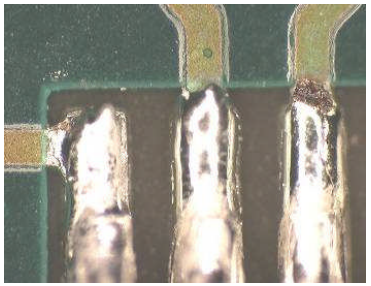
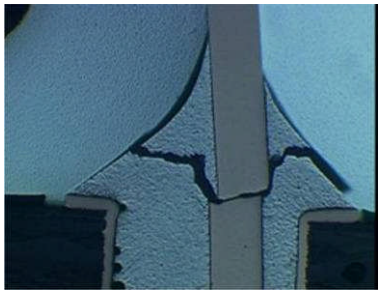
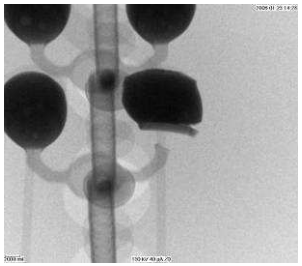
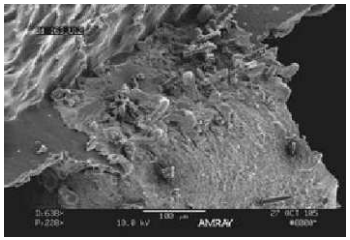
NASA-DoD Lead-Free Electronics Project

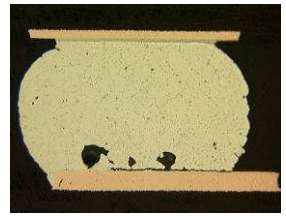
June 24, 2009
Tin Whisker Group Telecon

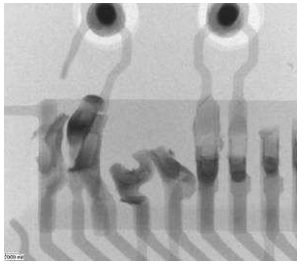


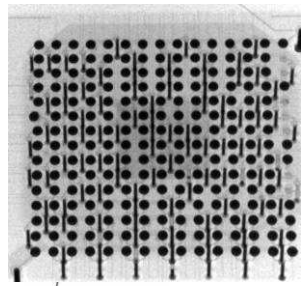












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Testing project will build on the results from the JCAA/JGPP LFS Project

The primary technical objective of this project is to undertake comprehensive testing to generate information on failure modes/criteria to better understand the reliability of:

Packages (e.g., Thin Small Outline Package [TSOP], Ball Grid Array [BGA], Plastic Dual In-line Package [PDIP]) assembled and reworked with lead-free alloys

Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with mixed (lead/lead-free) alloys.

Web Links:

NASA-DoD Lead-Free Electronics Project:
http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html

JCAA/JGPP Lead-Free Solder Project
http://www.teerm.nasa.gov/projects/LeadFreeSolderTestingForHighReliability_Proj1.html

Comparison of NASA-DoD LFE Project to predecessor JCAA/JG-PP LFS Project

Similarities
- Virtually identical test vehicle
- Procedures identical for most tests
- Same facility for assembly
- SN100C being used for wave soldering

Differences
- Test articles will be thermally aged after assembly
- Increased rework
- Increased solder mixing
- Mechanical shock test procedure
- Drop testing
- Immersion Ag surface finish for most test vehicles
  - Limited number will have ENIG
- SAC305 being used for reflow soldering
- SN100C being used for reflow soldering


