Large Payload Transportation and Test Considerations

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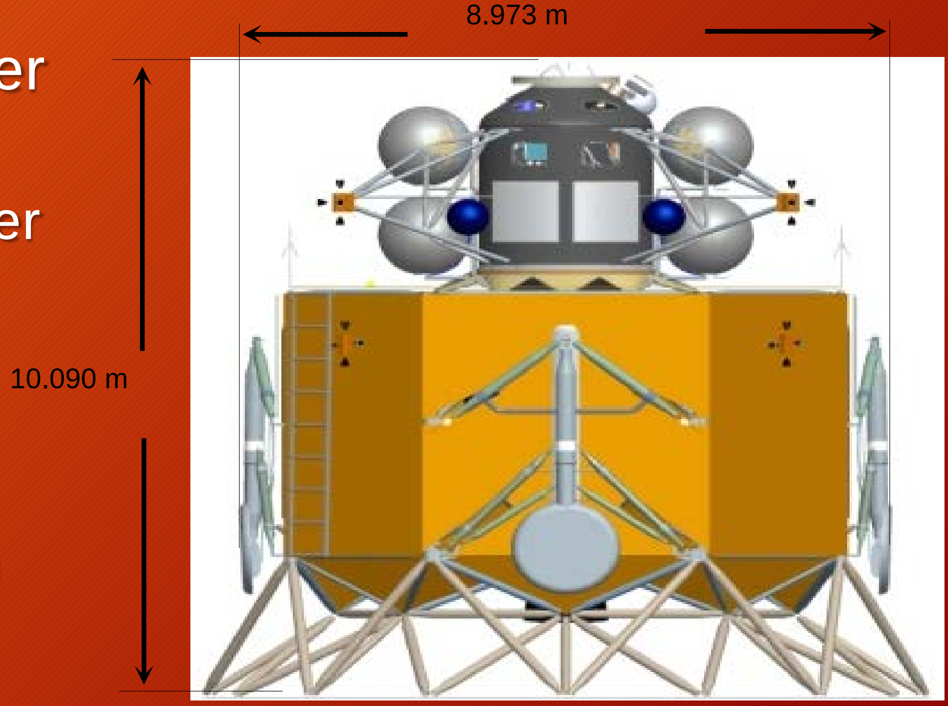
Background

