Cargo Bay Fire Suppression Using a Fuel Tank Inerting System

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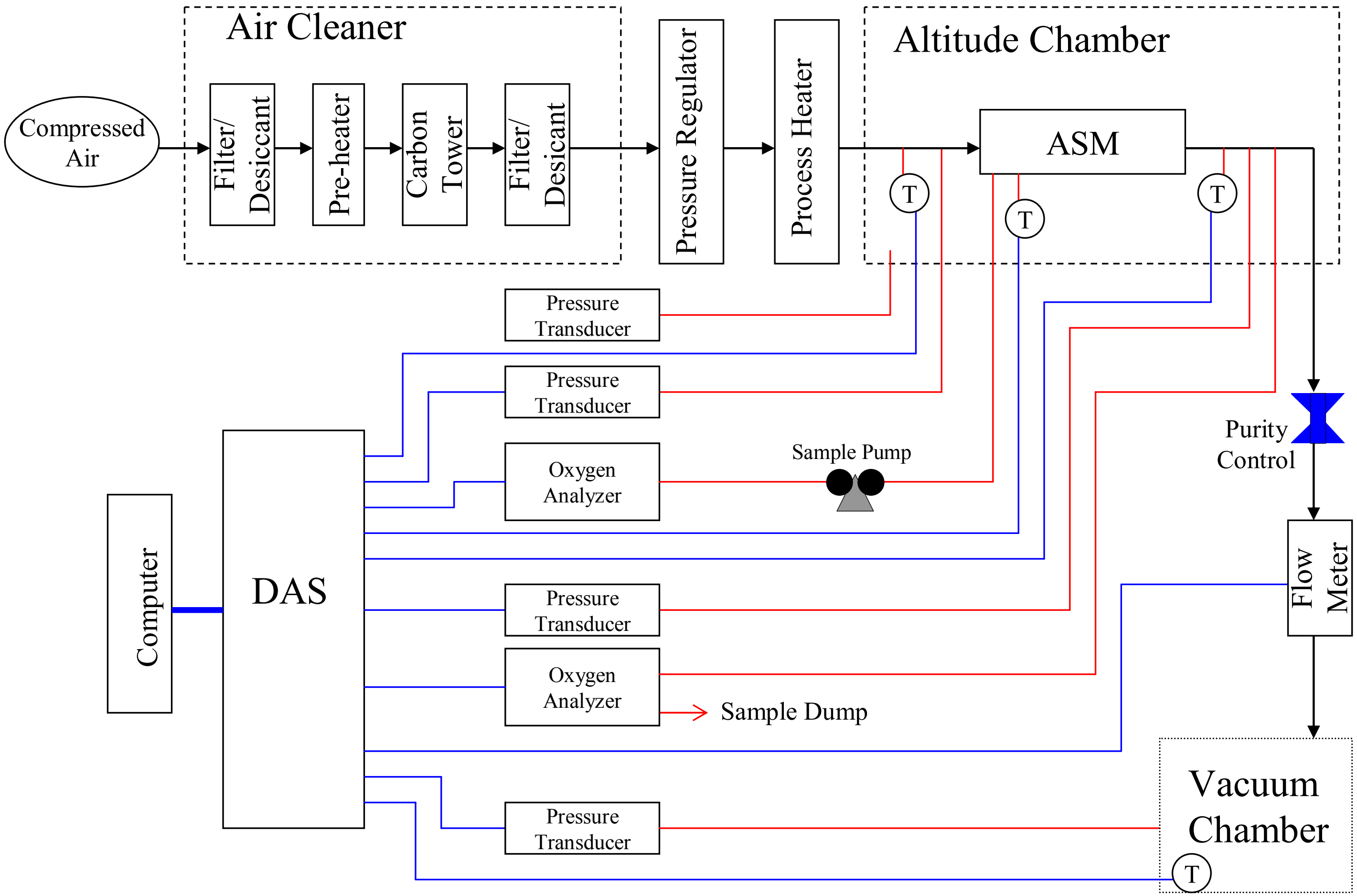
Background

- 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
- 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 for leakage, based on the aircraft type
  - It remains to be seen how useful an OBIGGS designed to inert the CWT of an aircraft would be for this purpose

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, bleed air pressures, and cargo bay altitudes to examine the ability for an inerting system to reduce the oxygen concentration of a cargo bay

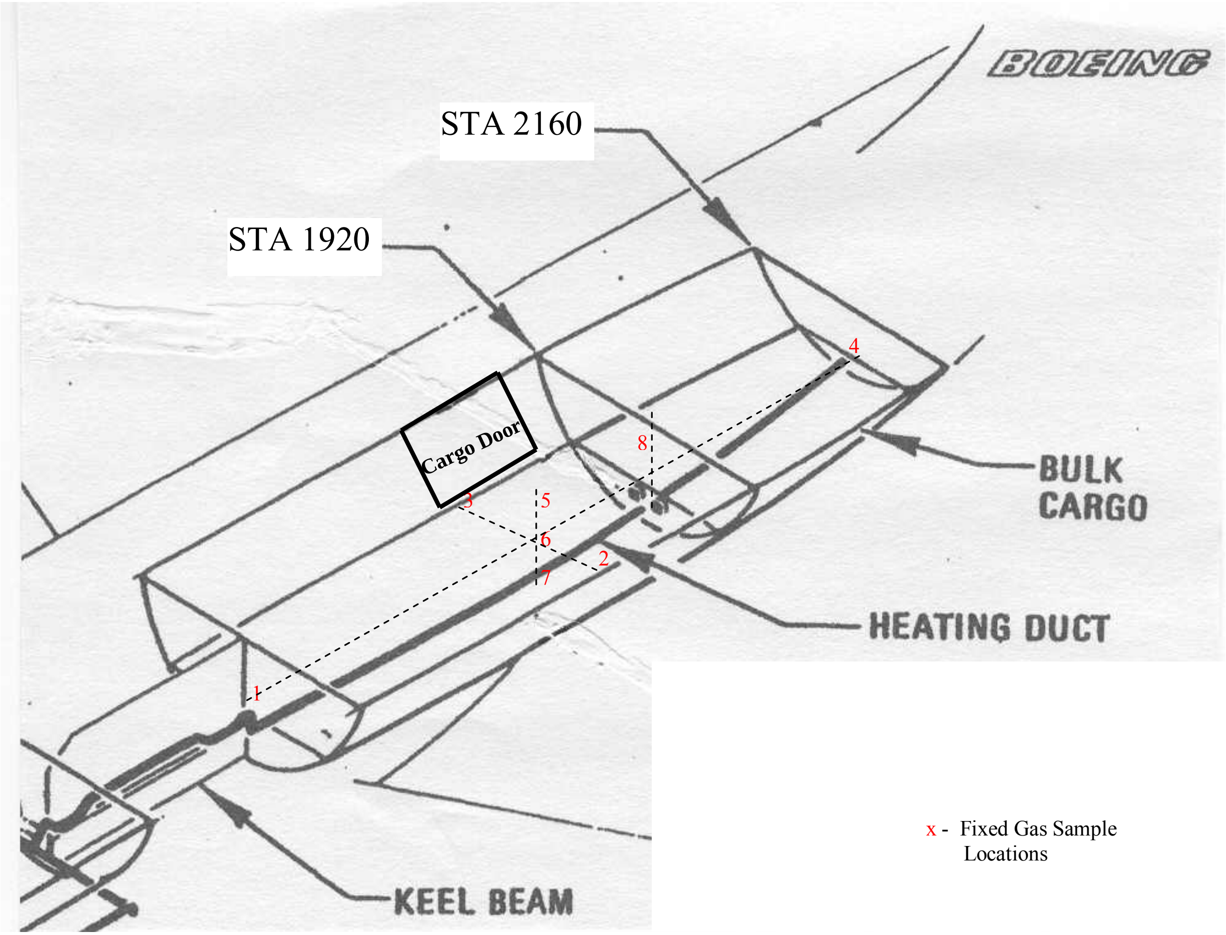
Block Diagram of ASM Performance Test Apparatus



