



Assessment of Al-Li Alloys for Cryotanks

by

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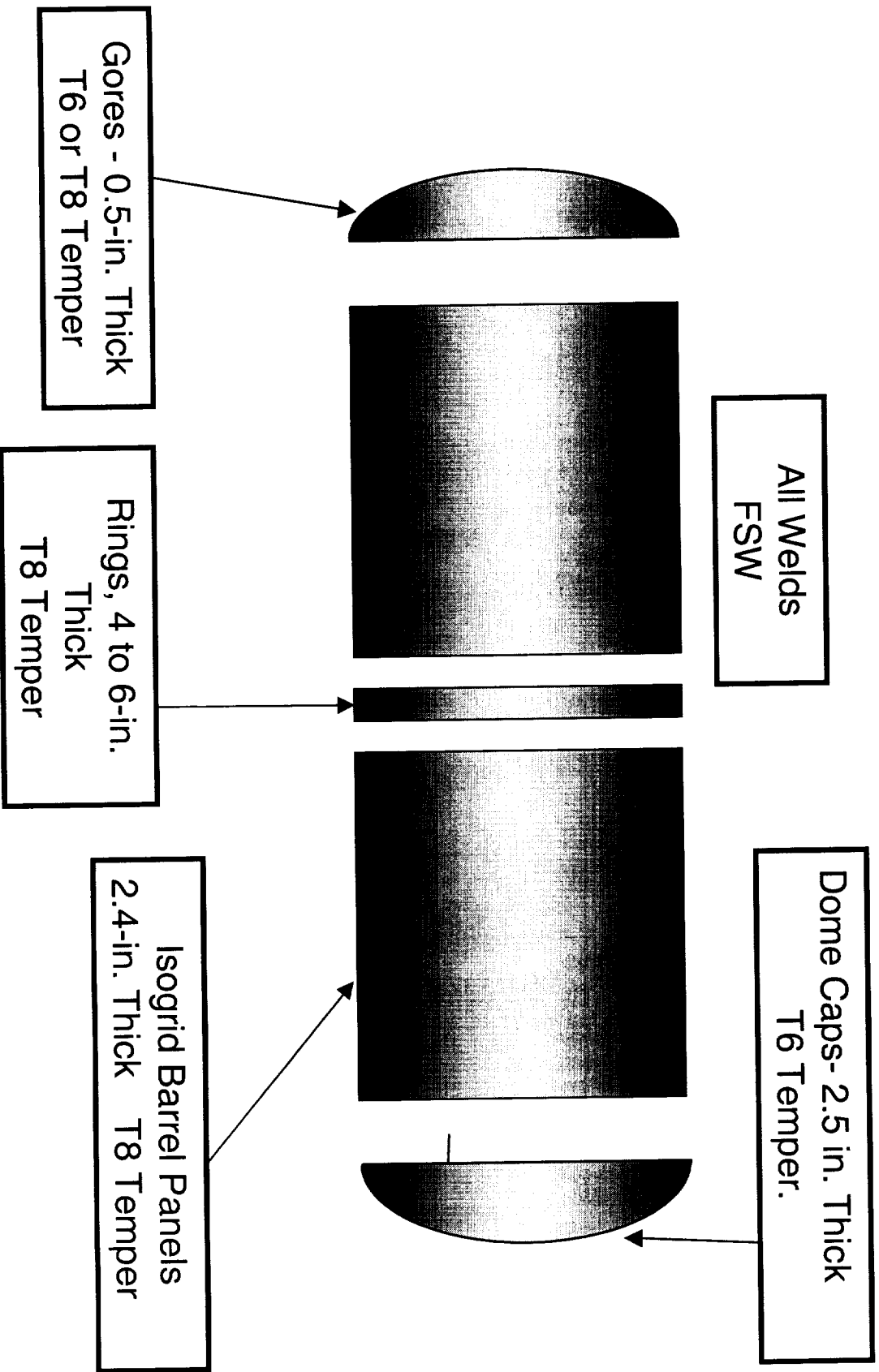
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Tank Elements, Gages, Tempers



