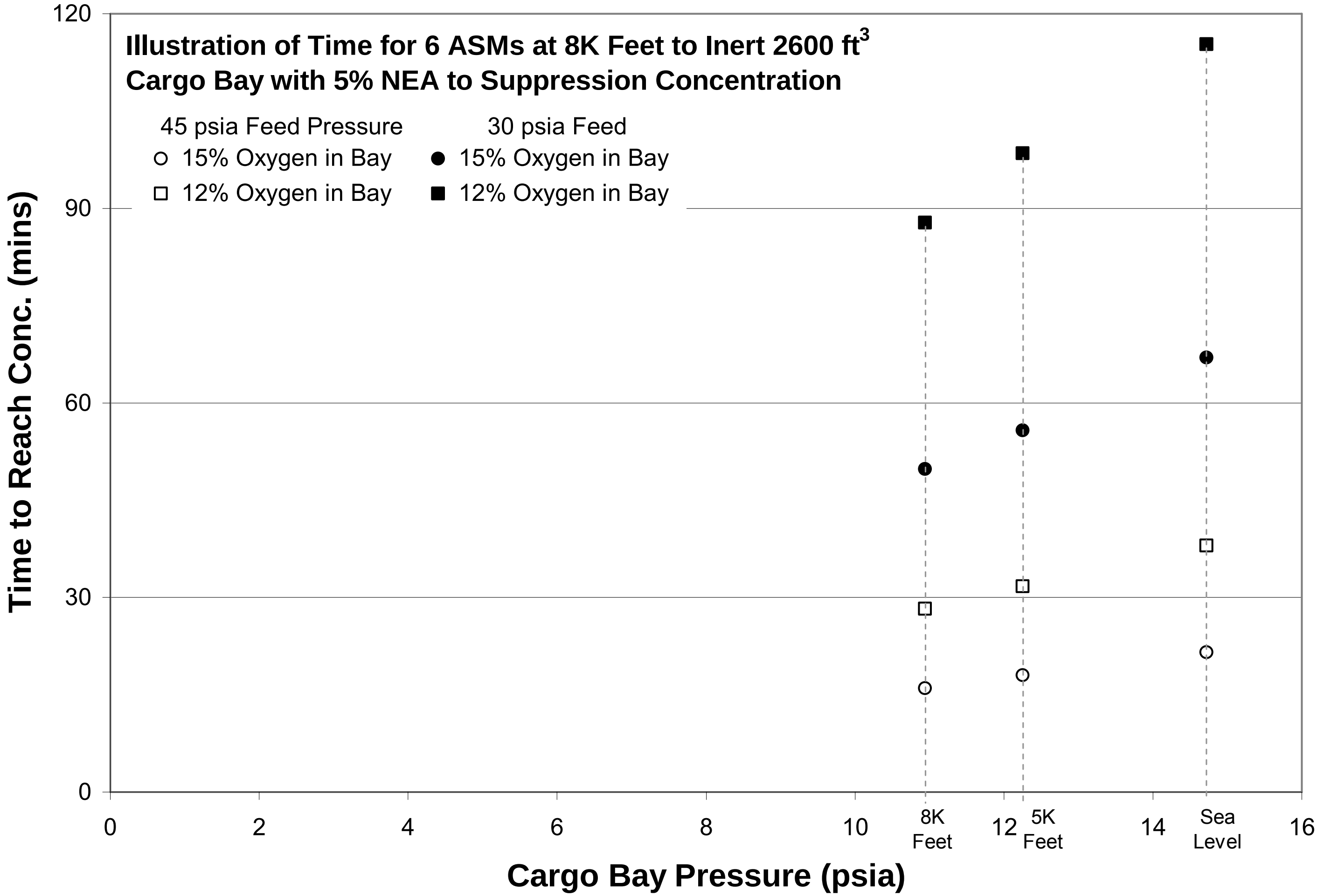
OBIGGS Cargo Bay Fire Protection

Results of Time to Inert Calculations



OBIGGS Cargo Bay Fire Protection

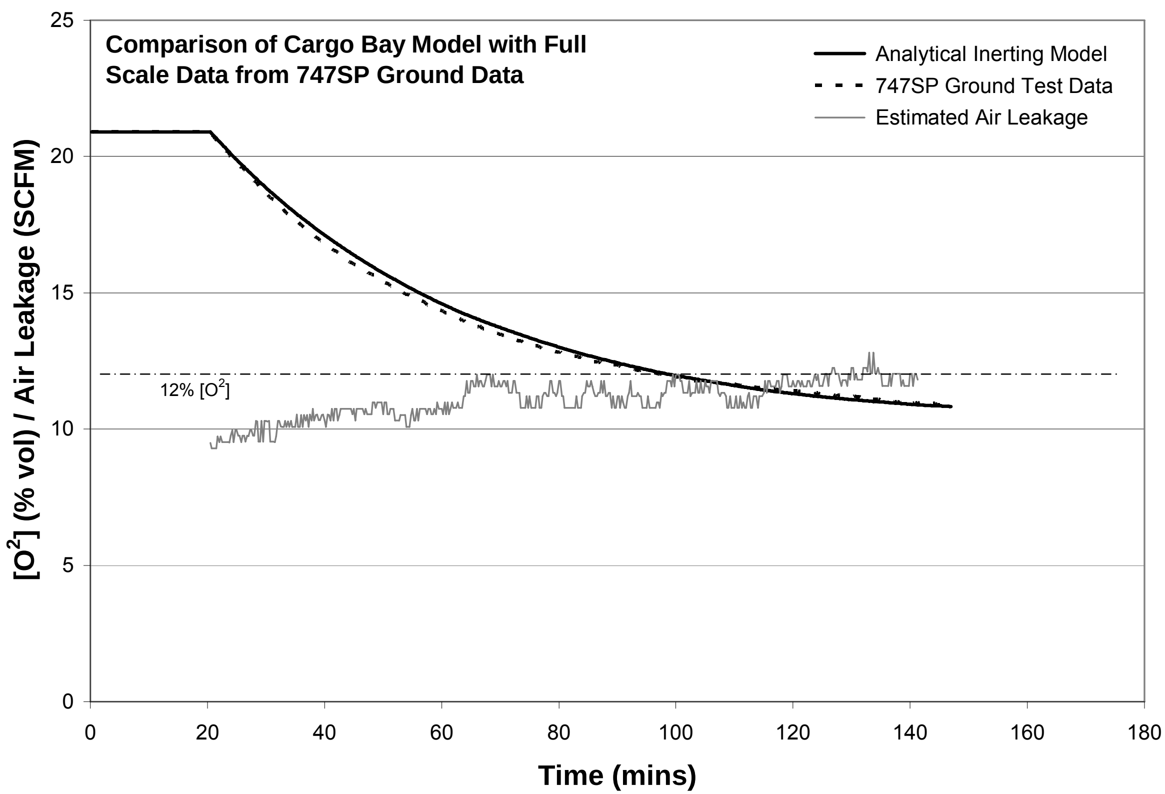
Results of Time to Inert Calculations



OBIGGS Cargo Bay Fire Protection

Results – Time to Inert Validation

