National Aeronautics and Space Administration

Composites Australia Conference
Composite Cryotank Project
Structures for Launch Vehicles

John Vickers

NASA Marshall Space Flight Center

March 5, 2013

The National Aeronautics and Space Administration

NASA Game Changing Development Program | **Composite Cryotank Project**

Human Exploration and Operations

Space Technology

Science

Aeronautics Research

Marshall supports three of the NASA Mission Areas

Vision of the National Network for Manufacturing Innovation


June 2011

REPORT TO THE PRESIDENT ON ENSURING AMERICAN LEADERSHIP IN ADVANCED MANUFACTURING

Executive Office of the President
President's Council of Advisors on Science and Technology

JUNE 2011


February 2012

A NATIONAL STRATEGIC PLAN FOR ADVANCED MANUFACTURING

Executive Office of the President
National Science and Technology Council

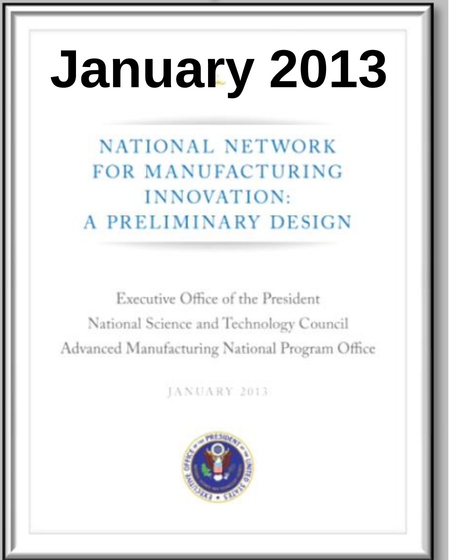
FEBRUARY 2012


July 2012

REPORT TO THE PRESIDENT ON CAPTURING DOMESTIC COMPETITIVE ADVANTAGE IN ADVANCED MANUFACTURING

Executive Office of the President
President's Council of Advisors on Science and Technology

JULY 2012


January 2013

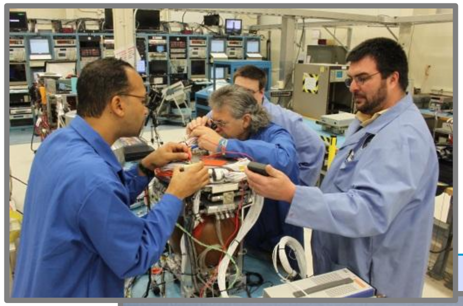
NATIONAL NETWORK FOR MANUFACTURING INNOVATION: A PRELIMINARY DESIGN

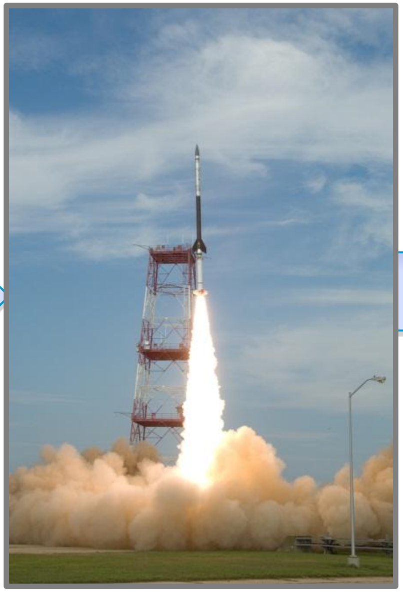
Executive Office of the President
National Science and Technology Council
Advanced Manufacturing National Program Office

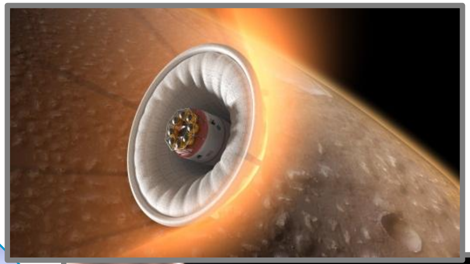
JANUARY 2013

Space Technology Mission Directorate Approach

- **Enabling Our Future in Space:** By investing in **high-payoff**, **disruptive technologies** that industry cannot tackle today, Space Technology matures the technology required for NASA's future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities.
- **NASA at the Cutting Edge:** **Pushing the boundaries** of aerospace technology and seizing opportunities, Space Technology allows NASA and our nation to remain at the cutting edge.







Space Technology Programs

NASA Game Changing Development Program | **Composite Cryotank Project**

Transformative & Crosscutting Technology Breakthroughs

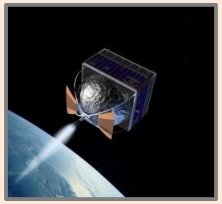
Pioneering Concepts/ Developing Innovation Community

Creating Markets & Growing Innovation Economy

Develop Technology Breakthroughs

Game Changing Development Program

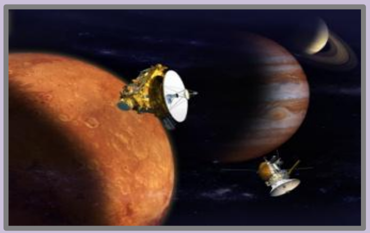
Technology Demonstration Missions Program



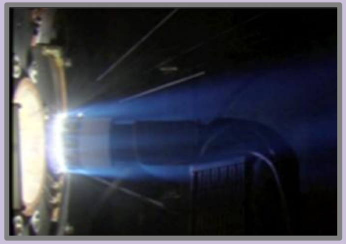
Small Spacecraft Technologies Program

New Concepts

Space Technology Research Grant Program



NASA Innovative Advanced Concepts (NIAC) Program



Center Innovation Fund Program

New Markets

Centennial Challenges Prize Program

Small Business Innovation Research & Small Business Technology Transfer (SBIR/STTR) Program

Flight Opportunities Program

The Game Changing Mission

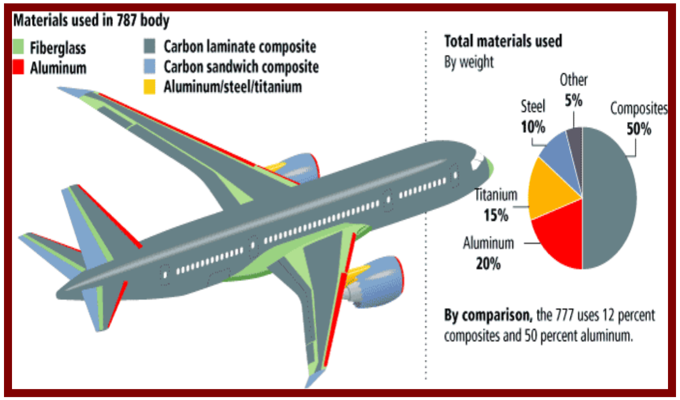
To focus on transformative space technologies that will lead to advances in space and terrestrial capabilities, serve as a stimulus to the US economy while providing inspiration and opportunity to our nation's youth

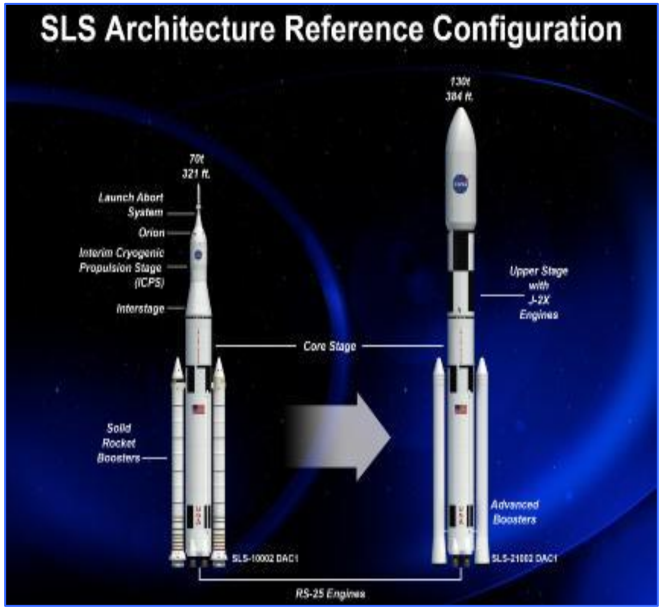
Goals

- Develop Game Changing technologies that produce dramatic impacts for NASA's Space Exploration and Science Missions
- Capitalize on opportunities to leverage funding and cost-share from external organizations in technology area mutually benefiting NASA and the other organizations
- Formulate and implement technology projects that deliver the required performance to stakeholders on schedule and within cost
- Deliver technology knowledge that is used internally for NASA missions as well as externally throughout the aerospace community

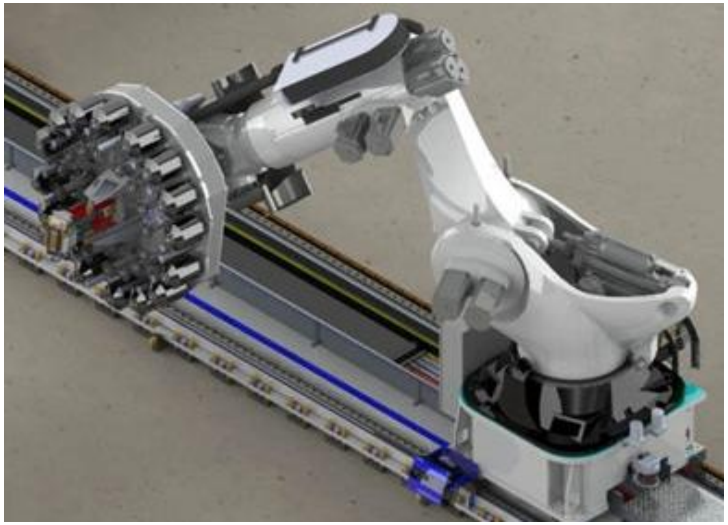
Composites Manufacturing Supports Agency and National Needs

- **Supports all Mission Directorates: Aeronautics Research, Science, Human Exploration and Operations, Space Technology**
- **Supports Advanced Manufacturing National Initiative, and National Network for Manufacturing Innovation**
- **Other Government Agencies: DOD, DARPA, DOE**
- **Identified in NASA's Space Technology roadmap TA12 (light weight materials and structures among the highest priorities identified by NRC)**
- **Spans multiple Centers and disciplines**
- **Industry and Research community**





Fully Integrated Research Across TRL Spectrum



TRL 1-3

Develop New Resins and Fibers

Pre-Pregging of Composite Tows

Develop Advanced Manufacturing and and NDE Processes

TRL 4-6

Design and Manufacture of Composite Structures

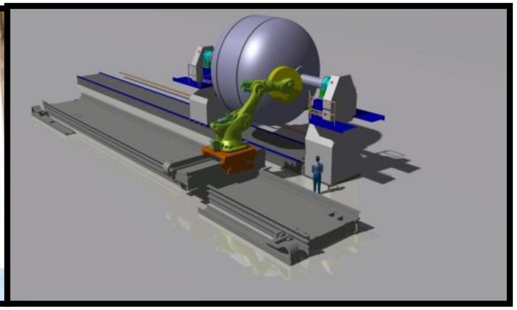
Post-Cure, In-Situ NDE of Composite Structures

Testing and Analyses of Composite Structures

TRL 7+

Manufacture of Flight Vehicle Structures

Composite Cryotank
Technologies and Demonstration



Objective: Advance technologies for lightweight cryotanks for heavy lift vehicles + spin-off capabilities for multiple stakeholders - NASA, DOD, and Industry

Concept: Develop and demonstrate composite tank critical technologies – Materials, Manufacturing, and Structures; Autoclave and/or Out-of-Autoclave

Approach: Focus on achieving affordability, technical performance, through agreement between experiment and analysis

Goal: Produce a major advancement in a demonstrated readiness; successfully test 5-meter diameter composite hydrogen fuel tank, achieve 30% weight savings and 25% cost savings compared to state-of- the-art

