



# Airplane Design Issues with Formation Flying

Massachusetts Institute of Technology  
16.899 Air Transportation Systems Architecting

Bob Liebeck  
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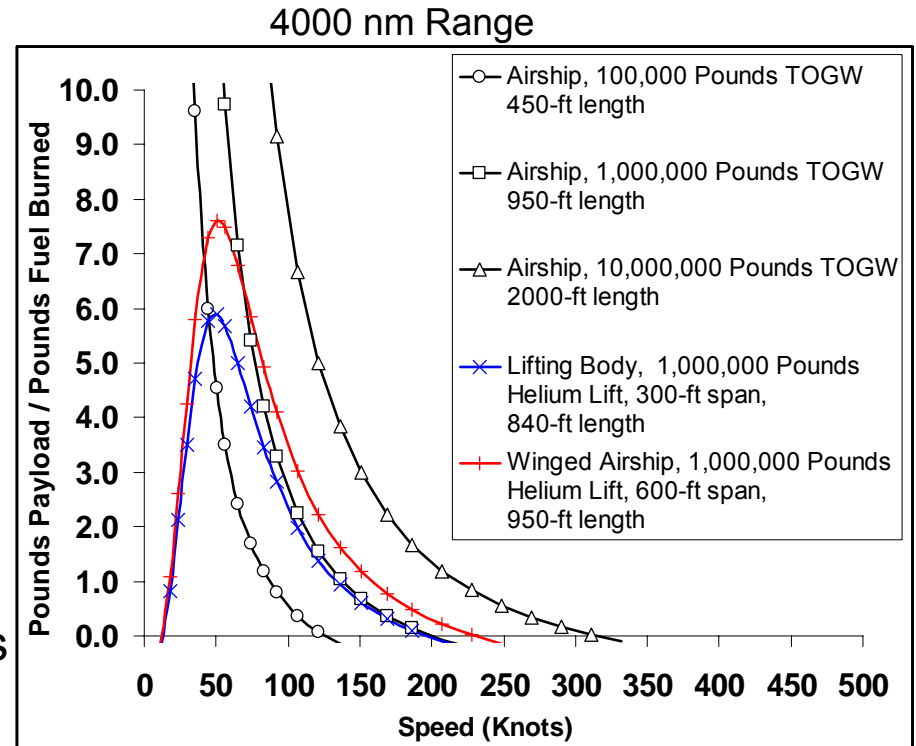


# Cargo Vehicle Designs

- Ships
  - very large displacement ships
  - semi-planing ships, fast catamarans
  - hydrofoils
- Airships
  - pure displacement
  - lifting body
  - hybrid (wing-body)
- Conventional Airplanes
- Modular/Convertible Airplanes
- Formation Flying
  - multiple airplanes in formation with one another
  - wing-in-ground-effect (airplane in formation with itself)