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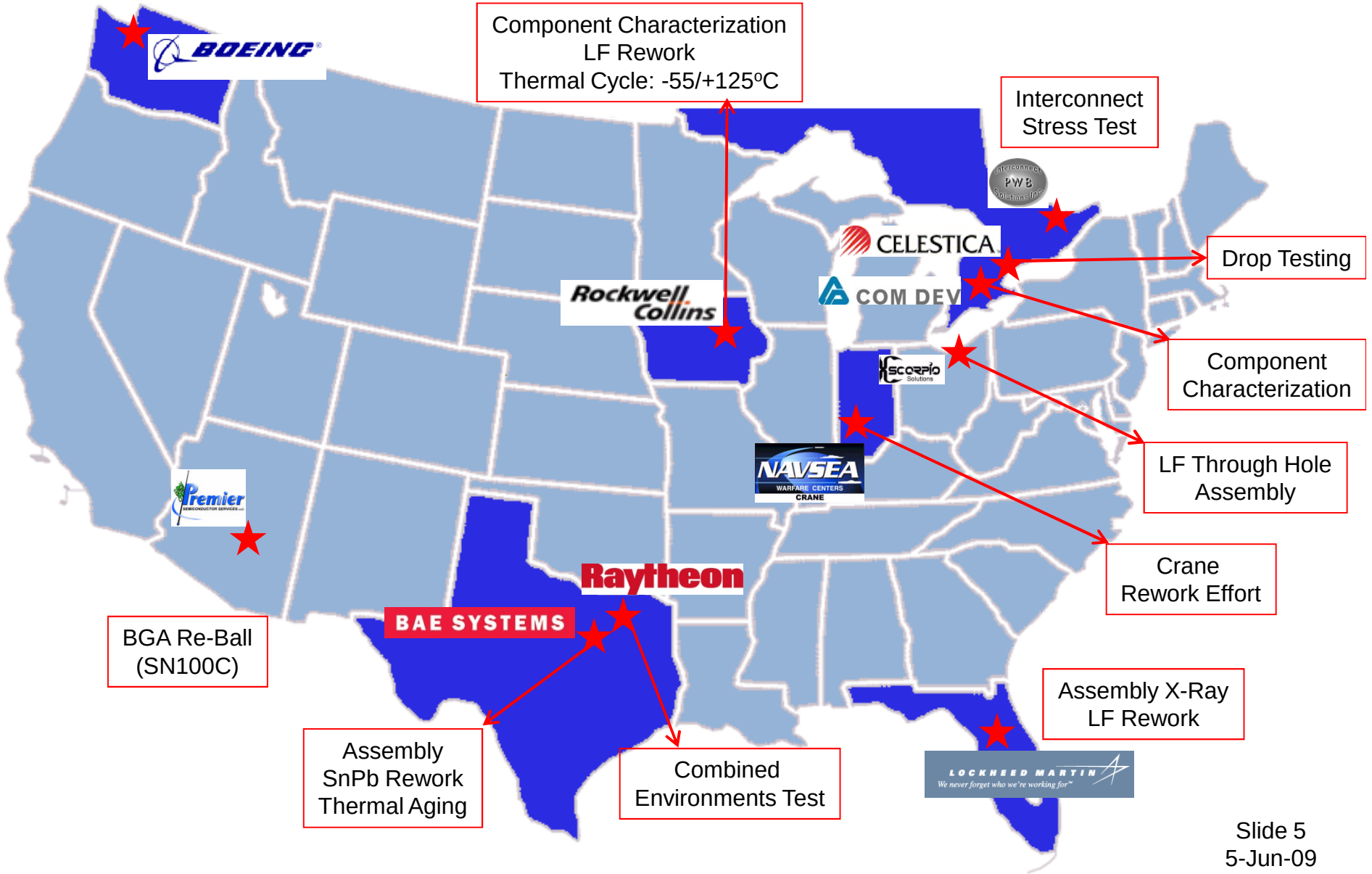
NASA-DoD Lead-Free Electronics Project Stakeholder Locations