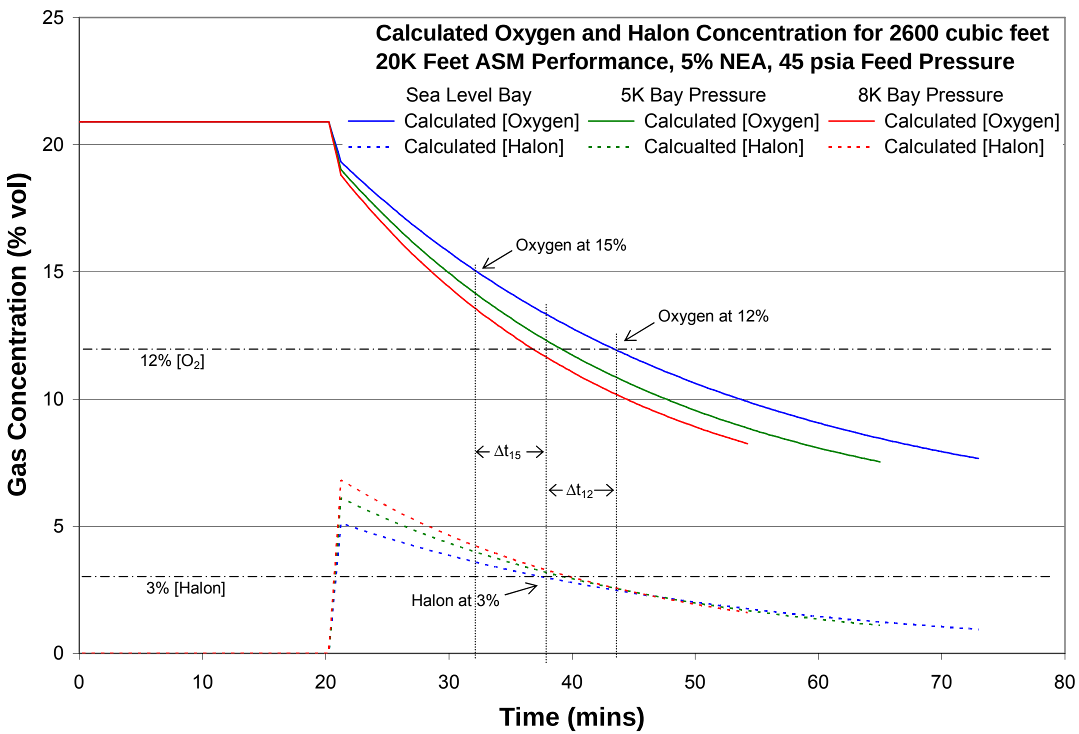
- Performed full-scale tests of time to obtain suppression concentrations in the 747SP cargo bay
- Results give good agreement but air leakage rate is assumed
  - With cargo bay size not being exact, there is room for data to be manipulated