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

Rendering of Cargo Bay with Gas Sample Locations



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 tank due to depositing inert gas, changing cargo bay pressure altitude, and a fixed air leak rate in
  - All model calculations were 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 cargo bay of fixed volume with a constant leakage using NEA
    - Model assumes NEA flow “holds back” the leakage
- Added routine to calculate Halon concentration
  - Used model to determine time not inert for previously studied OBIGGS/aircraft conditions using given Halon discharge in the same cargo bay with assumed leakage (assume 3% Halon inerting conc.)

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

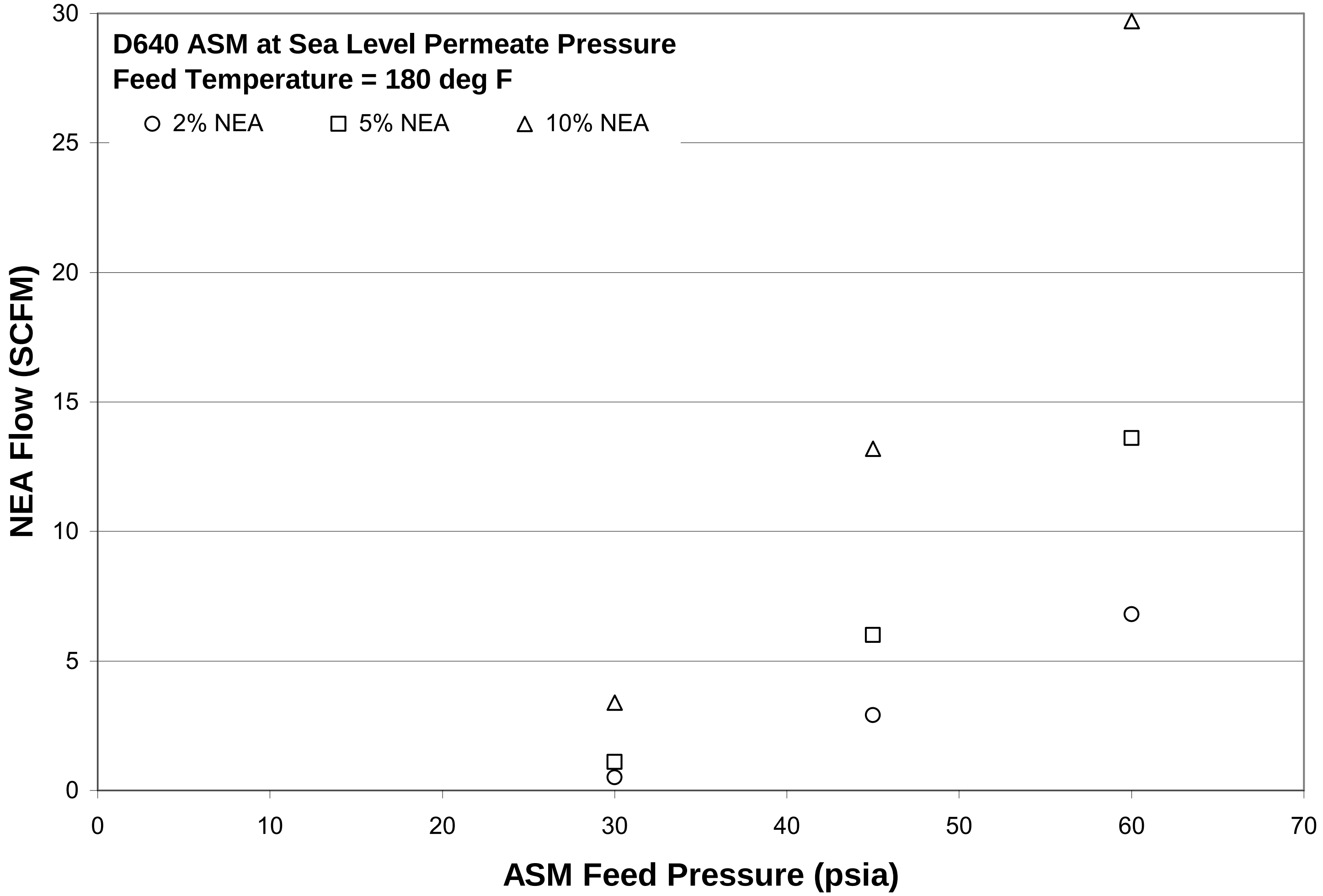
$$M_{\text{Halon}_{\text{Bay}}}(t) = M_{\text{Halon}_{\text{Bay}}}(t-1) + \Delta M_{\text{Halon}_{\text{Bay}}}$$

