Lockheed Martin Advance Welding at Michoud Assembly Facility

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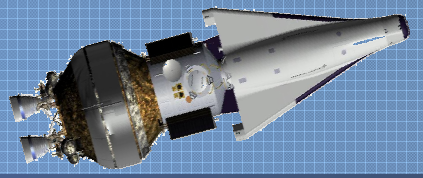
Welding Expertise at Michoud

Future

- FSW on Thin Gage Aluminum (<0.100") and Titanium
- Procurement of NCAM UWS II for Orion Production



2000s

- Procurement of NCAM UWS I and PDS
- Produce 1st full scale FSW ET barrel

1990s

- FSW Development Programs
- 1st FSW at Michoud

1980s

- Soft Plasma Arc Welding used on External Tank
- Variable Polarity Plasma Arc Welding used on External Tank

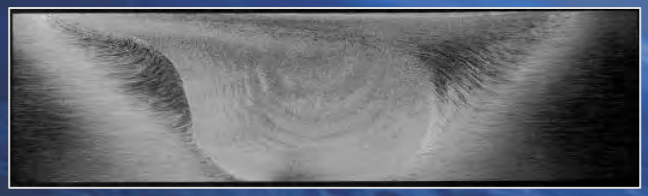
1970s

- Tungsten Inert Gas Welding used on External Tank

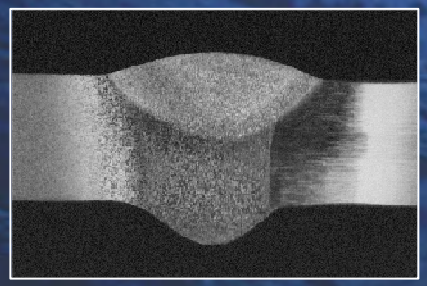
Lockheed Martin is an Industry Leader and Has Made Major Contributions to the Development of Joining Technologies

Friction Stir Welding Overview

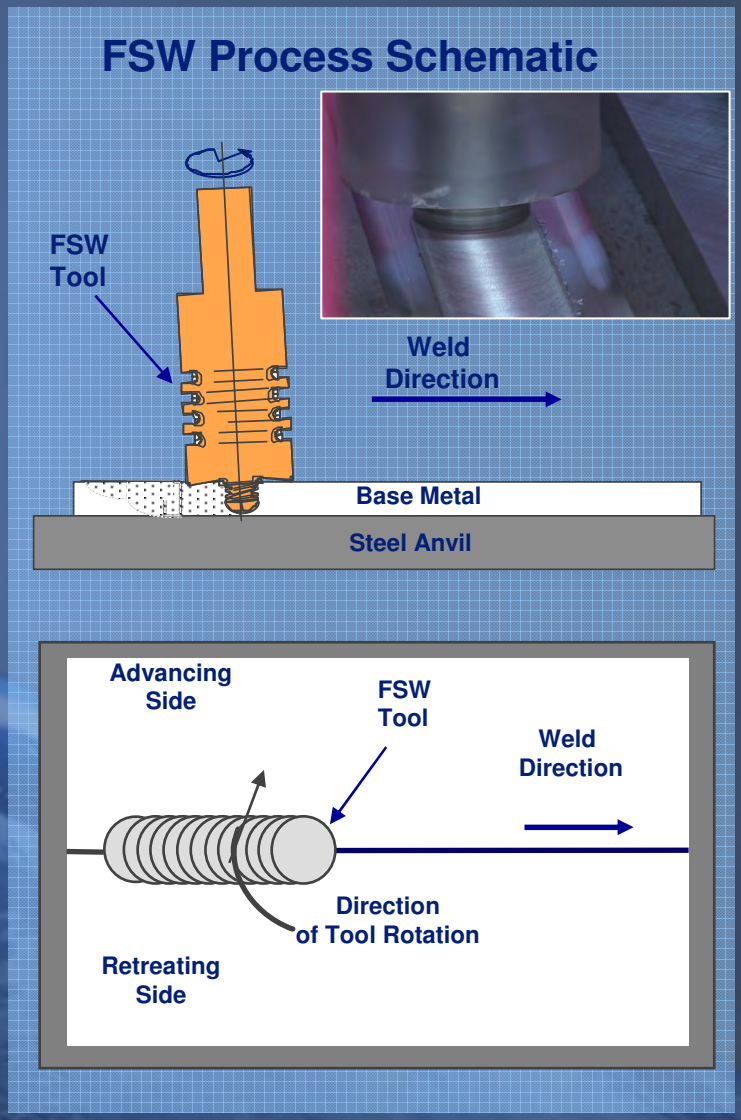
- *Frictional heating from the rotating tool plasticizes the material in the weld joint.*
- *The rotating tool then traverses along the weld seam, generating a high strength, solid-state (no melting involved) weld.*