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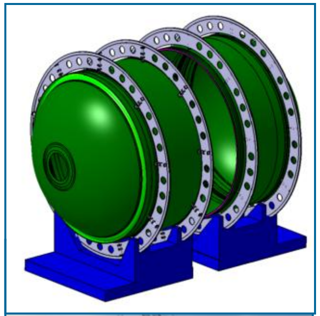
March, 2013

Composite Cryotank Capability Need



- NASA and industry continuously strive to reduce the weight and cost of the launch vehicles
  - Ares Upper Stage incorporated an extremely difficult common bulkhead configuration to save weight, approx. 1400 lbs (#1 project risk)
  - Shuttle External Tank - Standard weight tank 77,000 lb, light weight tank 66,000 lb, super light weight tank 58,500 lb
- "Of all the technologies that may reduce the mass fraction composite materials for the primary structures and for the liquid hydrogen tanks is projected to have the greatest potential" *(Harris, Starnes, and Shuart, Journal of Aircraft, July-August 2002.)*
- Tank Materials - Composites offer the potential for the greatest mass reduction of all of the materials (*Committee on Materials Needs and R&D Strategy for Future Military Aerospace Propulsion Systems; National Research Council, May 2011*)
- HEFT Affordability – Develop architecture scenario options that have potential to increase affordability & HLV current designs may not be affordable, based on existing cost models, historical data, and traditional acquisition approaches
- Projected budgets for the U.S. Air Force's Evolved Expendable Launch Vehicle (EELV) program will rise by more than 50 percent over the next few years as the cost of materials has increased sharply. *(Space News, Fri, 14 January, 2011)*
- Headline New Delhi "Boeing has offered to partner with India on manned space missions, including on the very significant "composite cryogenic tanks" for launch and propulsion control." *(India Strategic, February 2011)*

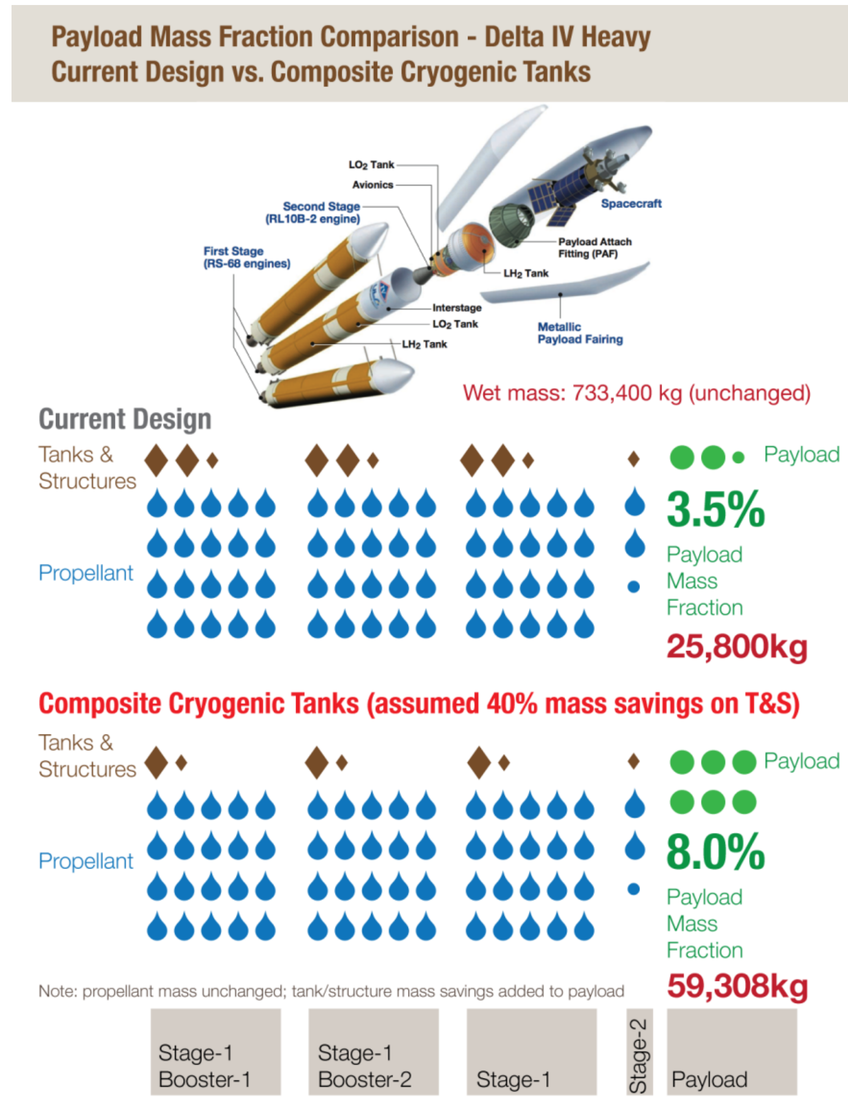
Why Composite Cryotanks

- **NASA chief technologist Robert Braun: "We intend to take considerable risks" to innovate**
- **Dr. Pete Rustan, retired Deputy, NRO,: "U.S. technological leadership was not achieved by people who were afraid of failure."**
- **DARPA chief Regina Dugan: "Failure is okay for us"**
- **Gene Austin, X-33 program manager, "X-vehicle programs are about taking risks and pushing the envelope. That is how we break through barriers that previously held us back. While composite technologies are a promising part of future space transportation, they require further research. "**
- **Final Report of the X-33 Liquid Hydrogen Tank Test Investigation Team (May 2000)**
  - **The tank design is highly innovative, pushing the limits of technology and <u>combining many unproven technology elements.</u> The interaction and integration of these elements created a highly complex system…**
  - **The most probable cause of the failure was determined to be a combination of the following phenomena:**
    - **Microcracking of the inner facesheet with gaseous hydrogen (GH2) infiltration**
    - **Cryopumping of the exterior nitrogen (N2) purge gas**
    - **Reduced bondline strength and toughness**
    - **Manufacturing flaws and defects**
    - **Infiltration of GH2 into the core, which produced higher than expected core pressures**

The Problem

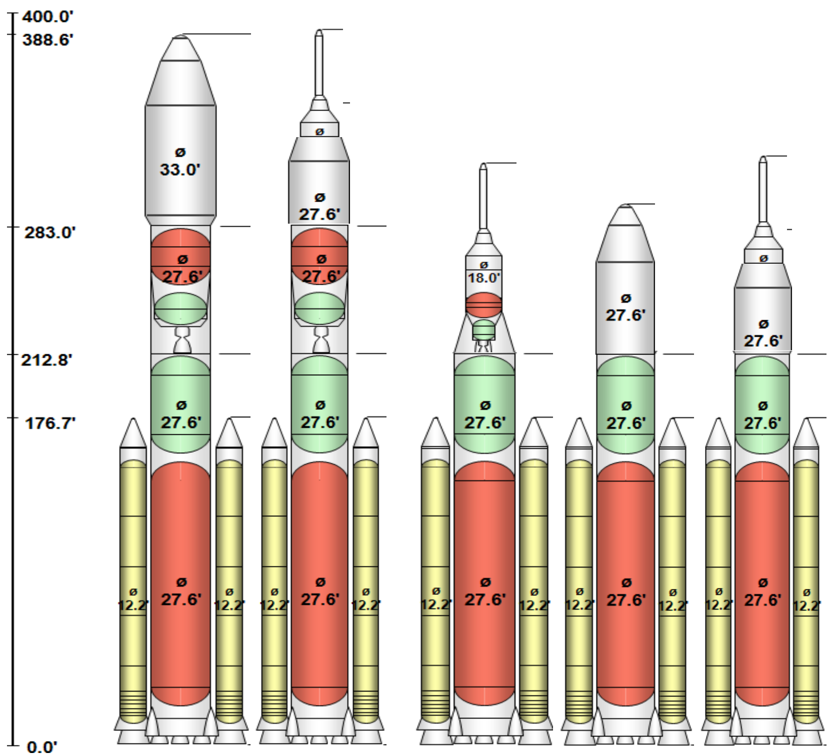
The Problem

- **Agency's need for an affordable lightweight heavy lift vehicle - Greater payload capability is required to enable future exploration missions**
- **No composites experience at this scale**
- **Cryo – LH_2 presents severe environment**
- **OoA technologies are untested**
- **Many materials, design and manufacturing challenges**



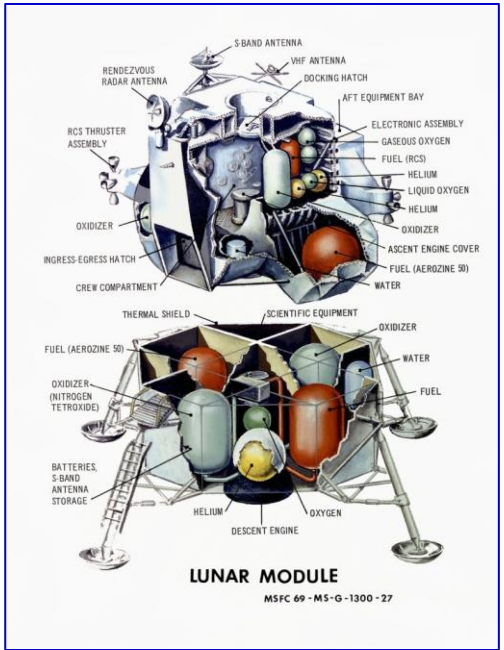
Composite Cryotank Capability Need

Space Launch System (SLS)
70 tonnes(t) evolvable to 130t



SLS Affordability Tenets

- ✓ **Evolvable Development Approach**
- ✓ **Manage Within Constrained Budgets**
- ✓ **Leverage Existing National Capabilities**
- ✓ **<u>Infuse New Design Solutions for Affordability</u>**



Approximately 60% of the dry mass of a launch vehicle is the fuel and oxidizer tanks.
A composite material can produce a cryotank structure that weighs <u>30% less</u> than aluminum

Composite Cryotank Concept

NASA Game Changing Development Program | **Composite Cryotank Project**

- ✓ Utilize 10 meter diameter reference design
- ✓ Build 5 meter diameter demonstrator
  - ☑ <u>Out-of-Autoclave</u>

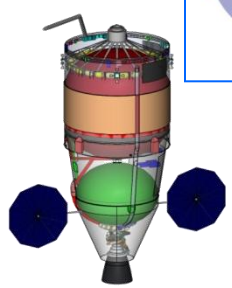
Mission

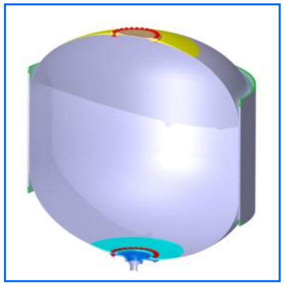
Mars
Near Earth
Lunar

Capability Needs

- Heavy Lift Vehicle
- Fuel Depot
- Departure/Service Stages
- Habitats

Composite Cryotank





Enabling Technology Needs

- ✓ Concept Trade Studies
- ✓ Technology trade studies
- ✓ <u>Structural Design</u>
- ✓ <u>Materials</u>
- ✓ <u>Manufacturing</u>
- ✓ Long duration permeability demos
- ✓ Composite resins/chemistry
- ✓ Joints
- ✓ Damage tolerance
- ✓ Test Capability

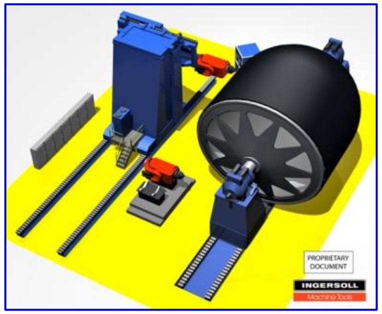
- ✓ Non Destructive Evaluation (NDE)
- ✓ Structural Health Monitoring
- ✓ TPS
- ✓ Repair processes
- ✓ Leak detection