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

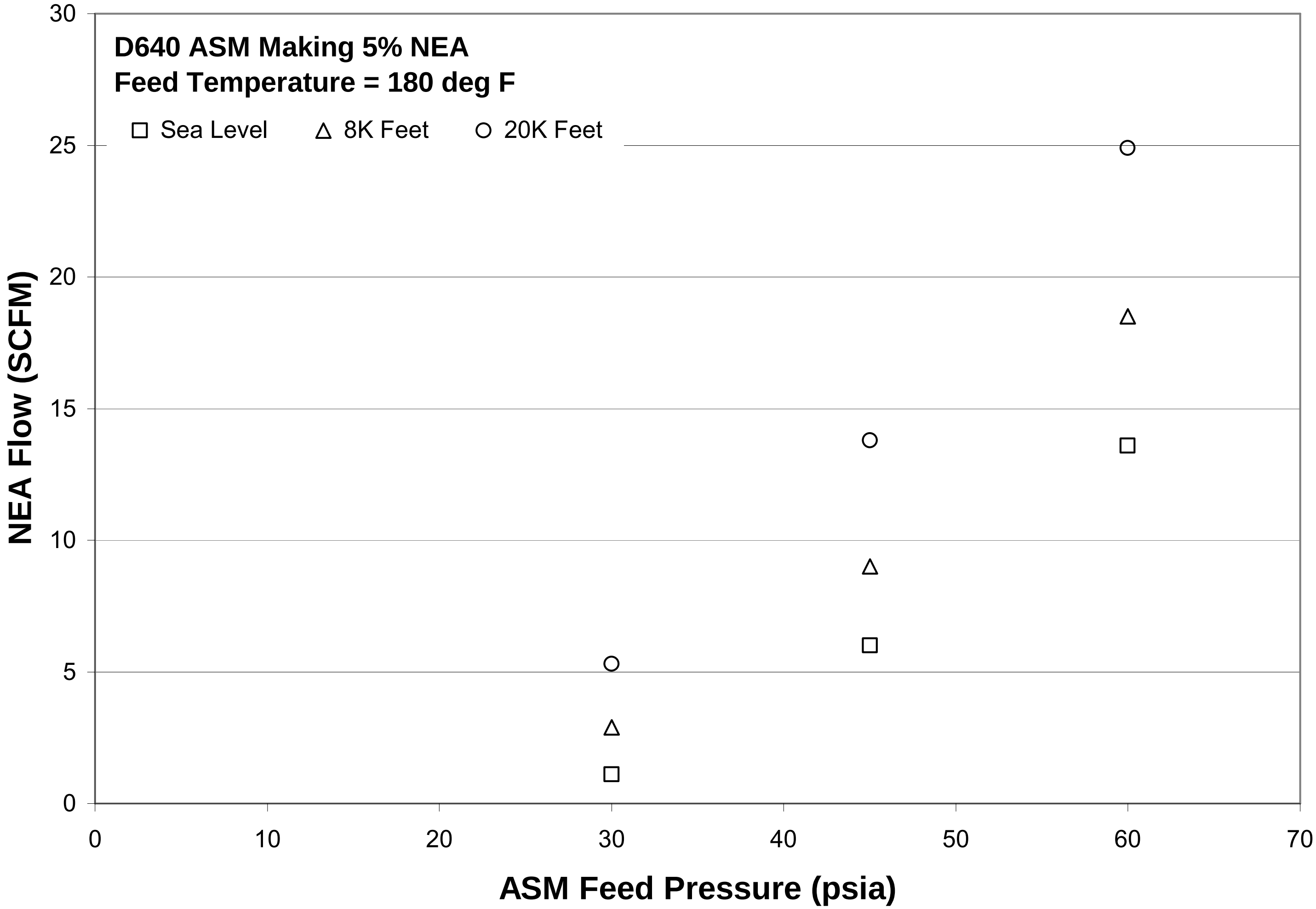
Results – ASM Performance Data

- 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

Results of ASM Performance Testing



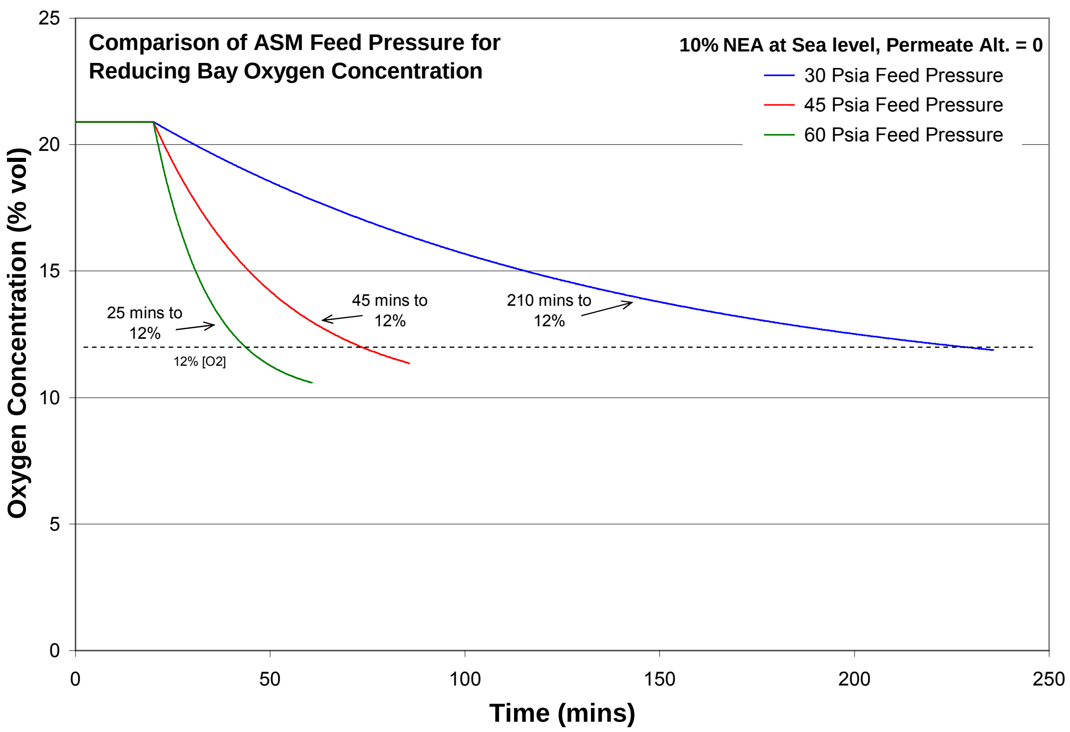
Results of ASM Performance Testing



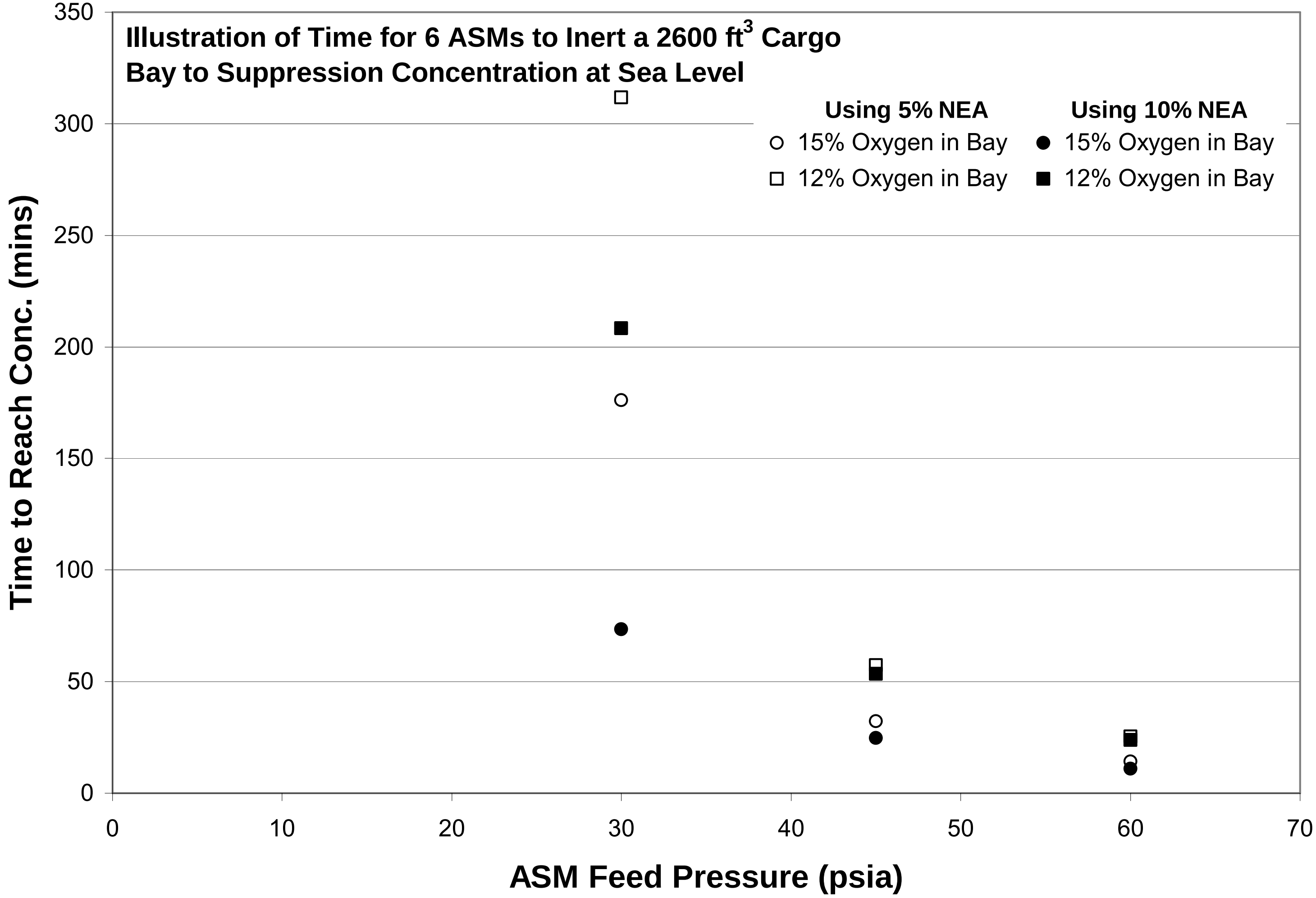
