BOEING

Low Cost Fabrication Approach for ARIES-CS Coil Structure

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17-18 November 2005

ARIES Meeting at UCSD, San Diego

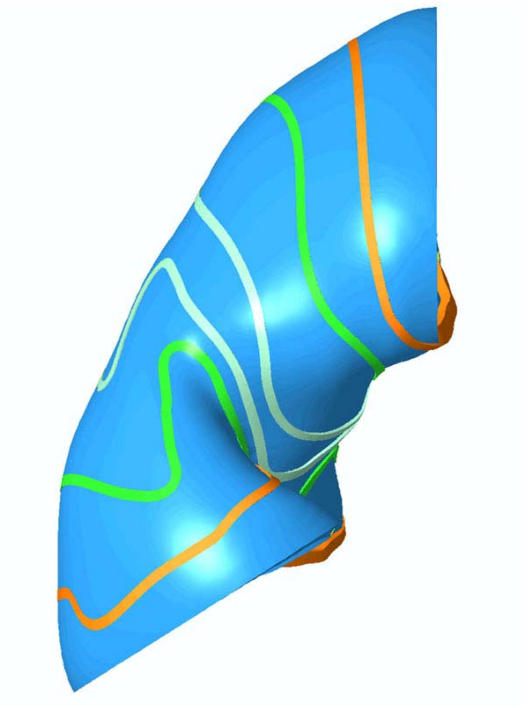
Need for a New Approach

- **The present coil structural concept documented in Jim's systems code (9/30/05) uses a strongback for radial loads plus a separate shell to react out-of-plane loads**

	Mass, Mkg	Unit Cost, $/kg	Cost, 2004$
Strongback	2.18	56	$118M
Shell	0.43	56	$24M
Total	3.5		$142M

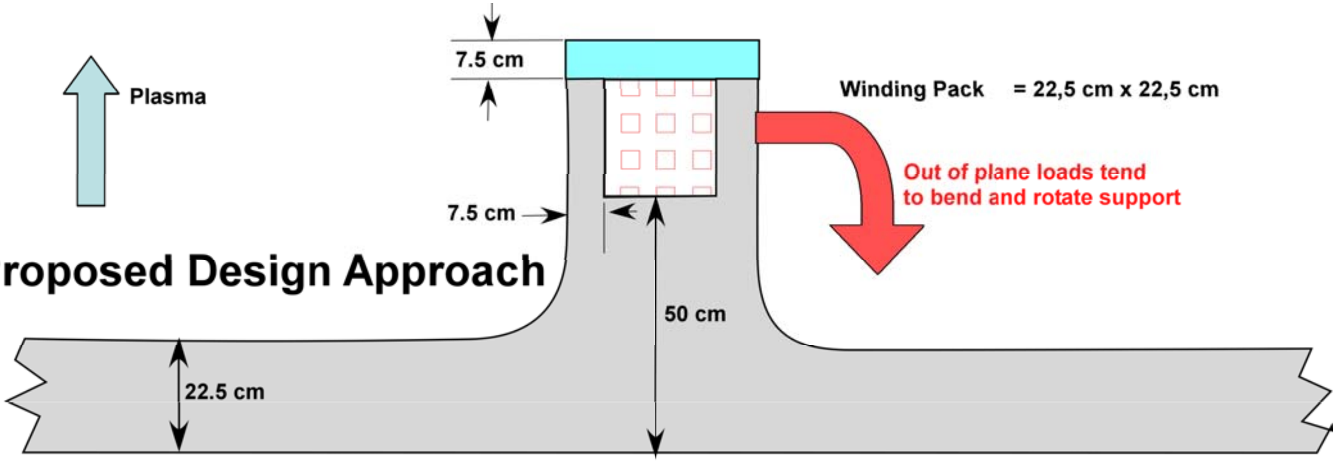
- **These costs represent 18% of the total Reactor System costs. This is a cost that can be reduced with some original thinking**
  - **We need to bring the mass of the coil structure down with innovative design concepts**
  - **We also can apply some low cost fabrication approaches that may be possible in this application**