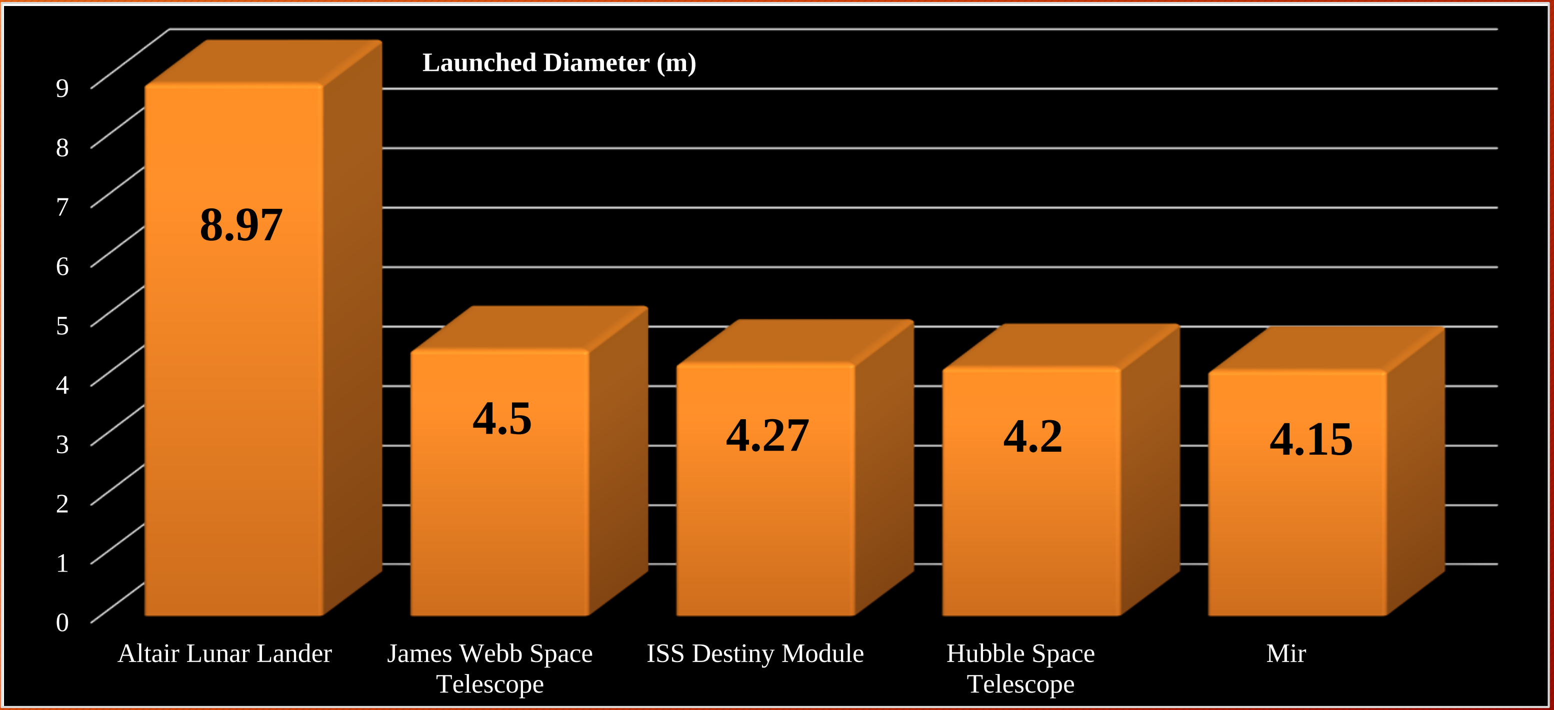
Altair Case Study

- Early Altair stowed diameter was 7.5 m (24.6 ft)
  - Sized to fit within the Ares V's payload shroud
- Ares V expanded to 10 m (32.8 ft) shroud
- Altair increased stowed diameter to 8.973 m (29.44 ft)
  - Designers hoped this would lower overall height
    - It did, but not by much
  - LDAC-3 Altair assembled height was 10.1 m (33.14 ft)
    - Descent Stage + Adapter is 6.5 m (21.32 ft) tall



Background

- Even at the original 7.5 m (24.6 ft) diameter, Altair would have exceeded spacecraft handling/transport experience
- At 8.973 m (29.44 ft), Altair was more than twice the diameter of even the largest Space Shuttle payloads



Transportation Issues

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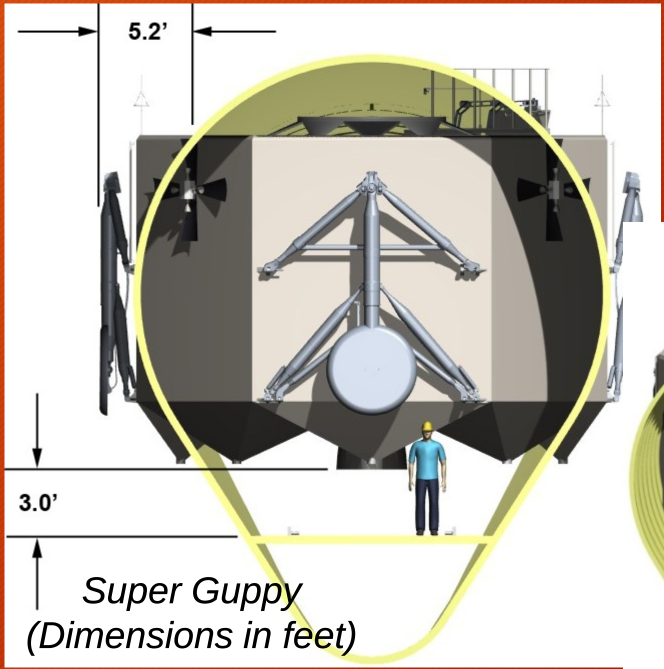
Study Approach and Assumptions

- **Approach**
  - Had to define point of origin to assess actual transportation routes
    - Created two hypothetical vendors
      - "Hypothetical Western Vendor" in Southern California
      - "Hypothetical Eastern Vendor" near MSFC
- **Assumptions**
  - Launch from KSC
  - Intermediate stop at Plum Brook for integrated environmental acceptance testing
    - Cx Program assumption that Altair would use test facilities that Orion had already paid for