Results – Time to Inert

- 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



Results of Time to Inert Calculations



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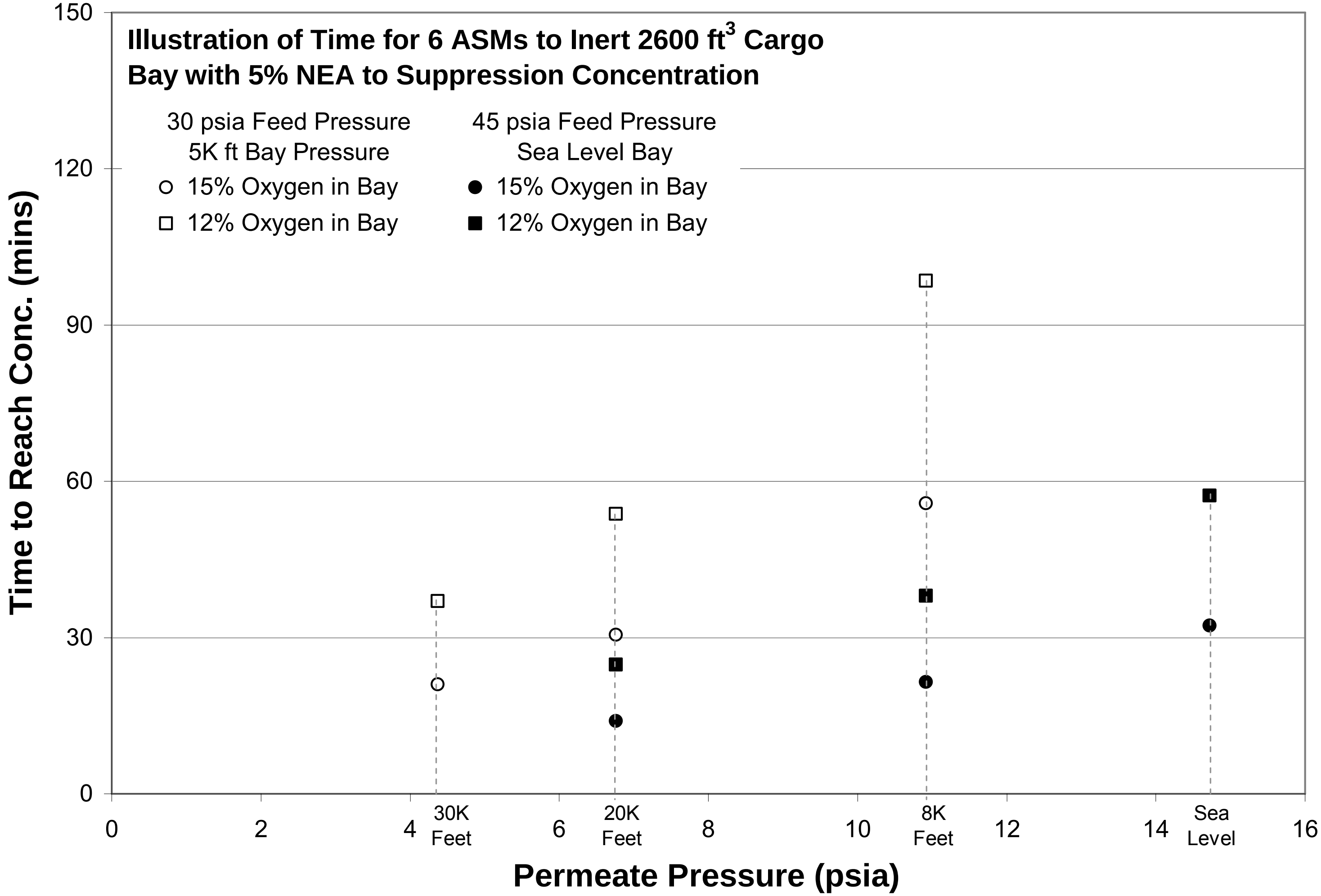
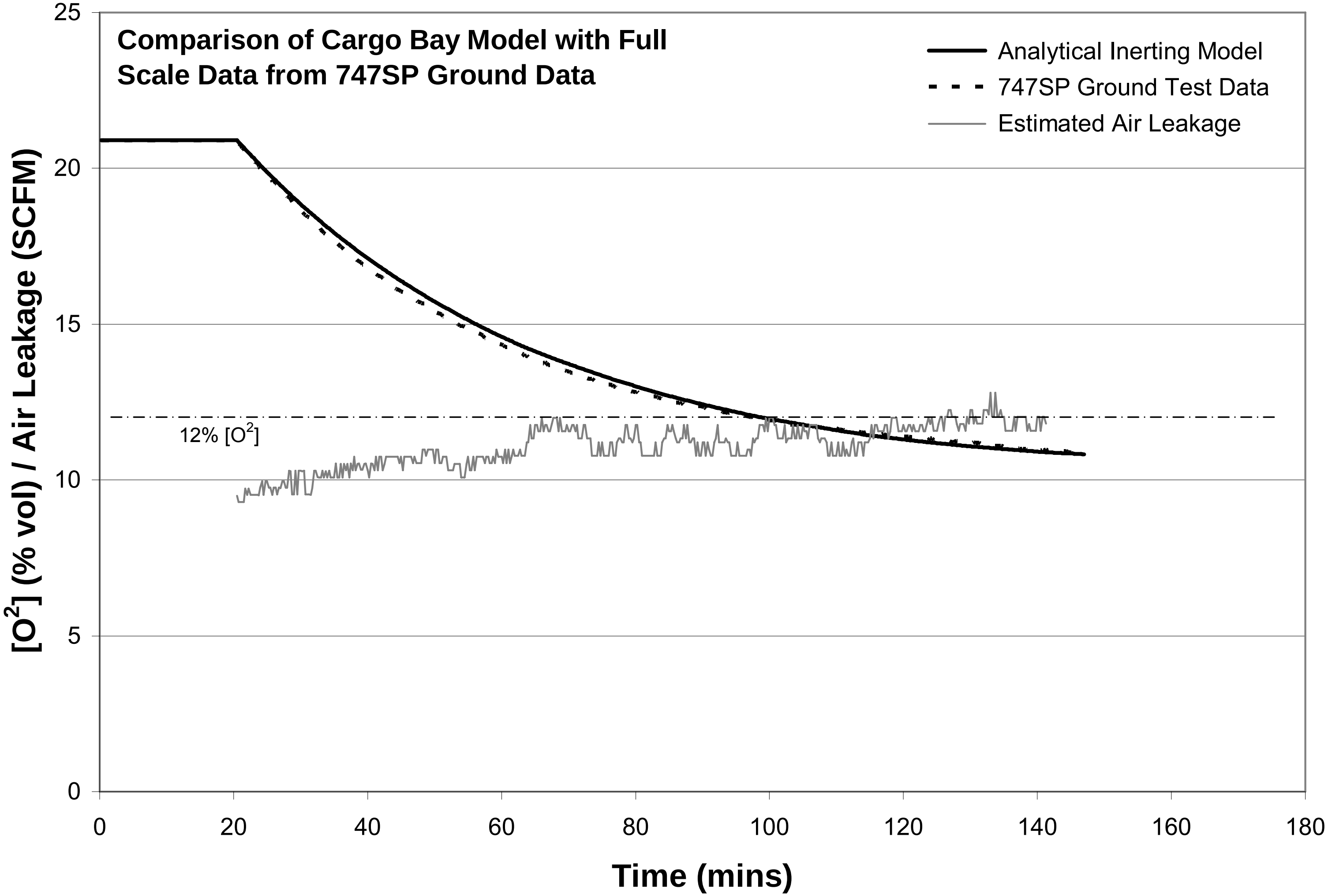
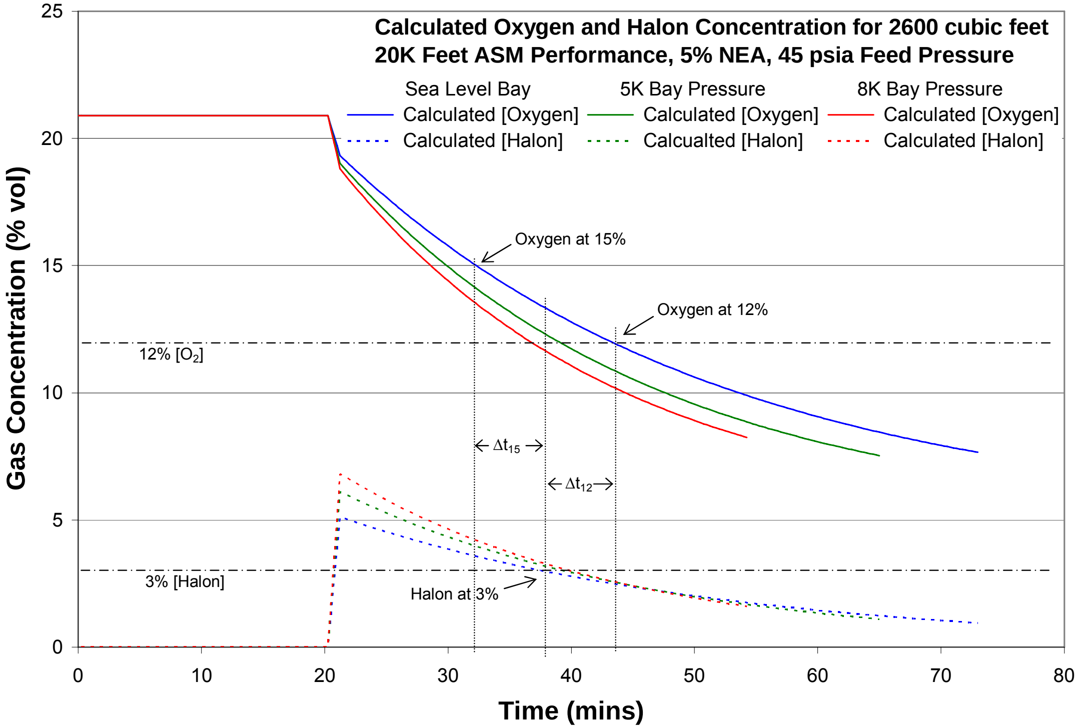