Cryogenic Tank Alloys Compared

2219 Al and Al-Li Alloys Selected

Alloy	Usage	Major Characteristics
Stainless	Atlas	Requires pressure stabilization to be weight competitive
Inconel	Small tanks	Same as SS, but alloy is more expensive
Titanium	Small tanks in LH ₂ , never for LOX	Highly flammable, rejected for new astronaut suit elbow in 1989
2219 Al	Many programs	Great reliability, excellent weldability, good properties except strength low
2014	Titan and Delta II	Poor short transverse. Banned for use on Delta IV, tough to weld, poor SSC
Al-Li	Shuttle ET	Fusion welding repairs difficult. Lightest weight, most expensive
7000 series	Never used	FT decreases at cryo temperatures. Not fusion weldable, but can be FSW



Relative Component Weights for an Aluminum Tank

Component	No. per tank	Temper	Relative Weights lb.	Weight Percent %
Barrels	32	T8	19,000	69.9
Rings	5	T8	4,500	16.6
Domes	2	T6	2000	7.4
FSW	----	TBD	1628	6.0

Design Controlling Characteristics

Component	Possible Design Controlling Factor	Key Properties
Cylinder	Stability, Cyclic Life, or Strength	da/dN, KIc, Ft_u, Fty, KIc
Rings	Strength and Stiffness	Ft_u, Fty, E
Domes	Cyclic Life	da/dN, KIc
FSW	Strength	Fty, KIc



Thickness Range of Candidate Alloys

Production	2219, 2195, 2097, 2297
Developmental	C458, C47A, L277, 2098

Alloy	Acceptable Thickness, inch				
	1	2	3	4	5
2195					
2098					
2097					
2297					
L277					
C458					
C47A					
2219					



Features of Candidate Alloys

Alloy	Key Characteristics
2195	<ul style="list-style-type: none">• In production for Shuttle External Tank• Thickness to 1.8 inch verified
2098	<ul style="list-style-type: none">• In production for 0.25-inch thick• 0.5% less Cu than 2195, sister alloy
2097 2297	<ul style="list-style-type: none">• In production for F-16• Two AMS specs evolving for same application• Not designed for FSW or cryogenic use
L277	<ul style="list-style-type: none">• Developmental alloy• Derivative of 2195 with 0.2% less Li• Similar to 2098 except Li reduced and Mn added
C458	<ul style="list-style-type: none">• Development alloy• Developed under AF sponsorship• Exceptionally high toughness
C47A	<ul style="list-style-type: none">• Development alloy for aircraft• Sister alloy to C458 with less Li, weaker, tougher



Plate Compressive Modulus, msi

Alloy	Longitudinal		45°	
	Et	Ec	Et	Ec
2219	10.5	10.8	10.5	10.8
2195	11.0*	11.3	10.7	11.0
L277	11.0	11.3	10.7	11.0
C458	11.6	11.9	11.1	11.5
2090	11.5	11.8	11.0	11.4