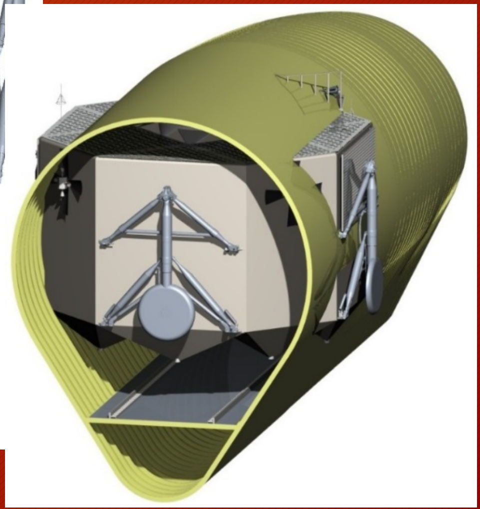
Air Transport Was No-Go

- Neither Ascent nor Descent Stage would fit inside available aircraft
    - Would require Ascent Module RCS boom removal, which invalidated testing
    - Study included: C-5 and C-17 aircraft, Boeing 747, Antonov AN-124, and Airbus A300-600 ST (Beluga), and NASA Super Guppy
- Could mount onto 747
    - Would require new carrier plus gantry system at Plum Brook and KSC

Conceptual Carrier



Super Guppy (Dimensions in feet)



Overland Transport Was Problematic

❑ Limited Trucking is Possible

- Most states won't permit a load this large over extended distances
  - Example: Florida severely restricts loads greater than 4.88 m (16 ft) wide
- **Overland transport alone is not an option**, but limited trucking to/from ports is likely allowed, assuming obstacles can be cleared or removed

❑ Rail is No Go

- Domestic railways do not typically handle cargo taller than 5.18 m (17 ft), or wider than 3.96 m (13 ft)

Parameter 13-Axle Trailer

Water Transportation May be the Only Option

- **Easier from the Eastern US**
- **From origin near MSFC to Plum Brook:**
  - Barge from Decatur, Alabama along the Tennessee River to the Illinois River
  - Enter the Great Lakes at Chicago, Illinois and continue to the Ohio Coast
  - Truck from the coast to Plum Brook
- **From Plum Brook to KSC:**
  - Back-track through Great Lakes, down Illinois River to the Tennessee Tombigbee Waterway
  - Enter the Gulf of Mexico at Mobile, Alabama
  - Sail around Florida to the Atlantic Ocean
  - Dock near KSC

NOTE: Transit through the Great Lakes in winter may require ice-breaker escort; transit through the Gulf of Mexico in summer may be subject to hurricane delays

West Coast Origin Involves the Panama Canal

- **From S. California Origin:**
  - Sail down the Pacific coast
  - Transit the Panama Canal to the Caribbean Sea
  - Cross the Gulf of Mexico to the Alabama coast
  - Enter the Tennessee Tombigbee Waterway at Mobile, Alabama
  - Remaining route would be the same as for Eastern origin

NOTE:

- ***Transit through the Panama Canal may incur schedule delays for cargo inspection;***
- ***Transit through Great Lakes in winter may require ice-breaker escort;***
- ***Transit through the Gulf of Mexico in summer may be subject to hurricane delays***