0.320-in Thick Al2219 FSW Macro



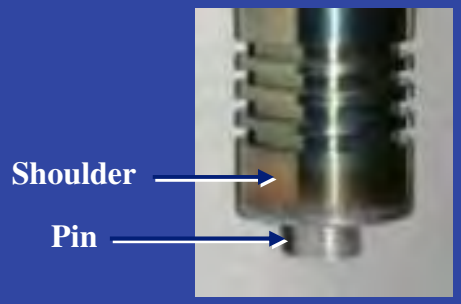
0.320-in Thick Al2219 Fusion Macro



Friction Stir Welding Methods

Fixed Pin Tool

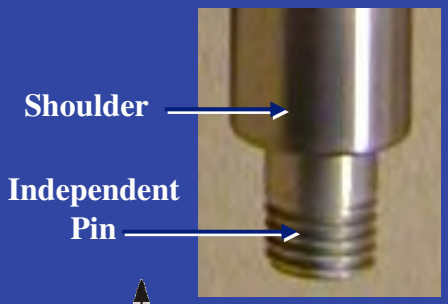
- Single piece tool
- Single thickness capability
- Requires a backing anvil



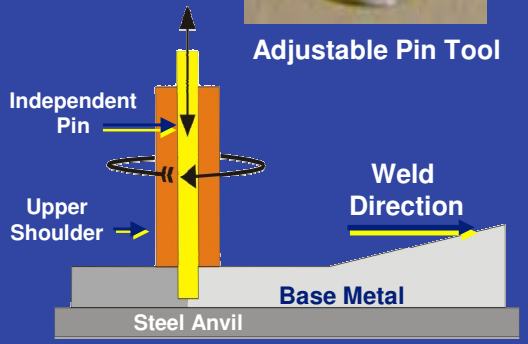
Fixed Pin Tool

Adjustable Pin Tool

- Two Piece Tool
- Accommodates multiple thickness welds
- Requires a backing anvil

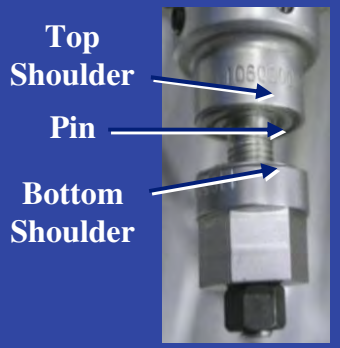


Adjustable Pin Tool

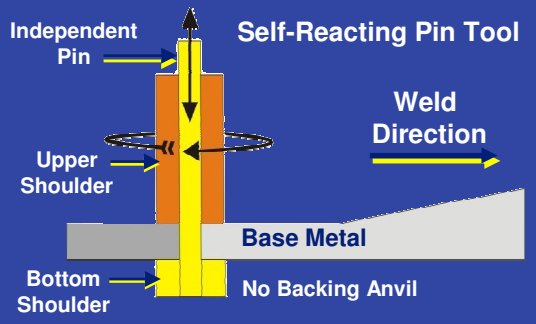


Self-Reacting Pin Tool

- Three Piece Tool
- Accommodates multiple thickness welds
- Requires less fixturing



Self-Reacting Pin Tool

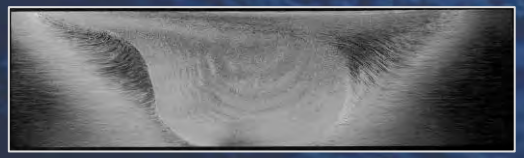


Michoud Capabilities Include All Methods of Friction Stir Welding

Benefits of FSW vs Fusion Welding

Process Enhancements

- Reduced weld process time
  - Single pass up to 1” thick versus multiple passes for welds 0.250”+
- Fewer process variables / reduced variability
  - 3 main parameters versus 10+ for fusion
- Simplified joint geometry at thicker gages
- Easily automated & controlled
- Less operator dependent
- Eliminates consumables – no gases, tungsten electrodes, or filler metals
- Health hazards (I.e., arc burn, UV Radiation) are eliminated
- Reduced surface weld prep
- Weld bead geometry easier to inspect
- Easier to weld dissimilar alloys



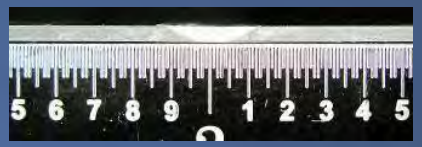
0.320-in Thick Al2219 FSW Macro

Material Enhancements

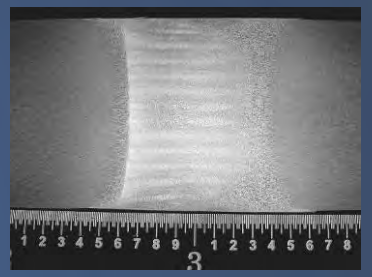
- Mechanical Properties
  - Improved strength (10-30% increase)
  - Improved fracture toughness
  - Improved ductility
  - Reduced knock-down factors
- Reduced weld defects
  - Elimination of porosity
  - Elimination of solidification cracking
- Microstructural benefits
  - Parent material chemistry – no dilution from filler metals
  - Very fine-grains versus normal cast structure from arc weld
- Reduced shrinkage
- Reduced distortion
- Allow welding of traditionally unweldable alloys