*Numbers in red are estimates

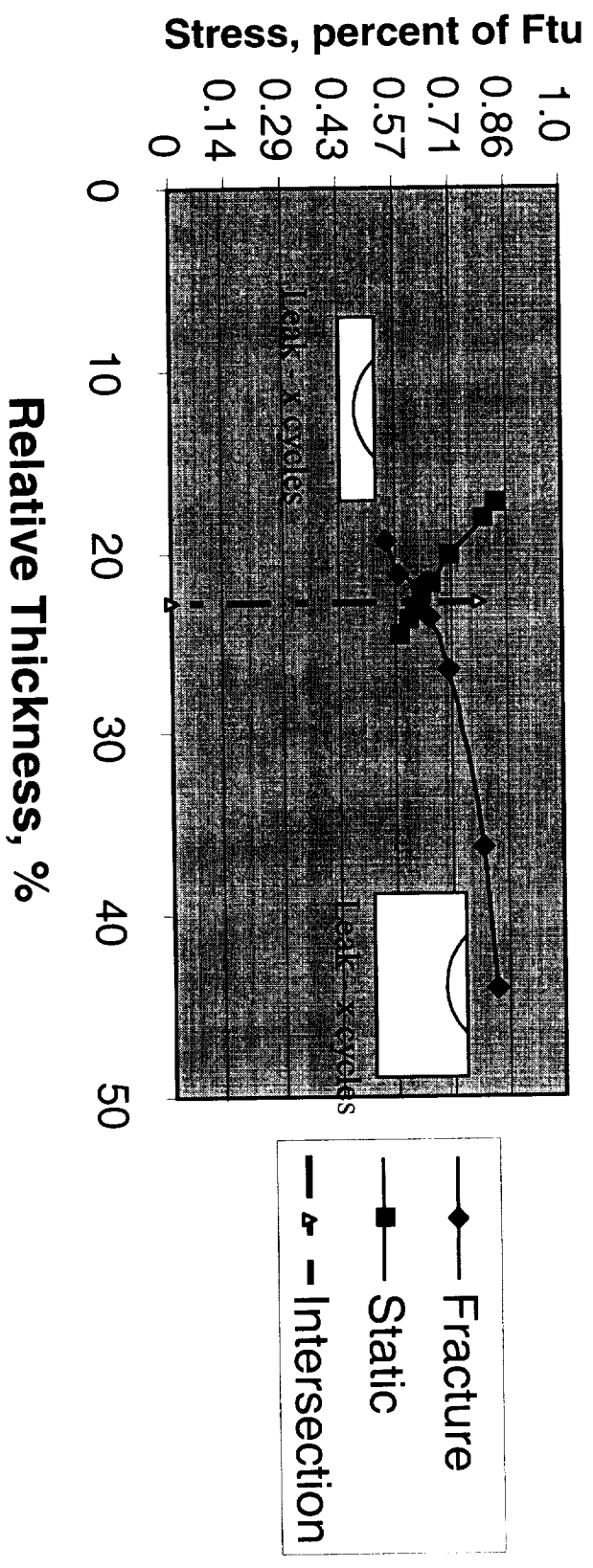


Cryogenic Enhancement of the Modulus, msi

Temp °F	Longitudinal		45°	
	Et	Ec	Et	Ec
RT	11.0	11.3	10.7	11.0
-320	12.2	12.5	11.9	12.2
-423	12.2	12.6	11.9	12.2

Cyclic Life vs. Pressure

Applied Stress Versus Wall Thickness Al-Li Alloy





Strength Comparison

Typical T8 Temper Values at Ambient Temperature
In 45° Direction for Al-Li Alloys

Alloy	Density lb/in ³	TUS ksi	TYYS ksi	e%	E, msi
2195	0.0975	76	71	9	11
L277	0.0975	73	66	9	11
C458	0.0945	73	62	11	11.1
2219	0.103	65	51	10	10.5

Joining - Goal is no MRB Actions Possible with FSW of Al-Li

- Preliminary assessment
 - Al-Li can be FSW as readily as other alloys
 - For joining same alloy, results to date show defect free joints
 - FSW dissimilar metals data limited
 - Different Al-Li alloys - no problem seen or expected
 - 2219 to Al-Li - 2219 quality joints obtained with a single sided pin tool
 - Circumferential FSW is required in addition to the longitudinal FSW already in production

