FSW Implementation on the Space Shuttle's External Tank

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Lockheed Martin Space Systems, Michoud Operations
New Orleans, Louisiana

The Friction Stir Welding process developed by The Welding Institute (TWI) has found application throughout the transportation industry. This technique has proven to be a viable joining process for aluminum alloys, producing virtually defect free welds with improved mechanical properties as compared to conventional fusion welding. Lockheed Martin Space Systems - Michoud Operations has been developing this technology for application on aluminum 2219 and 2195 cryogenic tankage since 1995. This effort will come to fruition with implementation on the longitudinal welds of the External Fuel Tank (ET) of the Shuttle. To this end, sub-and full-scale demonstration programs coupled with process development and optimization have been complete. Full size ET tool has been designed, fabricated and are being installed at the Michoud Assembly Facility. Upon completion of the tooling certification and materials allowables testing, production will commence. This implementation will result in increased reliability and safety of flight for the Shuttle.

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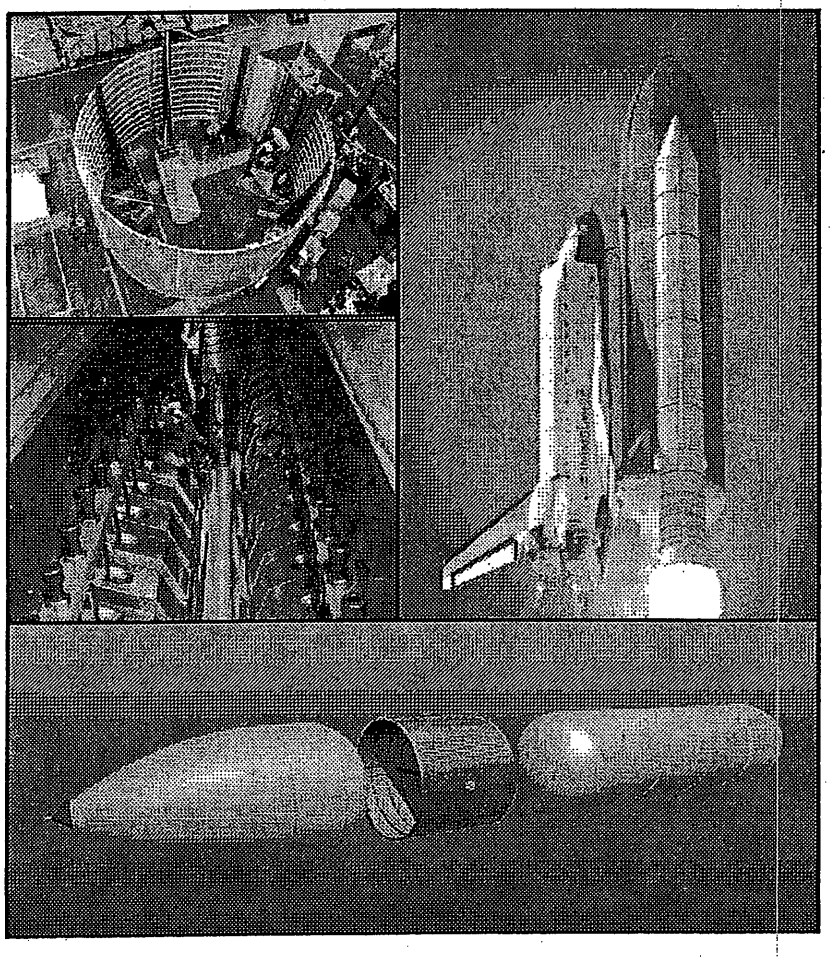


Friction Stir Welding Technology for Defense Applications

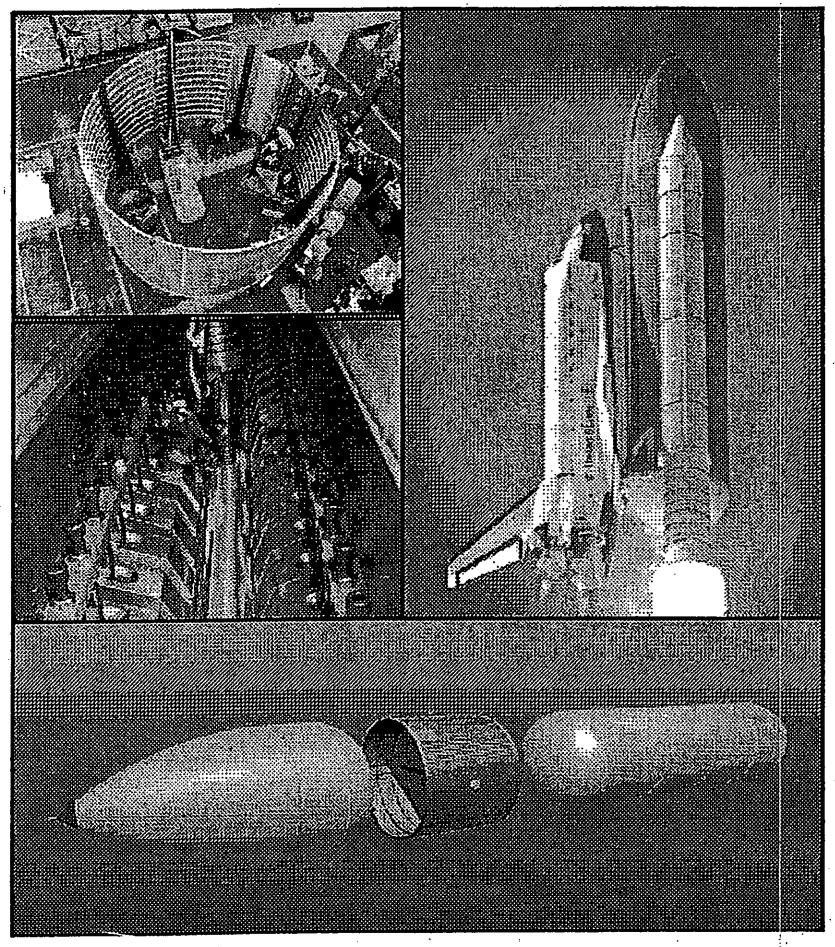
June 14-15, 2002

Paula J. Hartley
David E. Hartley

Friction Stir Welding on the External Tank

Friction Stir Welding - Agenda

- *Project Objective*
- *FSW Process*
  - *Process Overview*
  - *Benefits*
- *Implementation Status*
  - *Development Work*
  - *Process Mapping*
  - *Tooling Design*
  - *Facility Modifications*
- *Summary*