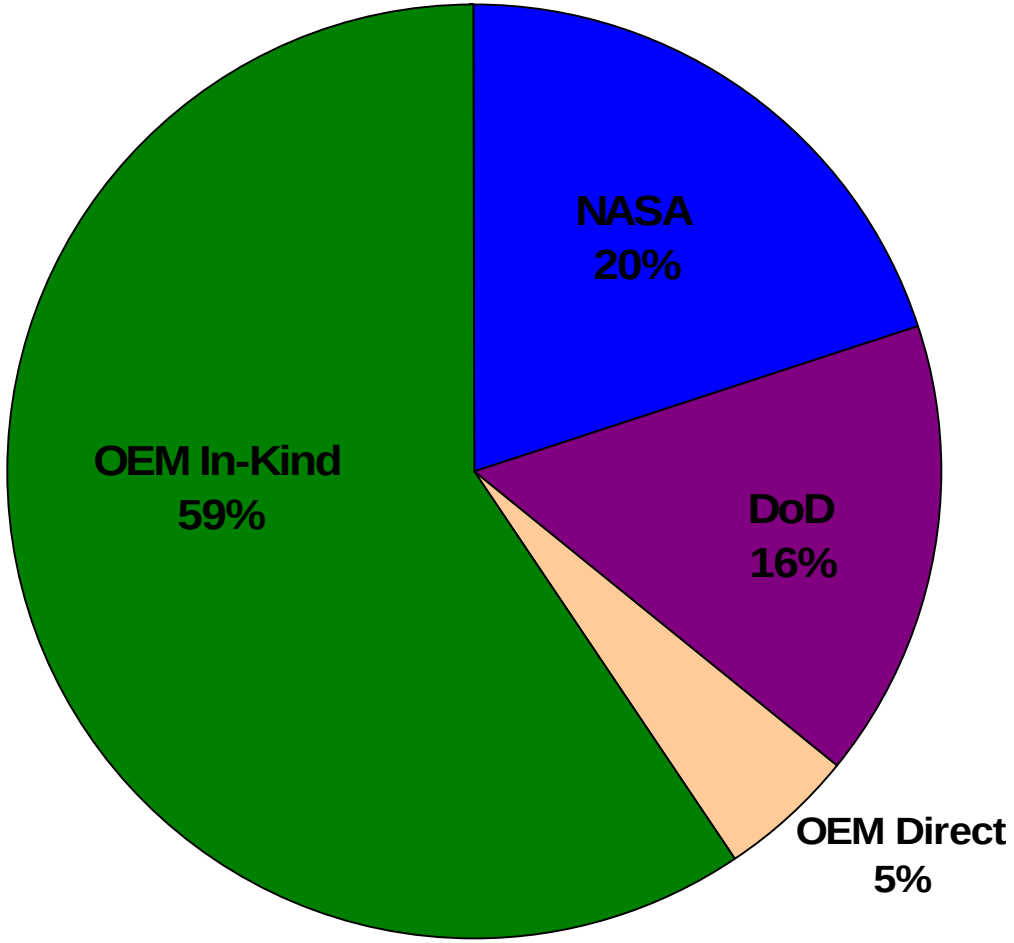


Joint Test Protocol Endorsement

Endorsement signifies agreement that the JTP contains performance and technical requirements applicable to specific applications within programs, and provides the consensus needed to move forward with testing.

- AIA (Aerospace Industries Association)
- Air Force - Electronic Engineer (WR-ALC/ENFM)
- Air Force - Director of Engineering (DOE) for the 312/326 Aeronautical Systems Wing (AESW); Wright-Patterson Air Force Base
- Army Research Lab
- Headquarters - Air Force Space Command
- NASA - NEPP Program
- NASA-MSFC - Packaging, EEE Parts & Electrical Manufacturing Branch Chief
- Naval Air Warfare Center, Aircraft Division
- MDA – PMP Program Lead
- NSWC Crane Division - 2M Project Manager
- NSWC Crane Division - 2M (Miniature/Microminiature) Electronics Technician
- NSWC Crane Division - Electronics Engineer, Testing: Printed Circuit Technologies Branch
- NSWC Crane Division - Materials Engineer; FA/MA Branch, Flight Systems Division
- BAE Systems - Principal Process Engineer
- BAE Systems - Vice President of Engineering for Electronics and Integrated Solutions
- Celestica - Director of Technology - IAD sector
- COM DEV - Director, Design Integrity
- General Dynamics - Design Assurance Engineering Manager
- Harris - Process Engineering Group Lead
- Lockheed Martin - Engineering Manager
- Nihon Superior - President of Nihon Superior
- Radiance Technologies, Inc. - AERI Program Manager
- Rockwell Collins - Director, Advanced Manufacturing Technology
- TT Apsco - Vice President and General Manager
- Willcor Inc. - Best Manufacturing Practices

Contributions to the NASA-DoD Lead-Free Electronics Project ~$1.8 Million



Lead-Free Solder Alloys

- SAC305 (Sn3.0Ag0.5Cu)
  - Surface mount assembly

    This alloy was chosen for reflow soldering because this particular solder alloy has shown the most promise as a primary replacement for tin-lead solder. The team decided that they wanted to select at least one “general purpose” alloy to be evaluated and it was determined that the SnAgCu solder alloy would best serve this purpose.