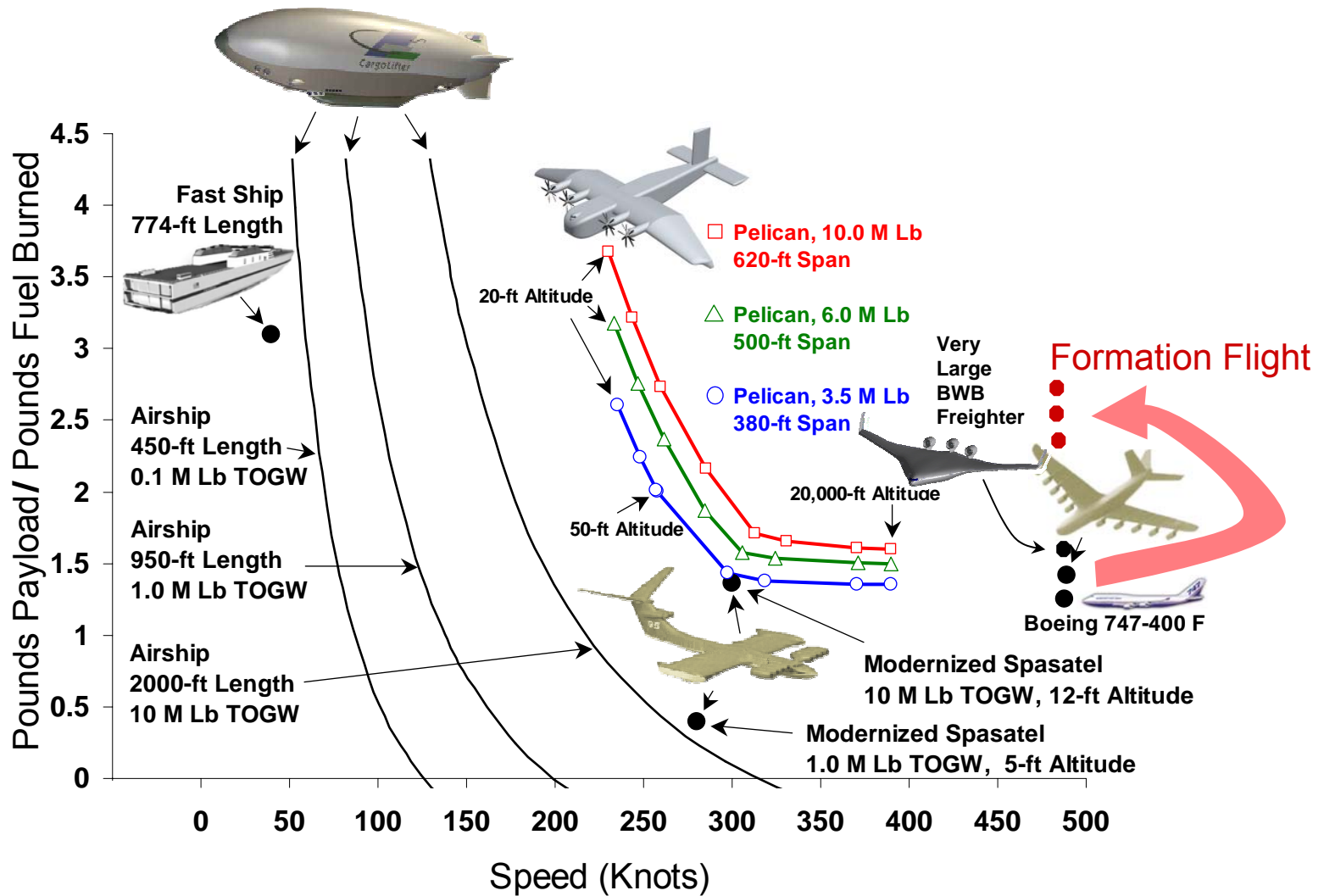
# Airships

- Airship performance increases with size
  - Fast and efficient airships are big
- Lifting body or wing-body airships can provide improved operational characteristics
  - Variation in load, altitude
  - Improved cargo handling
  - But:
    - No hover at higher weights
    - Little change in cruise performance



# Comparison of Freighters

4000 nm mission



# Existing Conventional Freighters



*747-400F*



*MD-11F*

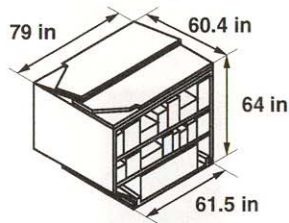
All Derivatives of  
Commercial  
Airliners



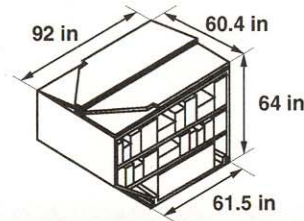
*Super Transporter*

# 747 Lower Hold Capability

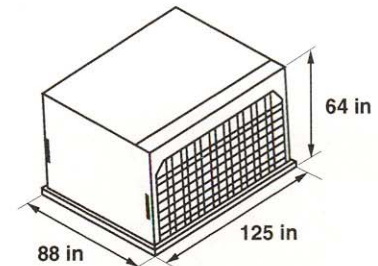
## Basic



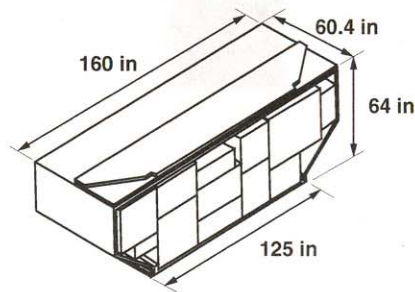
**3,500 lb (1,588 kg) MGW**  
**159 ft<sup>3</sup> (4.5 m<sup>3</sup>)**  
**(LD-3)**



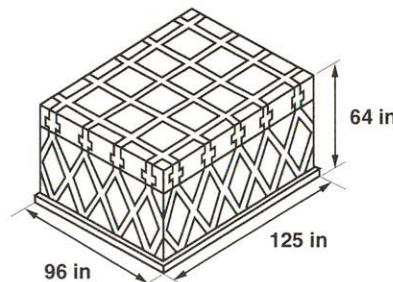
**3,500 lb (1,588 kg) MGW**  
**175 ft<sup>3</sup> (4.9 m<sup>3</sup>)**  
**(LD-1)**



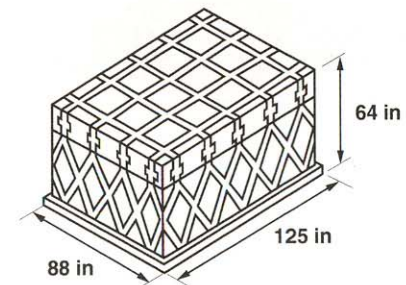
**10,200 lb (4,627 kg) MGW\***  
**381 ft<sup>3</sup> (10.8 m<sup>3</sup>)**  
**(LD-9)**



