Evaluation of AMSOIL®-ANT PGW Coolant Formula Change and Super Space AMSOIL® Development

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Summary

- **AMSOIL® Propylene Glycol Water (40% PG, 60% water) is the internal thermal control fluid for Gateway (HALO, IHAB, ALM), Orion, and baselined for use on some commercial vehicles**
  - *AMSOIL® brand was chosen after significant amount of materials compatibility testing completed by Collins and NASA between 2008 and 2015*
- **In April 2023, the NASA Orion ATCS System Manager received notice of a change in the AMSOIL® PGW corrosion inhibitor formula**
  - Driven by vendor relations and new formula had "similar or better performance" for areas considered (per conversation with Mark Nyholm, AMSOIL® technical rep)
  - Change occurred in 4th quarter of 2019
  - Primary change centered around a change and increase in the organic acids used as well as adding inorganic inhibitors
- **The effects of the new organic acid component was not verified for use within any ATCS systems, therefore L2 Gateway ATCS worked with the JSC/ES Group to develop simplified test using the initial screening tests conducted for Orion**
  - Collins Aerospace donated original AMSOIL® formula and brazed metal coupons to provide high fidelity results (similar to flight hardware)
- **Testing was started June 2024 with periodic sampling occurring at 3, 6, and 12 months**
  - Test 1: Corrosion rate testing - resulted in aluminum having higher coorosion rates than the original formula
  - Test 2: Coolant stability testing - resulted in formation of glycolate and formate within the coolant, indicating PG breakdown due to contact with a high surface area of aluminum (as in a heat exchanger)
- **As a result, AMSOIL® developed "Super Space AMSOIL®" which is a reformulation of the "original" PG formulation, and it is available for sale to all space users**

Change in Formula: Amalgatech Analysis

- **Organic acid has changed from Sebacic Acid to additional organic acids, which ultimately results in high reserve alkalinity**
  - Reserve alkalinity is a measure of a coolant's ability to neutralize an acid, indicating its buffering capability
  - Adding up organic acids, total makes up ~6% organic acids, vs. ~2% original formula (~3x higher than original formula)
  - Two inorganic inhibitors
  - Conductivity of solution could have increased due to added cations, which could increase conductivity of the new formula

Value	New Formula	Original Formula	% Change	Notes
Standard Measurements				
Lot #	M2216421	19-09-18 26281	-	
pH by ASTM D12871Δ	8.83	7.88	-	
% Antifreeze from chart *	100	100	-	
Reserve Alkalinity (mL) by ASTM D11211	12.3	5.3	124%	Doubling of buffering capability, likely due to increase of neutralized organic acid as carboxylates
Deleted				
2-Benzothiazolylthio Acetic Acid (BTTAA) mg/l*	ND	3243	Deleted	Utilizing a different organic acid (components that are added below) Uncertain of reasoning
Denatonium Benzoate by ASTM D73041 (ppm)	Proprietary	59	Deleted	Typically added as an embitterant
No Change				
Chloride (mg/l) ASTM D58271	10	7	N/A	
Sulfate (mg/l) ASTM D58271	9	6	N/A	
Increased/Decreased (likely found in every coolant on the market in different levels)				
Potassium (mg/l K ASTM D61301)	Proprietary	3,100	331%	Could increase conductivity
Sodium (mg/l Na ASTM D61301)		222	528%	Could increase conductivity
Benzotriazole mg/l*		783	382%	For yellow metal protection, provides some chelating agent
Sebacic Acid mg/l*		16,635	-41%	(~2% of original formula)
Tolyltriazole mg/l*		829	114%	For yellow metal protection
Added				
Proprietary Organic Acids mg/l*	Proprietary	ND	Added	New organic acid
Molybdenum (mg/l Mo) ASTM D61301		ND	Added	For cavitation protection. Typically added as Molybdates.
Nitrates (mg/l) by ASTM D58271		ND	Added	Good for aluminum protection. Typically added as sodium nitrate which increases sodium (above)

Test Objectives

- **Objectives: Demonstrate that AMSOIL® formula change 1) does not cause an increase in corrosion rates of common metals and 2) the coolant maintains stability when exposed to large surface area to volume of metals**