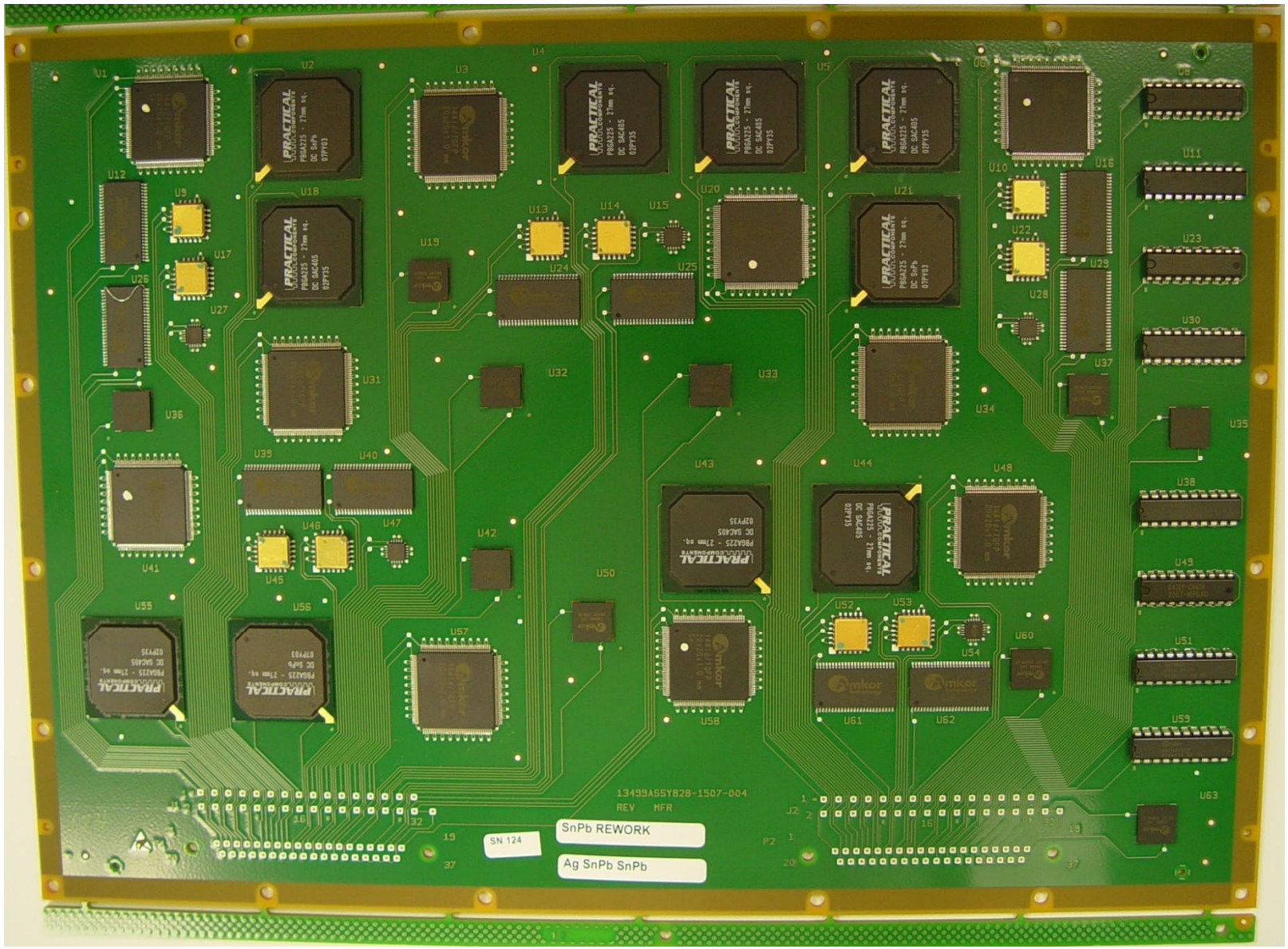
- SN100C (Sn0.7Cu0.05Ni+Ge)
  - Plated through hole
  - Surface mount assembly

    This alloy is commercially available and the general trend in industry has been switching to the nickel stabilized tin-copper alloy over standard tin-copper due to superior performance. In addition, this nickel-stabilized alloy does not require special solder pots and has shown no joint failures in specimens with over 4 years of service.