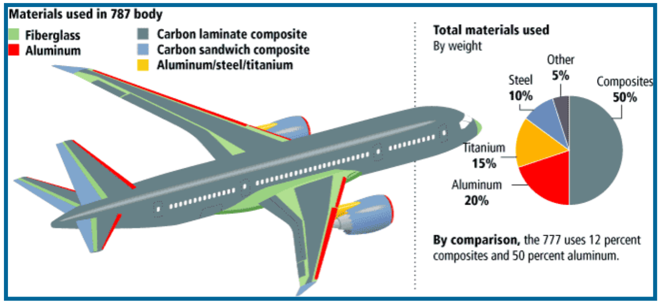
- ✓ Subsystems and interfaces
- ✓ System level trade studies and analysis
- ✓ Thermal attachments and penetrations
- ✓ MMOD design and analysis
- ✓ Space and Launch Environments
- ✓ Propellant management (vents/slosh)
- ✓ Certification

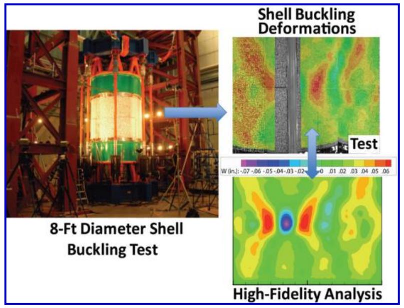
Operational System | Flight Demonstration | Subsystem / Component Demonstration | Technology Maturation

Composite Cryotank Concept

- Development demonstration activity: Design, Build, Test (accelerated building block), 5 meter diameter test articles in a relevant environment (autoclave and/or OOA)
- Tackle Critical Technologies
  - Materials -- out of autoclave (mechanical properties/porosity/out time - e.g. 25% improvement), processing, microcracking density/permeability level (quantitative measurement of permeation at defined temperatures and strain levels)
  - Structures -- conservative design/analysis/allowables criteria (geometries, loads/environments, factors of safety/knockdowns) philosophy of incorporating 10M tank features (thickness/pressure), accelerated building block approach
  - Manufacturing -- large scale, automated systems, design for manufacturing/ affordability (facilities, equipment, lay down rates, producibility/tooling issues)
  - Test -- full scale element test articles, precursor/subscale ~ 2 meter test, structural/cryo test of 5 meter diameter cryotank (key performance parameters)
- Multiple competing approaches, requirements, conceptual designs, modeling, cost, risk, TRL/MRL analysis, R&D equivalency testing (permeability, OOA materials)
- Increase the composite tank value enough to trigger a switch from existing solutions (Innovation!)

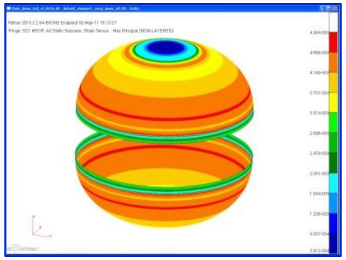


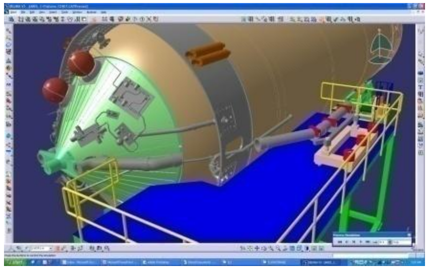


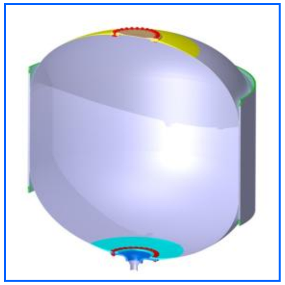


Why Now

- Critical technologies are converging
  - Advances in out-of-autoclave processing
    - Key technology developments in resin formulation, DoD investment in OOA ~$20 million
  - Materials and manufacturing technologies enable reduced manufacturing costs as well as diameters in excess current autoclave dimensions -- Airbus SAMPE 2011 “The Challenges for the future are Cost and Rate !”
  - Substantial growth in aerospace composites markets projected in next decade
  - Structures discipline is actively leveraging the explosion in computational capabilities and advances in simulation, -- to rethink/revise standard practices, – to rethink/revise testing requirements… NESC
- The Mission -- aligned with SLS, HEFT, HAT, and NASA Space Technology Roadmaps
  - Push technology for future architectures time is now
  - Affordability is top figure of merit - Innovative new processes, techniques, or best practices to improve the safety, cost, schedule, or performance
  - Required - Lightweight Structures and Materials (HLLV), Lightweight Structures and Materials (In-Space Elements)

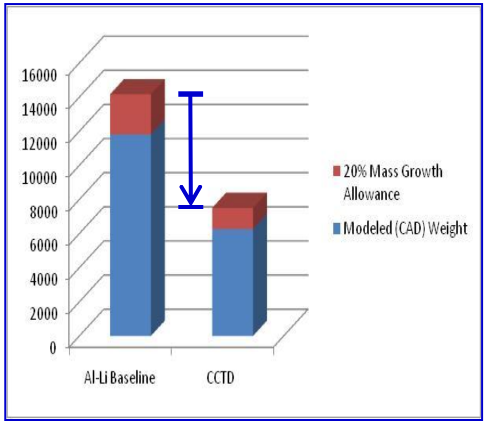


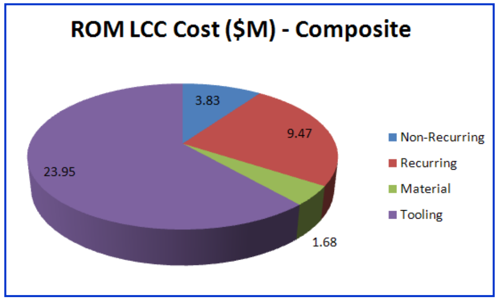




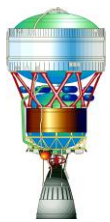
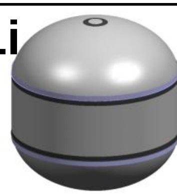
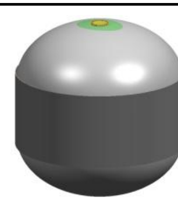
Composite Cryotank Phase I

- Phase I Project significant milestone – 10-meter diameter Composite Cryotank final design reviews with Lockheed Martin, Boeing and Northrop Grumman
- Background: NASA provided a reference design for an aluminum-lithium cryotank design that was a point of departure for developing a 10-meter diameter composite cryotank design
- Targets for weight and cost savings were 25-30% and 20-25%, respectively.
- Summary & Conclusions:
- Drastic weight savings were consistently predicted over the Al-Li baseline, 43% to 47%! (~12,000lbs vs 7000 lbs)
- Moderately good life-cycle cost reduction predictions ranged from 15% to more than 30%
- Evidence was presented that permeation rates due to microcracking can be controlled or eliminated with thin ply composite material





Projected Composite Cryotank Benefits

	Aluminum (unless otherwise specified)	**Composite**	**Weight Savings**	**Dollar Value of Weight Savings *PER LAUNCH***
1996 DC-XA 2.5 meter			**33%**	**N/A (experimental vehicle)**
2004 Delta IV 5 meter	 	Upper Stage (both tanks)	**43% & 26%**	**$4.3M - $9.3M**
		Common Booster Core (both tanks)	**35%**	**$12.6M - $27.8M**
2011 NASA 10 meter	**Al-Li**  **Upper stage LH_2 tank only**		**39%**	**$17M - $37M** **Estimated unit production cost savings: $7M**

“CCTD in the News”

Aviation Week & Space Technology
By Frank Morring Jr.
(Sep 21, 2011) “Boeing Will Test Composite Cryotanks For NASA”
(October 7, 2011) “Jumping-Off Point - New Space Economy”
(November 12, 2011) “Technology Readiness”

Boeing Selected by NASA for Composite Cryogenic Propellant Tank Tests

The Engineer
wwww.theengineer.co.uk
Boeing set to develop new technologies for NASA

NASA eyes a lighter heavy-lift

Marshall seeking new composite materials for future fuel tanks

By Lee Roop
lee.roop@htimes.com

America's next deep-space rocket may carry its fuel in composite tanks light enough to save millions in costs and make room for thousands of pounds of extra fuel and supplies.

NASA announced Tuesday that Huntsville's Marshall Space Flight Center will lead a new project to develop fuel tanks made of composite materials for future spacecraft. It's an effort to modify the greatest source of weight on a spacecraft, as 60 percent of a typical rocket's mass is in its propellant tank.

"Probably applicable to heavy-lift, propellant depots, advanced in-space transportation and any future landing systems," Marshall Director Robert Lightfoot said, listing some of the new tanks' potential uses.

Boeing will build two demonstration tanks in Seattle for testing at Marshall, NASA said. For Boeing, the contract is worth $24 million.

"NASA and industry are constantly striving to reduce the weight and cost of launch vehicles," Marshall's John Vickers told a Tuesday teleconference. Vickers is project manager of what is formally called the Composite Cryotank Technologies Demonstration effort at Marshall.

The goals of the test, Vickers said, are a 25 percent cost

See LIGHTER on B4

Lighter

Continued from page B1

savings and tanks weighing 30 percent less than current aluminum and aluminum/lithium models.

Boeing's two test tanks will be five meters and two meters in diameter. They will be filled with liquid hydrogen and tested in "a realistic environment," Vickers said. Testing will begin at Marshall in late 2013.

"There's lots of opportunity here for us to really push the envelope on what we're trying to do," Lightfoot said.

Among the challenges facing composite tanks are micro-cracks that could lead to leakage. Characteristics of the Boeing design to stop micro-cracks include a "fluted core sandwich wall geometry" for the tank cylinder, Vickers said.

Vickers noted that other NASA centers are also working on the demonstration project. It takes cooperation, he said, to do this kind of cutting-edge technological development.

Marshall will manage the project and lead the overall technical effort.

The Glenn Research Center in Ohio will lead the materials work, and the Langley Research Center in Virginia will lead design and structure research.

The Kennedy Space Center Florida is handling operations and repair, and Vickers said NASA may flight-test the composite tanks after they pass ground tests.

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Sept. 20, 2011

RELEASE: 11-305

NASA PICKS BOEING FOR COMPOSITE CRYOGENIC PROPELLANT TANK TESTS

WASHINGTON -- NASA has selected The Boeing Company of Huntington Beach, Calif., for the Composite Cryotank Technologies Demonstration effort. Under the contract, Boeing will design, manufacture and test two lightweight composite cryogenic propellant tanks. The demonstration effort will use advanced composite materials to develop new technologies that could be applied to multiple future NASA missions, including human space exploration beyond low Earth orbit.

Boeing will receive approximately $24 million over the project lifecycle from NASA's Space Technology Program for the work which starts this month. The tanks will be manufactured at a Boeing facility in Seattle. Testing will start in late 2013 at NASA's Marshall Space Flight Center in Huntsville, Ala.

"The goal of this particular technology demonstration effort is to achieve a 30 percent weight savings and a 25 percent cost savings from traditional metallic tanks," said the Director of NASA's Space Technology Program, Michael Gazarik at NASA Headquarters in Washington. "Weight savings alone would allow us to increase our upmass capability, which is important when considering payload size and cost. This state-of-the-art technology has applications for multiple stakeholders in the rocket propulsion community."

By investing in high payoff, disruptive technology that industry does not have today, NASA matures the technologies required for future missions, while proving the capabilities and lowering the cost of government and commercial space activities.

Continuing the advancement of technologies required for NASA's missions in deep space exploration, science and space operations, the composite cryotank demonstration effort will advance the areas of materials, manufacturing and structures.

The tanks incorporate design features and new manufacturing processes applicable to designs up to 10 meters in diameter. Tanks could be used on future heavy-lift vehicles, in-space propellant depots and other Earth-departure exploration architectures.

"This technology demonstration effort is different in the fact that we're focused on affordability concurrently with performance," said John Vickers, NASA project manager for the Composite Cryotank Technologies Demonstration effort at Marshall. "This technology has excellent transition potential for NASA and commercial product lines. Critical technology advances such as out-of autoclave composites are being matured, and when demonstrated in an operational environment will let us go well beyond the state-of-the-art."