Friction Stir Welding on the External Tank

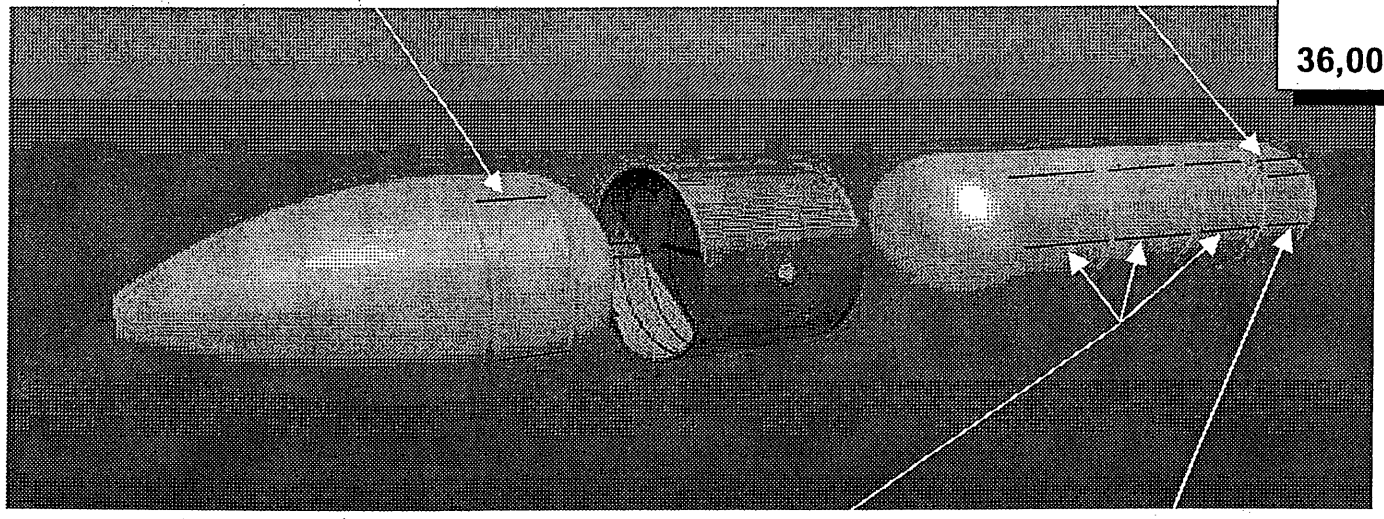
Objective

Increase the Safety, Reliability, & Producibility of the ET by Implementing the FSW Process

LO2 Barrel Welds
4 Each 8 -Feet Long
Tapered Thickness

LH2 Barrel 1 (Longeron Welds)
4 Each 15-feet Long
Tapered Thickness

Barrel Welds
8,000 Inches
Out of
36,000 Total Inches

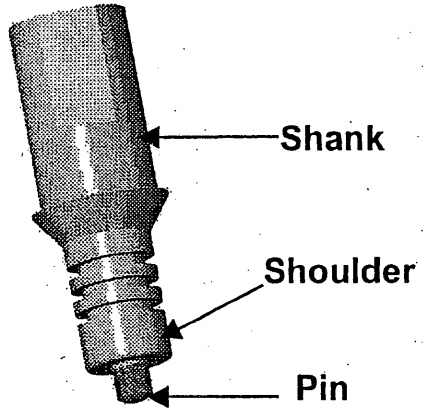


LH2 Barrels 2, 3 and 4 Welds
24 Each 20-feet Long
22 Each Constant Thickness
2 Each Tapered Thickness

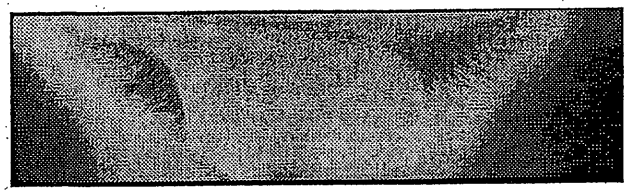
LH2 Barrel 1 Welds
6 Each 15-feet Long
Constant Thickness