193 Test Vehicles Assembled

BAE SYSTEMS

120 = Manufactured
73 = Rework



Component Finish/Solder Combinations Example

SnPb Manufactured Test Vehicles				
Component	**Component Finish**	**Reflow Solder**	**Wave Solder**	**Board Finish**
BGA-225	SAC405	SnPb		Immersion Silver
BGA-225	SnPb	SnPb		
CLCC-20	SAC305	SnPb		
CLCC-20	SnPb	SnPb		
CSP-100	SAC105	SnPb		
CSP-100	SnPb	SnPb		
PDIP-20	NiPdAu		SnPb	
PDIP-20	Sn		SnPb	
QFN	Matte Sn	SnPb		
TQFP-144	Matte Sn	SnPb		
TQFP-144	SnPb Dip	SnPb		
TSOP-50	SnBi	SnPb		
TSOP-50	SnPb	SnPb		

Profiles used during initial assembly

Reflow Profile = SnPb
Preheat = ~ 120 seconds @140-183°C
Solder joint peak temperature = 225°C
Time above reflow = 60-90 sec
Ramp Rate = 2-3 °C/sec

Wave Profile = SnPb
Solder Pot Temperature = 250°C
Preheat Board T = 101°C
Peak Temperature = 144°C
Speed: 110 cm/min

Component Finish/Solder Combinations Example

Lead-Free Manufactured Test Vehicles							
Component	Component Finish	Set A			Set B		
		Reflow Solder	Wave Solder	Board Finish	Reflow Solder	Wave Solder	Board Finish
BGA-225	SnPb	SAC305		Immersion Silver ------- A limited Number of Boards will be Built with ENIG	SN100C		Immersion Silver
BGA-225	SAC405	SAC305			SN100C		
CLCC-20	SnPb	SAC305			SN100C		
CLCC-20	SAC305	SAC305			SN100C		
CSP-100	SnPb	SAC305			SN100C		
CSP-100	SAC105	SAC305			SN100C		
PDIP-20	NiPdAu		SN100C			SN100C	
PDIP-20	Sn		SN100C			SN100C	
QFN	Matte Sn	SAC305			SN100C		
TQFP-144	SnPb Dip	SAC305			SN100C		
TQFP-144	Matte Sn	SAC305			SN100C		
TSOP-50	SnPb	SAC305			SN100C		
TSOP-50	SnBi	SAC305			SN100C		