Michoud FSW Experience and Capabilities

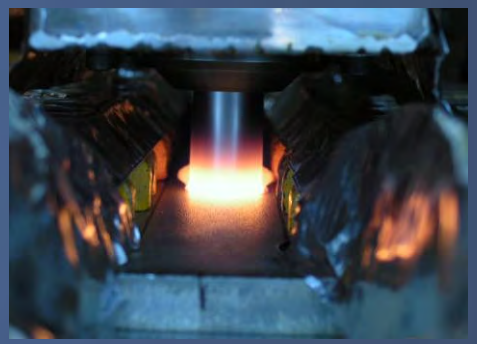
- FSW Process Capabilities
  - Fixed Pin
  - Adjustable Pin
  - Self-Reacting
- Wide Range of Materials
  - Al1XXX, Al2XXX, Al3XXX, Al5XXX, Al6XXX, Al7XXX
  - Ti alloys
  - Inconel 625, 718
  - Haynes 214
  - Stainless Steel
- Wide Range of Thickness
  - 0.015-in to 1.5-in plus tapers
- Configurations
  - Butt Joints
  - Lap Joints
  - T-Joints
  - Fillets
- Wide Range of Part Configurations
  - Linear, Complex Curvature, Circular, Spherical



0.040-in Thick Al2024 FPT Macro

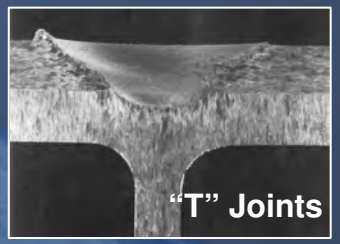


1.0-in Thick Al2219 SRFSW Macro



High Temperature Friction Stir Weld

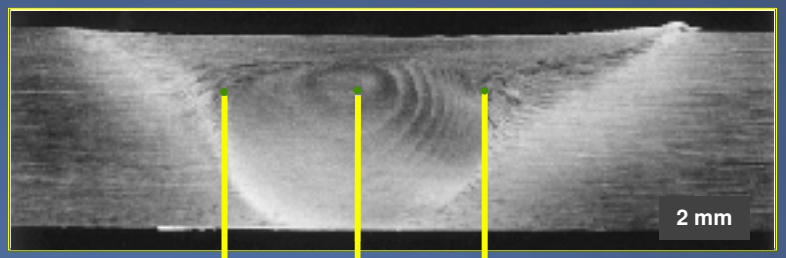
"L" Lap Joints



"T" Joints

"Fillet" Joints

Microstructural Evaluation

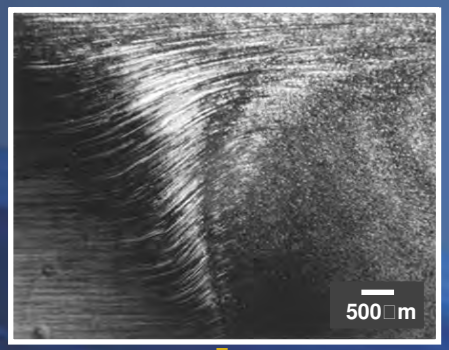


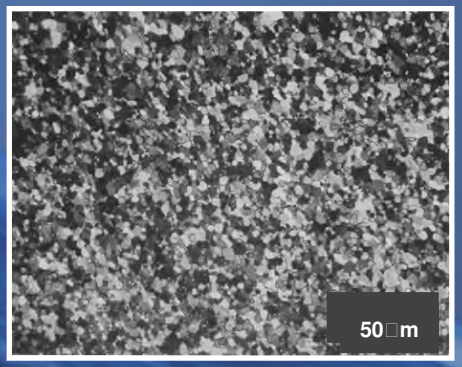
0.25 in.

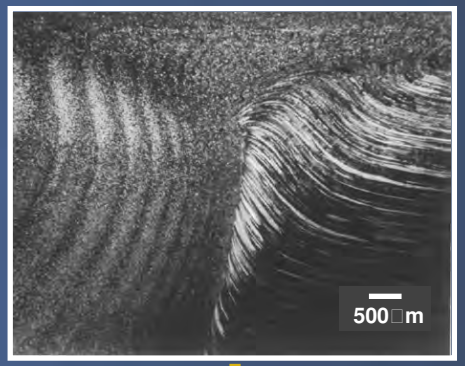
Advancing Side

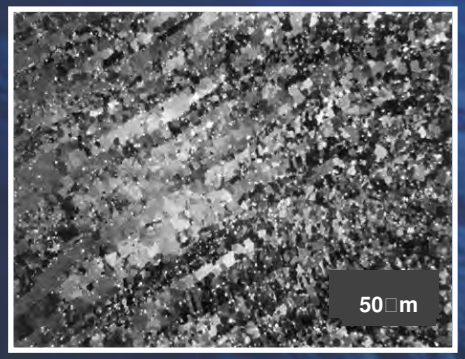
Weld Center

Retreating Side

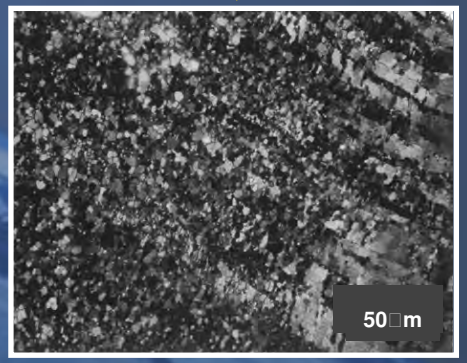








(Dynamically recrystallized zone)



(Thermomechanical zone)