OBIGGS Cargo Bay Fire Protection

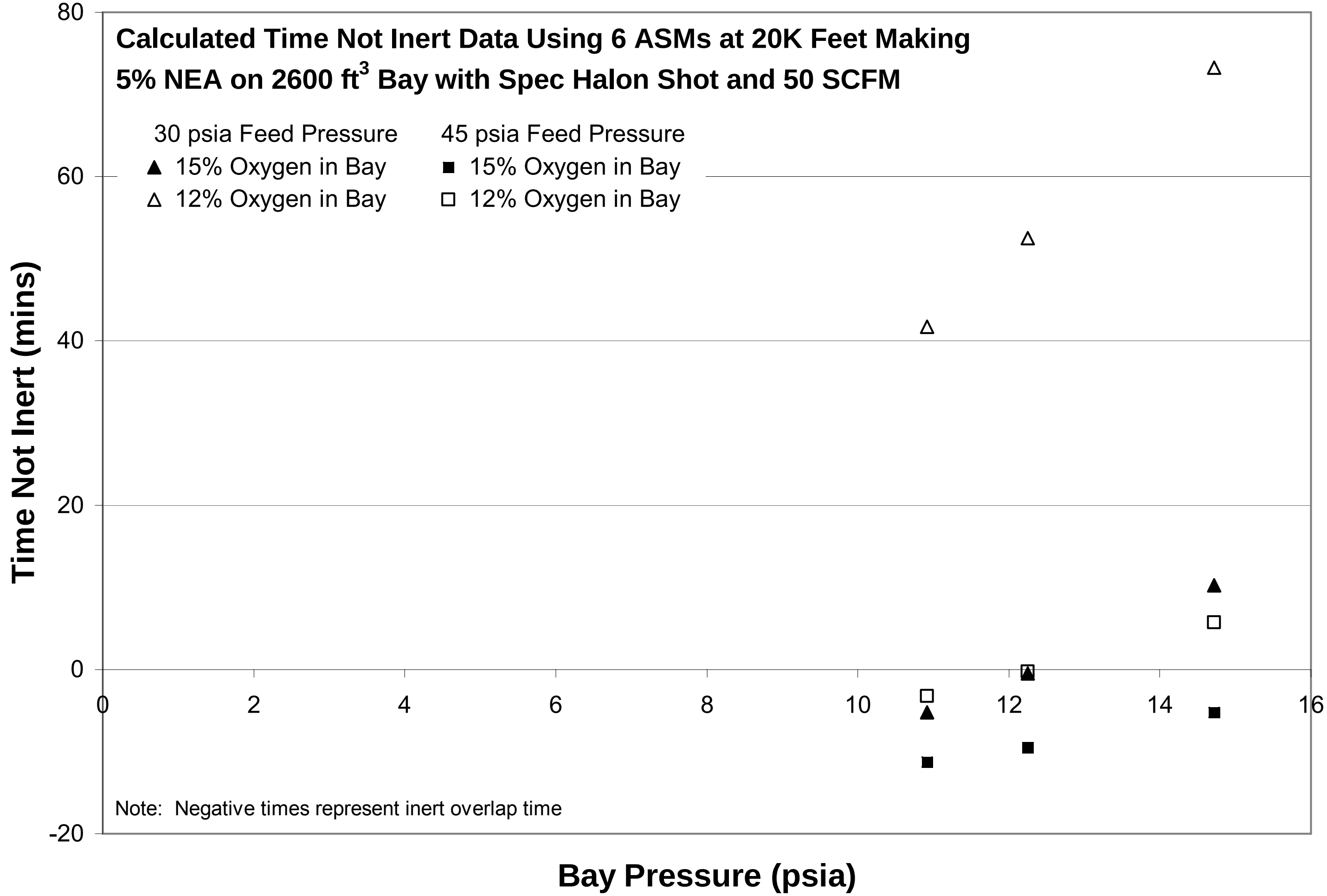
Results – Time not Inert

- Used model to calculate oxygen and Halon concentration time traces given different ASM and cargo bay conditions varying feed pressure with empty 2600 ft^3 bay and 50 SCFM Leakage and 5% Halon Shot
- Similar Trends Except:
  - Can't get lower than 16% with 30 psia Feed P below 20K feet Permeate
  - 5% NEA better than 10% because flow displaces less Halon