Results of Model Full-Scale Validation



Results – Time not Inert

- Used model to calculate oxygen and Halon concentration time traces given different ASM, cargo bay, and feed pressures 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



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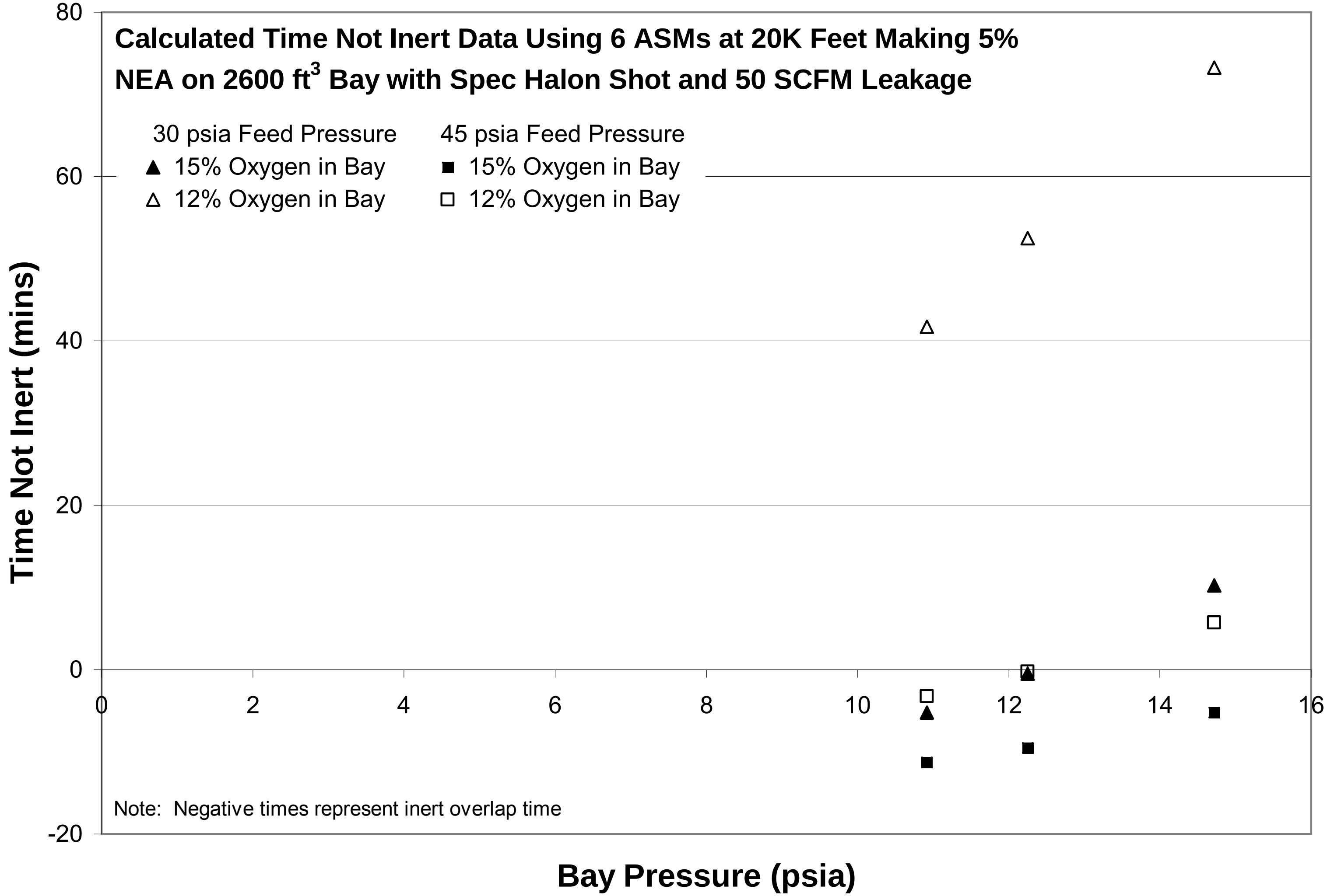