Friction Stir Welding on the External Tank

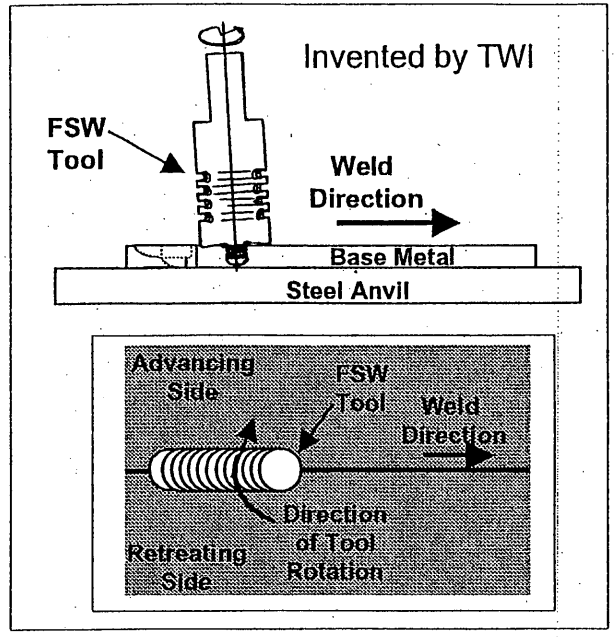
FSW Process Overview



Typical FSW Tool



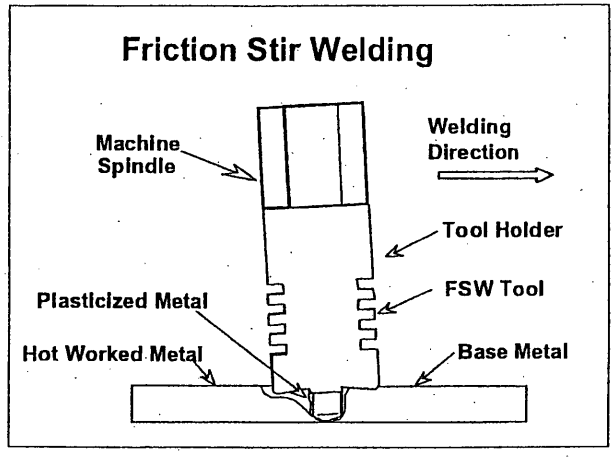
Typical FSW Transverse Macro

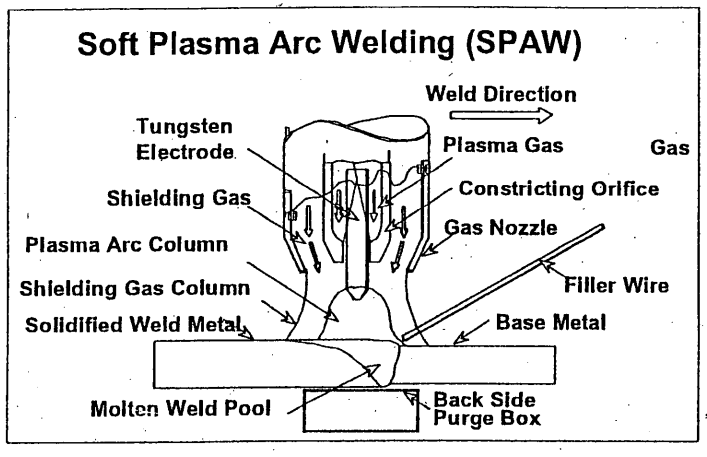


- *The base material is clamped to a backing anvil*
- *A FSW pin tool consists of a concave shoulder and a pin with a length approximately equal to the material thickness*
- *The pin tool is rotated and plunged into the material until the shoulder penetrates below the top surface*
  - *Frictional heating from the rotating tool plasticizes the material between the anvil and the shoulder. The rotating tool is then traversed along the weld seam, generating a combination of extrusion and forging between the tool shoulder and the anvil resulting in a ductile, high strength, solid state weld.*

Friction Stir Welding on the External Tank

FSW/Fusion Process Comparison





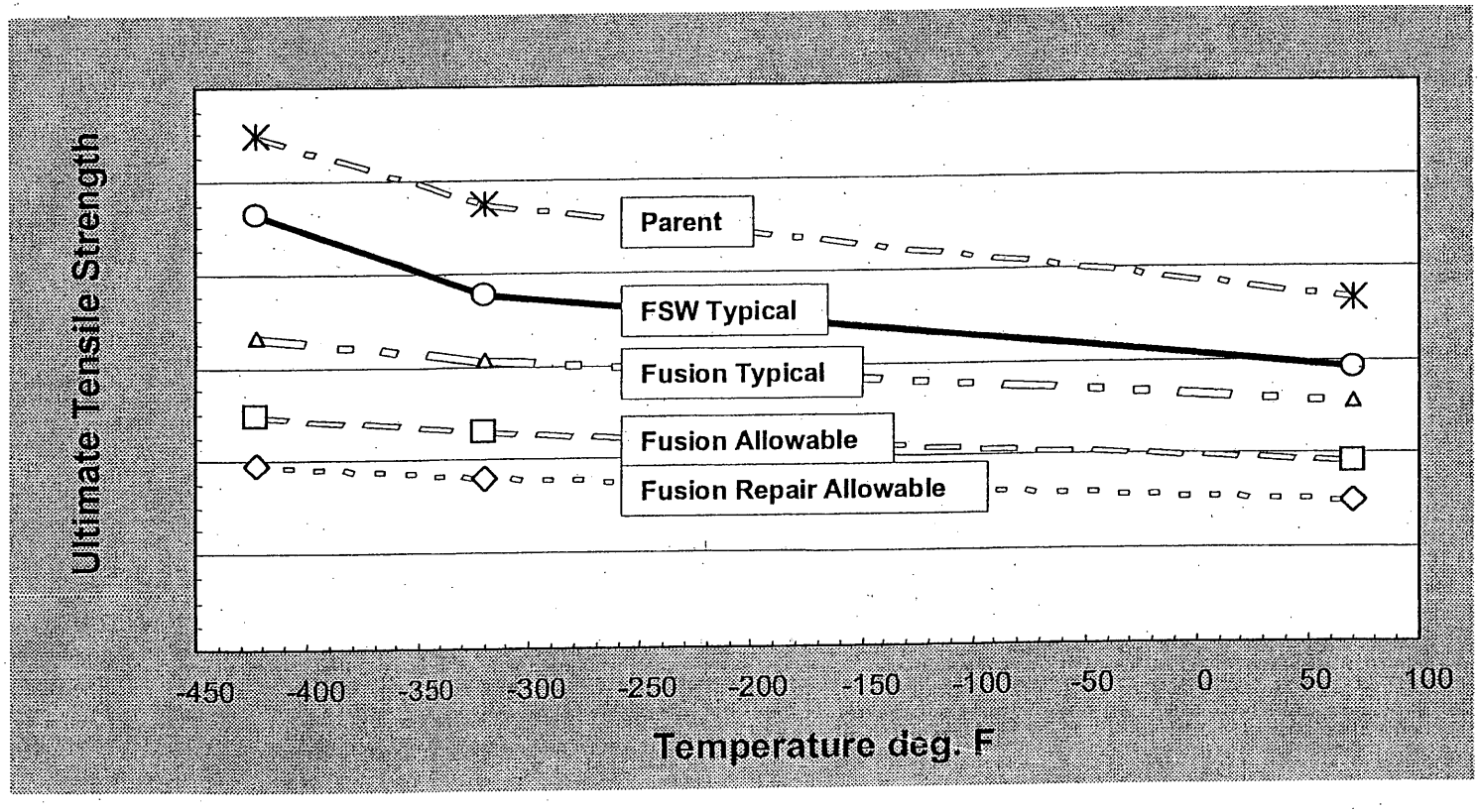
	FSW	Fusion	
Weld Set Up	Schedule Selection Pin Tool Selection	Schedule Selection Shield Cup Design Orifice Size	Tungsten Position Tungsten Size/type Wire Alloy and Diameter
During Welding	Plunge Depth/load Rotation Speed Speed Travel Centerline Position Pin Length (Tapers)	Current Voltage Travel Speed Wire Feed Rate APC/AVC Reverse Current Plasma Gas	Shield Gas and Flow Back Side Purge Gas and Flow Pulse Frequency/Duty Cycle Arc Gap Oscillator Width (Cover Pass) Oscillator Dwell (Cover Pass) Oscillator Speed (Cover Pass)

Friction Stir Welding Vastly Reduces and Simplifies Process Variables

Friction Stir Welding on the External Tank

FSW Process/ET Benefits

- Increased Margin Through:
  - Improved Strength
  - Improved Toughness (CIFS)
  - Improved Cryogenic Enhancements
  - Reduced Peaking and Mismatch
  - Reduced Rework and Repairs