- **Test 1: Corrosion Rate Test**
  - Testing conducted side-by-side with identical samples on Original and New formula coolant
  - Determine corrosion rates of the new formula are not significantly greater than original formula
  - Conducted with materials not easily replaceable in brazed HX's and coldplates
    - Aluminum Multiclad 4104 as recieved, Multiclad 4104 brazed, Ni 201, 347 CRES brazed with BNi-2, Al 6951
  - Conducted with 30 PG/70 water (PGW) to match prior test data from Collins Aerospace data. It has been previously demonstrated that corrosion rates increase with increasing water content (
  - Samples stripped and coorosion rate determined after 3, 6, and 12 months

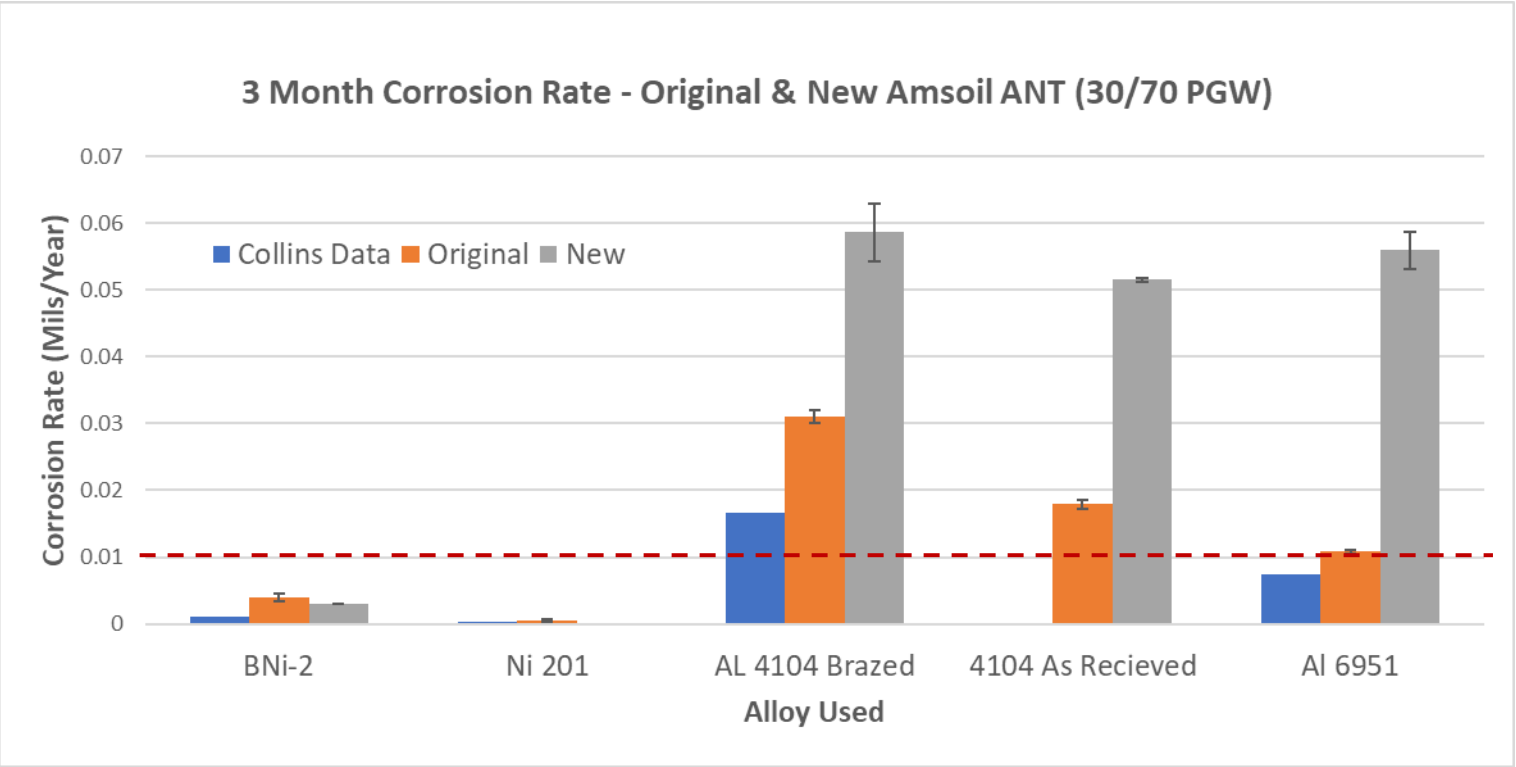
- **Test 2: Coolant Stability Test**
  - Testing specifically addressed the formation of precipitates within the fluid (i.e. chemical reactions from inhibitors)
    - Found when aluminum ions from new, uncoated aluminum form an insoluble compound
  - Conducted with 40/60 PGW to match prior test data
    - The concentration of the inhibitor package will be the highest, increasing the chance of a reaction
    - Control samples with no fin were also tested in same bath