Goal - use FSW for all joints

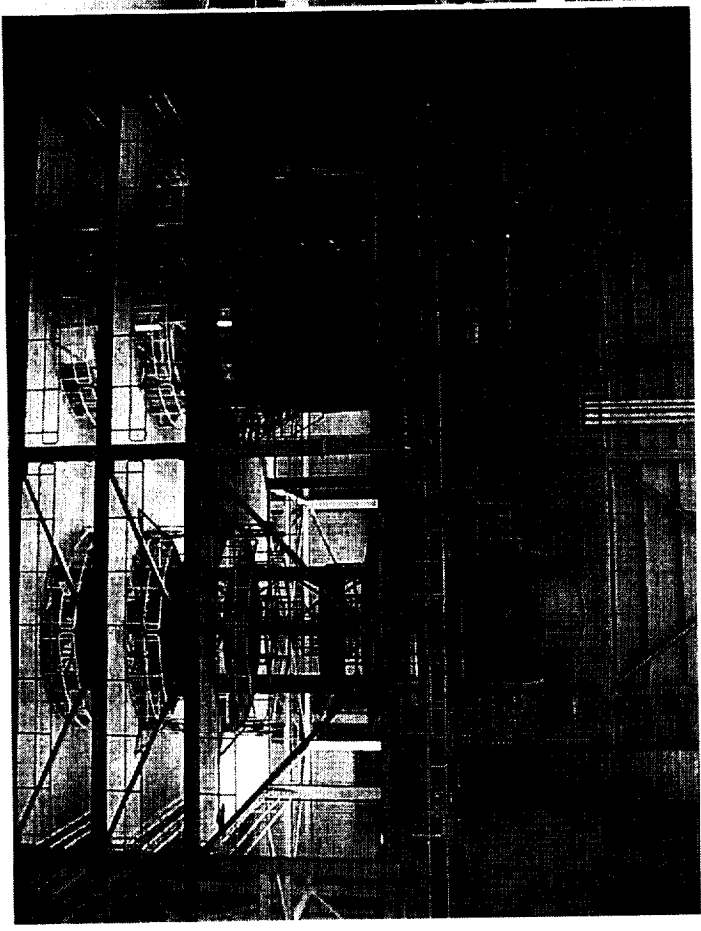
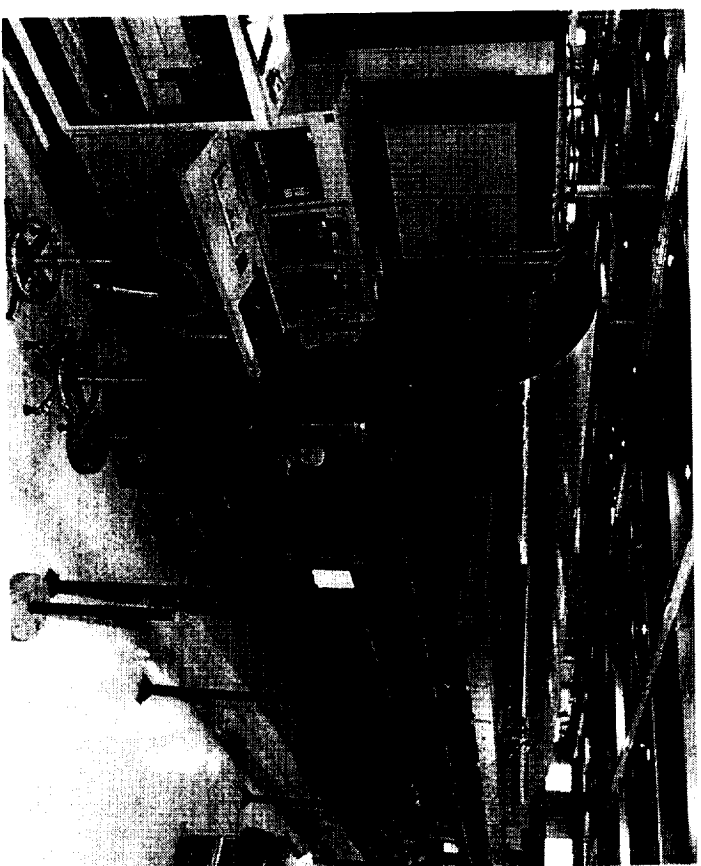


FSW Key Technology for Al-Li

In Production on Delta Launch Vehicles

Delta II/III 2014 Al

Delta IV 2219 Al



**FSW resulted in outstanding weld quality
compared to fusion welds**

Some Closing Comments & Opinions

- Al-Li continues to receive attention because of the performance benefits it provides and availability of new alloys that avoid the problems with earlier alloys
 - Higher stiffness than 2219
 - Higher strength than 2219
 - Lower density, 0.103 for 2219 and 0.0945 to 0.975 for Al-Li
- Work on developmental alloys should continue to bring them to production maturity level so they may be selected for a production program with minimum risk
- FSW will permit re-examining design options set aside because of fusion welding difficulties