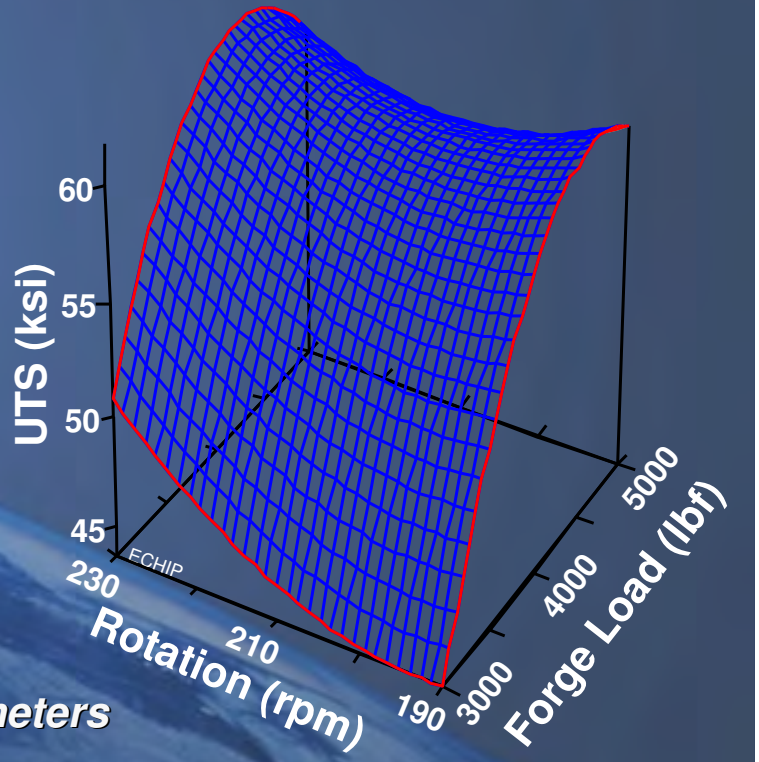
(Thermomechanical zone)

Michoud utilizes microstructure evaluation to assess weld quality

Basic Process Development

Design of Experiments used to Optimize Process

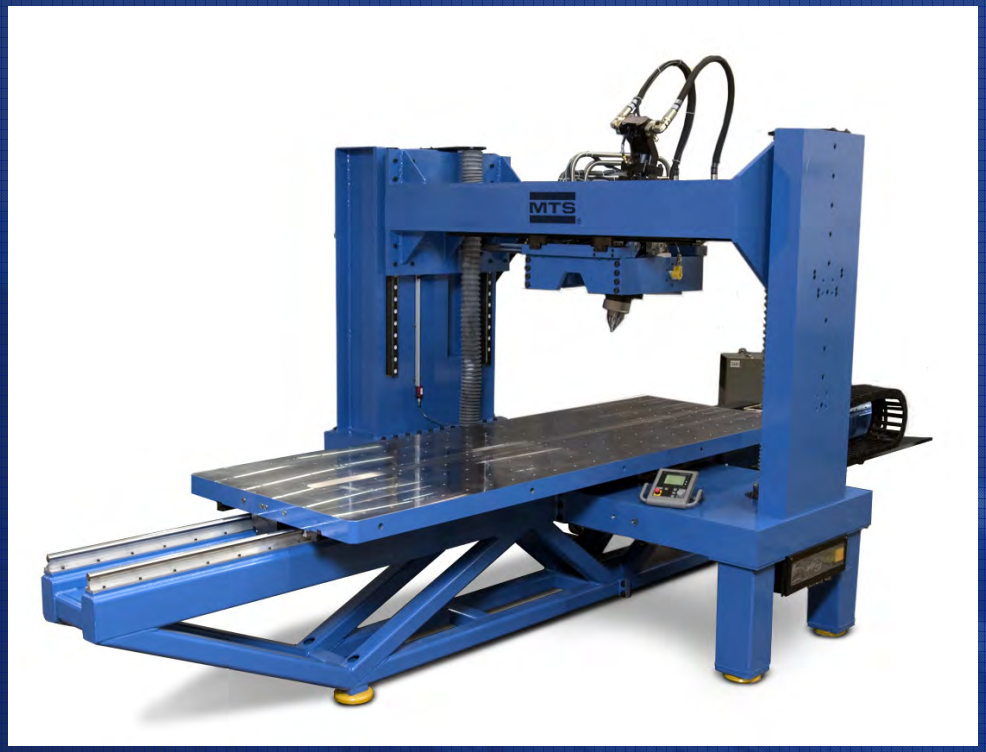
- **Phase I: Bounding Panels**
  - Broad range of weld parameters used to determine the limits for DOE
- **Phase II: Design of Experiment (DOE)**
  - 3 parameters at 5 levels (Low, Nom, High)
    - RPM, IPM, Forging Load
  - Resulting Data used for Evaluation
    - NDE and visual results
    - Mechanical properties (Ftu, Fty, Elongation)
    - Machine loads (Spindle Torque, Travel Load)
  - Trends and interactions are determined and used to define operating window
- **Phase III: Verification Welds**
  - Nominal and "edge of operating window" parameters
  - NDE, metallurgical and properties testing
  - Results in verification of the process parameters



Michoud uses a well-defined, rigorous approach to process development

Process Development System

Currently developing manufacturing processes for multiple structures and vehicles