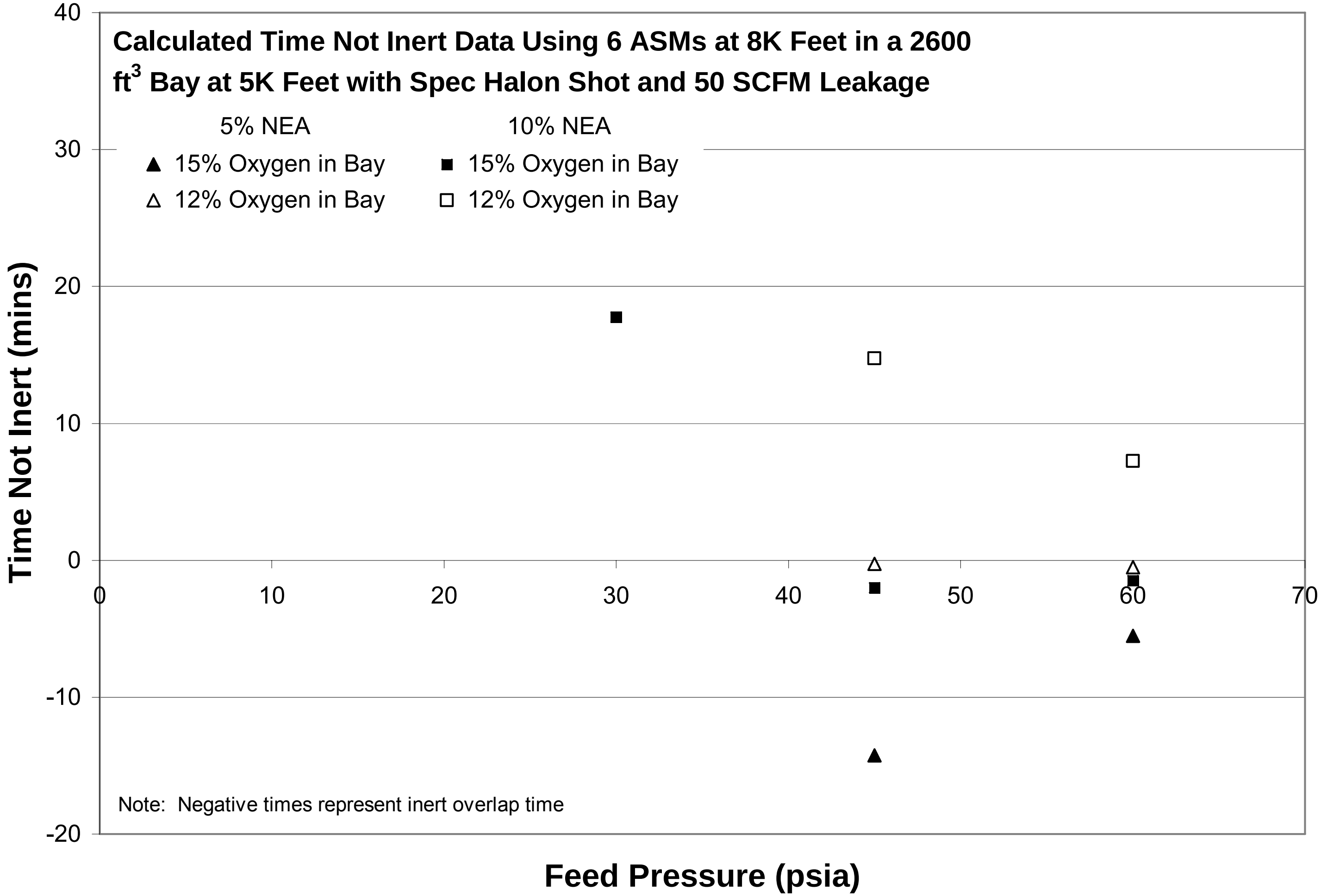
OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Calculations