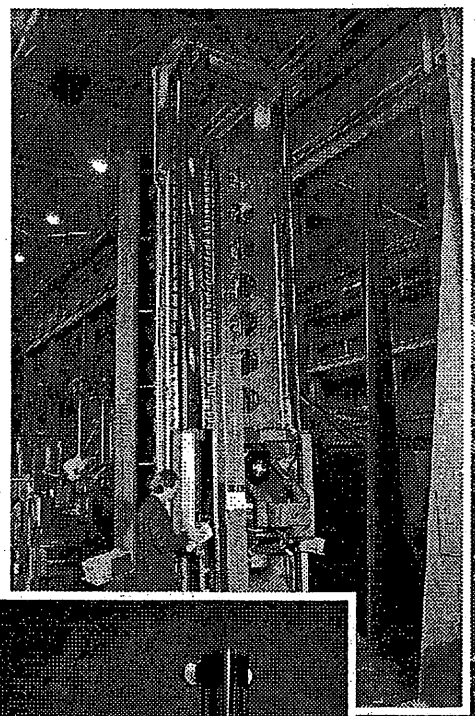
Friction Stir Welding on the External Tank

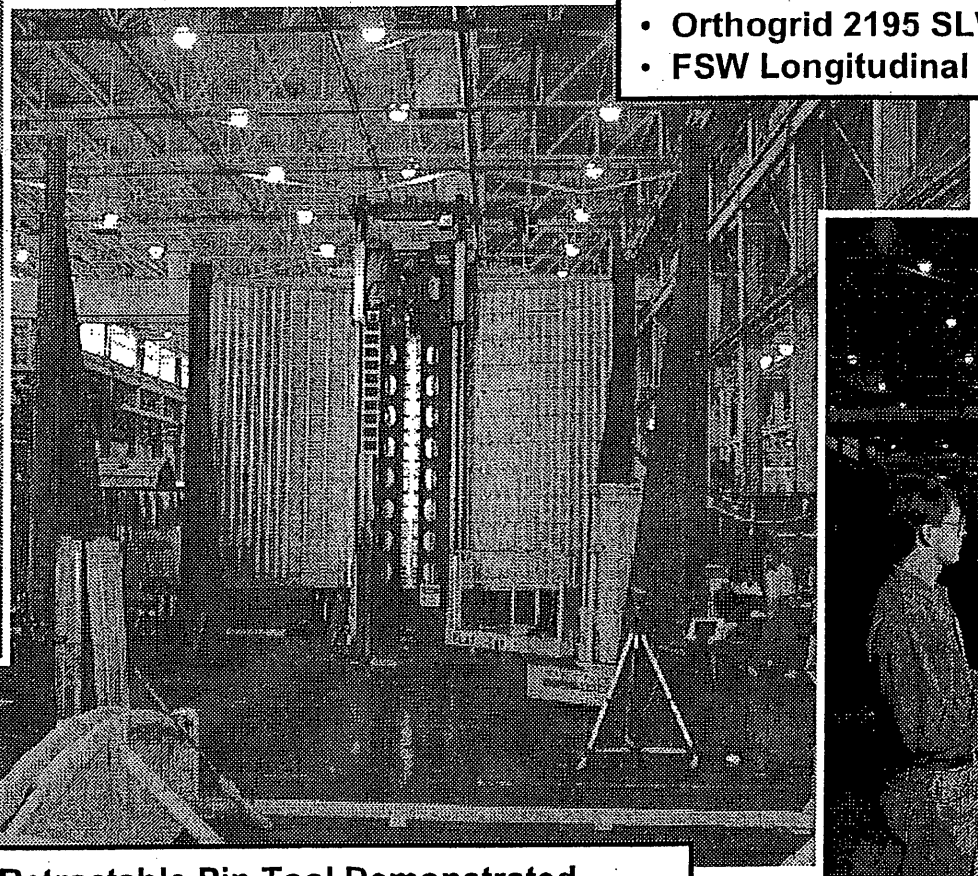
FSW Process/ET Benefits

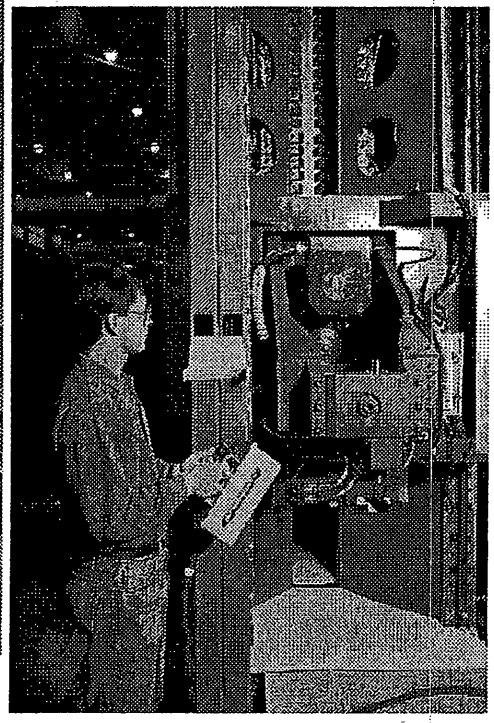
- Process Enhancements
  - No filler material or shielding gases required
  - Fewer variables to control
  - Low residual stresses and distortion
- Manifest Supportability
  - Reduced weld defect rate will result in improved cycle time
  - Two new universal tools will improve throughput
  - Weight savings through elimination of weld wire
- Cost Reductions
  - Reduction in labor associated with process improvements
  - Fewer consumables required
  - Reduced manufacturing steps
- Other Safety Improvements
  - Reduced personnel exposure to hazardous operations

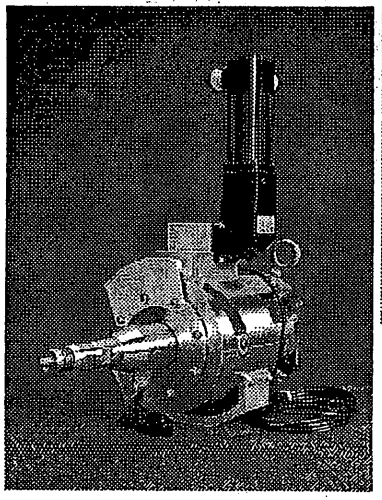
FSW Will Improve ET Safety, Reliability and Producibility