- *Capable of welding aluminum, steel, inconel and titanium alloys*
- *Capable of welding all friction stir welding methods from 0.025” to 2” thick*
- *Capable of welding parts that are 4’ x 10’ x 1 ½’*
- *Capable of welding complex configurations*
  - *Six (6) axes of motion*

State of the Art Friction Stir Weld System Enables Innovative Research and Development

Universal Friction Stir Welding System (UWS I)

2003 NASA - NCAM - State of Louisiana Sponsored

State of the art tool with conventional, adjustable and self-reacting pin tool capability

- Horizontal 192”
- Vertical 246”
- Reach 118”
- Pitch -5º / +95º
- Roll +/- 15º
- Turntable 360” Diameter
- X-travel is expandable to 45 ft in length

The world’s largest FSW working envelope and most sophisticated capability

Universal Friction Stir Welding System (UWS II)

NCAM - State of Louisiana Sponsored

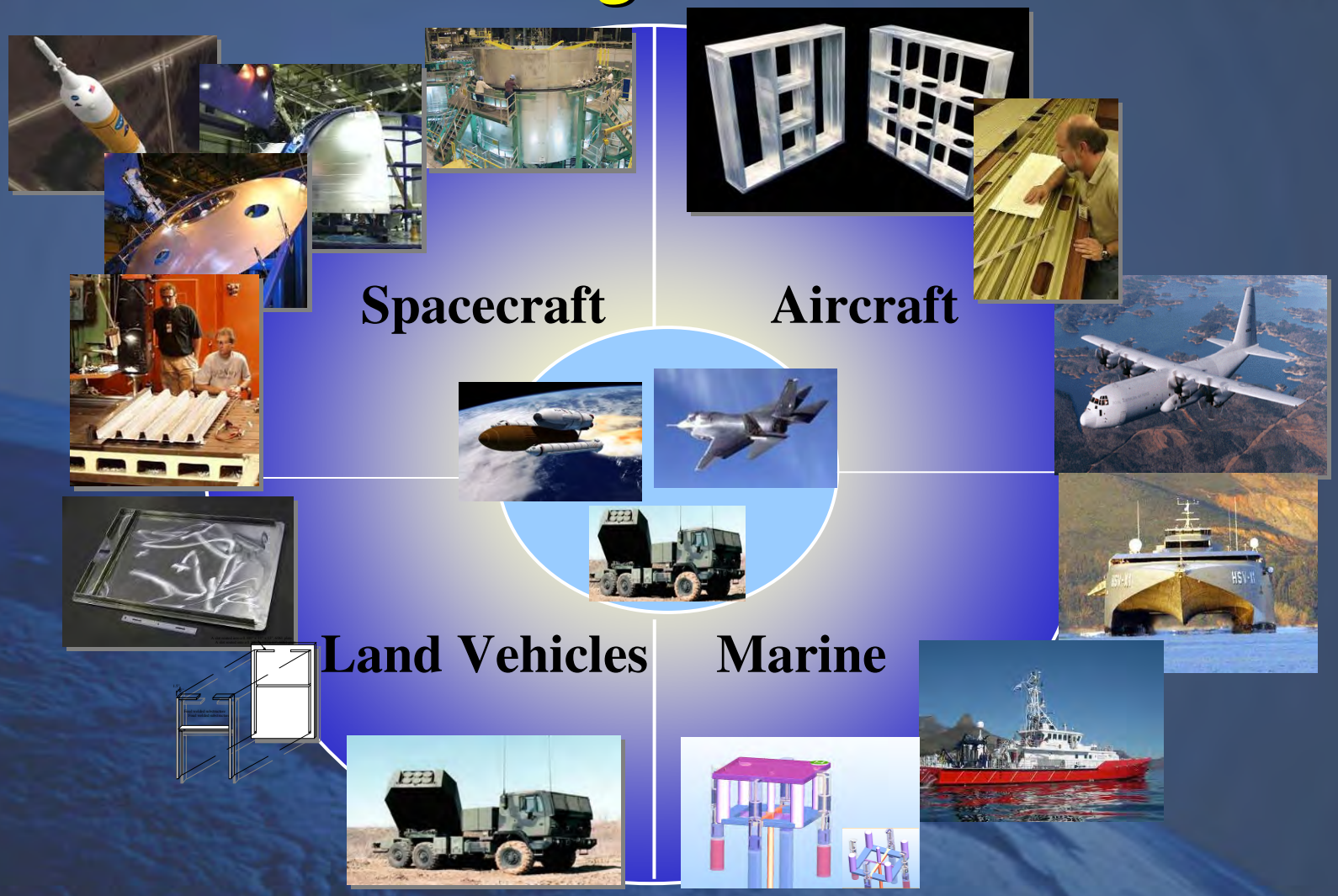
- *Activated in 2009*
- *Similar to UWS I*
- *Includes system upgrades*

- *Stationary stage: 21'x40'*
- *Turntable: 21.8' Dia.*
- *Higher load capacities*

- *7+ Axes of Motion*
- *Horizontal 682"*
- *Vertical 270"*
- *Reach 144"*
- *Pitch -5º / +95º*
- *Roll +/- 15º*
- *Turntable 264" D*
- *Floor Grid 204" x 480"*

Latest Multi-Axis FSW Tool with Several Advanced Upgrades.