Use of a Grooved Continuous Shell Is a Good Approach



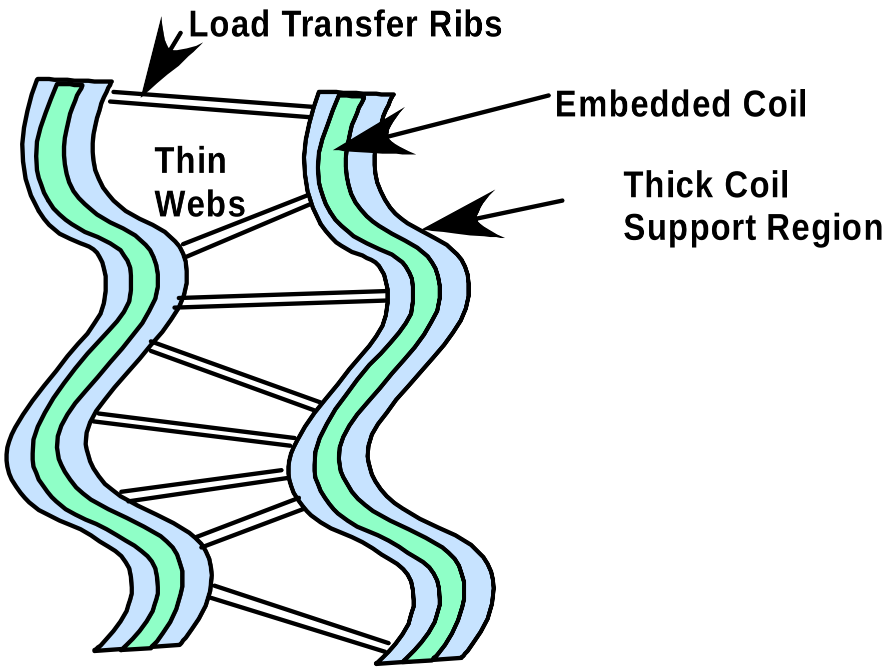
- **One piece construction, efficient load transfer, and minimal distortion are good attributes**
- **However, assumption of uniform thickness shell is too massive and not an efficient structure**

Next Improvement Considered a Thinner Shell with Local Structure Around Coils



- **The structure resisting the radial loads is 45-55 cm thick to resist the JxB forces that are significantly greater than NCSX**
- **The continuous shell thickness still seems to be too thick at 20-25 cm**
- **The continuous shell is not aligned with the out-of-plane forces, thus creating an overturning moment and deformation**
- **Suggest aligning the continuous coil structure with the coils to eliminate overturning moments**
- **Add ribs to strengthen thinner shell**