- **All samples are slightly heated in a 130F water bath for acceleration**
  - 130F is above common life support applications while significantly below automotive use

- **General test procedures included in our ICES paper and are not fully discussed in this presentation**

Test 1

Test 1: Corrosion Rate Data 3-Months

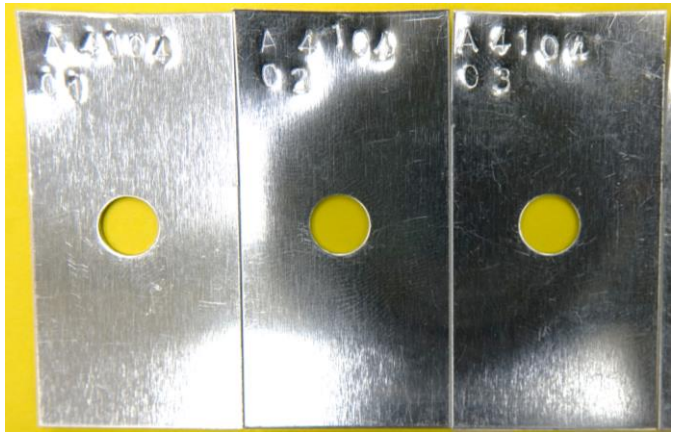


Metal	PGW Formula	Corrosion Rate (Mils/Year)	% Change Original to New
BNi-2	Original	0.0039	-
	New	0.0030	-22%
	Collins	0.0011	-
Ni 201	Original	0.0005	-
	New	-0.0002	-129%
	Collins	0.0004	-
AL 4104 Brazed	Original	0.0310	-
	New	0.0586	89%
	Collins	0.0167	-
4104 As Recieved	Original	0.0179	-
	New	0.0515	185%
	Collins	-	-
Al 6951	Original	0.0108	-
	New	0.0559	419%
	Collins	0.0075	-

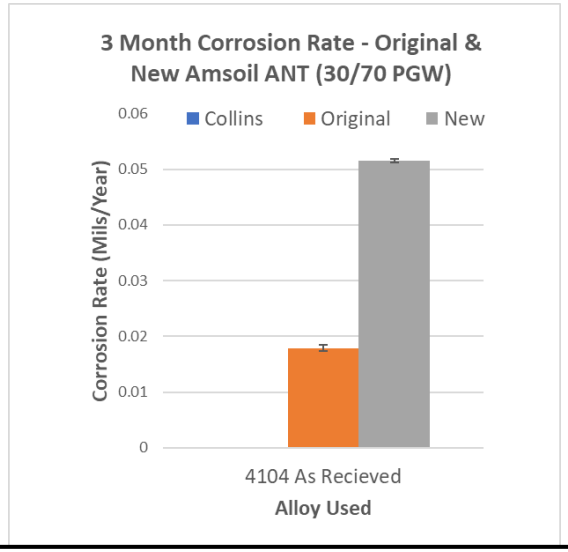
Aluminum corrosion rates are ~2-5x higher for the new formula when compared to the old formula

- Corrosion rate standardized for all samples to mil/year
  - 0.01 mils/year is a target corrosion rate to stay below, based on previous Collins testing (red, dashed line)
- 3-month corrosion rates are likely higher due to passivation of base metal
  - More representative, long term corrosion rates are likely to be found at 6 and 12 months
  - However, with high corrosion rates found in 3-month test, even if corrosion rates decrease, it is still likely to be >0.01 mils/year
- For reference, CRES parting sheets are generally 6-8 mils thick (including braze foils), Al parting sheets are 20-22 mils

Aluminum 4104 No Braze (Post Strip)