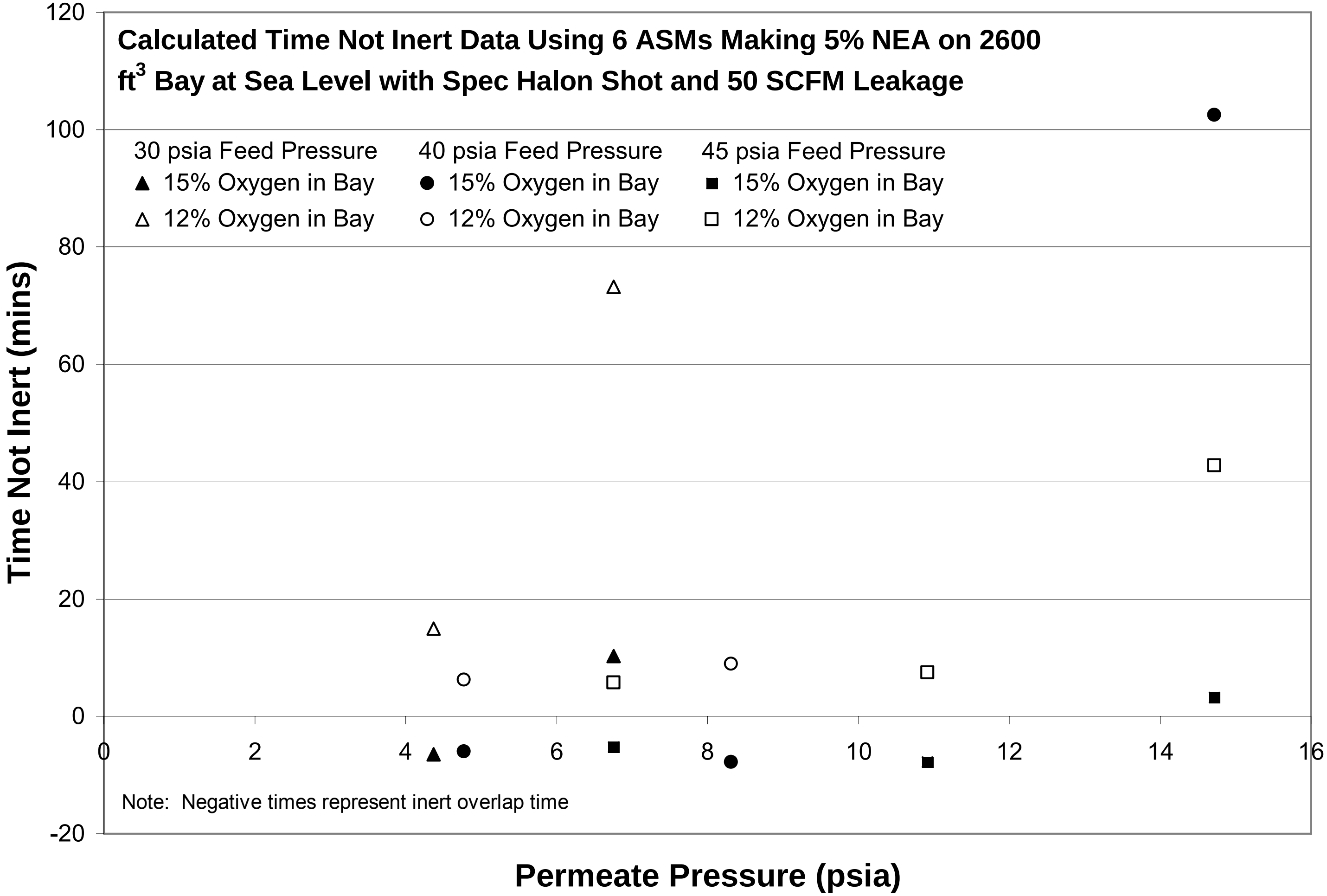
OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Calculations



OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Calculations



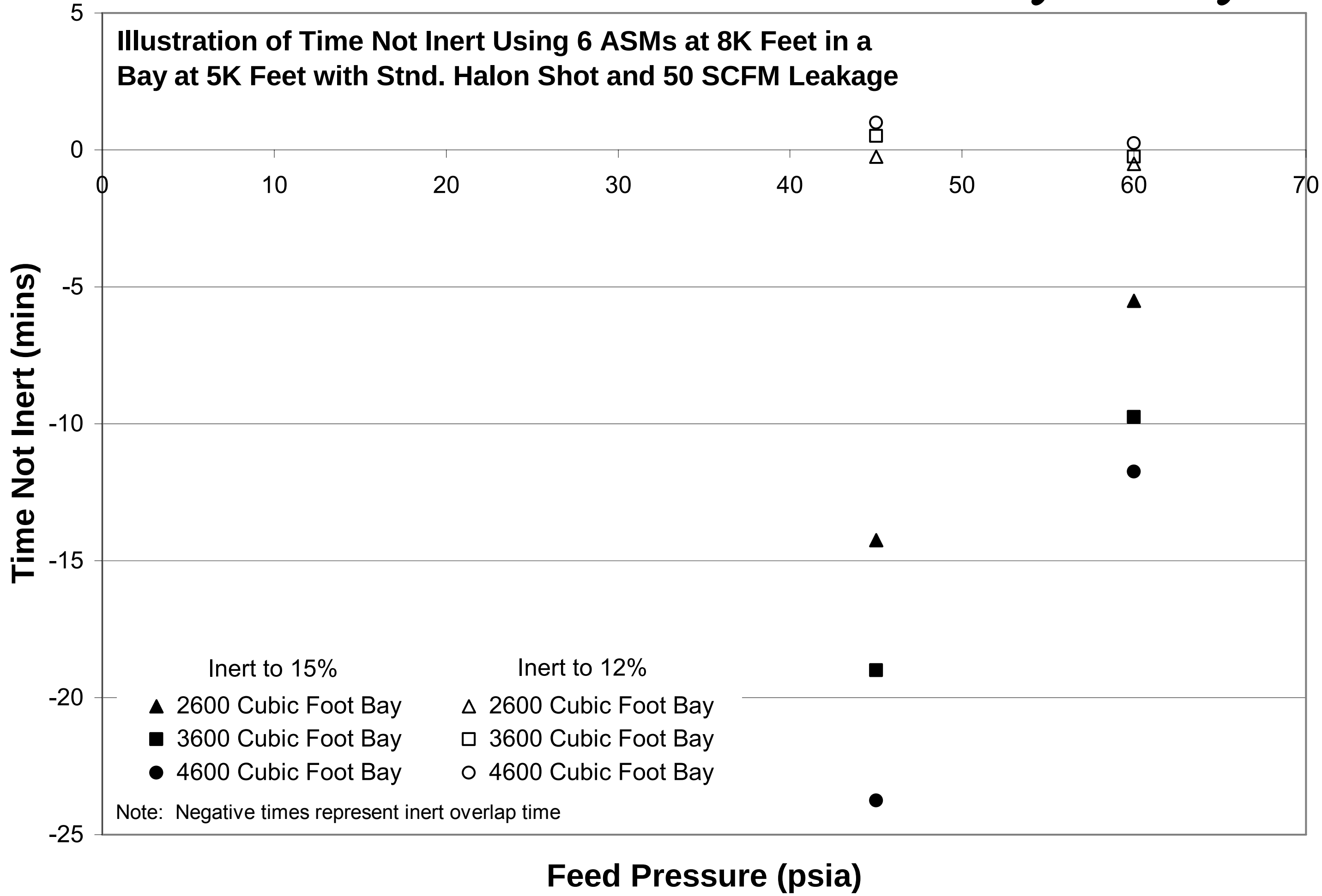
OBIGGS Cargo Bay Fire Protection

Results – Time not Inert Sensitivity

- Wanted to see sensitivity of results to the constant parameters of bay size, Halon shot, leakage rate, and cargo load
- Size of cargo bay had very little impact on time not inert
  - Bigger cargo bay means bigger Halon shot
- Halon shot size decreased time not inert as expected
- Sensitivity to leakage rate is expected
  - Need to have a good idea of leakage rate and bleedair pressure during your descent to ensure the cargo bay stays protected during remainder of flight
- Increased cargo load also has the expected result of decreasing time not inert
  - 50% cargo load decreased 90 minute time not inert to 0

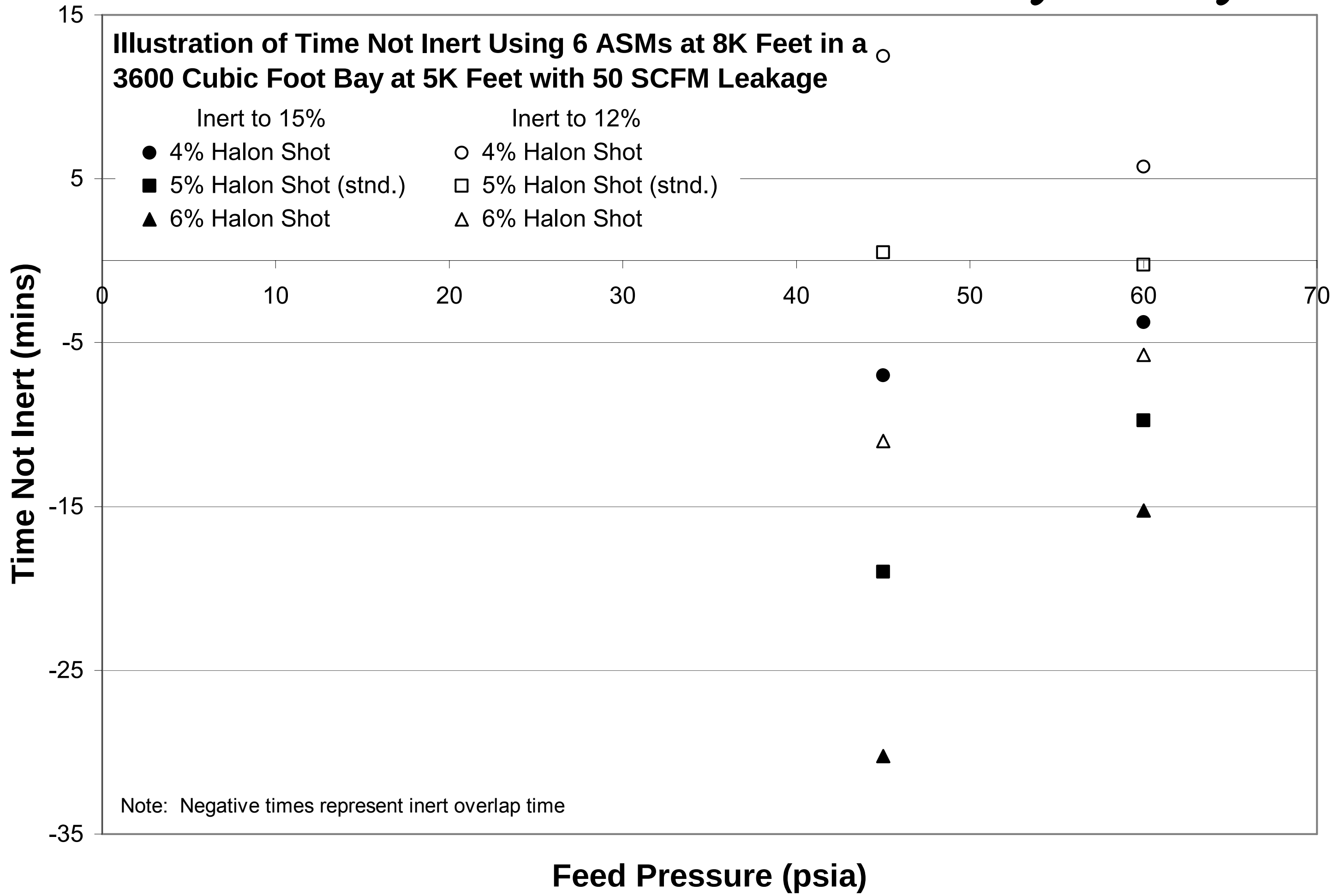
OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Sensitivity Analysis