Summary of Water Transport Times

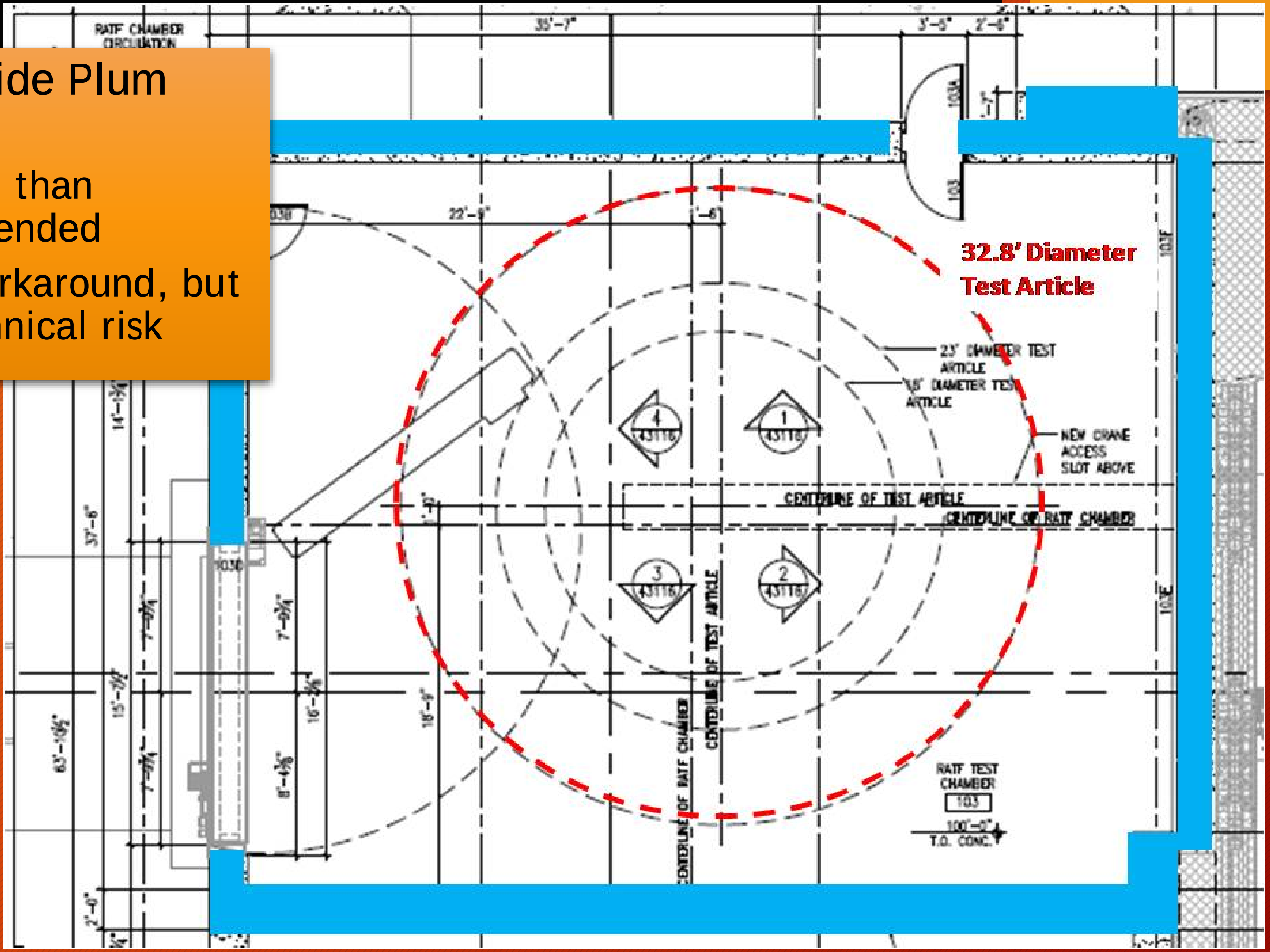
Transport Mode		Time for each Transport Route Leg: Western Vendor to Plum Brook	Eastern Vendor to Plum Brook	Plum Brook to KSC	TOTAL TRANSPORT TIME TO KSC
Surface		32 to 41 days	14 to 20 days	20 to 26 days	**Up to 34 days**
	Truck to/ from port	2 to 4 days	2 to 4 days	2 to 3 days	**(from Eastern vendor)**
	River	13 to 15 days	10 to 12 days	13 to 15 days	**or**
	Ocean	15 to 18 days	--	3 to 4 days	**Up to 67 days**
	Lake	2 to 4 days	2 to 4 days	3 to 4 days	**(from Western vendor)**
Air		3 to 6 days	3 to 6 days	3 to 5 days	**6 to 11 days**
	Truck to/ from airport	2 to 4 days	2 to 4 days	2 to 3 days	
	Plane	1 to 2 days	1 to 2 days	1 to 2 days	

Plum Brook from West OR Plum Brook from East PLUS Plum Brook to KSC = Total Trip Time