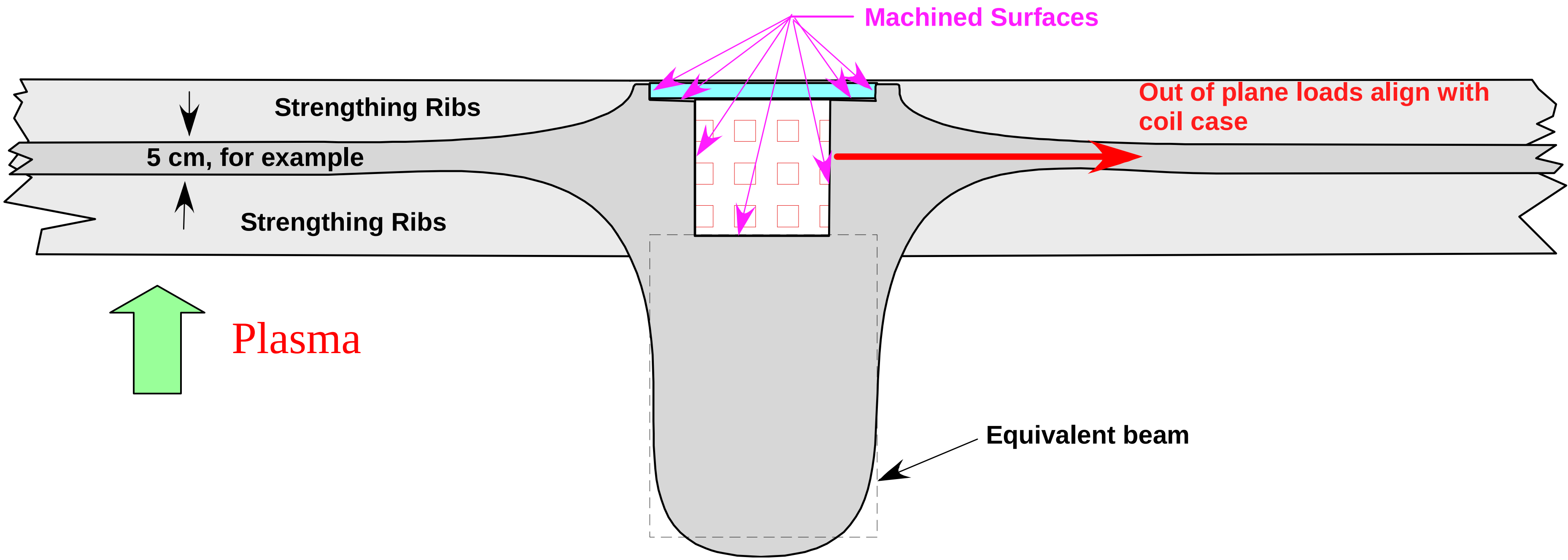
Rib-Stiffened Inter-Coil Structure



View from Outboard of Coil Support Structure with ribs and thin webs

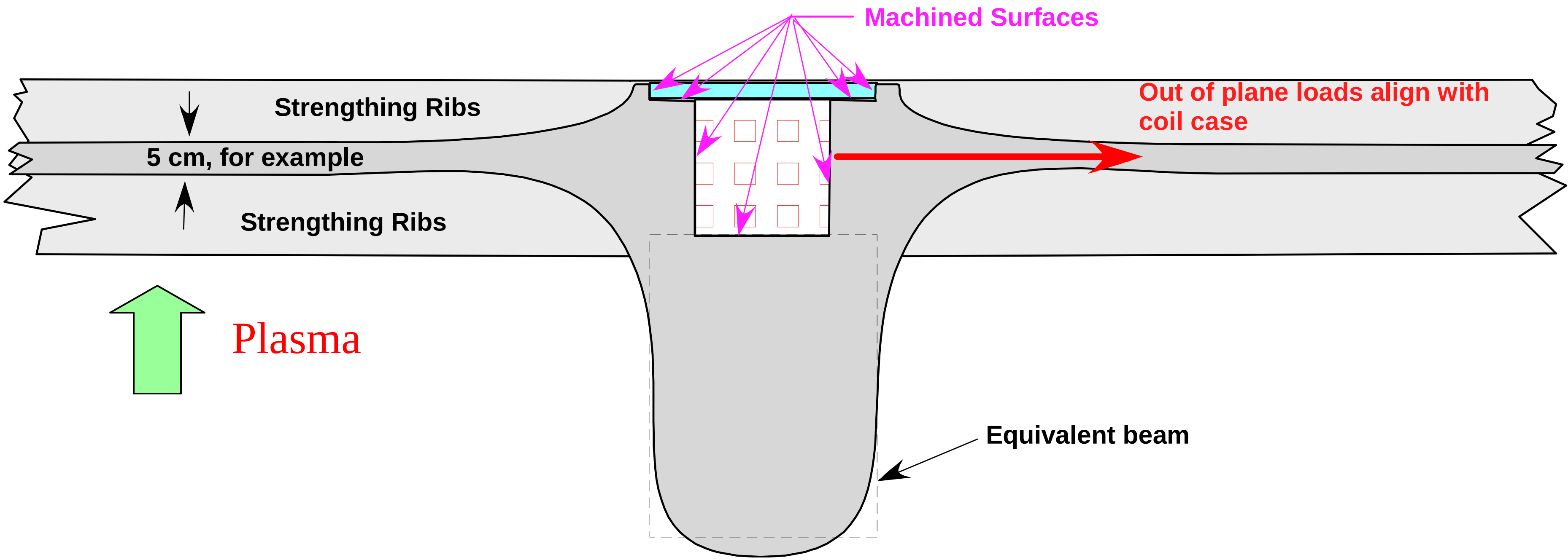
- Ribs help transfer loads between thicker main coil structures
- Continuous inter-coil can be thinner without buckling
- Rib placement can be tailored to high-load regions with efficient load transfer

Rib-Stiffened, Thinner Inter-Coil Structure



- This approach places sufficient structure outboard of the coils to resist the radial magnetic loads – the amount of material can be adjusted for local loading conditions
- A much thinner inter-coil structure is enabled with integral strengthening ribs and aligned with inter-coil forces
- Tailoring of the structure is enabled with an advanced plasma arc deposition system

Plasma Arc Deposited Structure Features



- Only minimal machining will be required for the coil, coil cover, period interfaces, and gravity support surfaces
- All other surfaces can be left as fabricated
- Errors and deformations can be removed and reformed
- Tailoring of structure to local loads results in efficient, lower-cost design
- Single piece construction possible with high fidelity placement of coil grooves