Marshall will lead the project with support from NASA's Glenn Research Center in Cleveland; NASA's Langley Research Center in Hampton, Va.; and NASA's Kennedy Space Center in Florida. The composite cryogenic tank effort is part of the Space Technology Game Changing Development Program, managed by the Office of the Chief Technologist.

For more information about NASA's Marshall Space Flight Center, visit:

http://www.nasa.gov/marshall

For information about NASA's Office of the Chief Technologist and Space Technology Program, visit:
http://www.nasa.gov/oct

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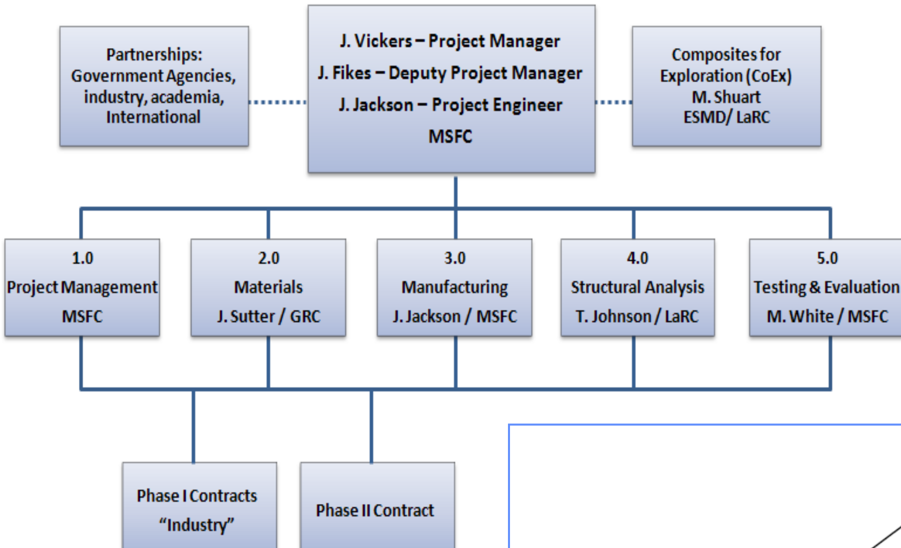
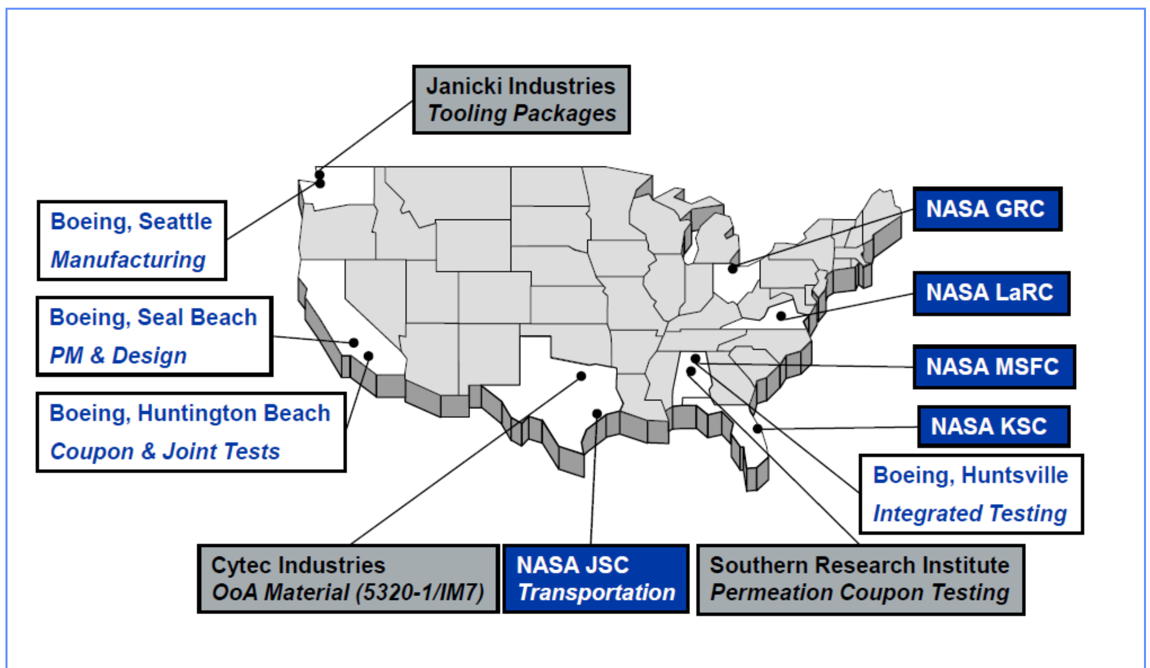
NASA & Industry Team

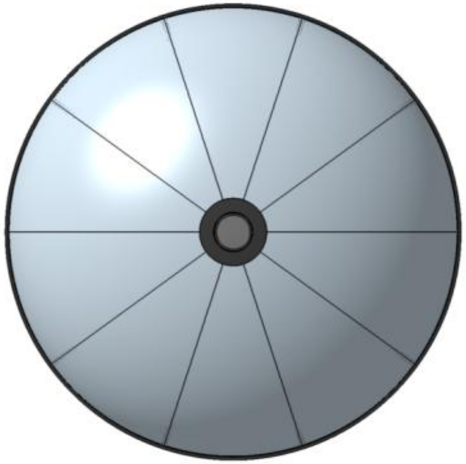


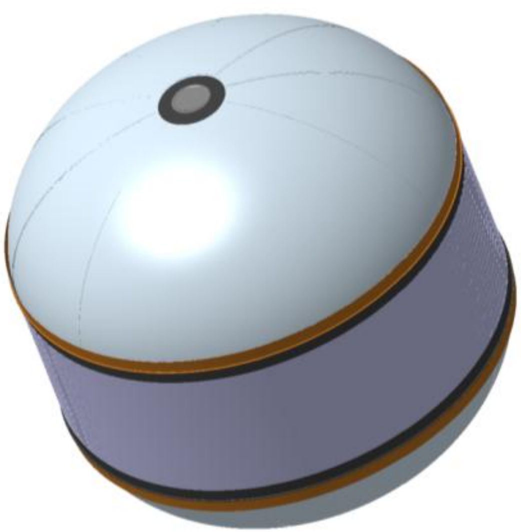


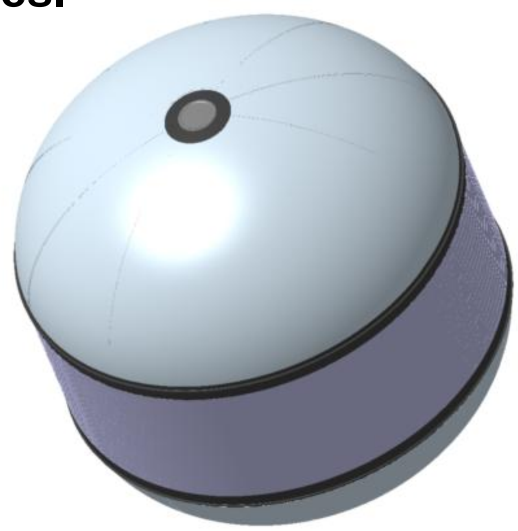
Al-Li Tank Design Overview

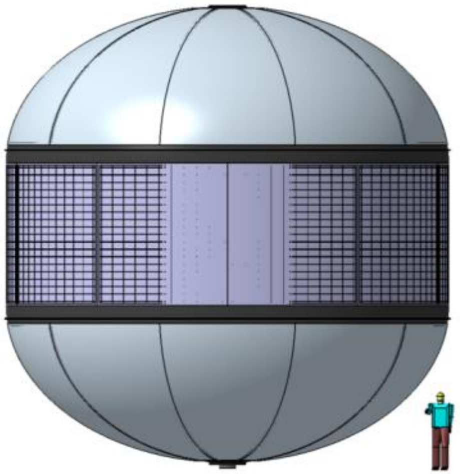
<u>Orthogrid Stiffened 33 Foot tank Design</u>

- 33 Foot Inner Diameter
- .707 Elliptical dome
- Tank Volume = 38.7 E 6 in ^3
- Weight ≈10,925 lbs
- Length ≈ 413 in
- Design is based on TRL 9+ materials and manufacturing techniques.