Friction Stir Welding on the External Tank
Implementation Status - Development Work









- Full Scale Barrel Demonstration
- Orthogrid 2195 SLWT Panels
- FSW Longitudinal Welds

- Retractable Pin Tool Demonstrated
- Close-out/Repair Welds
- Variable Thickness Welds

NASA and LMSSC are Bringing this Technology to the "Next Level"

Friction Stir Welding on the External Tank

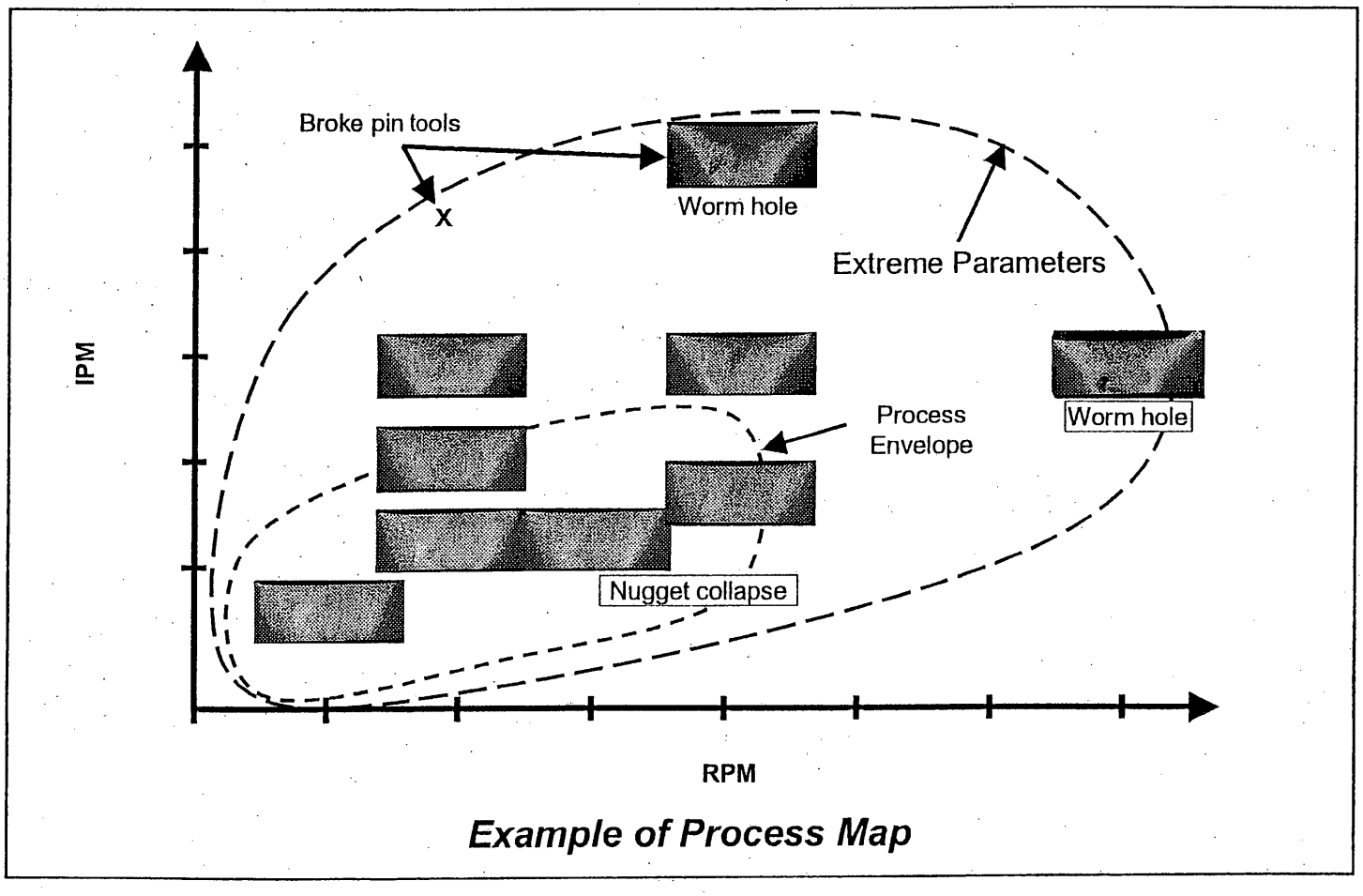
Implementation Status - Process

- **Trades Completed**
  - Anvil Material
  - Pin Material & Configuration
  - Pin Measurement Errors
  - Process Envelope for constant thickness welds
- **Key Issues Resolved**
  - Pin Breakage on Thicker Welds
  - Anvil Material and Heat Sink
  - Allowables/Characterization Test Plan

Friction Stir Welding on the External Tank

Project Status - Development (In Work)

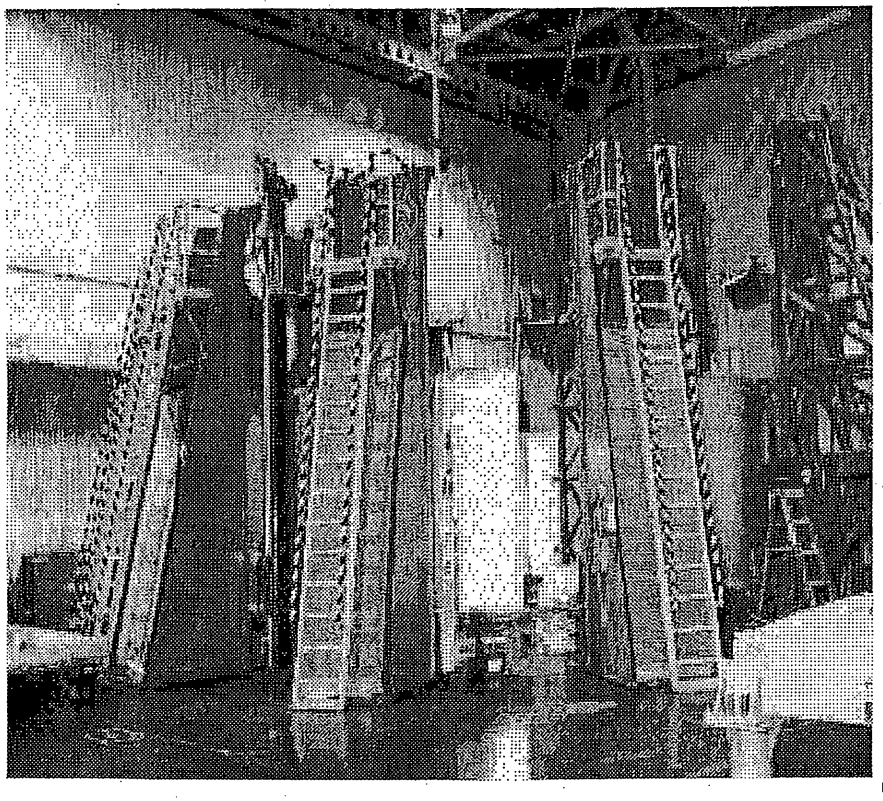
- **Process Mapping**
  - *Determine effect of process variables on IPM vs. RPM process map*
  - *Process maps include strength, microstructure, NDE results, flash, and pin fracture*