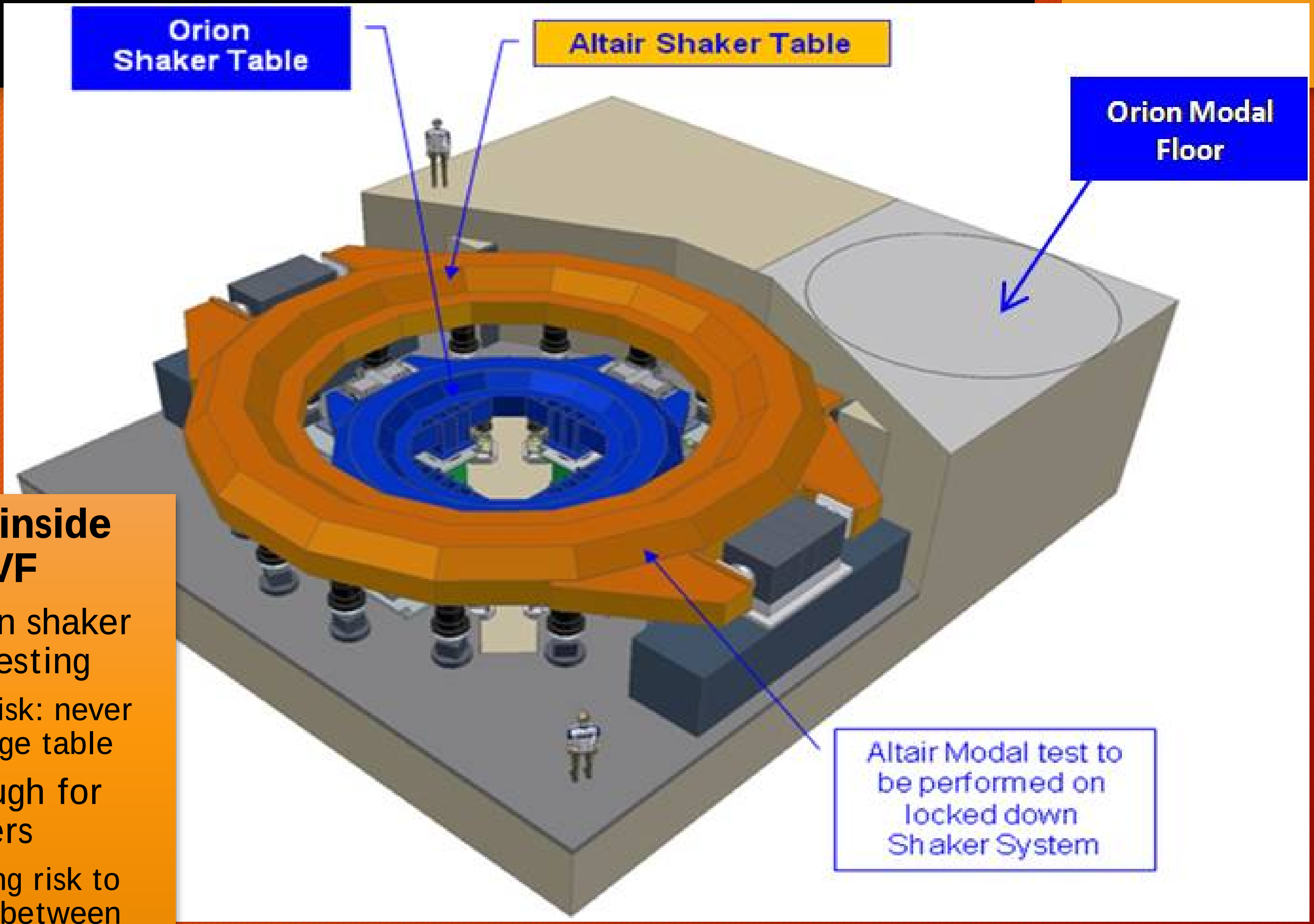
Test and Launch Processing

Acoustic Testing

- Altair does fit inside Plum Brook's RATF
  - But closer to walls than generally recommended
  - May be able to workaround, but there is some technical risk