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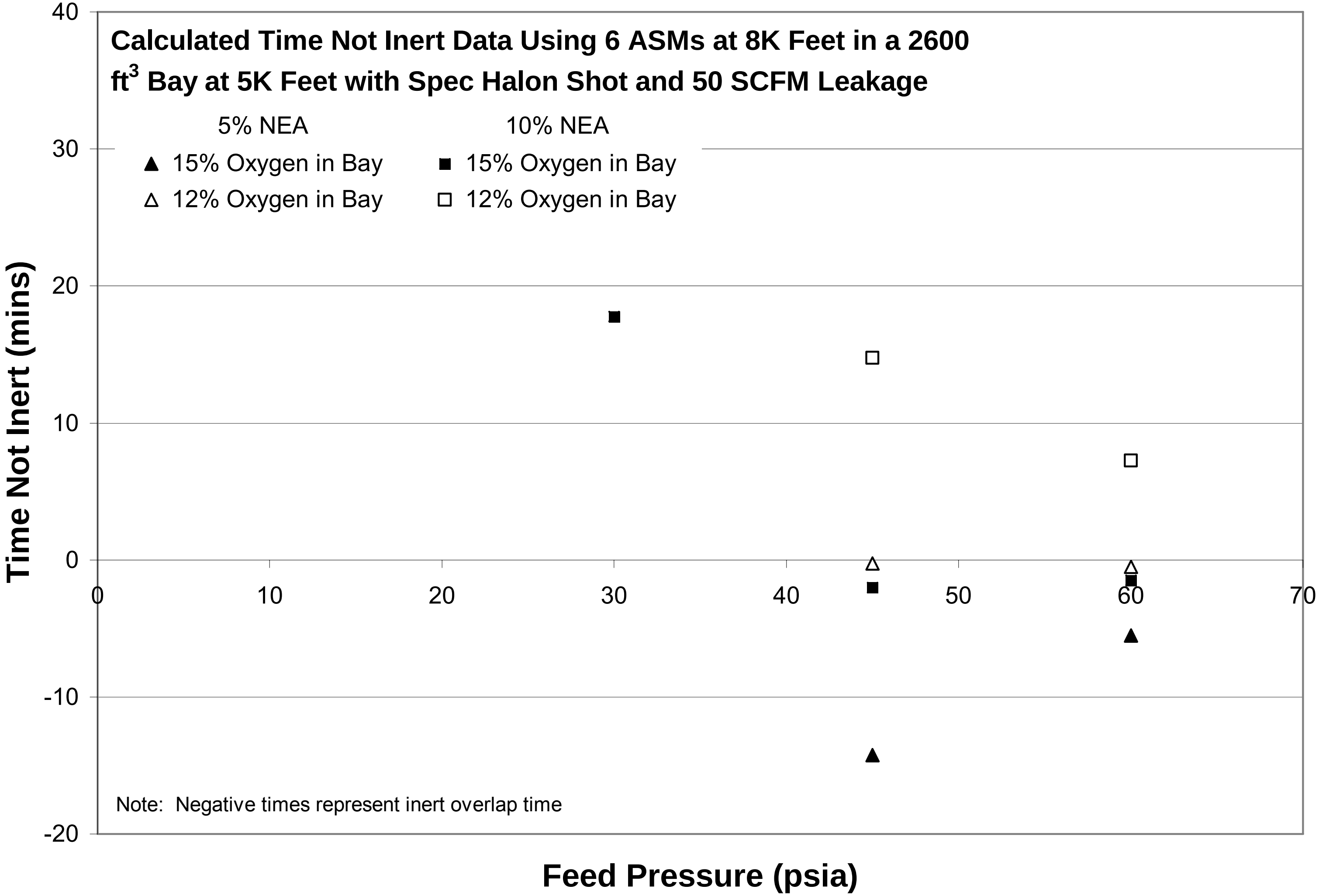
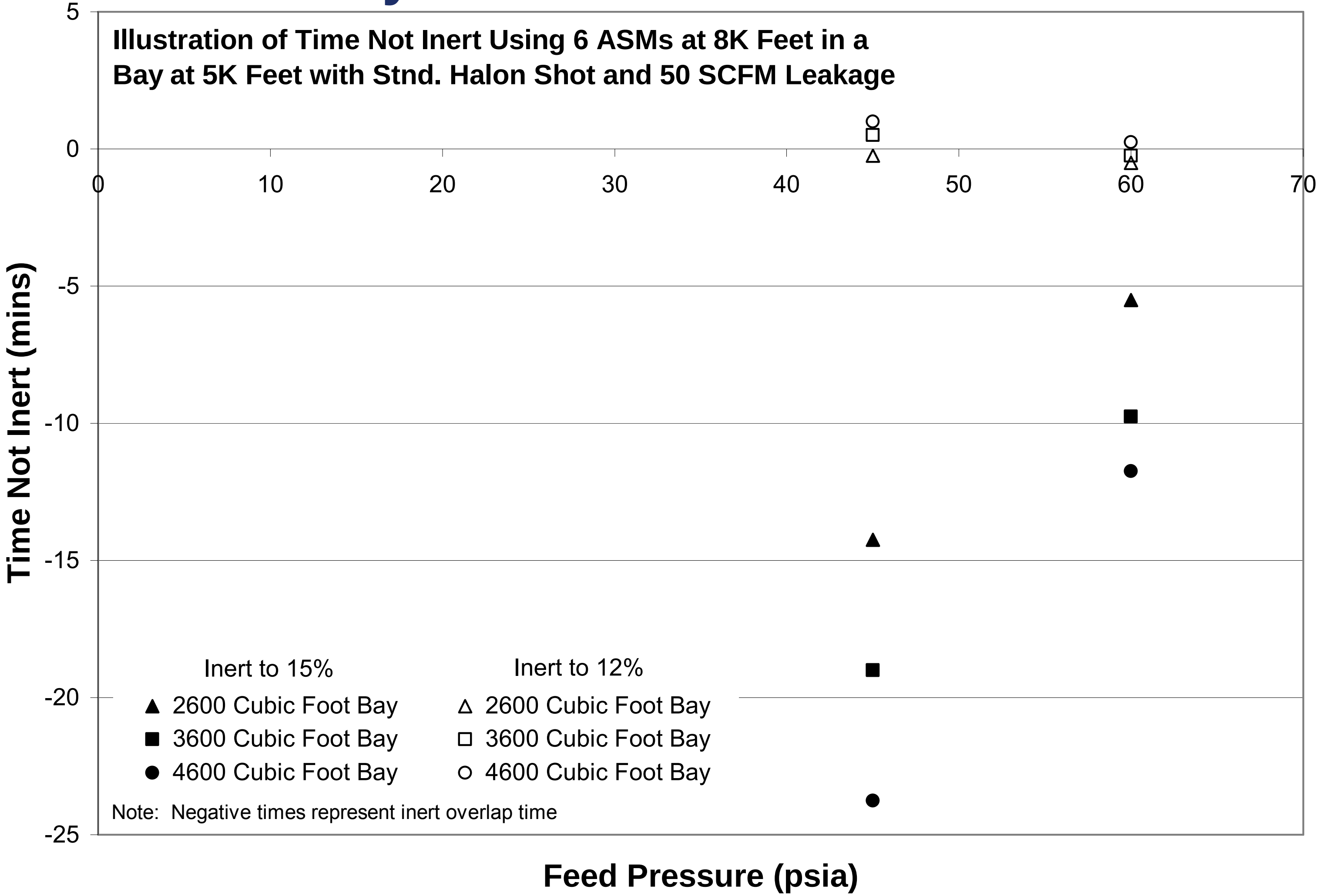