**7,000 lb (3,175 kg) MGW\***  
**322 ft<sup>3</sup> (9.1 m<sup>3</sup>)**  
**(LD-6)**



**11,100 lb (5,035 kg) MGW\***  
**415 ft<sup>3</sup> (11.8 m<sup>3</sup>)**

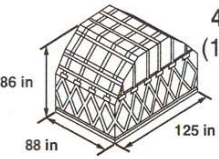
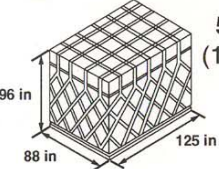
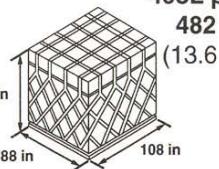
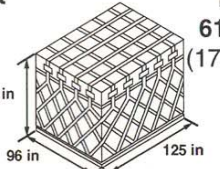
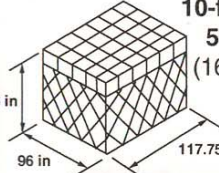
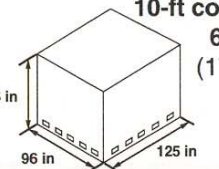
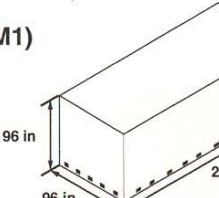
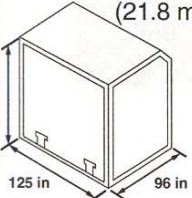
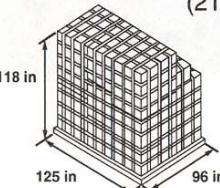
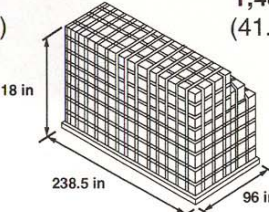
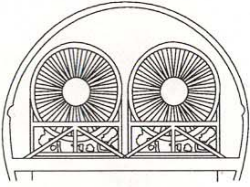
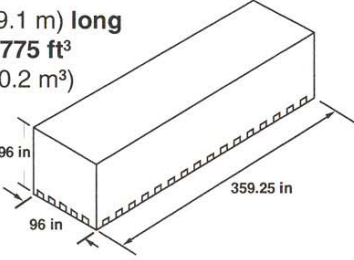
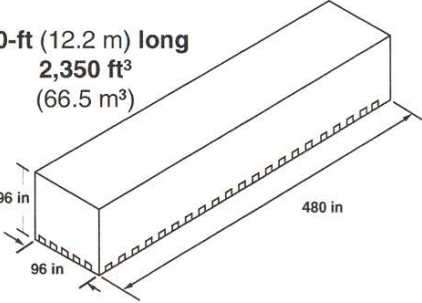


**10,200 lb (4,627 kg) MGW\***  
**372 ft<sup>3</sup> (10.5 m<sup>3</sup>)**

\* Maximum gross weights (MGW) shown are based on lower hold running load capability (116 lb/in), subject to overall airframe structural limits



# 747 Main Deck Capability

<p>Either nose or side cargo door loading</p>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p><b>Type A*</b> 440 ft<sup>3</sup> (12.4 m<sup>3</sup>)</p> <p>86 in 88 in 125 in</p> </div> <div style="text-align: center;">  <p><b>M1A</b> 560 ft<sup>3</sup> (15.8 m<sup>3</sup>)</p> <p>96 in 88 in 125 in</p> </div> <div style="text-align: center;">  <p><b>463L pallet</b> 482 ft<sup>3</sup> (13.6 m<sup>3</sup>)</p> <p>96 in 88 in 108 in</p> </div> <div style="text-align: center;">  <p><b>M1</b> 613 ft<sup>3</sup> (17.3 m<sup>3</sup>)</p> <p>96 in 96 in 125 in</p> </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;">  <p><b>10-ft pallet</b> 585 ft<sup>3</sup> (16.5 m<sup>3</sup>)</p> <p>96 in 96 in 117.75 in</p> </div> <div style="text-align: center;">  <p><b>10-ft container (M1)</b> 623 ft<sup>3</sup> (17.6 m<sup>3</sup>)</p> <p>96 in 96 in 125 in</p> </div> <div style="text-align: center;">  <p><b>20-ft container (M2)</b> 1,190 ft<sup>3</sup> (33.6 m<sup>3</sup>)</p> <p>96 in 96 in 238.5 in</p> </div> </div>
<p>Side cargo door loading only</p>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p><b>10-ft-high container (M1H)</b> 773 ft<sup>3</sup> (21.8 m<sup>3</sup>)</p> <p>118 in 125 in 96 in</p> </div> <div style="text-align: center;">  <p><b>10-ft-high pallet (M1H)</b> 745 ft<sup>3</sup> (21.0 m<sup>3</sup>)</p> <p>118 in 125 in 96 in</p> </div> <div style="text-align: center;">  <p><b>10-ft-high pallet (M6)</b> 1,480 ft<sup>3</sup> (41.8 m<sup>3</sup>)</p> <p>118 in 238.5 in 96 in</p> </div> <div style="text-align: center;">  <p><b>Engines</b></p> </div> </div>
<p>Nose cargo door loading only</p>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p><b>30-ft (9.1 m) long</b> 1,775 ft<sup>3</sup> (50.2 m<sup>3</sup>)</p> <p>96 in 96 in 359.25 in</p> </div> <div style="text-align: center;">  <p><b>40-ft (12.2 m) long</b> 2,350 ft<sup>3</sup> (66.5 m<sup>3</sup>)</p> <p>96 in 96 in 480 in</p> </div> </div>