Fabrication of Near-Net Shape Structures with Advanced Metal Deposition Systems

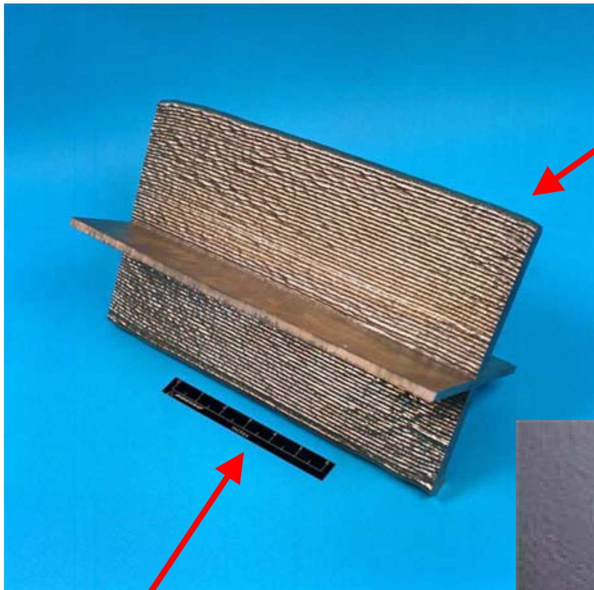
- **Many different techniques are being investigated in this field**
  - **Different heat sources (lasers, plasma arc, electron beams)**
  - **Many materials demonstrated (aluminum, titanium, steel, et al)**
  - **Powder metal and wire feed are the typical input metal forms**
  - **Density and strength can vary from sintered particles to fully dense weldments**
- **Parts are usually intricate and produced in a small quantity**
- **Part size ranges from small, low stress parts to larger aircraft structural parts**
- **Principal near-term benefit is direct fabrication from CAD models to near net shape followed by minor final machining**
- **Future promise is low-cost fabrication determined by low cost material forms, energy to melt metal, minimal labor, and low cost equipment**

DoD Manufacturing Technology Program (ManTech)
2007 Objective - Use laser additive manufacturing to reduce cost and cycle time for aerospace structural components such as wing carry through structures and bulkheads.

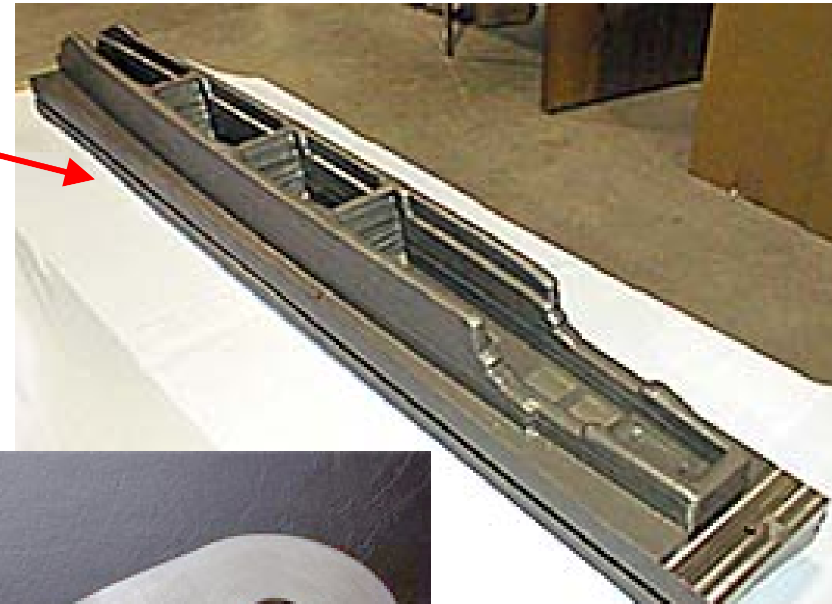
Examples of Fabricated Parts

AeroMet Corporation has produced a variety of titanium parts. Some are in as-built condition and others are machined to final shape. (Note: AeroMet has discontinued operations.)

Larger, Structural Parts



As-Fabricated Condition



6” Ruler

18” Ruler

Arc-Transferred Deposition Approach

- **A Plasma Arc process is probably the most energy efficient method to produce the melt layer**
- **Laser deposition had been qualified for aircraft flight hardware**
- **Current plasma arc deposition technology is 100 lb/hr in steel, so no invention is needed to obtain necessary fabrication rate**
- **Multiple torches on NC-controlled positioners would speed fabrication time of entire period sectors**
- **Ferritic steel should be possible with final properties in the wrought condition**
- **Local inert atmosphere protection would eliminate need for vacuum chamber**
- **Differential GPS should provide necessary part accuracy**
- **Near-net shape coil grooves with final machining**
- **Envision machining a location feature along the coil length to guide portable milling machines to create grooves**
- **Location feature could be used in coil fabrication and/or installation**

Next Steps

- Finalize on coil type (NCSX or MHH2) and coil geometry
- Determine coil forces in and out of plane
- Develop, analyze, and refine efficient coil structure
  - Assume wrought ferritic steel properties
- Provide coil structure geometry and mass for costing
  - Until detailed cost data is developed, assume $10/kg
- Refine Systems Code cost estimate with new cost data