Example of Process Map

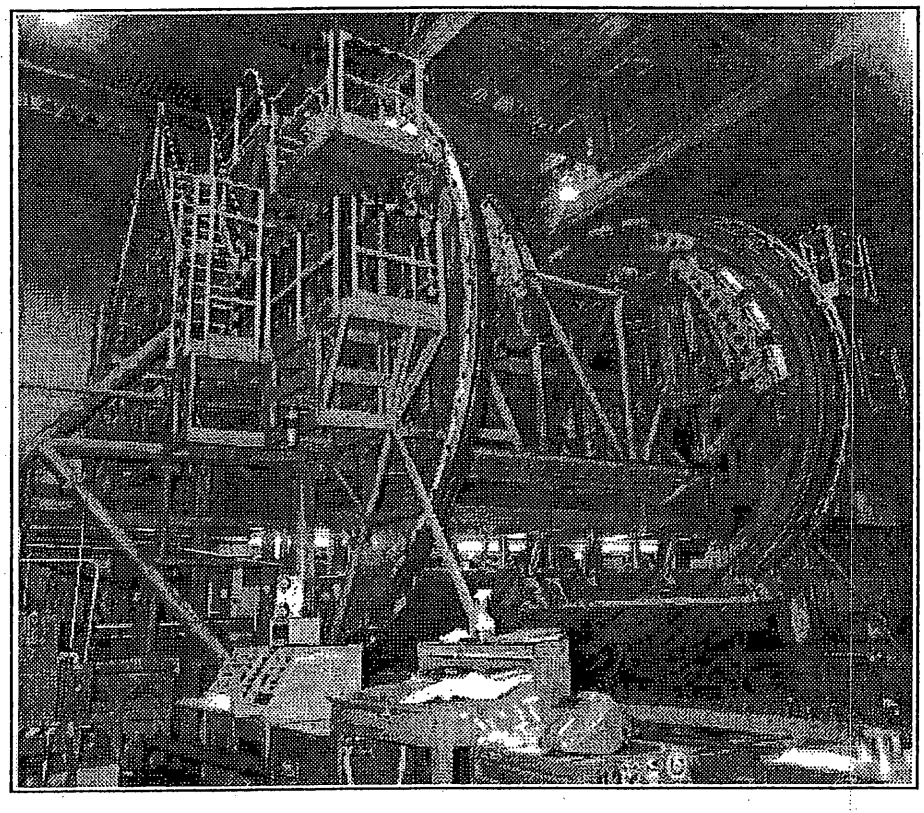
Friction Stir Welding on the External Tank