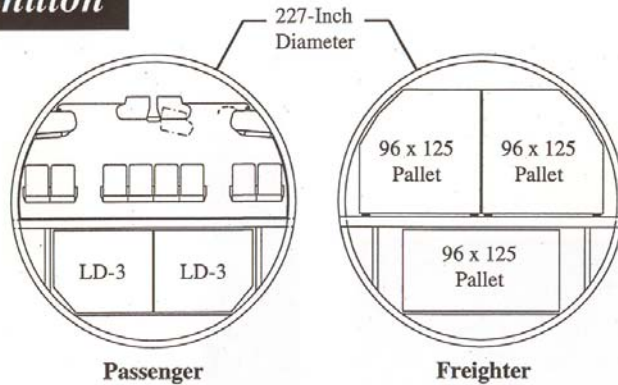
Volumes are based on SAE Aerospace Standard, AS 1825

\* Maximum height varies from 78 to 86 in (198 to 218 m), depending on airplane type (e.g., 707, 727, 757, DC-8)

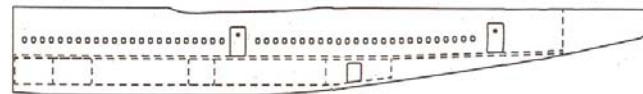
# Intermodal Transport Studies

## Definition of Selected Concepts — V-9 “Strong Back” Module Definition, Loading and Transport

### Definition



Passenger module



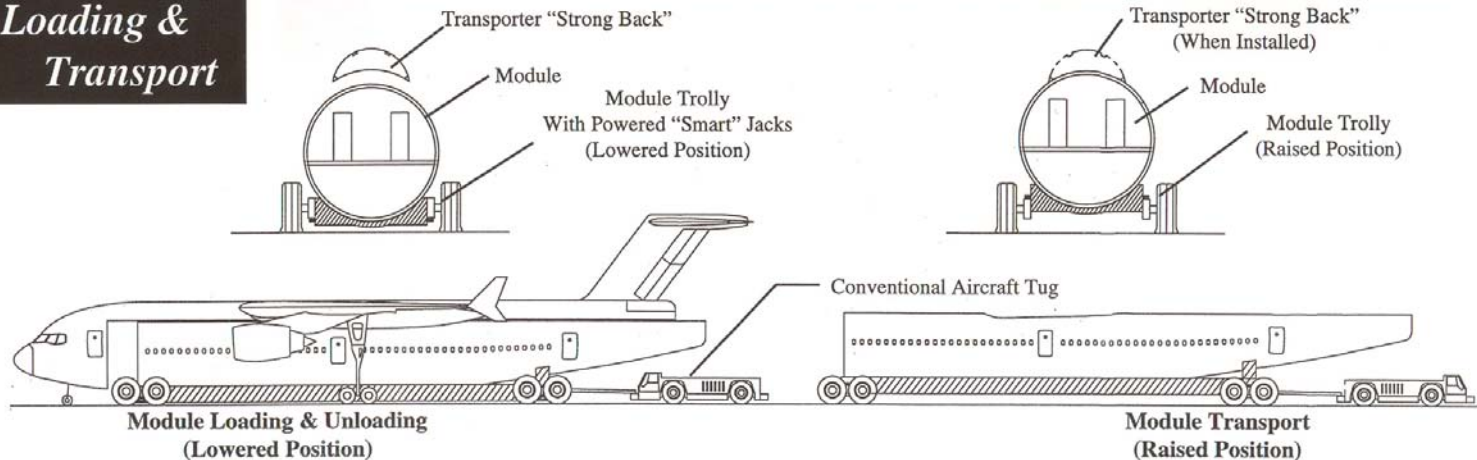