Pre-Test



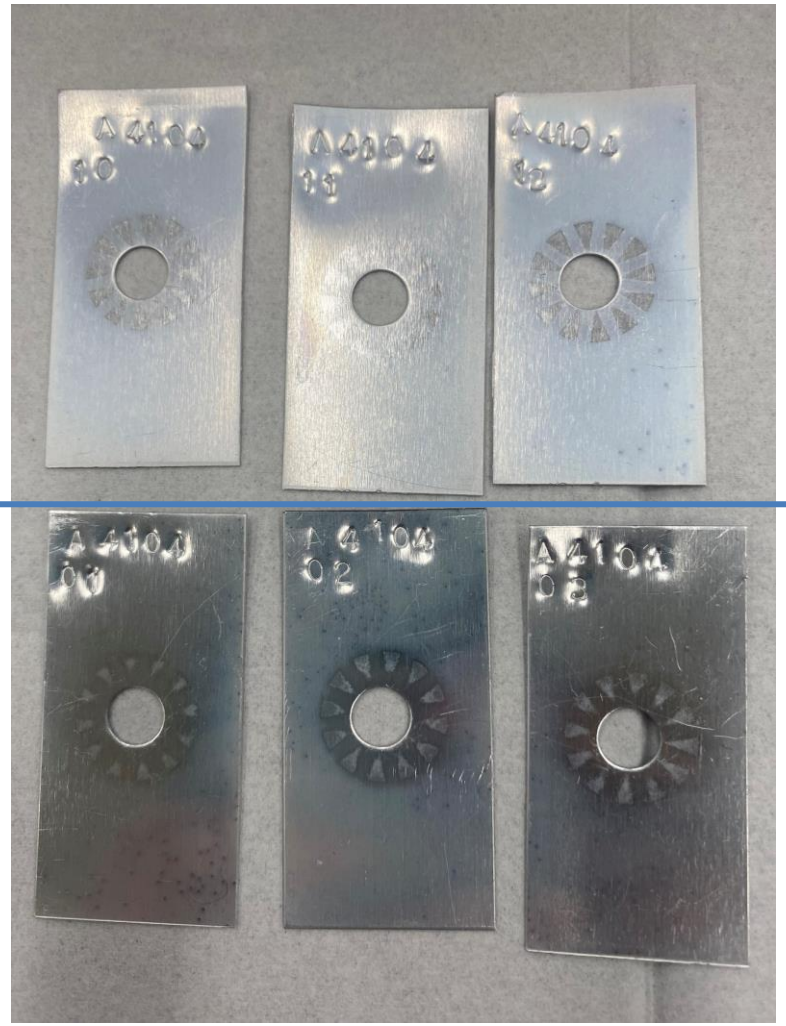
- Corrosion rate is ~3x higher for new formula when compared to original formula
- Significant visible “frostiness” difference in pre- & post-test samples