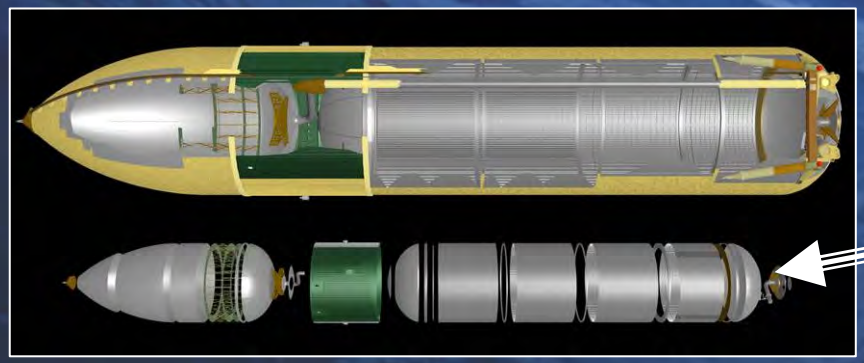
Michoud's FSW Programs

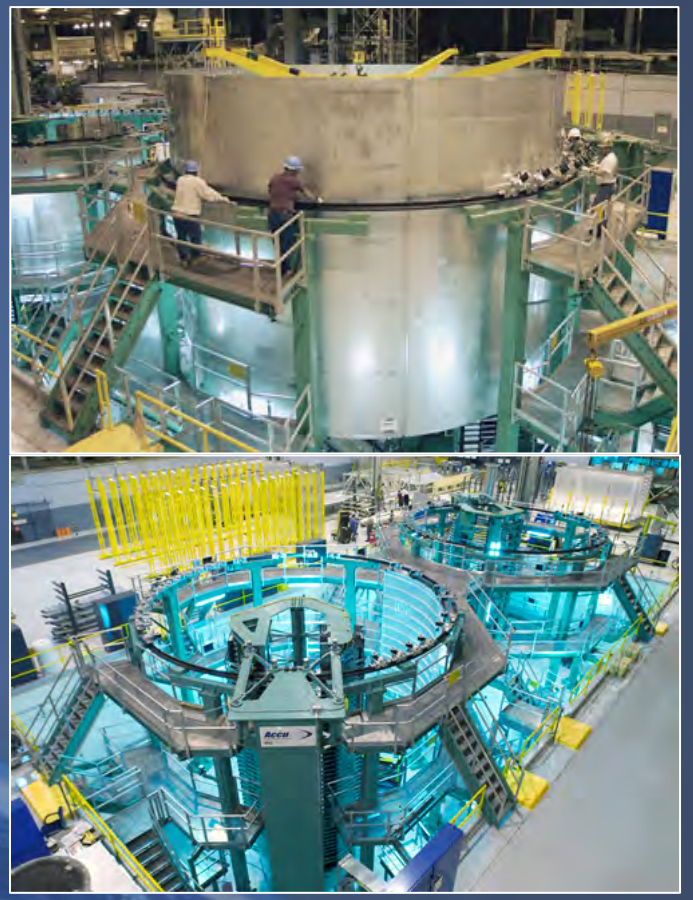


Michoud has Demonstrated Large Tankage and Structures for Multiple Applications

External Tank Barrels

- Description
  - Manufacture of 2195 External Tank Barrels using FSW
  - Over 650 feet of weldments per ET
- Improvements
  - Robust 0.320, 0.550 & 0.650 weld process
    - Extremely low defect rate
  - Strength/Ductility/Toughness
  - Tapered weld joints
  - Defect Free



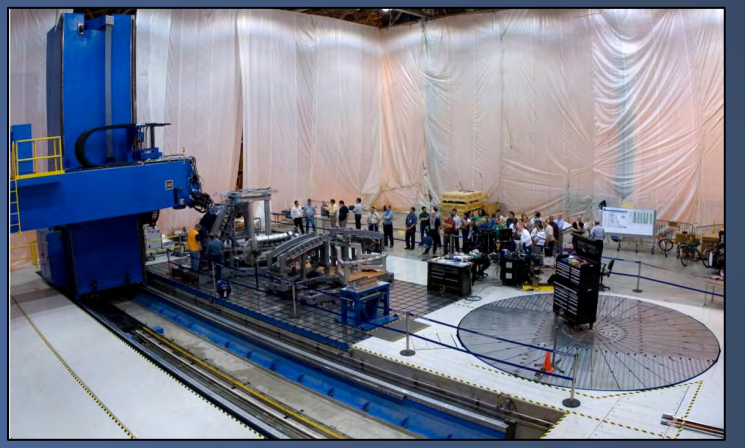


Photograph: Production 27.5' Dia. ET Barrel Tools

All Longitudinal Barrel Welds Are Friction Stir Welded

Orion Crew Module

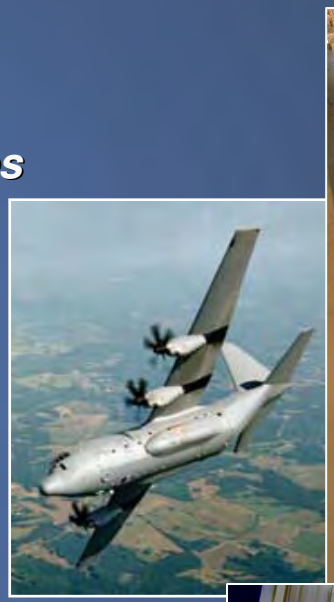
- Description
  - Manufacture of Al2195/Al2219 External crew module
  - 100% Friction Stir Welded
- Improvements
  - Robust process
  - Strength
  - Ductility
  - Toughness