Results – Time not Inert Sensitivity

- 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 (12% O_2)

Sensitivity of Time Not Inert Calculations



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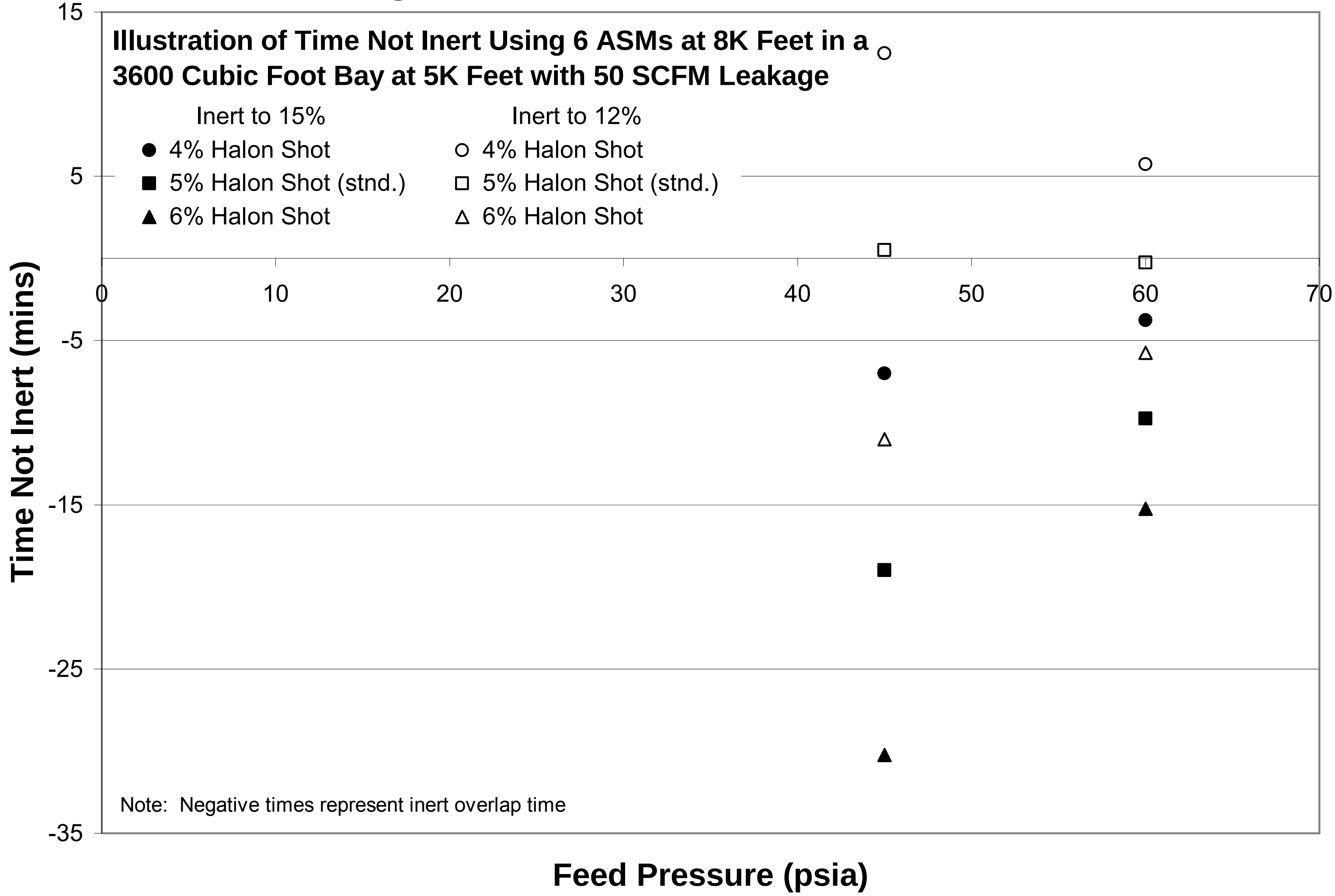