Length = 141 Feet



“Clam Shell” Cargo Door

Freighter module

### Loading & Transport

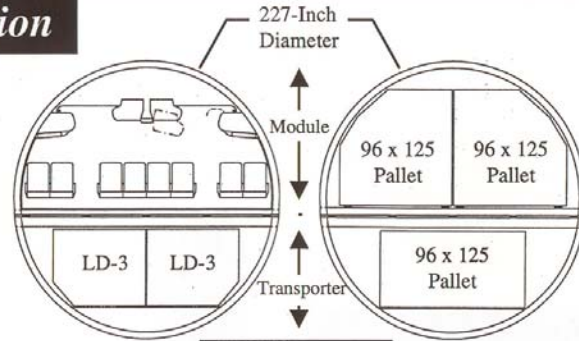




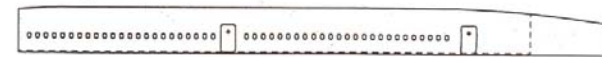
# Intermodal Transport Studies

## Definition of Selected Concepts — V-10 “Strong Bottom” Module Definition, Loading & Transport

### Definition

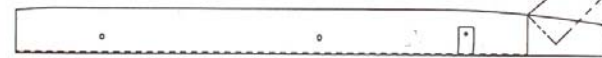


### Passenger module



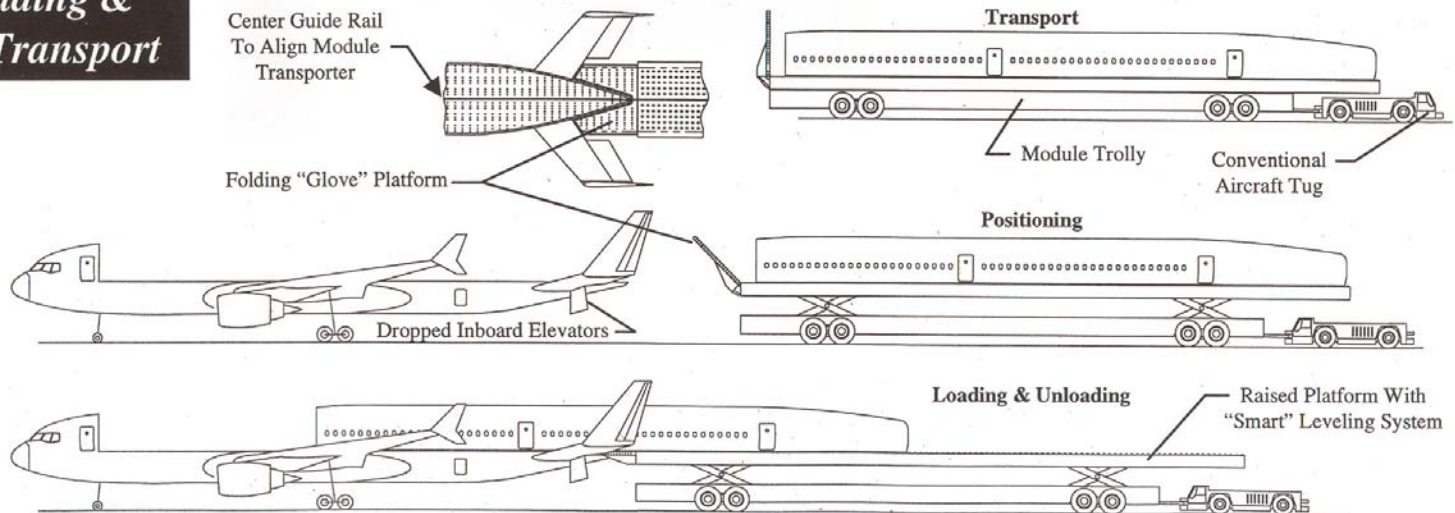
Length = 141 Feet