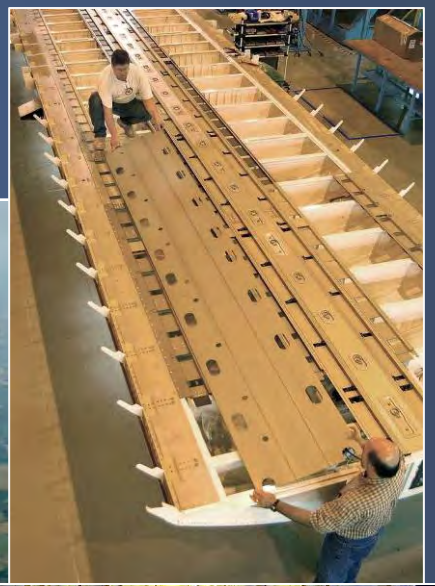


All Crew Modular Welds Are Friction Stir Welded

Cargo Floor, Bulkheads for C-130

- Description
  - Riveted structure replacement
  - Redesign and manufacture test articles
    - 7249 cargo floors (MAI program)
    - 7075 center wing bulkhead
- Customer
  - LM Aeronautics - Marietta
- Challenges / Accomplishments
  - Robust 0.080 & 0.150 weld process
  - Strength & ductility
  - Stress Corrosion (SCC)
  - Exfoliation Corrosion
  - Flatness
  - 20% Cost Reduction
  - Static Test at Vought Aircraft
    - Ultimate Load





Friction Stir Welding performs as well or better than riveted structure

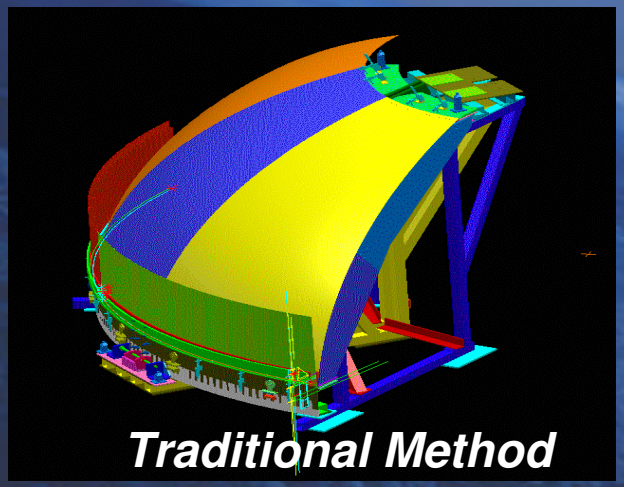
Thin Gage Tank for Atlas

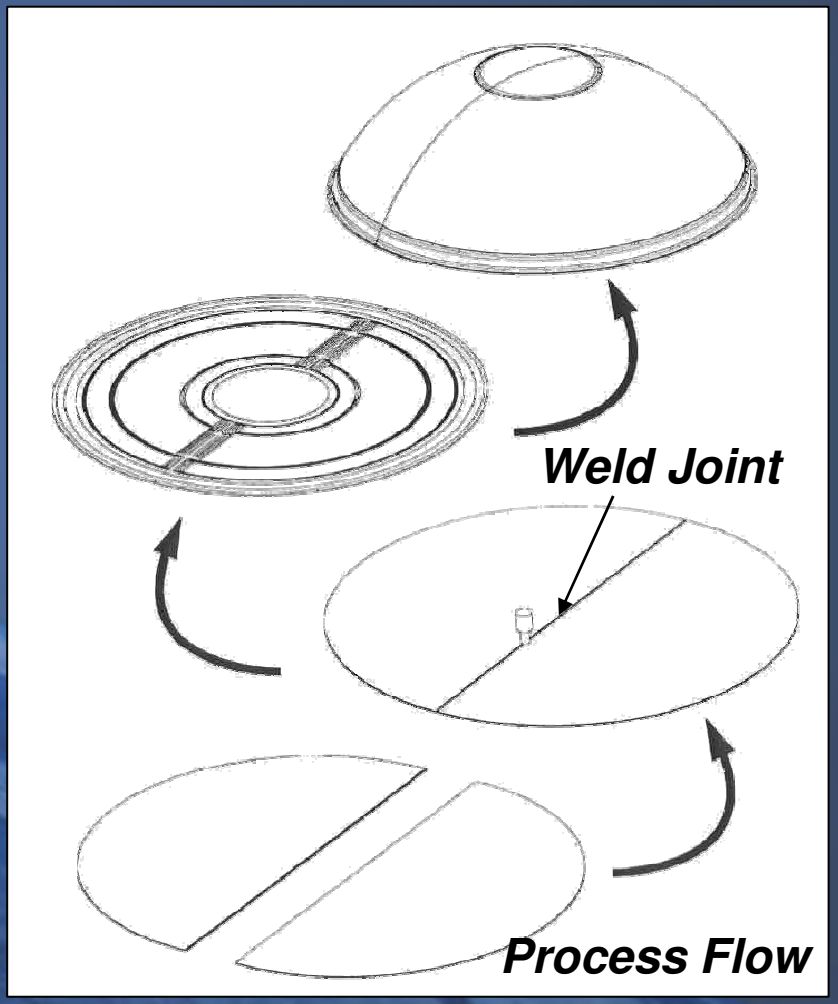
- Description
  - Friction Stir Lap weld three thin gage barrel sections together
- Challenges / Accomplishments
  - Lap and Butt Joints
  - Thin Gage (0.080”)
  - Traditionally unweldable alloy (2090)
  - Internal Tooling only
- Enabling Technology for
  - H&RT Contract
  - SDLV Upper Stage
  - Wide Centaur Tank