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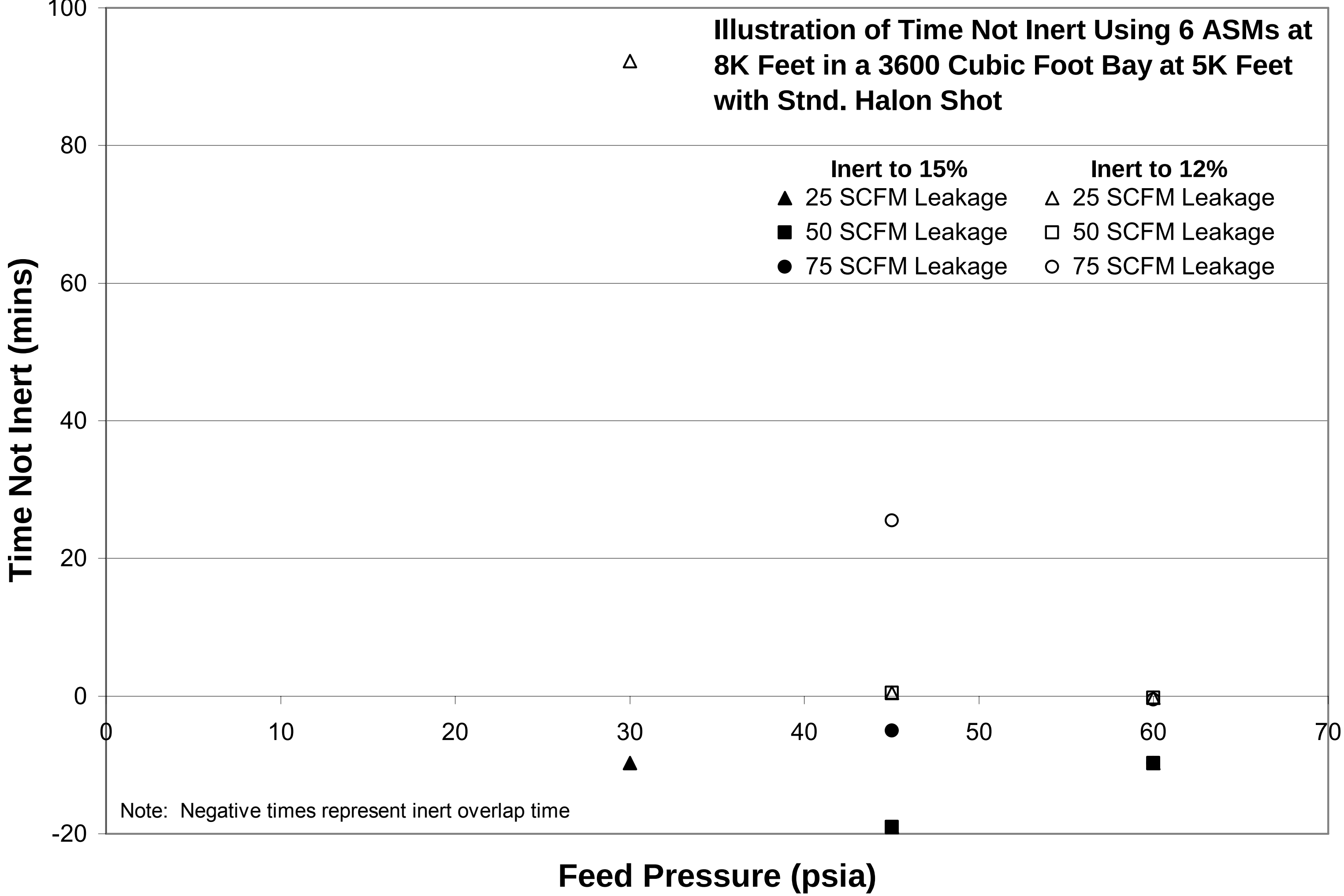

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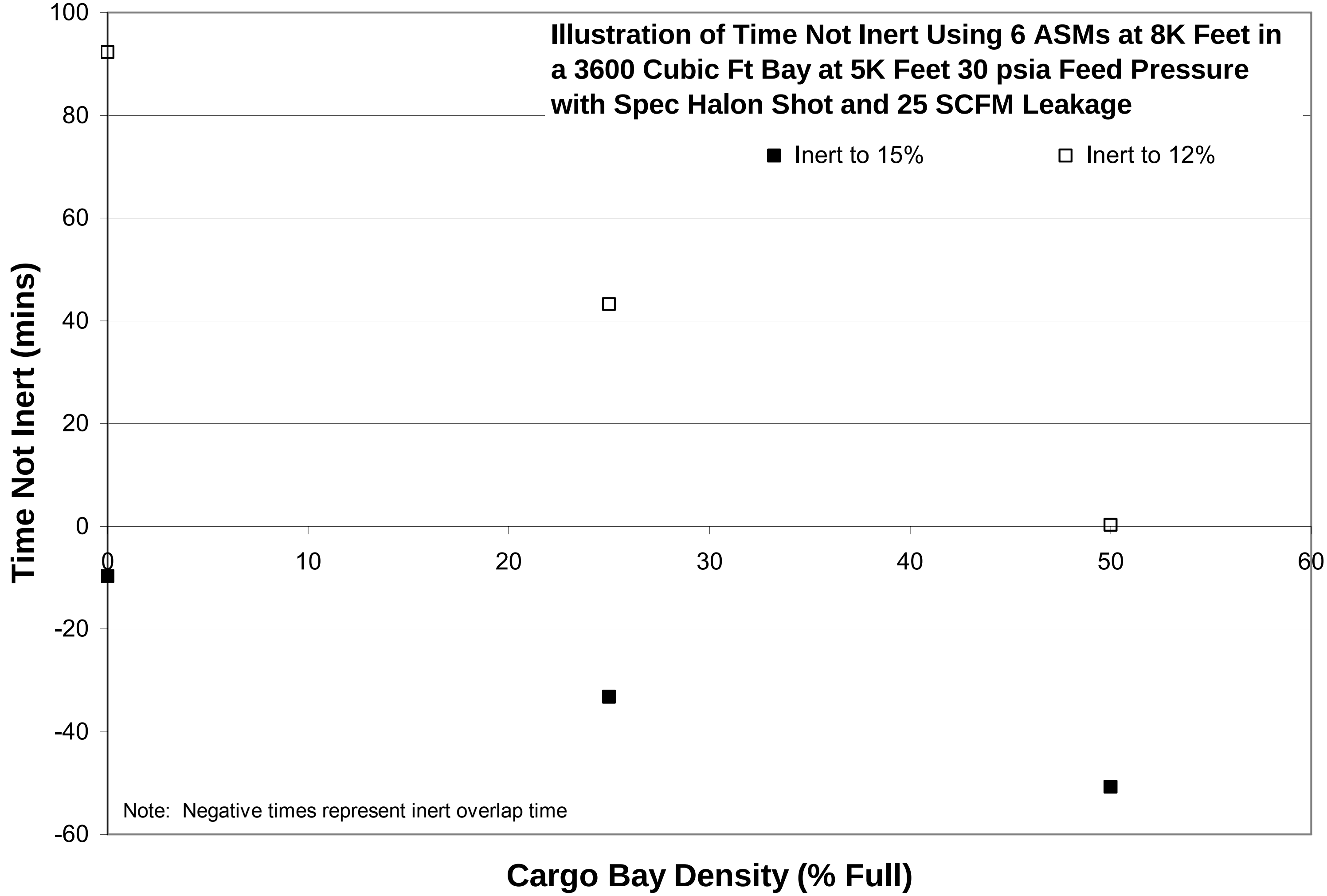

Summary

- 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
  - Decrease in permeate pressure (alt. increase) decrease time to inert
- Time not inert results (with Halon) illustrate expected trends
  - Decrease in permeate pres. (alt. increase) decrease time not inert
  - Decreases in bay pressure also decrease the time not inert
  - Leakage rate makes many 30 psia feed pressure points unattainable
- Sensitivity of time not inert results show results not sensitive to cargo bay size, but cargo density has large effect
  - Feed pressure and leakage rate to need to be analyzed and accounted for in design