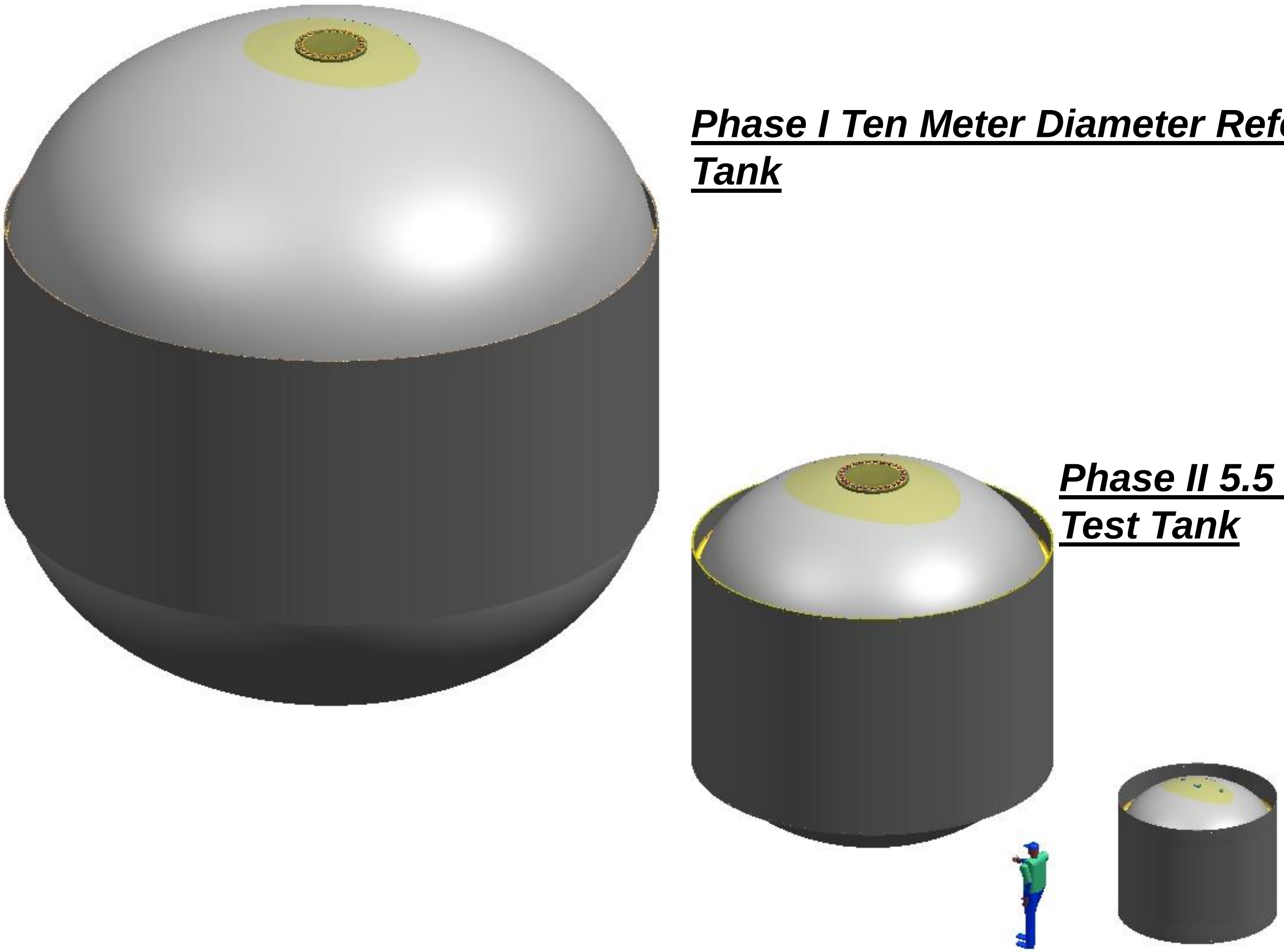








CCTD Tank Designs



Phase I Ten Meter Diameter Reference Tank

Phase II 5.5 Meter Diameter Test Tank

Phase II 2.4 Meter Diameter Precursor Tank

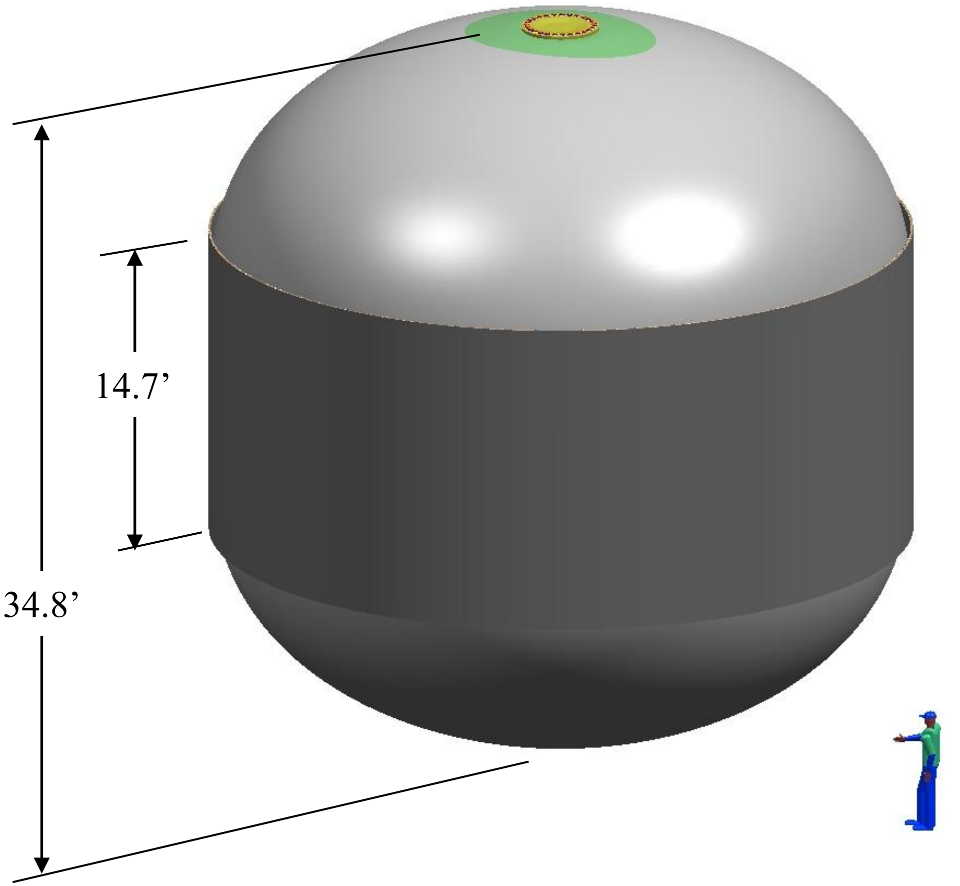
“10-Meter” Composite Cryotank

Design Information:

- Diameter: 33 ft (~10 m)
- Height: 34.8 ft (10.6 m)
- Volume: 22,396 ft³ (634 m³)

➔ 167,533 Gallons

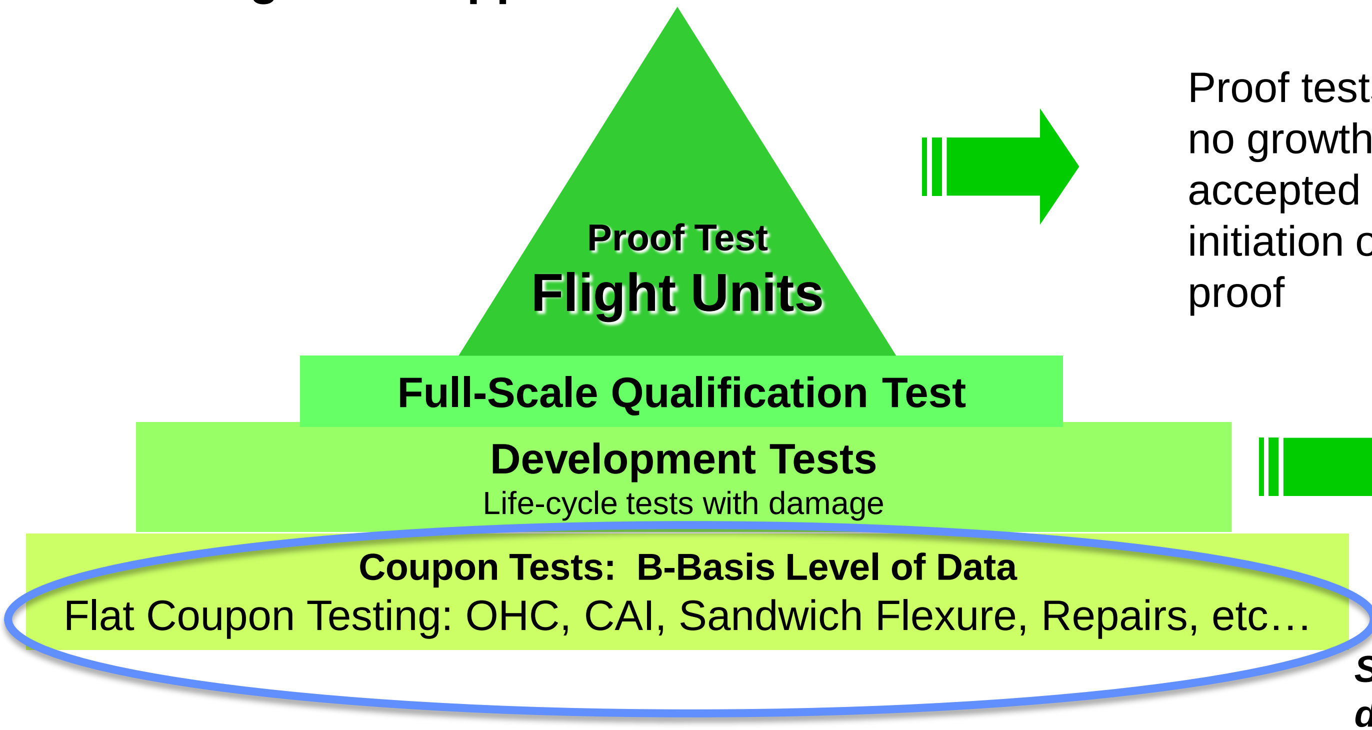
- Operating Pressure: 42 psi (290 kPa)
- Empty Weight: 6,696 lbs (3,037 kg)
- LH2 Weight @ .00256 lb/in³: 99,072 lbs (44,938 kg)
- Full Tank Weight: 105,768 lbs (47,976 kg)



("Anthroman" is 5' 8.5" tall)

Typical NASA Design and Certification Methodology

Building Block Approach



Proof tests to demonstrate no growth of damage accepted pre-proof and no initiation of damage during proof

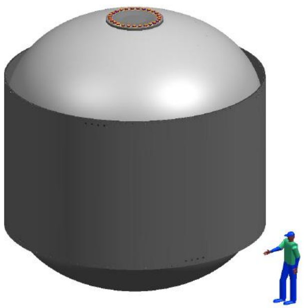
Building Block Tests For Damage Tolerance Verification

Substantial materials database already exists for candidate materials

NASA design and certification standards are not an impediment, but they must be applied differently for composite structures:

- **More emphasis on allowables at structural scales rather than material scales.**
- **Collaborative approach to tailoring with U.S. industry to leverage the experience already applied to commercial aircraft, military aircraft, and EELV.**