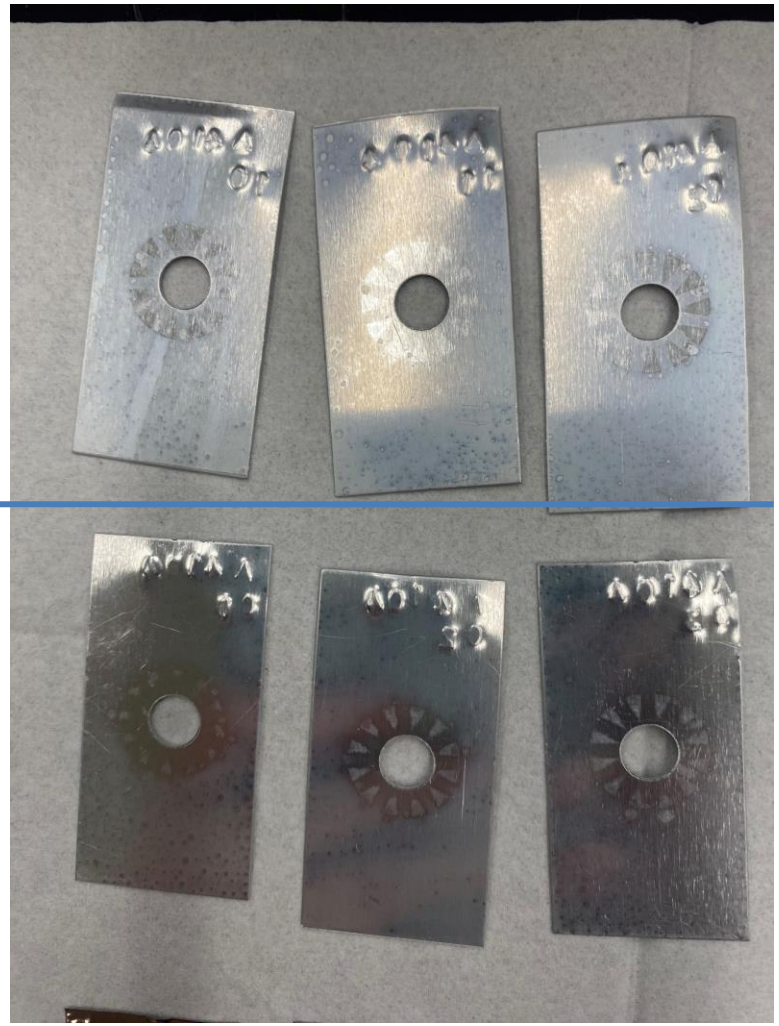
Front

Back

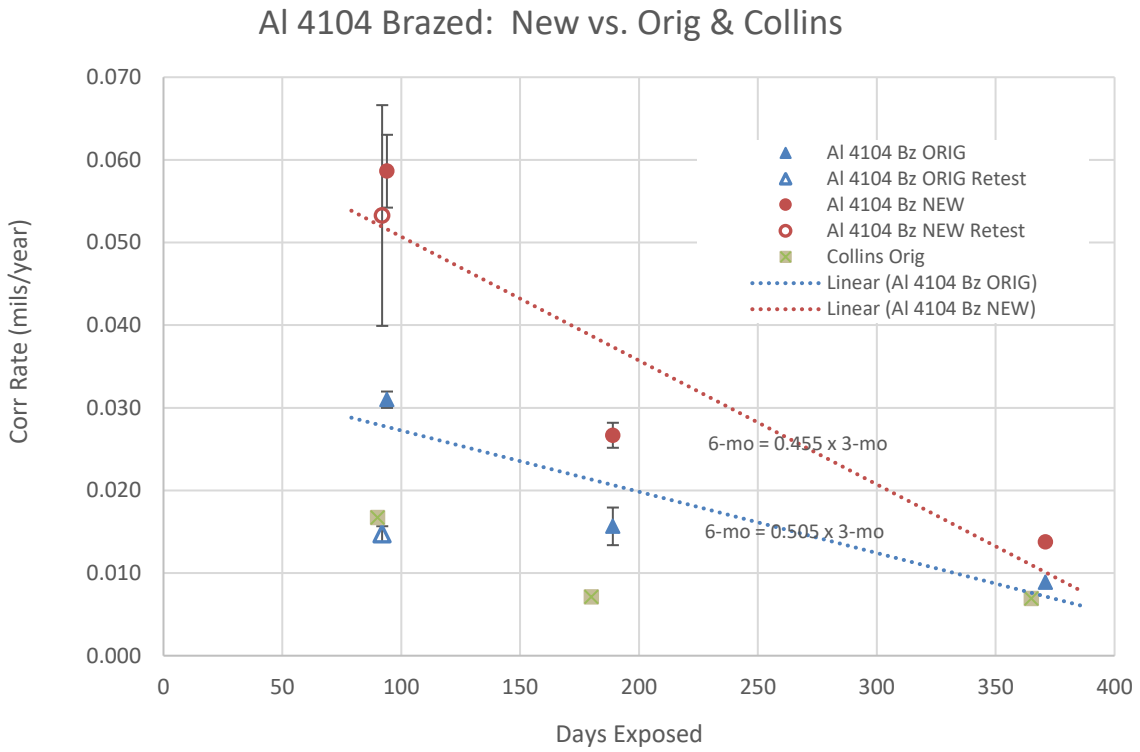
New

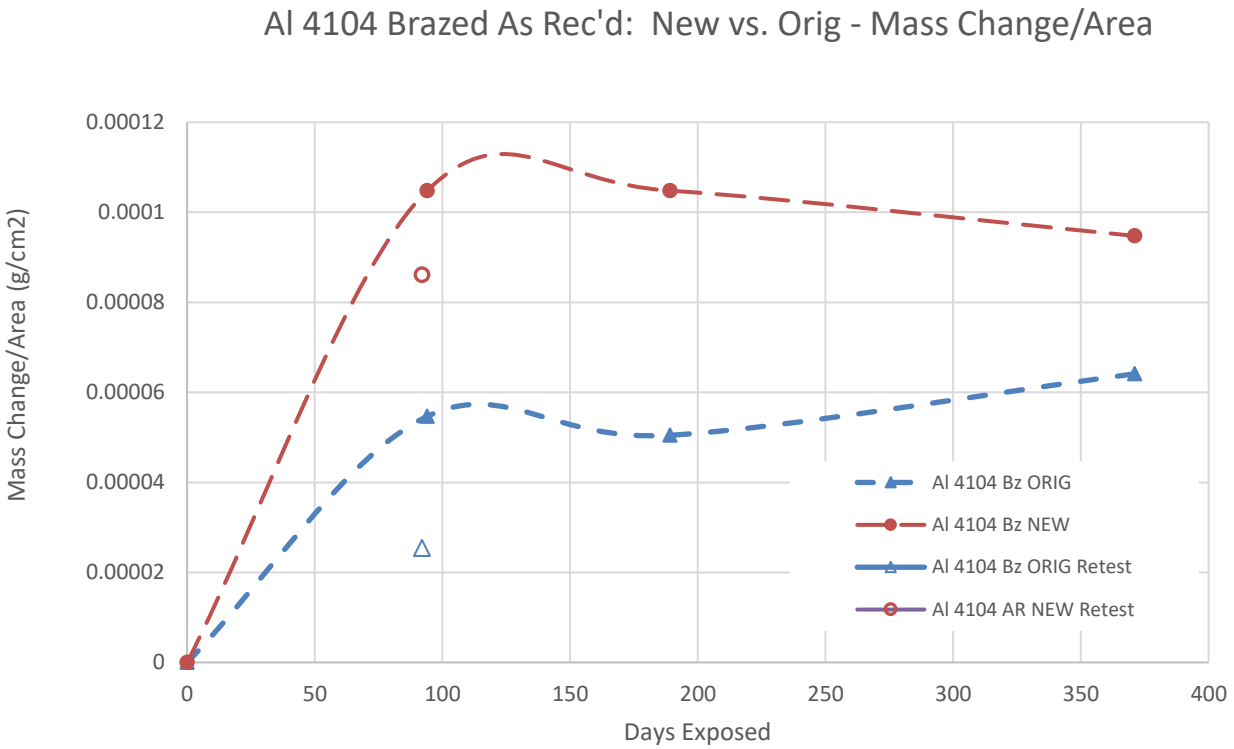
Old





3, 6, and 12-Month Corrosion Rates – Al 4104 Brazed

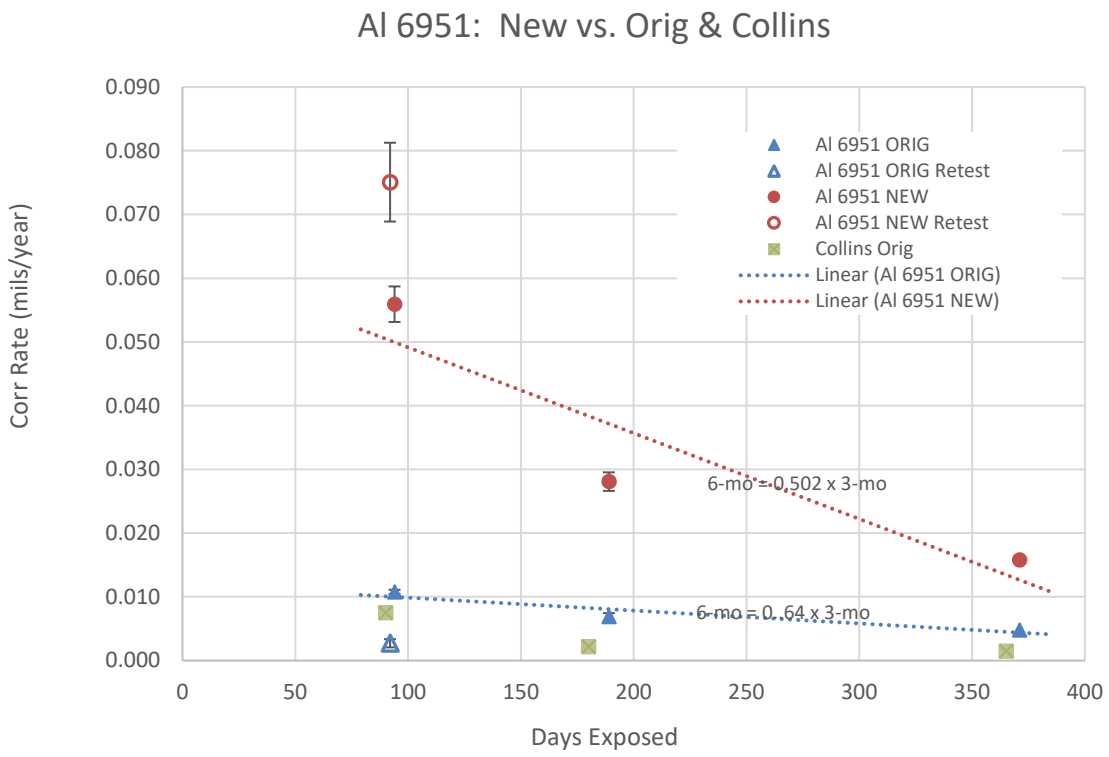


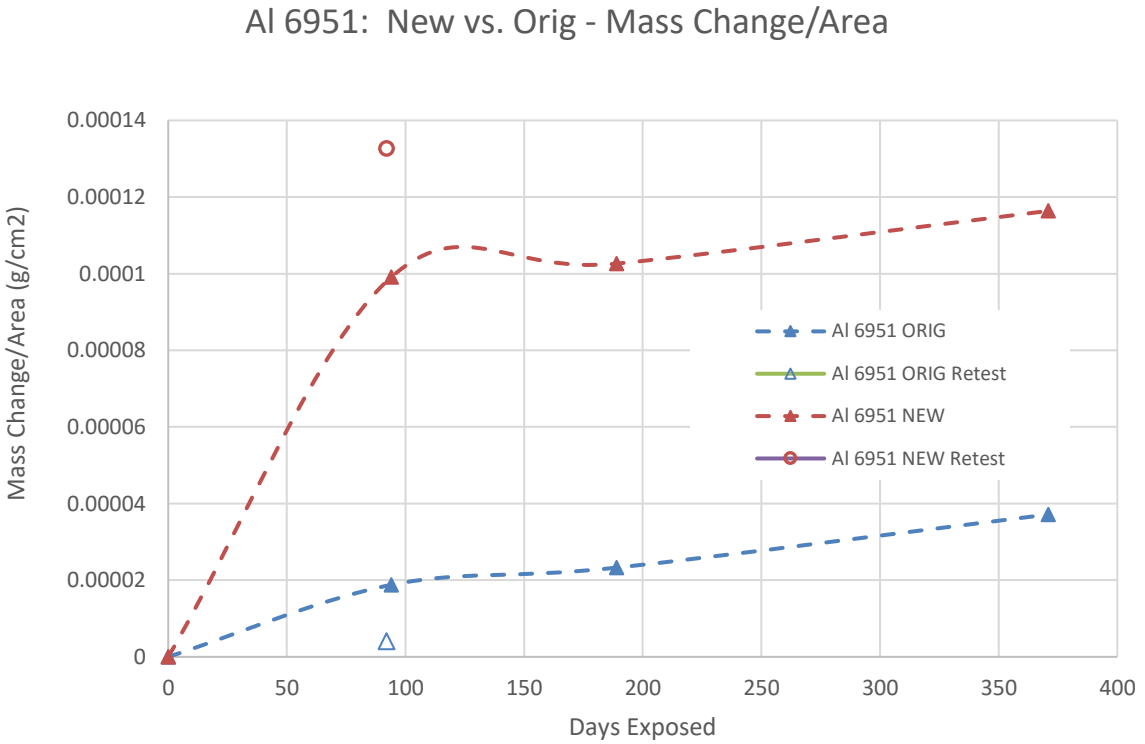


- Corrosion rate halved from 3 to 6 months & from 6 to 12 months, as expected
- New formula corrosion rate is ~50% higher than old
- Still above 0.010 mils/year goal

- Mass change stabilized from 6 to 12 months

3, 6, and 12-Month Corrosion Rates – Al 6951





- Corrosion rate halved from 3 to 6 months & from 6 to 12 months, as expected
- New formula corrosion rate is ~225% higher than old
- Still above 0.010 mils/year goal

- Uncertain why mass change/area has increased at 1-year

Test 1 Conclusions

- **For 3-month test**
  - New formula corrosion rates are ~2-5x higher for aluminumalloys tested when compared to the original formula
    - Visible frostiness observed on new formula for 3-month samples, indicative of aluminum corrosion (typically white in color)
- **For 6-month test**
  - Corrosion rate of aluminums trended to half of 3-month data, as expected
  - Mass change has stabilized
- **For 12-month test**
  - Corrosion rate of aluminum trended towards half of 6-month data, as expected
  - Aluminum remain at corrosion rates slightly above 0.010 mils/year for the new formula
  - Uncertain why Al 6951 mass change has increased

- **For all testing, stainless steel and nickel are well below the 0.01mils/year threshold**

- **Based on 3- 6- and 12-month results, NASA M&P and TCS recommended utilizing the “original” PG formula for all spacecraft applications**