Mechanical Vibration Testing



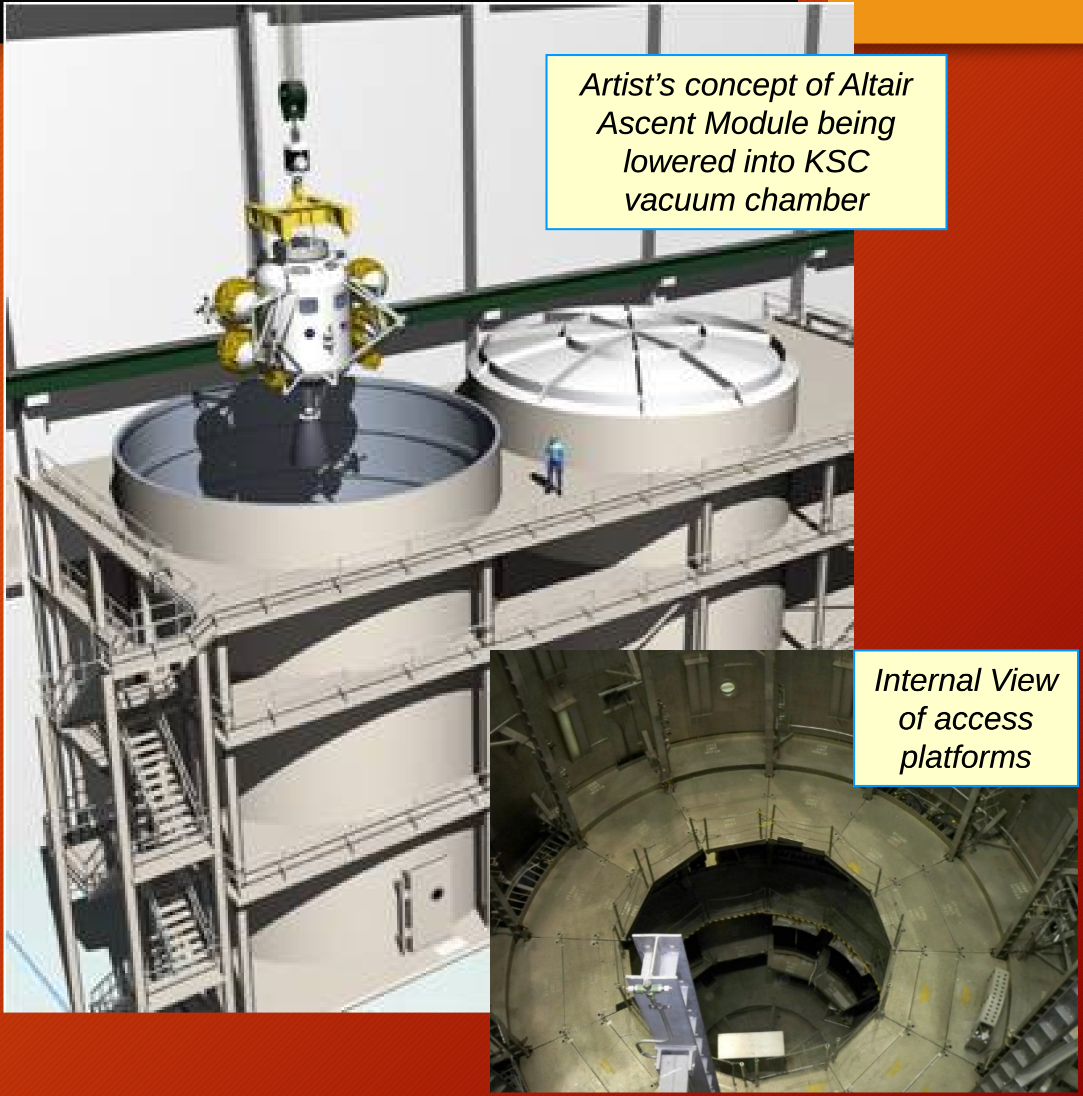
- **Altair would fit inside Plum Brook's MVF**
  - Have to lock down shaker table for modal testing
    - Some technical risk: never been done on large table
  - MVF not big enough for orthogonal shakers
    - Schedule/handling risk to pick up & rotate between axes

Integrated Propulsion Testing
At Altitude Conditions

- Altair would fit inside Plum Brook's 10.67 m diameter B2 chamber
- ***But it won't fit through the 8.23 m diameter chamber door!***
- Would have to disassemble legs for installation then reassemble inside chamber
  - Do-able, but time-consuming and adds handling risk