Hinged Cargo Door



### Cargo module

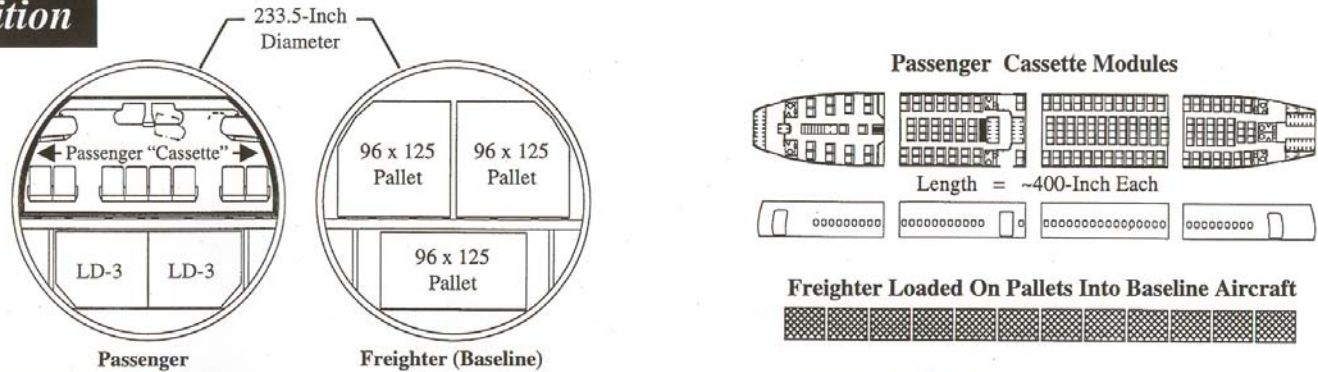
### Loading & Transport



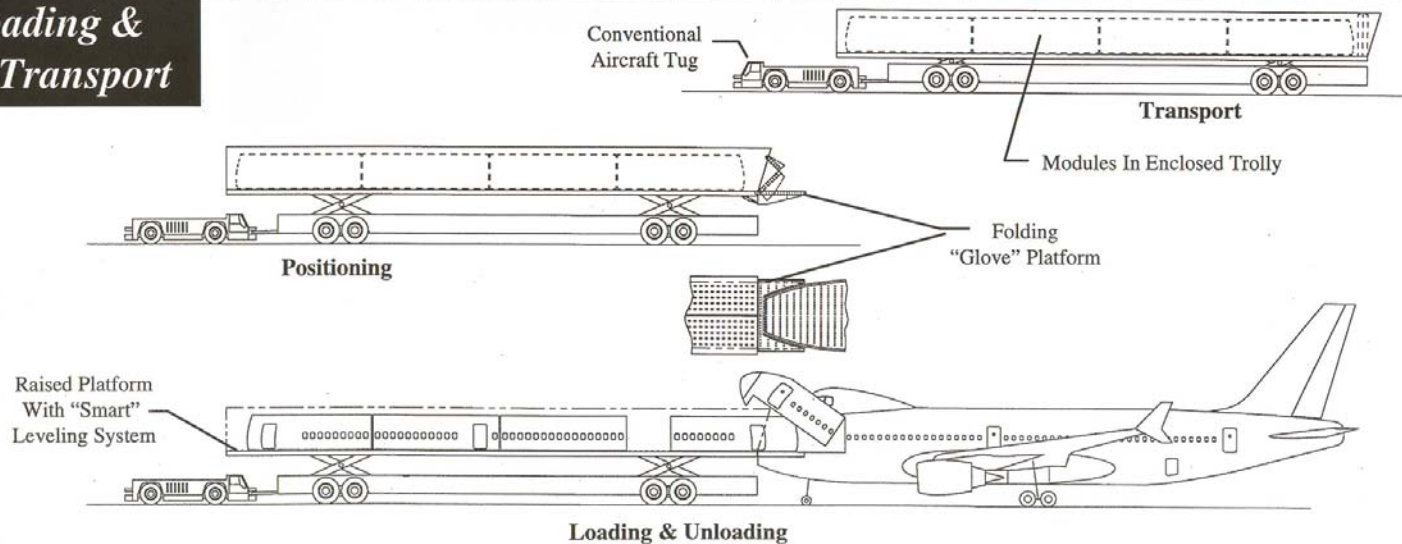
# Intermodal Transport Studies

## Definition of Selected Concepts — V-11 “Cassette” Module Definition, Loading & Transport

### Definition



### Loading & Transport

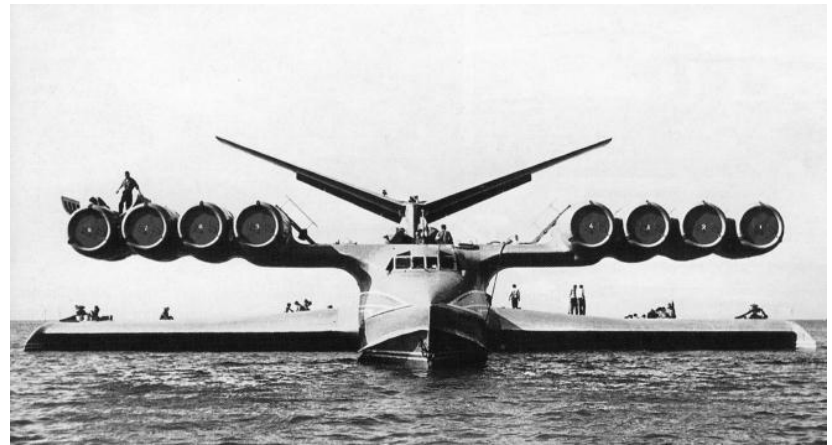
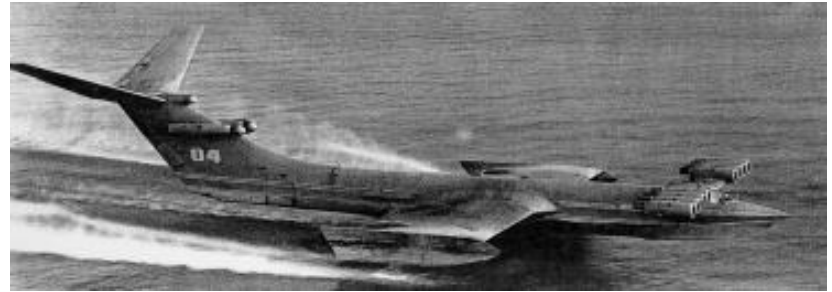
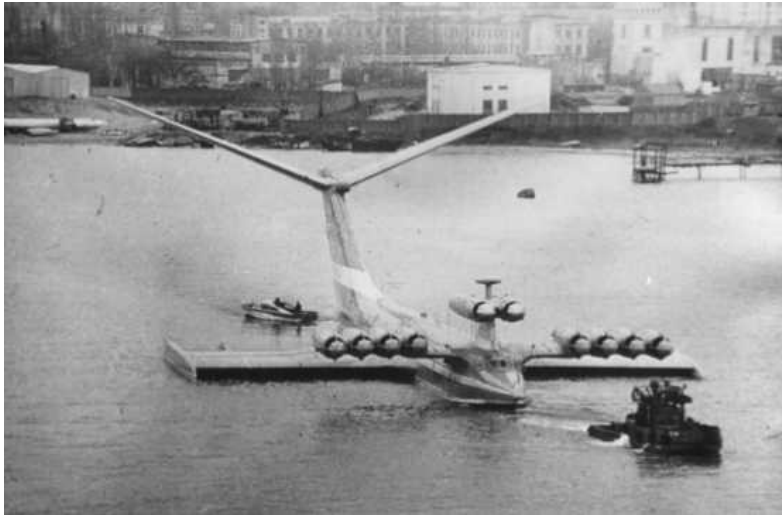