Implementation Status - Today's Fusion Tooling



Existing Short Barrel Weld Tool

Vertical VPPA welding of LH2 Barrel 1 and LO2 Barrel

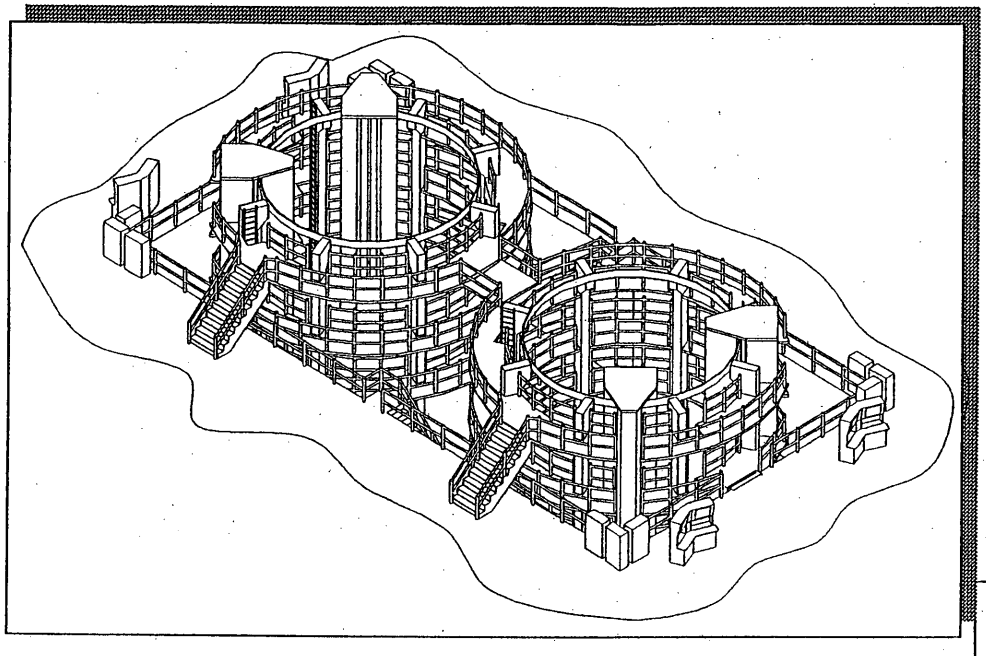


Existing Long Barrel Weld Tool

Horizontal SPA welding of LH2 Barrels 2, 3 & 4

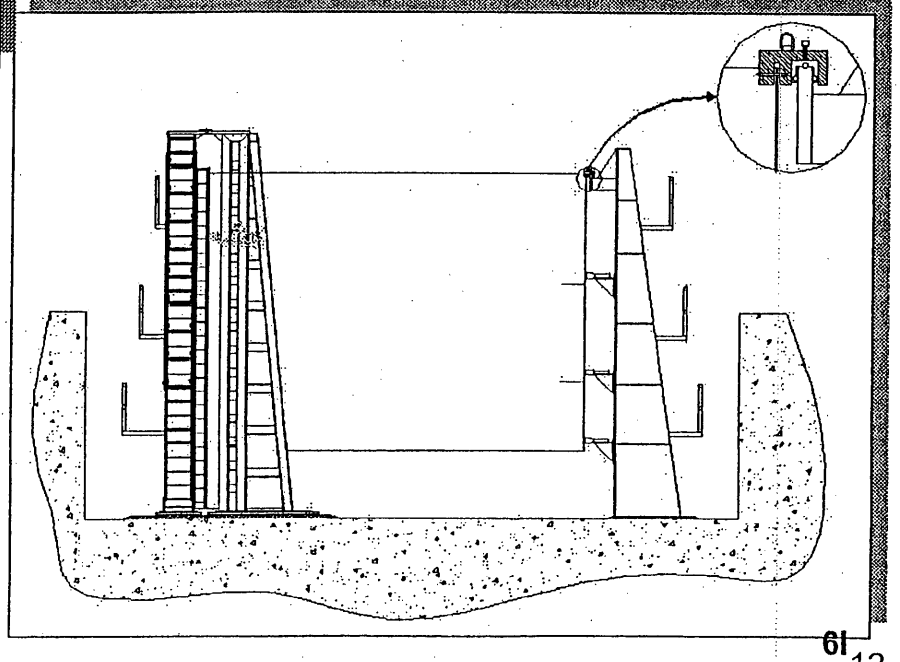
Friction Stir Welding on the External Tank

Implementation Status - Tomorrow's FSW Tooling



Mechanical

- Universal Tool That handles all Barrel Configurations
- Utilizes Retractable Pin Tool for Tapered Welds
- Provides Access to entire barrel
- Integral Test Fixture
- Reacts clamp and force loads
- Accommodates facility hook height



Electrical Controls

- Complete Automatic Operations
- Process Observation Cameras
- Automatic Seam Tracking
- Touch Screen Operation
- Process Data Acquisition and Archival

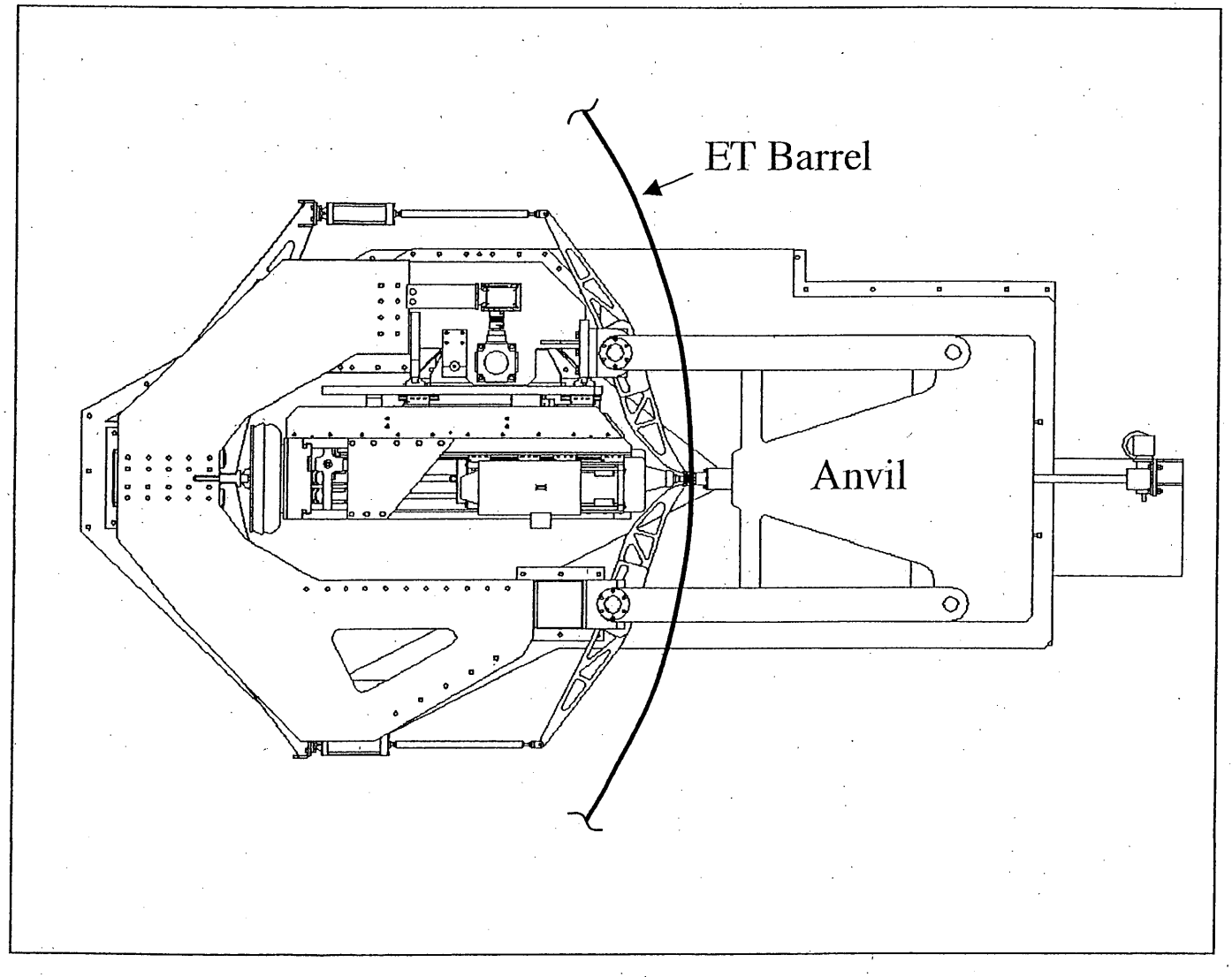
Implementation Status - FSW Tooling

- **Tooling Status**
  - Contract Awarded to General Tool Company (GTC)
  - Prototypes Demonstrated
    - Clamping
    - RPT Measurement
    - Force Control
  - Design Complete
    - Production Tool
    - Development/Trainer
    - Platforms
  - Fabrication Complete
  - Installation in Progress