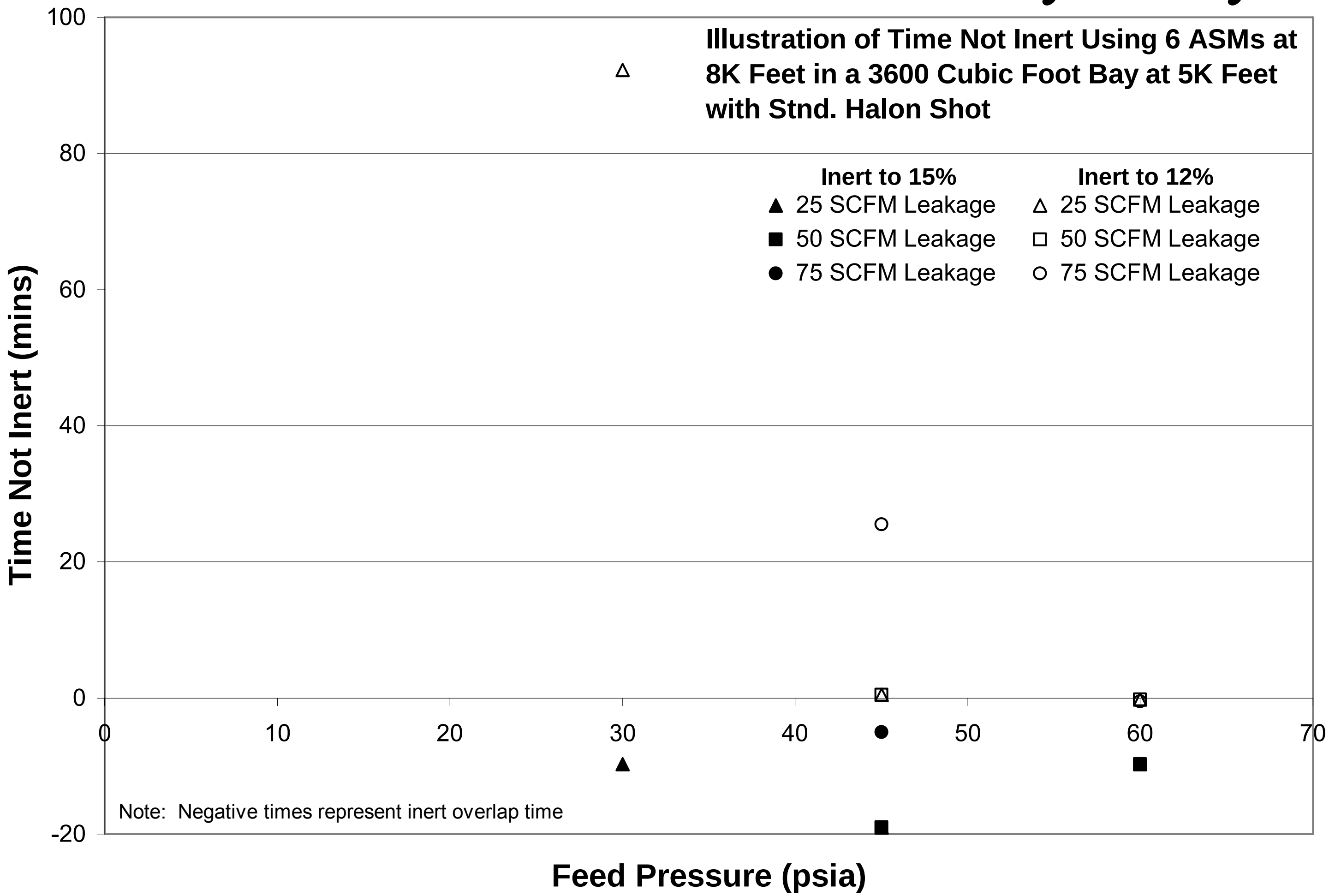
OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Sensitivity Analysis