Thermal Vacuum Testing

- If we push environmental testing off to the launch site, there aren't good options at KSC
- Large-spacecraft environmental acceptance testing at KSC limited to vacuum testing
- Altair fit inside KSC's 10 m diameter vacuum chambers
  - But access platforms would have to be removed, which complicates test article set up and instrumentation
  - No room to install thermal conditioning equipment, so testing would be limited to ambient temperature (no thermal vac testing)

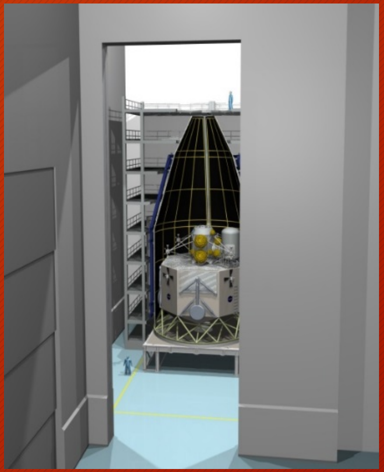


Artist's concept of Altair Ascent Module being lowered into KSC vacuum chamber

Internal View of access platforms

Hazardous Processing

- Altair design requires hazardous processing operations at the launch site, including:
  - Install and arm pyrotechnic devices;
  - Fill, drain, and service hypergolic fuel reaction control systems;
  - Fill, drain, and service high pressure oxygen tanks;
  - Fill, drain, and service cryogenic oxygen and hydrogen tanks;
  - Lift and stack large spacecraft elements, including encapsulation;



- CxGO project evaluated the following KSC-area facilities:
  - Space Station Processing Facility (SSPF),
  - Vehicle Assembly Building (VAB)
  - Orbiter Processing Facility (OPF)
  - The National Reconnaissance Office Eastern Processing Facility (NRO EPF)
  - Astrotech Facility (Titusville)

No single KSC facility is capable of performing all of these functions on a spacecraft as large as Altair