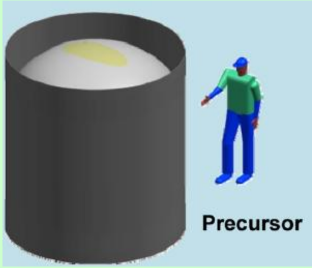
Building Block Program supports 5.5m

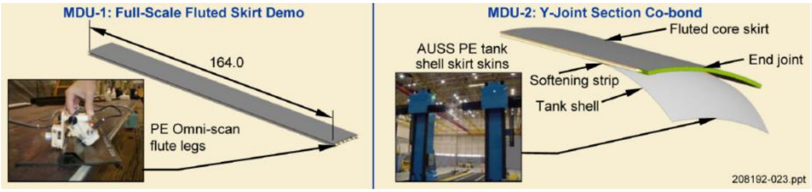


5.5 meter Tank

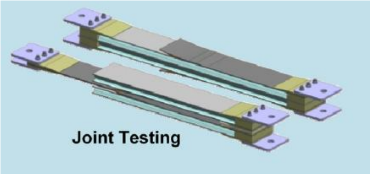
Available to Support 5.5m Tank

2.4 meter Precursor Tank

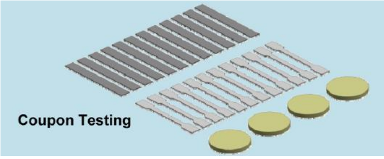




Manufacturing Demonstration Units



Joint Testing



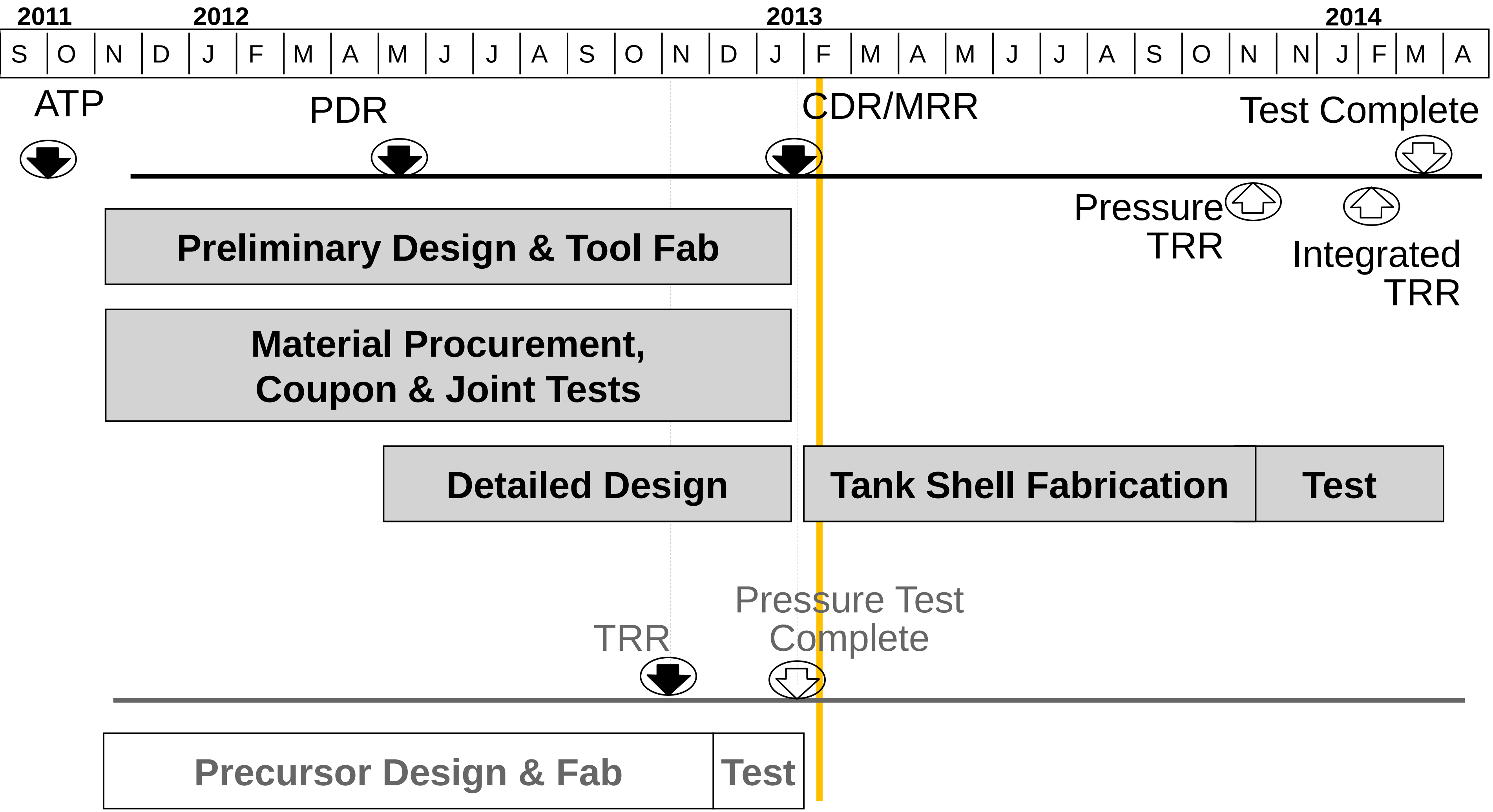
Coupon Testing

Coupon, Joint, and MDUs are Complete

Baseline Master Schedule - Overview

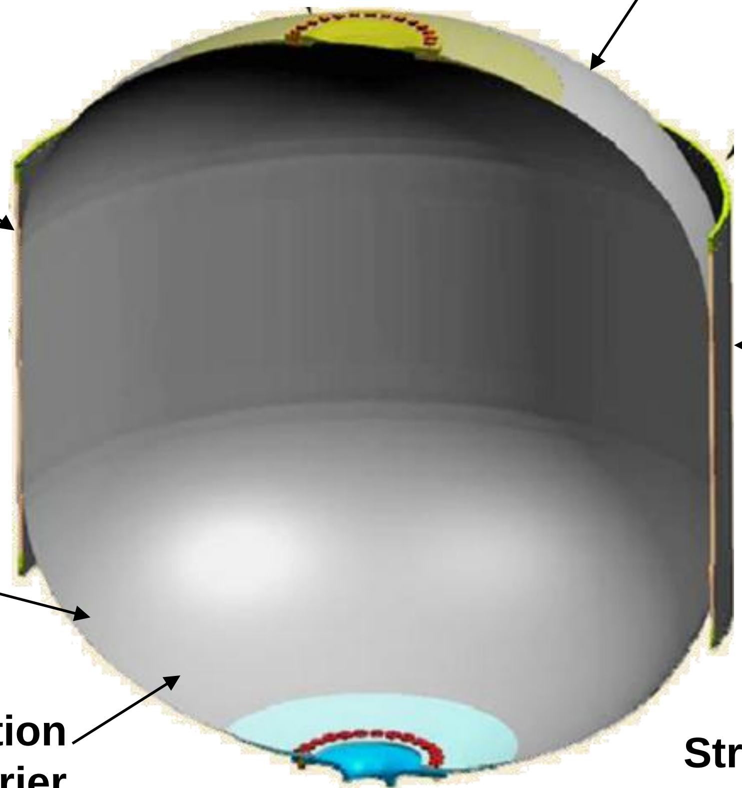
5.5m
2.4m

NASA Game Changing Development Program | Composite Cryotank Project



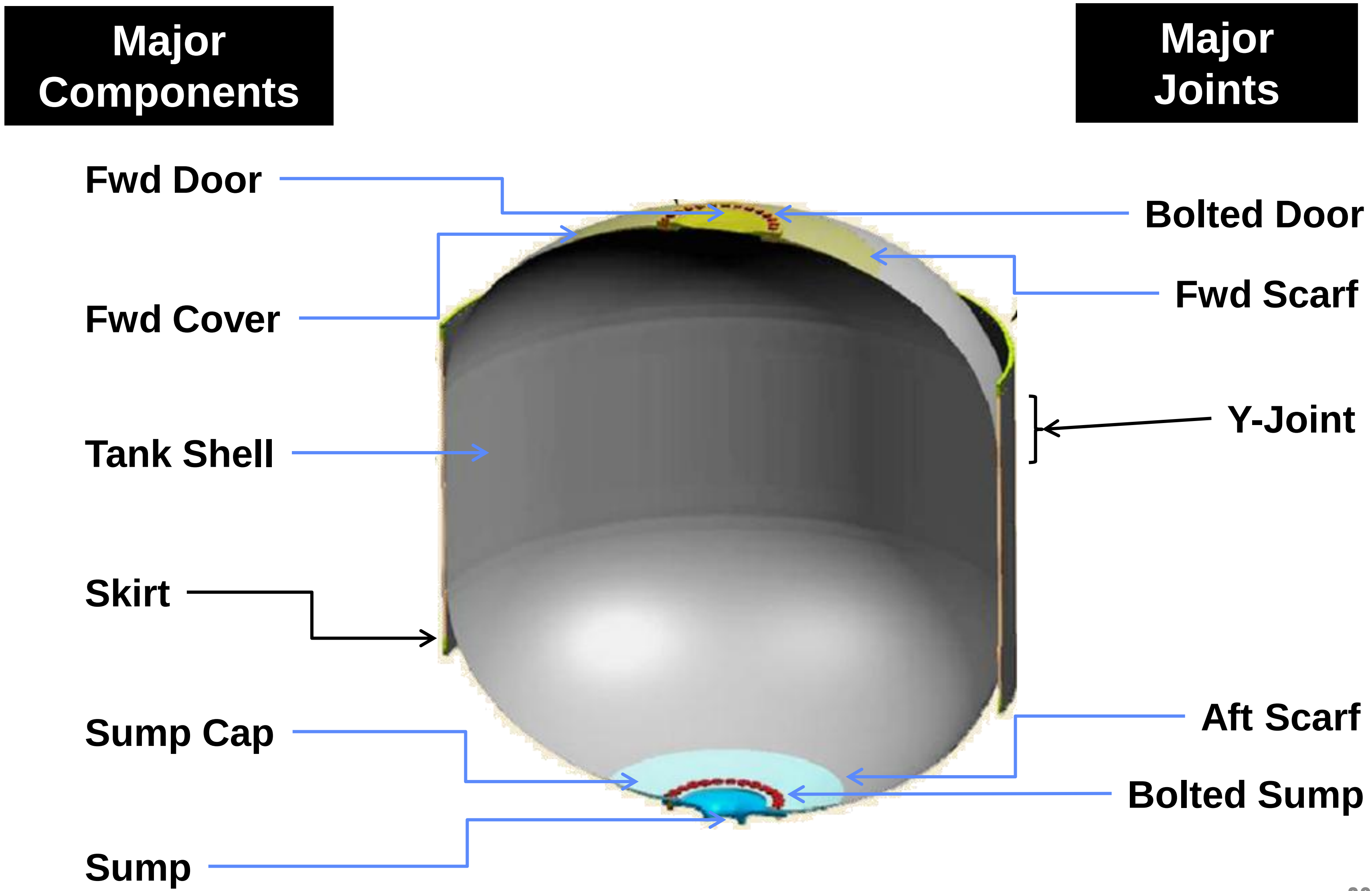
Saves 13months Compared to More Typical Serial Development