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# JSC R.E. Alexeiev Central Hydrofoil Design Bureau “KM”

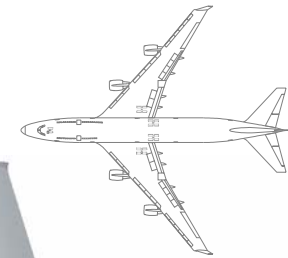


# JSC R.E. Alexeiev Central Hydrofoil Design Bureau “KM”

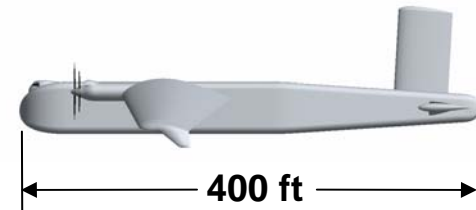
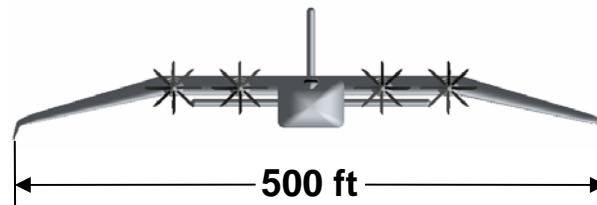
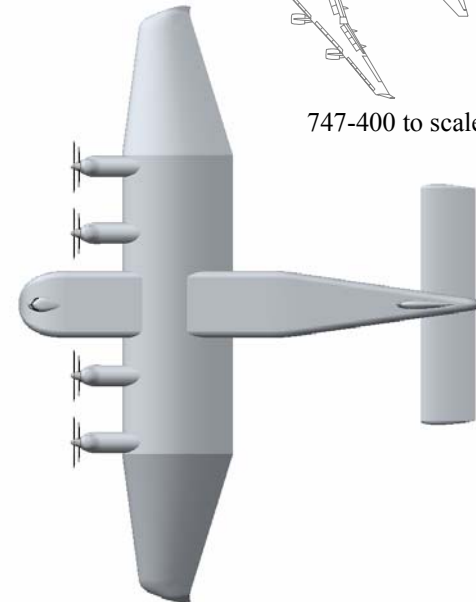


# Land-Based WIG “Pelican ULTRA”

- Conventional wing-body-tail configuration
- Turboprop
- Unpressurized except crew station
- Numerous fuselage-mounted landing gear
- Anhedral to enhance ground effect
- Dimensions and weights:
  - 500 ft span, 400 ft length overall
  - 6.00 Mlb MTOGW
  - 2.16 Mlb OEW
  - 2.80 Mlb maximum payload
  - 2.20 Mlb maximum fuel
- 10,000 nm range w/ 1.5 Mlb payload in ground effect at 20 ft (over water only)
- 6500 nm range w/ 1.5 Mlb payload out of ground effect