Previously Unweldable, High Performance, Affordable Materials Are Now Available For Pressure Vessel Applications

Full Scale spun formed Dome Flow

- Full scale dome (5+ meters)
  - Two plates (20ft x 10ft x 0.750in) are FSWed together to form a single dome blank
  - Contour machining is done in an attempt to create a near net dome
  - 25 percent cost reduction over standard method of build





Post Process of Friction Stir Welds to Lower Costs and Increased Reliability

Second Forming Attempt (9/14/2009)

- Successfully formed full scale dome (5+ meters)
  - Two plates (20ft x 10ft x 0.750in) are FSWed together to form a single dome blank
  - 18-20 warm passes are performed to create the dome shape before SH&Q and final cold forming to create T8 properties

Blanks Welded together

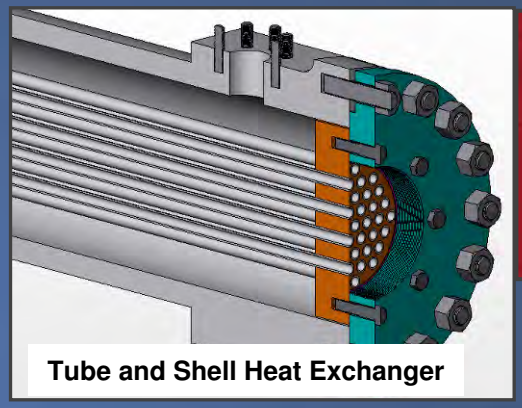
Ready for solution heat treat and quench

5.4ft dome depth.

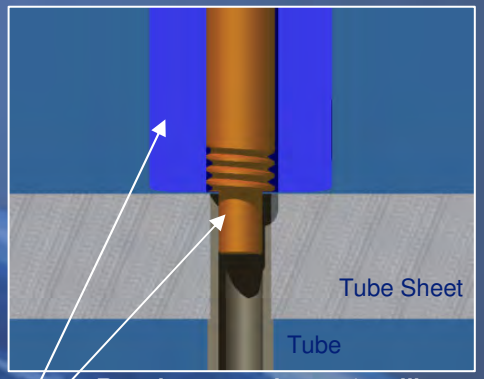
Final 'warm' forming pass.

Heat Exchanger / Ocean Thermal

- *Description*
  - *Friction stir welded heat exchange*
- *Challenges / Accomplishments*
  - *Low cost heat exchanges*
  - *Welding of tube and shell heat exchanger*
  - *Thin wall tubes*
  - *Shell used as tooling*
  - *Low cost heat exchanges*
  - *Low corrosion rate than traditional welding*


Tube and Shell Heat Exchanger


Carbon Foam enhancement



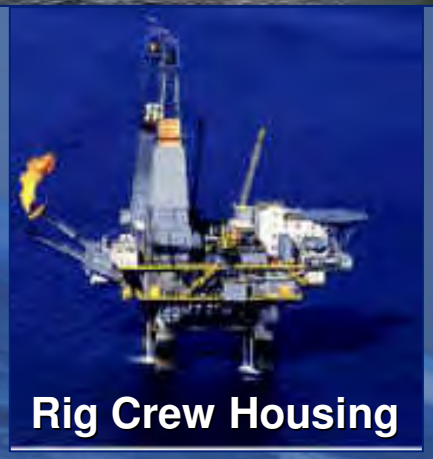

Traditional Friction Stir Method Weld

High Performance, Affordable Materials, Low Cost Heat Exchanger Applications

Industry Joining Applications

Shipbuilding & Marine

Aircraft



Aerospace

Other Applications
- Railway (Japan)
- Construction
- Automotive

Land Transportation

Friction Stir Weld Highlights

- Friction Stir Welding (FSW) has revolutionized the weld process
  - Enables joining of traditionally non-weldable alloys
  - Conventional, adjustable and self-reacting techniques enable a wide variety of joint types and gages

- Process development is rapidly transforming into near- and far-term production implementation
  - Ares I
  - Orion
  - Delta/ Atlas
  - Ares V
  - Commercial Space
  - Marine Applications

- Michoud team brings together unique capabilities
  - Manufacturing expertise plays role in R&D/ product development
  - Innovative tooling concepts enable various designs/ reduce costs
  - Nondestructive and destructive testing readily available
  - Statistical analysis used to develop robust processes