Technologies Matured by CCTD

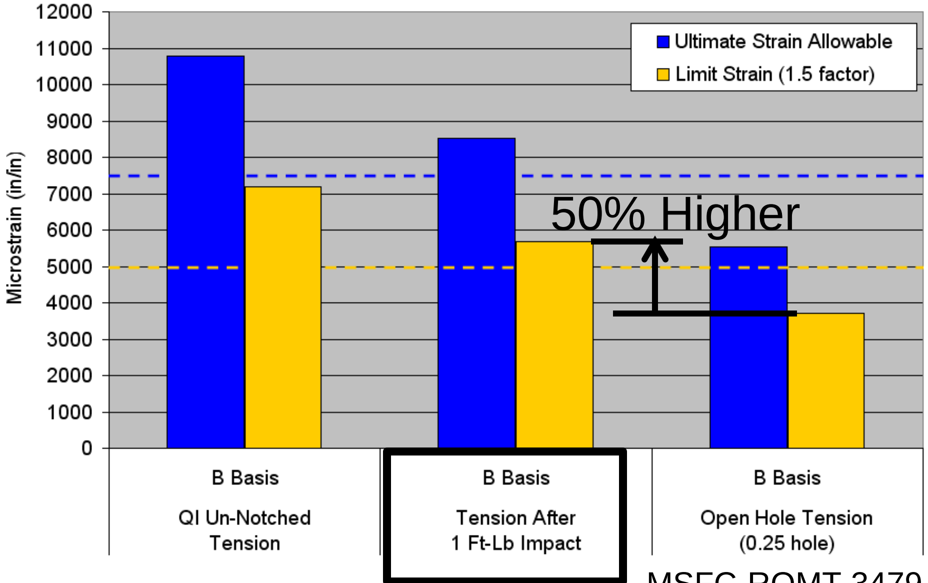


Matured & Demonstrated in Building Block Program

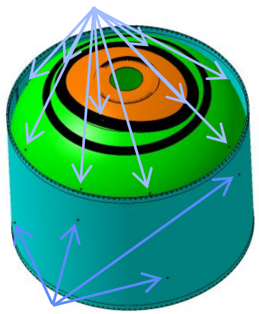
Structural Arrangement Overview



SHM Enables Higher Strength Allowable

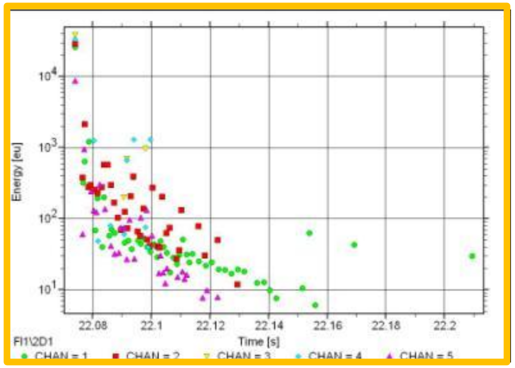


MSFC-RQMT-3479



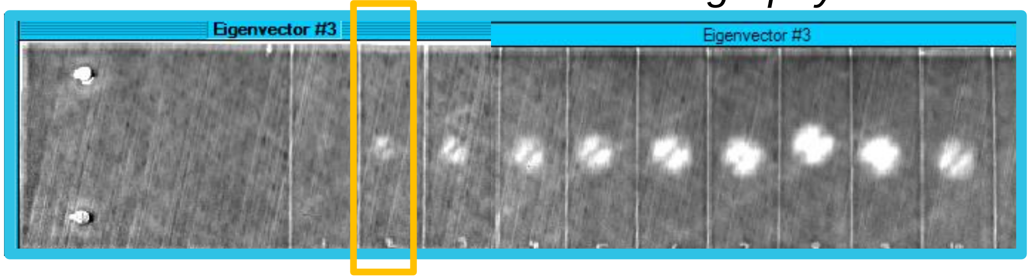
38 sensors

Acoustic Energy Detection



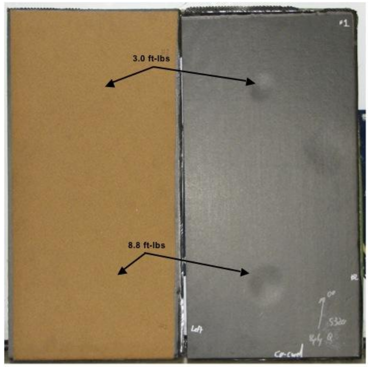
1 ft-lb

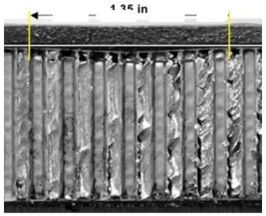
Thermography Detection

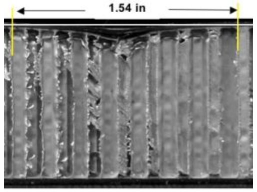


Impact damage is both SHM and thermography detectable

Composites Damage Tolerance Approach



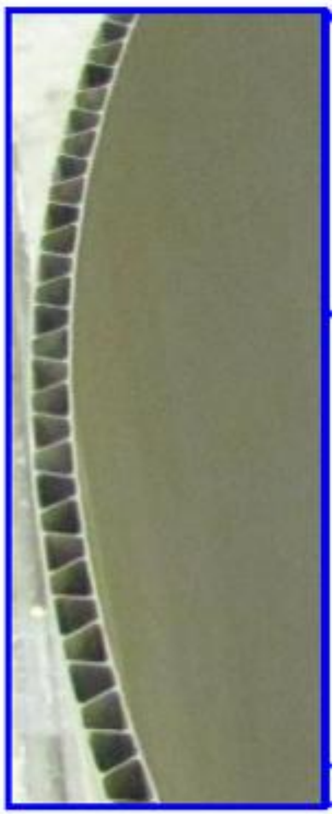




- **Assess possible accidental and fabrication induced damage threats**
  - For payload fairing blunt impact damage is the most likely type of accidental damage
- **Investigate effect of damage size with respect to structural scale**
  - Boundary conditions can affect the impact energy level necessary to produce a given size of damage.
- **Repair all detectable damage**
- **Demonstrate through element and sub-component testing that under simulated flight loads the structure is insensitive to undetectable size damage**
  - Ten meter diameter curved composite sandwich panels (3ft by 5ft) representing fairing acreage were impacted at 5.5 ft-lb to produce barely visible damage (golf ball size shallow indentation) and loaded to buckling at Room and Elevated Temperatures.

Test specimens were found to be insensitive to barely visible damage.

Fluted Core Composites



Thin laminate angled web members with structural radius fillers evenly spaced between laminate face sheets

- **10’ H x 13.1’ D (4m)**
- **Delivered to NASA/LaRC COLTS**
- **Test planned for August**

- Web Orientation Provides Efficient Compressive Load Capability
- Integral Web to Facesheet Construction Improves Damage Tolerance

2.4m Precursor Status / Accomplishments

NASA Game Changing Development Program   Composite Cryotank Project

Thin & Thick Ply AFP – July 17

OoA Cure – July 20

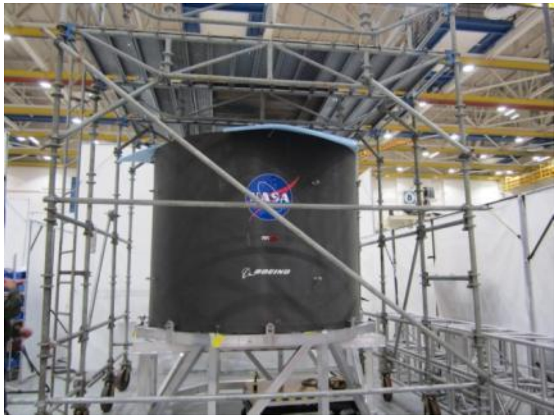
NDI

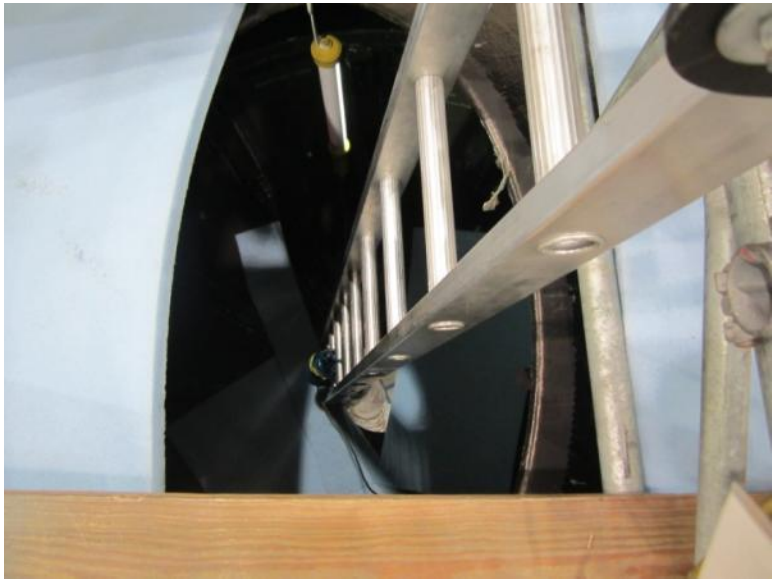
2.4m Precursor Status / Accomplishments

Sept 1, 2012　　Initial Skirt Plies

2.4m Precursor Status / Accomplishments

NASA Game Changing Development Program | Composite Cryotank Project





Segmented Tool Extraction

2.4m Precursor Status / Accomplishments

At NASA/MSFC: http://www.nasa.gov/topics/technology/features/cryotank.html

2.4m Precursor Status / Accomplishments

Dec 12, 2012

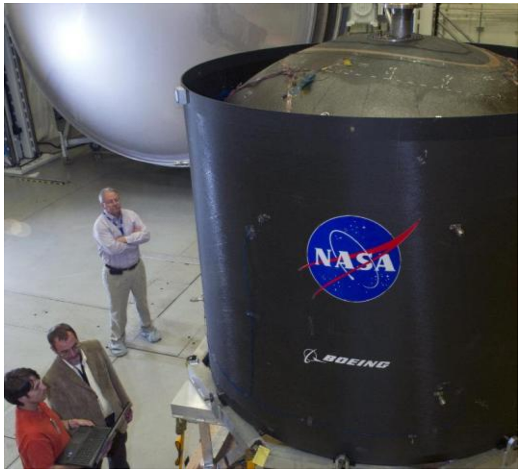
NASA-MSFC West Test Area

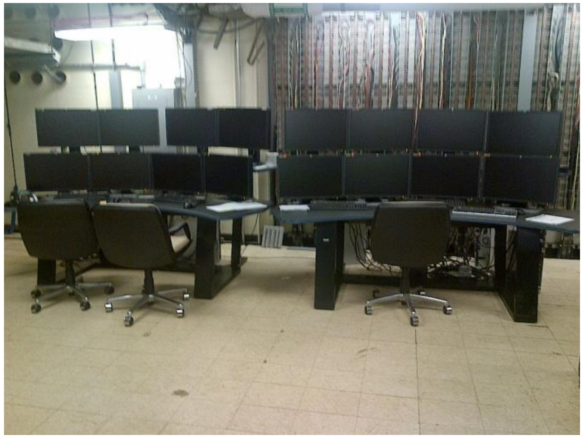
Dec 18, 2012

2.4m Status Summary

NASA Game Changing Development Program — **Composite Cryotank Project**



Successful Design and Fabrication. Test Site Prep In Work.

2.4m Design, Fab, and Test Summary

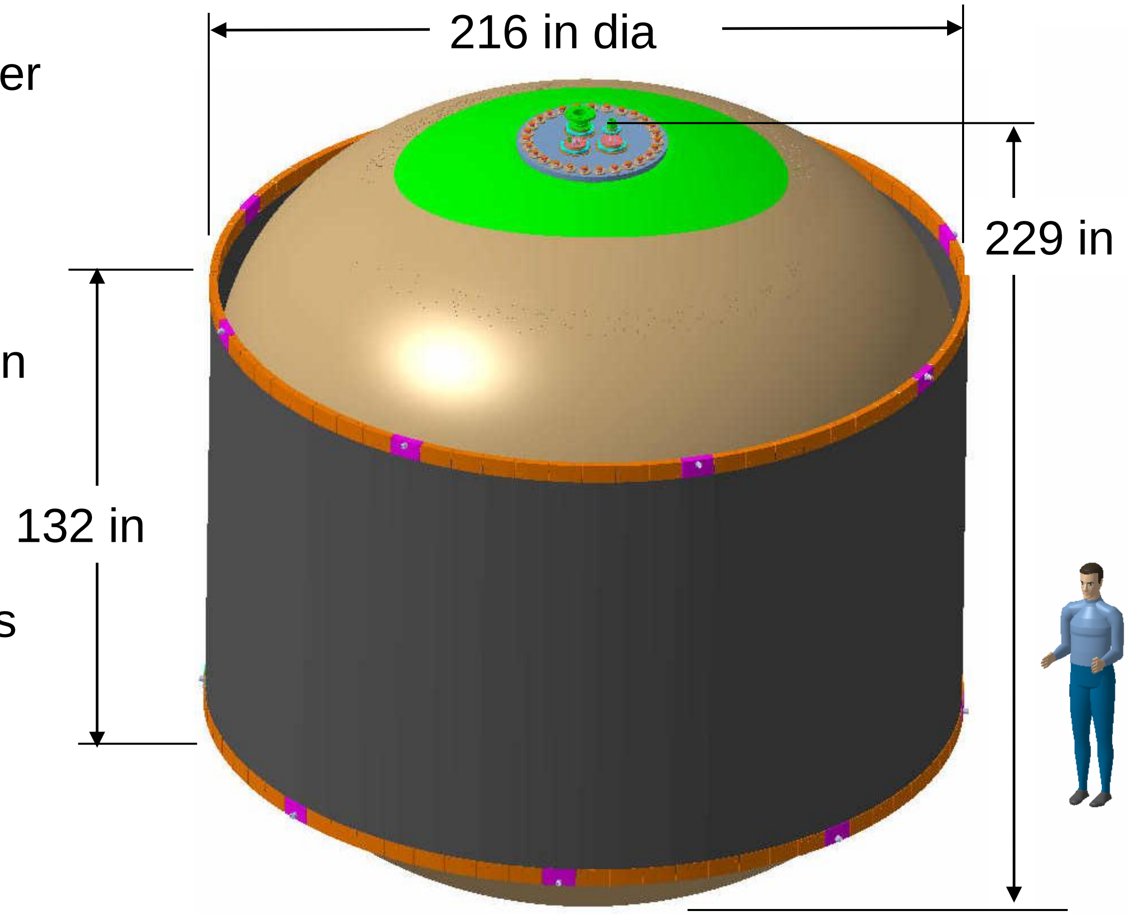
- **Accomplishments**
  - 1st successful large AFP test article using 5320-1/IM7
  - 1st successful 70gsm fiber placed cryotank (hybrid laminate)
  - 1st successful spherical segmented tool use
  - 1st successful all composite bolted sump/fwd cover joint

- **Next Steps**

– Tank Leak Check	Complete
– Test Site with Tank Leak Check	Complete
– Facility Test Readiness Review	2/19/13
– Ambient Proof Test (190psi)	2/26/13
– Cryogenic Proof Test (190psi)	3/5/13
– Test Report Delivered	4/2/13