Test 2

Test 2: Coolant Stability Test PGW Analysis

	Original Formula				New Formula			
Sample ID ->	Baseline – ORIG, from Collins	Baseline Orig at 41% dilution	Control – Orig 40/60 In Bath	Orig Fin 3-mo Test, Filtered 40/60	Baseline New-, Pretest #2	Baseline New at 43% dilution	Control – New 40/60 In Bath	New Fin 3-mo Test, Filtered
Properties								
Concentrate Lot #	19-09-18 26281				M22116421			
Color	Yellow	Yellow	Yellow	Amber	Yellow	Yellow	Yellow	Amber
pH ASTM D12871A (1)	7.88	7.88	7.92	7.75	8.83	8.83	8.65	8.43
% Antifreeze from chart	100	41	41	45	100	43	43	45
Freezing Point (F) ASTM D3321	-28 at 50/50 mix	'--	-5	-12	-28 at 50/50 mix	--	-5	-12
1 Reserve Alkalinity ASTM D1121	5.3	2.2	2.2	2.1	12.3	5.3	3.7	2.9
Inhibitors								
4 Sebacic Acid, mg/l	16,335	6,820	6,625	6,786	Proprietary			
BTTAA, mg/l	3,243	1,330	1,324	1,364	Proprietary			
Benzotriazole, mg/l	783	321	310	289	Proprietary			
Tolyltriazole, mg/l	829	381	328	311	Proprietary			
2 Wear Indicators								
Aluminum, mg/l	ND	ND	ND	ND	ND	ND	ND	ND
Magnesium, mg/l	ND	ND	ND	11.9	ND	ND	1.4	2.8
Chloride, mg/l	7	3	3	2	10	4	2	9
Sulfate, mg/l	6	2	5	6	9	4	1	ND
Formate, mg/l	ND	ND	ND	57	ND	ND	ND	41
3 Glycolate + Lactate, mg/l	ND	ND	ND	51	ND	ND	ND	447

1
- RA decreased
- During formation of Glycolate (a carboxylate), carboxylic acid is formed, which is neutralized, reducing the RA.

2
- No aluminum detected. Oxide likely produced on surface and may prohibit aluminum from dissolving. Some magnesium detected, however.

3
- ~9x Glycolate produced, indicating glycol degradation
- Speculation: Aluminum ions may facility breakdown of the glycol
- Formate is further breakdown of glycolate
- Could be related to increase in organic acids in the new formula

4
- No significant difference with organic acid inhibitors
- Would expect to see drop in drop in organic acids with formation of glycolates

Test 2: Repeat Test Results & Conclusions

- **Coolant stability test was repeated with new fin-stock in Spring 2025**
  - Result show no formate or glycolate found after 3-month test
  - Uncertain as to why, but a couple of minor variables
    - New fin stock used, cleaned to GC specification
    - No vent hole in top of lid

- **For initial test, formation of formate and glycolate in new formula is a potential concern**
  - New formula may be more susceptible for decomposition by the high surface area of aluminum
    - ~450ppm of glycolate found, indicating glycol breakdown (~9x higher than original formula)
  - Could be a concern
    - Fluid flow may help (mixing)
    - Flight system will be operated at lower temperatures, up to ~100F (test run at 130F)
  - Samples from Artemis I vehicle using Original formula did not show formate or glycolate in analysis after 5 years including one flight

- **These test results support NASA M&P and TCS recommendation on utilizing the "original" PG formula for all spacecraft applications**

Super Space AMSOIL® Development

- **3- and 6-month data shared with AMSOIL® in November 2024 and Janurary 2025**
  - AMSOIL® indicated after 3 months that we may have potentially found an issue with their “new” formula, potentially unique to spaceflight applications

- **In mid March 2025, NASA received a new point of contact (David Brockett) at AMSOIL® who indicated they may be wiling to manufacture the original PG formulation**
  - Old PGW Lot number provided to AMSOIL® as a reference

- **Working to update MPCV 70156 (Cross Program Fluid Procurement and Use Control Specification) to included an updated to Propylene Glycol procurement specification**
  - Specification developed jointly by NASA & AMSOIL®
  - Updated procurement specification to meet “original” PG formulation
  - Working with AMAOSIL® to ensure Super Space AMAOSIL® CofA will meet MPCV 70156 procurement specification.
    - “As-delivered to the interface” specification would still be required by entity filling spacecraft

- **SSA can be ordered by contacting representative at AMSOIL® (currently David Brockett) and setting up an account**
  - Product is not available online
  - Only available by the barrel
  - Leadtime 7-8 weeks

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Backup

3, 6, and 12-Month Corrosion Rates – BNi2 Brazed