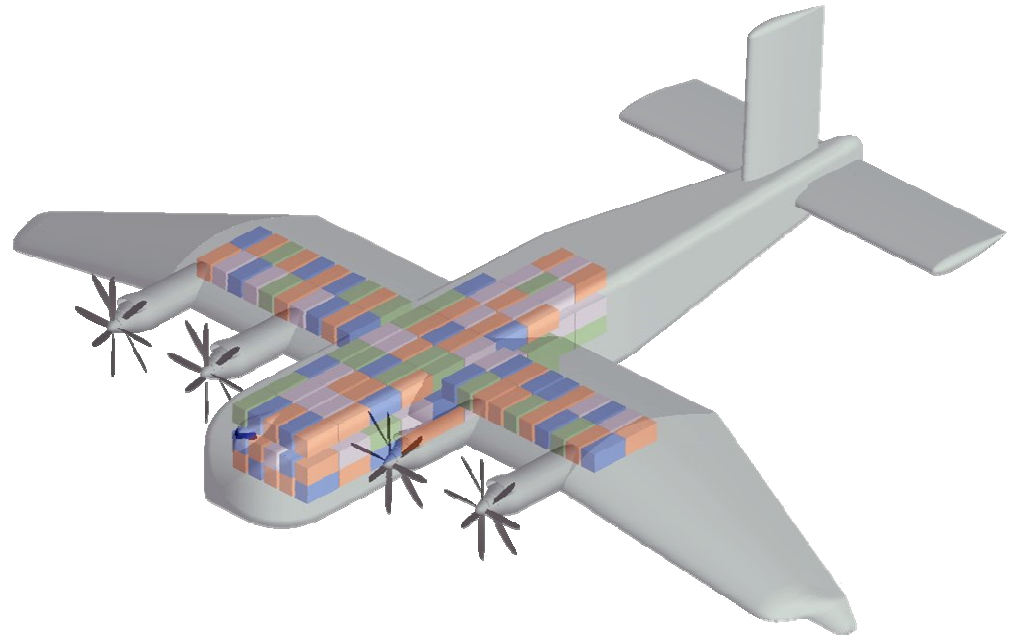
747-400 to scale

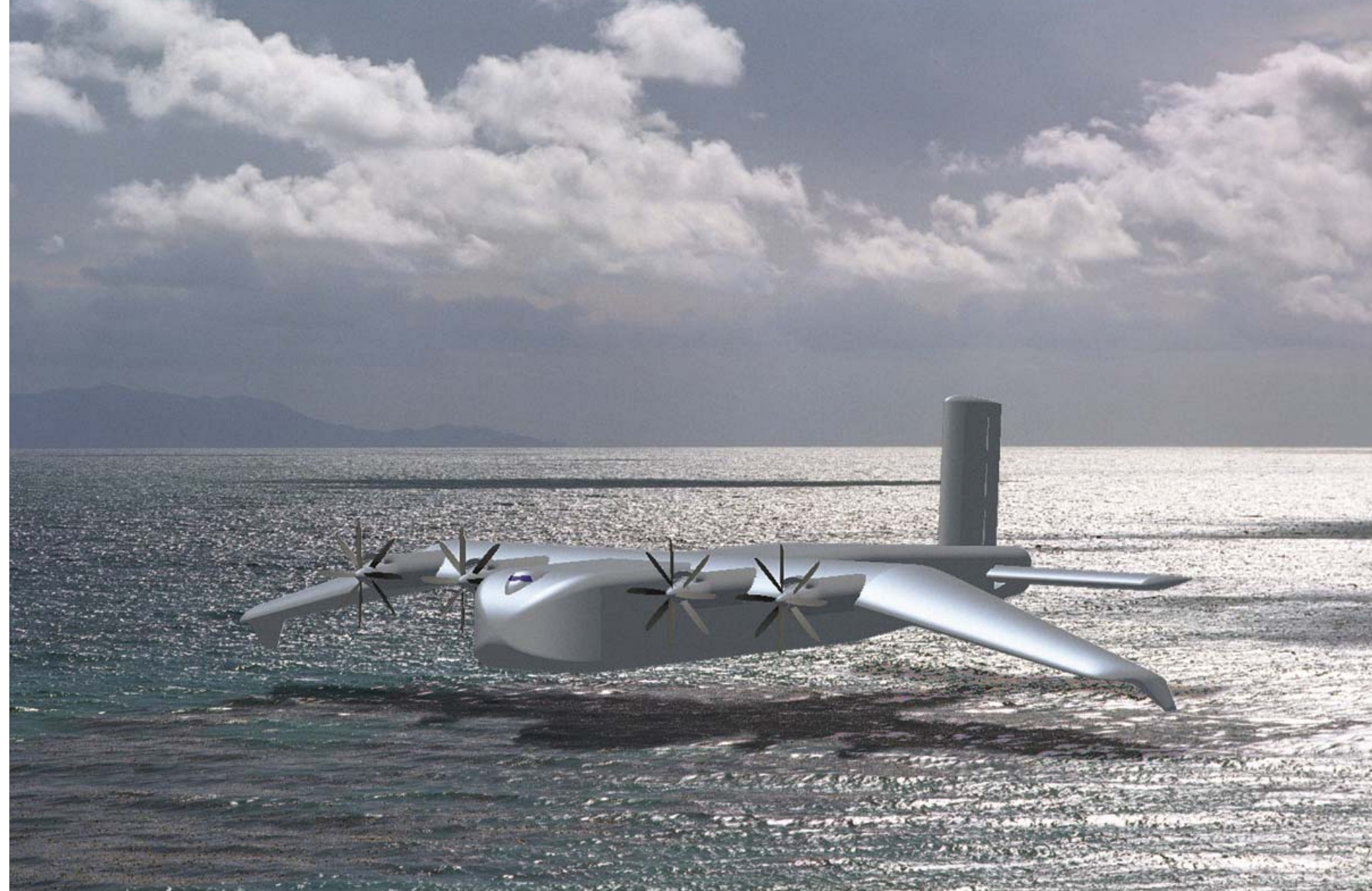




# Land-Based WIG “Pelican ULTRA”

- High efficiency
  - Low empty weight fraction
  - High L/D
    - 21 out of ground effect
    - 36 at 20 feet
  - High propulsive efficiency
- ISO container cargo
  - Exploits existing ground cargo infrastructure
  - 20 and 40 ft containers
  - Loads through nose into:
    - Main deck (two high)
    - Upper deck
    - Inboard wing





The "Pelican" Container Cargo Aircraft concept has arisen from a request by Gerry Janicki of Market Development to investigate "air vehicles to carry a million pounds a long way". This paper describes a preliminary effort to identify promising candidates for this mission and to explore the potential of one promising concept we have dubbed "Pelican". The Pelican has the potential to create a large new business in commercial cargo transport and to practically resolve a shortfall in military deployment and sustainment capability.