5.5m Tank Overall Dimensions

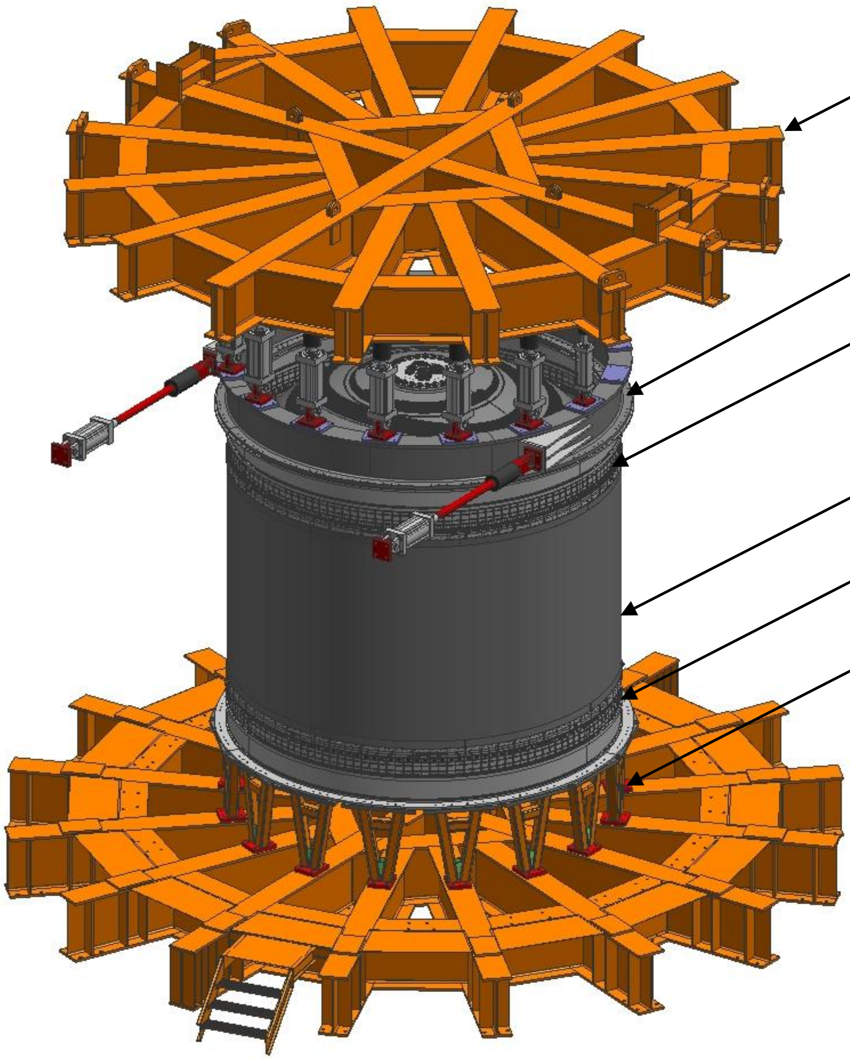
- Pressure wall mid-surface diameter = 216.54 in
- Pressure vessel cylinder height = 69.6 in
- Skirt end-to-end length = 131.88 in
- Dome to dome length = 229.70 in
- Volume = 3785 cu. ft.
- Two (2) 30-in dia access openings at fwd and aft dome



Test Site & Test Hardware Overview

Test Stand 4699, NASA MSFC

Test Site & Test Hardware Overview



5.5m Cryotank Status / Accomplishments

5m Segmented Tool Mandrel Fabrication

5.5m Cryotank Status / Accomplishments

5m Spindle Fabrication

5.5m Cryotank Status / Accomplishments

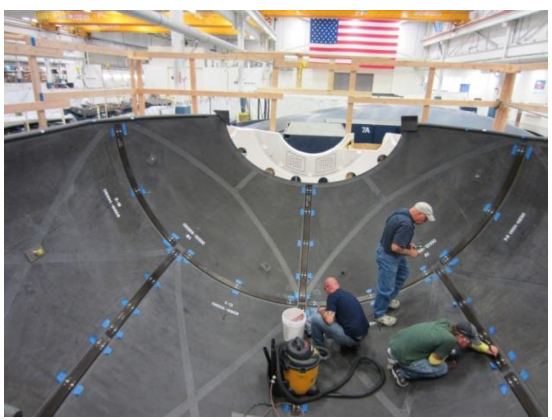
5.5m Cryotank Status / Accomplishments

5.5m Robotic AFP Cell Install




5.5m Cryotank Status Overview

NASA Game Changing Development Program | **Composite Cryotank Project**



CDR Held. 5.5m Tank Shell Mandrel Arrived Jan 27th.

5.5m Design, Fab, and Test Next Steps

• Approval to proceed with Component Fab	Started
• Approval to proceed with Tank Shell Fab	Late March
– At completion of Delta CDR/MRR	
• 5m Pressure and Integrated Load Testing	1Q2014

Summary

- **Permeation**
  - **Mechanism is understood**
  - **Solutions validated by coupon tests**
  - **System demo in relevant environment planned within CCTD**

- **CCTD aims to mature & demonstrate several technologies**
  - **8.4m subscale designs *(increased stress at lower OoA allowables)***
  - **Ventable and purgeable structures eliminates trapped gas risks**
  - **AFP of large structure using thin ply**
  - **Segmented breakdown tool use and extraction for lightweight design**

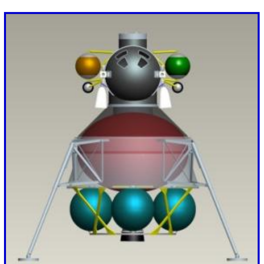
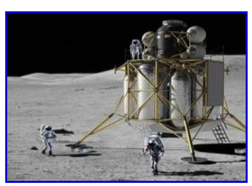
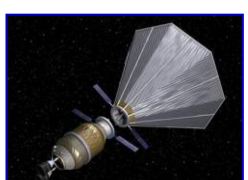
Transition Potential

- Communicate with stakeholders and customers
  - (Lockheed Martin, Boeing, Northrop Grumman, Space X, MSFC, LARC, NESC, JSC, KSC, and DOD)
  - Synergy with HLV study concepts

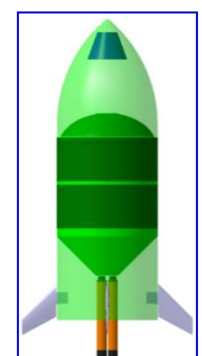
- Composite cryotank technologies for HLV (8.4m-10.0m) architectures + spin-off capabilities to meet multiple customer needs
  - NASA, DoD, and Commercial customers + in-space propulsion, propellant depot, and LOX or RP tank capabilities

- In-Space Cryogenic Propellant Depots and Landers are needed in New Exploration Architecture (The In-Space Cryogenic Propellant Storage and Transfer Demonstration Mission Concept Studies BAA)

- Multiple flight opportunity identified in phase I (benefits commercial flight)





Conclusions

- The Composite Cryotank Technologies and Demonstration Project will make significant advancement to achieve 30% weight and 25% cost savings over SOA cryotanks at the 10-meter diameter scale

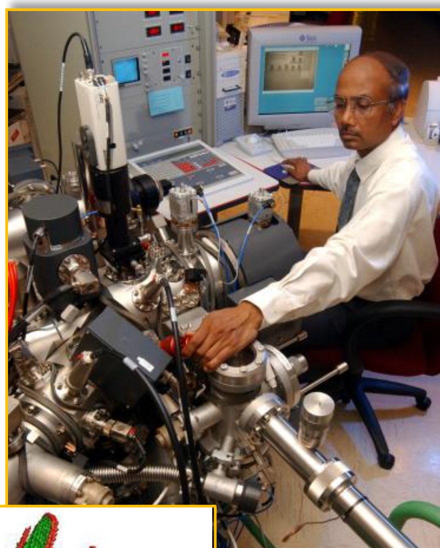
- Critical Technologies
  - Materials
  - Structures
  - Manufacturing
  - Testing -- 5-meter diameter composite hydrogen tank

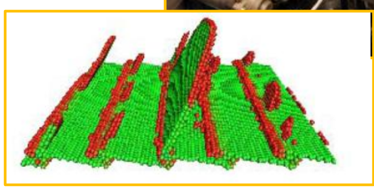
- Technology provides important benefits to NASA and Commercial needs plus diverse sectors of the economy/enhances global competiveness -- Composites are important materials for the future of aerospace strategic leadership -- Leapfrogging the SOA puts NASA in a leadership position

"The goal of this particular technology demonstration effort is to achieve a 30 percent weight savings and a 25 percent cost savings from traditional metallic tanks," said the Director of NASA's Space Technology Program, Michael Gazarik at NASA Headquarters in Washington. "Weight savings alone would allow us to increase our upmass capability, which is important when considering payload size and cost. This state-of-the-art technology has applications for multiple stakeholders in the rocket propulsion community."

Materials Modeling and Simulation

NASA Game Changing Development Program **Composite Cryotank Project**





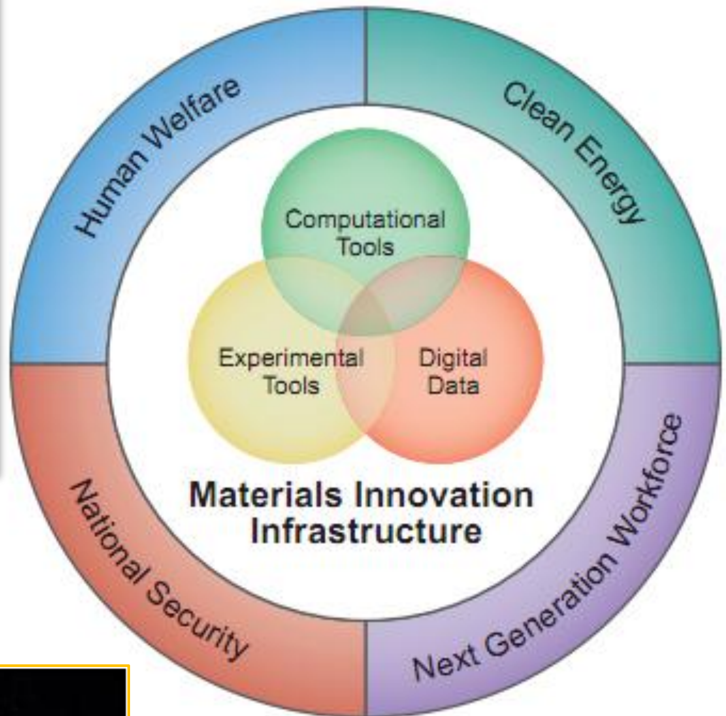
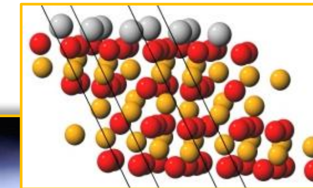
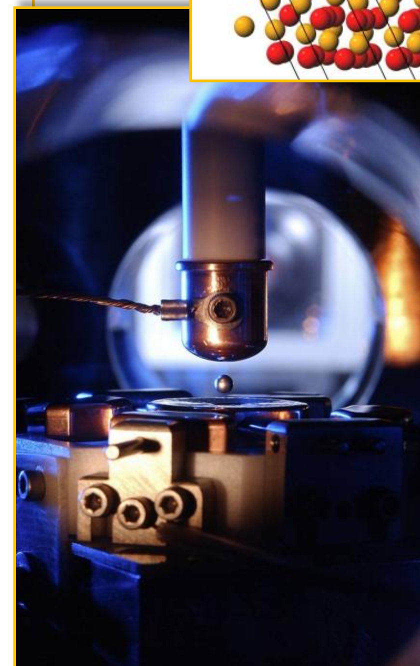
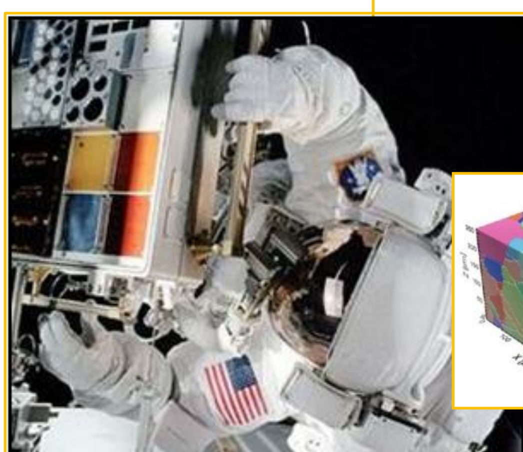
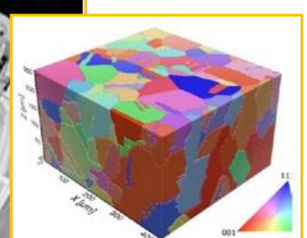


Figure 3: Initiative overview









Manufacturing Modeling and Simulation

NASA Game Changing Development Program

Composite Cryotank Project