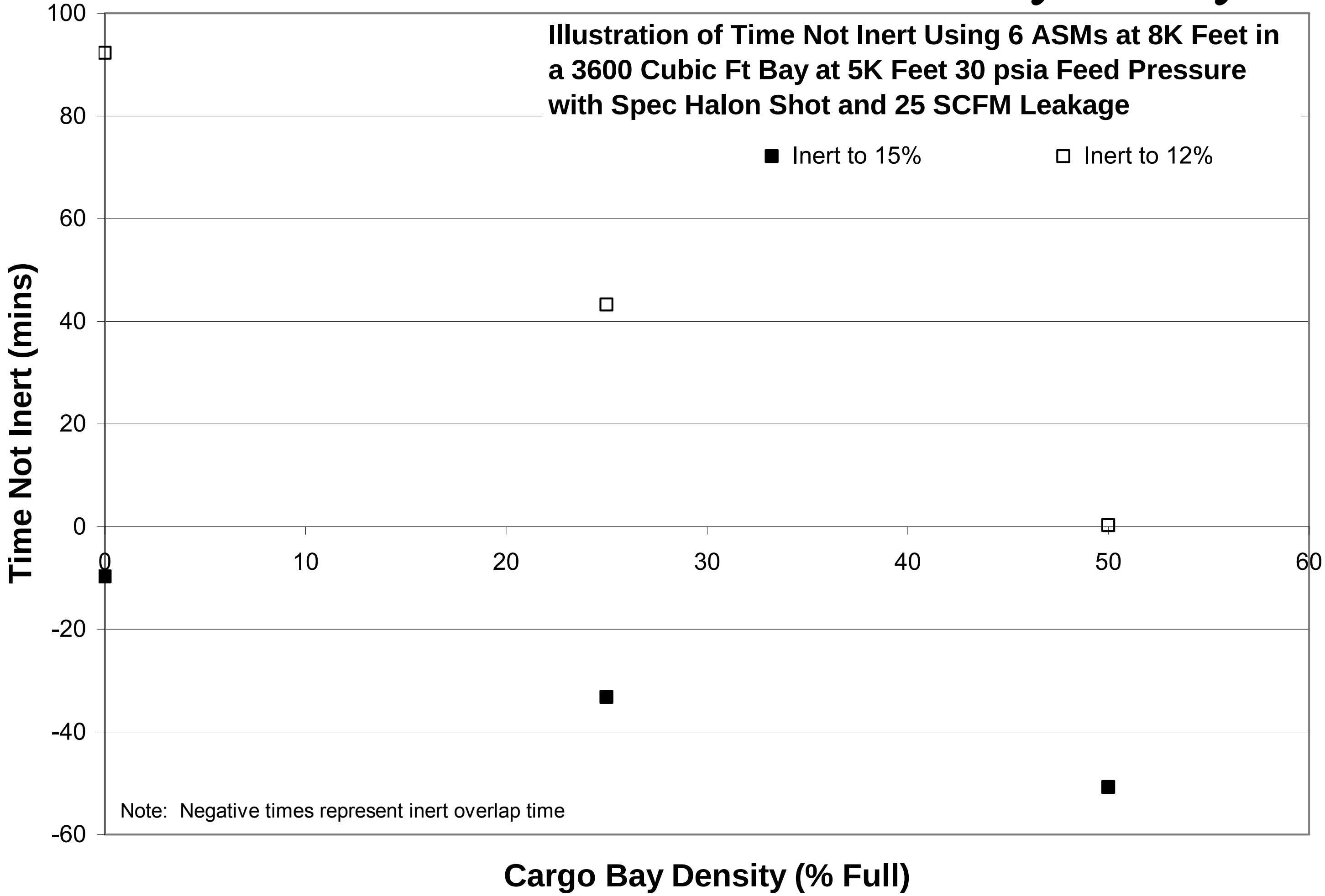
OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Sensitivity Analysis



OBIGGS Cargo Bay Fire Protection

Results of Time Not Inert Sensitivity Analysis



OBIGGS Cargo Bay Fire Protection

Summary

- Results indicate OBIGGS requirements are consistent with cargo bay fire protection
  - NEA flow very sensitive to bleed air pressure
- Time to inert results illustrate expected trends
  - Decreases in permeate pressure (alt. increase) decrease time to inert
- Time not inert results (with Halon) illustrate expected trends
  - Decreases in permeate pressure (alt. increase) decrease time to inert
  - Decreases in bay pressure also decrease the time to inert
  - Leakage rate makes some 30 psia feed pressure points unattainable
- Sensitivity of time not inert results shows results not sensitive to cargo bay size, but cargo density has large effect
  - Feed pressure and leakage rate to need to analyzed and accounted for in design

OBIGGS Cargo Bay Fire Protection

Recommendations

- Need to understand better the benefit of any interaction between Halon and reduced oxygen concentration on cargo bay fire scenarios
- Need to validate the existing cargo bay inert gas/halon model
- Need to better understand air leakage cause and effect in cargo bays and specifically how the leakage rate changes with altitude and with the amount of NEA deposited in the bay