BUILT-UP Al-Li STRUCTURES FOR CRYOGENIC TANK
AND DRY BAY APPLICATIONS

W. Barry Lisagor
NASA Langley Research Center
SPF TECHNOLOGY FOR AI-Li BUILT-UP STRUCTURES

ADVANCED LAUNCH SYSTEM
Structures, Materials & Manufacturing
Built-up structures for ALDP #3104

Responsible Org: NASA/LaRC
Execution: LaRC/Rockwell/GD
Funding ($M):

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Built-up panel concepts defined
SPF and RSW parameters established
Test stiffener and column buckling panels
Materials characterization and properties
Fab and test subscale barrel section

Objectives:
- Demonstrate the cost benefits of built-up cryotank & dry bay structures
- Conventional Al alloys
- Low density Al-Li alloys
- Evaluate alternative low-cost stiffener and joining concepts

Payoffs:
- Lower weight/lower system costs
- Significant reduction in tank costs
- Reduced scrap rate/lower material costs
- Reduction in major machining costs
- Avoid thick plate issues

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### TASK #3104 BUILT-UP STRUCTURE FOR CRYOTANKS

**Program Participants**

**Organization**

- NASA-LaRC
- Martin Marietta
- Reynolds
- Rockwell
- General Dynamics

**Key activity**

- SPF/RSW
- Alternate forming & joining methods
- SPF of chemistry modified Weldalite™
- Weldalite stiffener extrusions
- SPF of Al & Al-Li alloys
- RSW of Al & Al-Li alloys

### ADP TASK #3104 BUILT-UP ALUMINUM CRYOTANKS

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BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS

15% tank weight savings due to improved specific properties

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<th>Al-Li</th>
<th>Tank weight 42.5K lbs</th>
<th>Raw material 213K lbs</th>
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<td>2219 @ $3.5/b</td>
<td>Al-Li @ $10/lb</td>
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<td>Large reduction in buy to fly ratio due to reduced scrap rate</td>
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Material costs

- $0.9 M
- $2.1 M
- + $1.2 M

System costs savings

- + $1.2 M
- - $15.0 M
- - $13.8 M

$2000/lb to orbit

Cost-to-orbit benefit

- $100 M
- $85 M
- - $15 M

SPECIFIC PROPERTIES VERSUS TEMPERATURE FOR SELECTED AL ALLOYS IN T8 TEMPER

- ○ Weldalite 049
- ● 2090
- △ 8090
- ▲ 2219

Strength

Specific yield strength, $10^6$ in.

0 - 1.2

0 - 300 -200 -100 0 100

Temperature, °F

Stiffness

Specific modulus, $10^6$ in.

90 - 130

0 - 110

Room temperature

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EXPERIMENTAL VERIFICATION OF SUPERPLASTIC FORMING PROFILE

OPTIMUM POST-SPF PROPERTIES OF AL-LI ALLOYS

Legend:  
- Ultimate Strength  
- Yield Strength  
- Elongation

Considerations:  
(i) Maximum Strength (Under-aged)  
(ii) Adequate Ductility (>5%)  
(iii) Practical Aging Time (<40 hrs)

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<tr>
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Tensile Strength, ksi

Elongation, %

Legend:
- Ultimate Strength
- Yield Strength
- Elongation

Considerations:
(i) Maximum Strength (Under-aged)
(ii) Adequate Ductility (>5%)
(iii) Practical Aging Time (<40 hrs)

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CHARACTERIZATION OF RESISTANCE SPOT WELDS
8090 T-6 to 2090 T-8E50
Splitting, High strength (1603 lbs overlap shear)

Current, kiloamps
Electrode force, lbs/50

Feedback from welder

Top view X-ray of weld
Side view of cross-sectioned weld

RESISTANCE SPOT WELDS OVERLAP SHEAR STRENGTHS

Strength, lbs

± 25%

± 12.5%

MIL-W-6858D avg strength

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BUILT-UP STRUCTURE APPROACH TO REINFORCE FUSION WELDS

Conventional weld land arrangement

Doubler reinforced fusion weld

Weld land

Fusion weld

Skin

Fusion weld

Resistance spot weld

Skin

Fusion weld

Tested at NASA LaRC

2090-T6(SPF)/2090-T8 Al-Li COMPRESSION PANELS

Load, lbs

0 1000 2000 3000 4000 5000 6000 7000

Head displacement

0 .02 .04 .06 .08 .10 .12 .14

Beaded web curved cap

Stepped-hat curved cap

Beaded web flat cap

Stiffener configuration

70 000 6000 5000 4000 3000 2000 1000

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SUPERPLASTICALLY FORMED AI-Li MULTIPLE STIFFENED PANEL

Built-up Al-Li Structures for NLS

- SPF stiffeners
- Reduced part count
- Minimum machining
- RSW assembly
- 15% weight savings
- Lower fabrication costs
PERFORMANCE BENEFITS USING AL-LI (G.D.)

- Direct substitution of Al-Li for conventional Al alloys can add 6000 lbs of payload to the baseline 11/2 stage vehicle. Redesigning the structure to take full advantage of the higher properties of Al-Li alloys could add >12000 lbs in payload savings.
- Weight savings of ~10% achievable by making the propellant tank of the 11/2 stage vehicle from Al-Li.
- Weight savings of ~5% achievable by making the adapter and thrust structure of the 11/2 stage vehicle from Al-Li.
- High raw material costs of Al-Li are the primary driver in selecting the appropriate fabrication approach.
- Dependent on the material substitution approach and fabrication method the increased cost of using Al-Li could range from $0.5M to $4.0M per vehicle.
- In the baseline 11/2 stage vehicle the cost performance for Al-Li ranges from $150/lb to $750/lb of payload increase compared with the current projected payload performance of $1500/lb using other alternatives.

ALDP BUILT-UP STRUCTURE FOR CRYOGENIC TANKS #3104

STATUS

- SPF OF Al-Li ALLOYS
  - Post-forming mechanical properties determined
  - 3’ x 5’ multiple stiffener panel formed
- RSW OF Al-Li ALLOYS
  - RSW schedules optimized using taguchi design of experiments
  - RSW strength of Al-Li alloys exceeds standard military specs
- STRUCTURAL TESTING
  - Crippling panels tested and shown to meet design req’ts
  - Stiffener design selected for column buckling panel
- COST/TRADE STUDIES
  - Cost analysis comparing roll forming, brake forming, extrusion and SPF fabrication methods near completion
- Current program focus assessing the benefits of Al-Li built-up dry-bay structures (intertank, fwd adapter, aft skirt)
8.3.2 Orbital Lessons Learned - A Guide to Future Vehicle Development by H. Stan Greenberg, Rockwell International