Tool Design and Fabrication are Complete

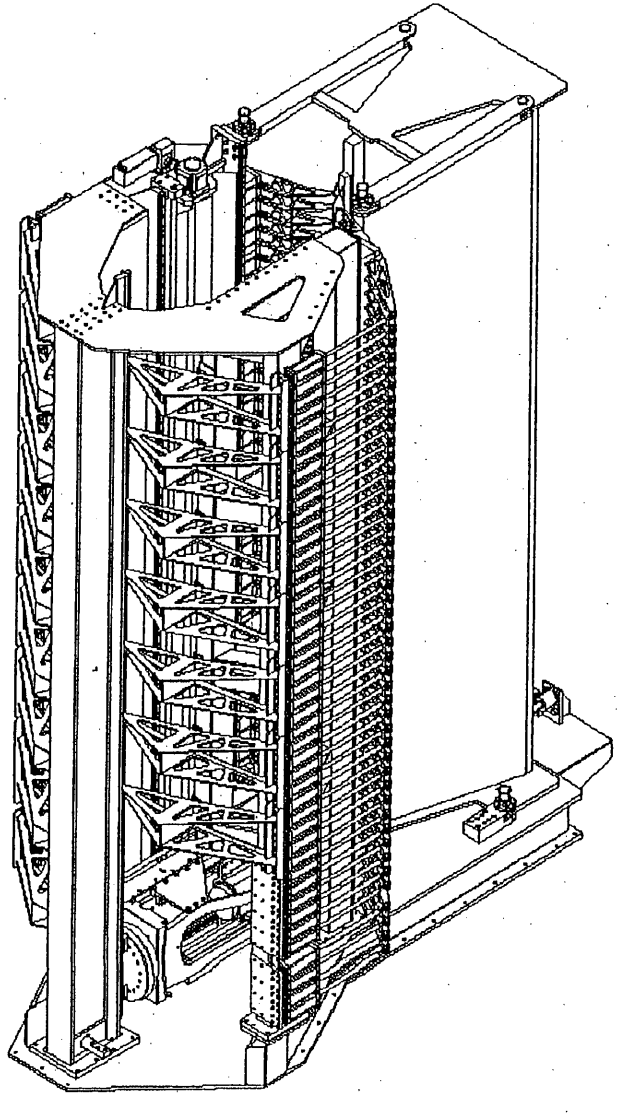
Friction Stir Welding on the External Tank

Implementation Status - Production Tooling



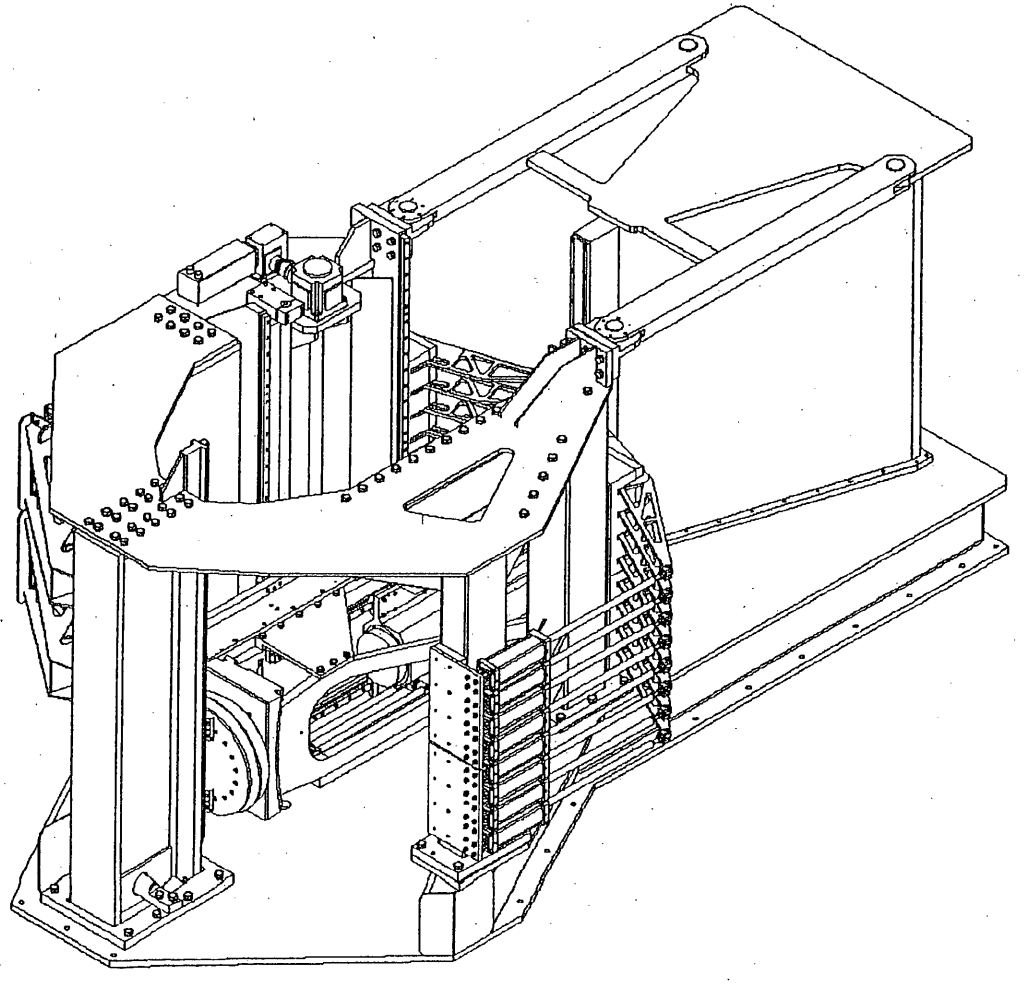
Friction Stir Welding on the External Tank

Implementation Status - Production Tooling



Friction Stir Welding on the External Tank

Implementation Status - Trainer



Friction Stir Welding on the External Tank

Implementation Status - Facility Modifications

- **Facilities Modifications**
  - Pit to Accommodate Hook Height
  - Pit Designed to Accommodate Louisiana Soil Conditions
  - Both Tools in Single Pit
- **Modification Status**
  - Test Pilings driven to verify No ET Production Impacts
  - Contract Awarded
  - Foundation Started
    - ˜ piles complete
    - ˜ excavation complete
  - On target for July completion

Facility Modifications are Ahead of Schedule

Summary

- *FSW Is a Significant Safety Benefit for Shuttle Program*
- *FSW Is a Major Process Improvement for the External Tank*
- *Project Is Fully Staffed using NASA/Contractor Integrated Process Teams*
- *Tool Design is Complete and Fabrication Underway*
- *Facilities Modifications Nearing Completion*
- *Project Is on Target to Weld Flight Hardware in 1Q03*
- *Flight Hardware Projected to Fly in 2005*

FSW Improves ET Safety Margins, Reliability and Producibility