May have to modify facilities, use multiple facilities, or build new facilities

Mitigation Options

Transportation & Test Challenges

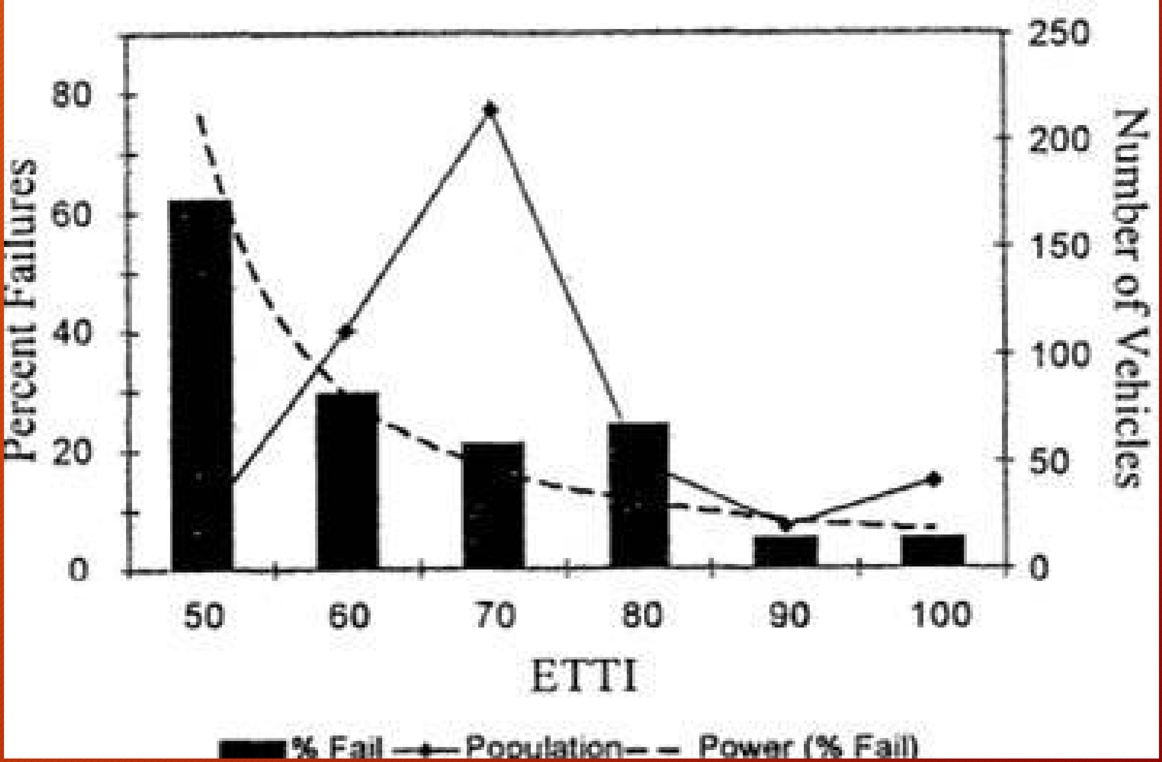
Mitigation Options

Option	Pros	Cons
Constrain spacecraft designs to ~7 m dia.	Mitigates most transportation & test issues	May need to launch more spacecraft, since they're smaller
Manufacture and Acceptance Test at the Launch Site	Mitigates the need to transport large components	• May require new acceptance test facilities at the launch site • May preclude International partners from providing large components • Concentrates bulk of spacecraft life cycle (and $) at one field center
Eliminate Integrated Environmental Acceptance Testing	Mitigates the need to transport production units to Plum Brook	• Probably still need to transport Qual unit to Plum Brook • May not be able to verify spacecraft will meet high reliability requirements
Test only at Lower Levels of Assembly	• Don't need to transport production units to PBS • Don't need new test facilities at launch site	• Increased risk that integrated assembly issues go undetected • Worked for Shuttle, but Shuttle was reusable so each flight = acceptance test for next flight • Probably still need to transport large Qual unit somewhere for qual tests
Design for Test and Transportation and	Mitigates high transportation & integrated test costs	May result in overly complicated or expensive design, lower reliability, or lower performance

Cutting Corners on Environmental Testing Is Not A Good Strategy

2001 Aerospace Corporation study of 454 U.S. satellites found an exponential relationship between percentage of satellite failures and Environmental Test Thoroughness Index (ETTI), the degree to which a spacecraft's acceptance and qualification test program complies with MIL-STD 1540B

- <10% of spacecraft fully complying with the MIL-STD suffered failures
- More than 60% failed when only half the recommended environmental tests were performed



Conclusions

- Altair-size s/c exceeds transport & handling experience
  - *We can't launch it if we can't get it to the launch pad!*
- If it's too big to fly, transport will be expensive and risky
- Water transport to Plum Brook and KSC is easier from point of origin in the East than from the West
  - Up to 33 days from MSFC area vs. up to 66 days from West Coast
  - *This should factor into procurement strategies*
- Transportation challenges could color international agreements
  - Affects the size of parts provided by partners, or limit types of integrated testing we can do
- Integrated environmental test facilities can accommodate large spacecraft, but transporting to/from test is challenging
- Once at the launch site, hazardous ground processing and encapsulation for a large spacecraft will also be challenging
  - Potentially no good roll-back options

Recap of Issues

- **Transportation Issues**:
  - Air Transport isn't an option because large spacecraft won't fit in available airframes
  - Ground Transport alone is not an option because most States will only permit "super-loads" over very short distances
  - Water Transport is viable, but could take months per production unit
- **Facility Issues**:
  - Integrated environmental acceptance testing can't be done at KSC without upgrading/building new facilities
  - The only facility large enough for integrated acoustic or mechanical vibration testing is at Plum Brook
    - Would still require workarounds that add to test complexity & cost
  - Assembled spacecraft may be too large to fit through Plum Brook B2 Propulsion Test Facility chamber door
    - Could assemble inside the chamber, but this adds to test complexity & cost
  - KSC facilities cannot currently accommodate hazardous processing for large spacecraft

Applicability to EMC

- Testing and transportability should be considered in architecture studies
  - Could swing some trades (modular vs. monolithic hab, for example)
- Failure to carefully consider where and how large spacecraft are Manufactured, Tested, and Launched could drive cost and risk

The limiting factor to a heavy lift strategy may not be the rocket technology needed to throw a heavy payload

The weak link may be the terrestrial infrastructure—roads, bridges, airframes, and buildings—necessary to transport, acceptance test, and process large spacecraft

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Questions?