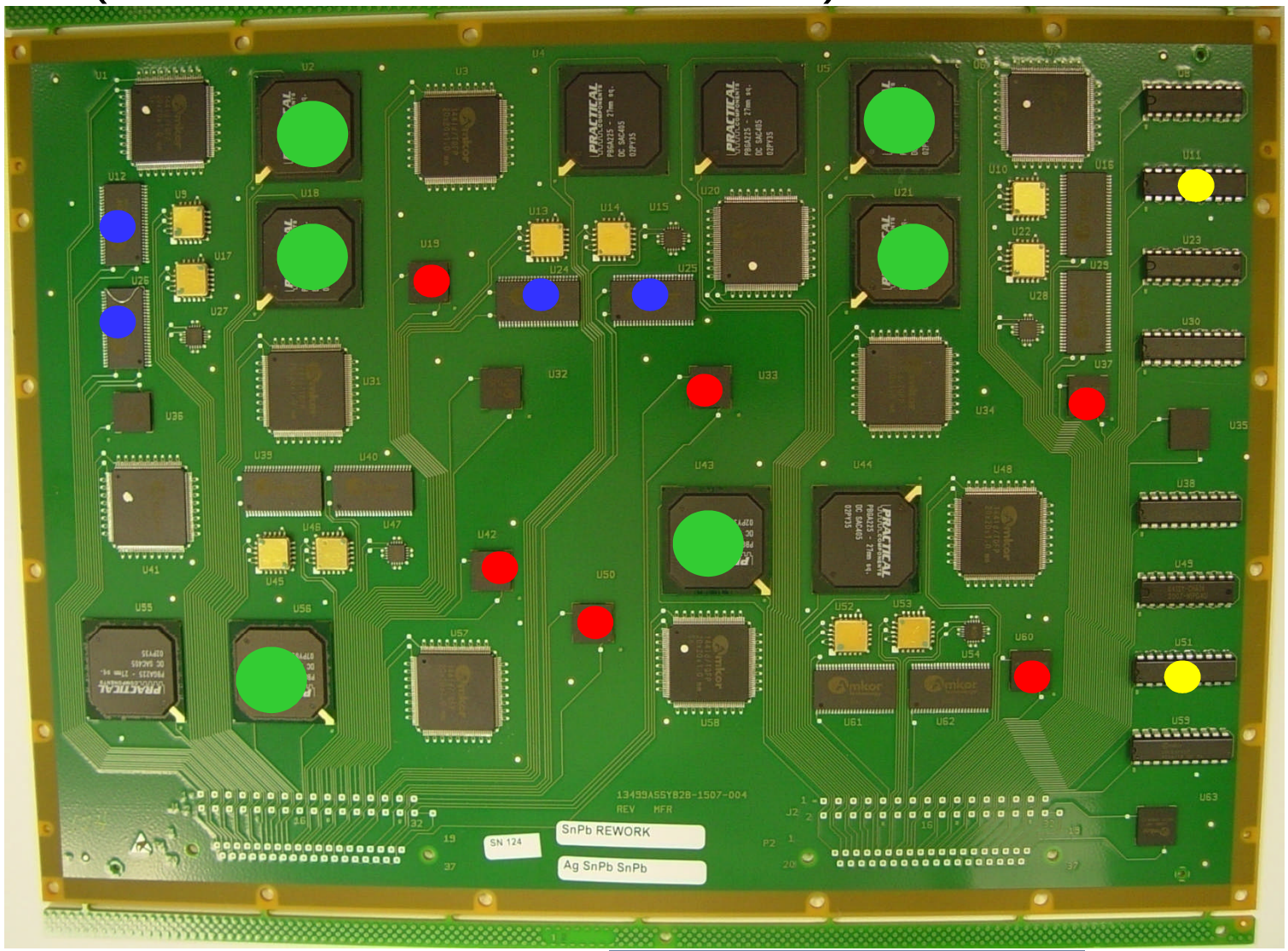
Profiles used during initial assembly

Reflow Profile = SAC305
Preheat = 60-120 seconds @150-190°C
Peak temperature target = 243°C
Reflow:~20 seconds above 230°C
~30-90 seconds above 220°C

Wave Profile = SN100C
Solder Pot Temperature = 265°C
Preheat Board T = 134°C
Peak Temperature = 157°C
Speed: 90 cm/min

73 Test Vehicles Being Reworked
(sub-set of the 193 assembled)

RefDes	Component
U18	BGA-225
U43	BGA-225
U06	BGA-225
U02	BGA-225
U21	BGA-225
U56	BGA-225
U33	CSP-100
U50	CSP-100
U19	CSP-100
U37	CSP-100
U42	CSP-100
U60	CSP-100
U11	PDIP-20
U51	PDIP-20
U12	TSOP-50
U25	TSOP-50
U24	TSOP-50
U26	TSOP-50



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Component Finish/Solder Combinations Example

SnPb Rework Test Vehicles						
Component	**Original Component Finish**	**Reflow Solder**	**Wave Solder**	**New Component Finish**	**Rework Solder**	**Board Finish**
BGA-225	SAC405	SnPb				Immersion Silver ------- A limited Number of Boards will be Built with ENIG
BGA-225	SnPb	SnPb		SAC405	SnPb	
BGA-225	SnPb	SnPb		SnPb	Flux Only	
CLCC-20	SAC305	SnPb				
CSP-100	SAC105	SnPb				
CSP-100	SnPb	SnPb		SnPb	Flux Only	
CSP-100	SnPb	SnPb		SAC105	SnPb	
PDIP-20	NiPdAu		SnPb			
PDIP-20	Sn		SnPb			
PDIP-20	SnPb		SnPb	Sn	SnPb	
QFN	Matte Sn	SnPb				
TQFP-144	NiPdAu	SnPb				
TQFP-144	SnPb Dip	SnPb				
TSOP-50	Sn	SnPb				
TSOP-50	SnBi	SnPb				
TSOP-50	SnPb	SnPb		SnPb	SnPb	
TSOP-50	SnPb	SnPb		Sn	SnPb	

Profiles used during initial assembly

Reflow Profile = SAC305
Preheat = 60-120 seconds @150-190°C
Peak temperature target = 243°C
Reflow:~20 seconds above 230°C
~30-90 seconds above 220°C

Wave Profile = SN100C
Solder Pot Temperature = 265°C
Preheat Board T = 134°C
Peak Temperature = 157°C
Speed: 90 cm/min

Component Finish/Solder Combinations Example

Lead-Free Rework Test Vehicles						
Component	**Component Finish**	**Reflow Solder**	**Wave Solder**	**New Component Finish**	**Rework Solder**	**Board Finish**
BGA-225	SnPb	SAC305				Immersion Silver
BGA-225	SAC405	SAC305		SAC405	SnPb	
BGA-225	SAC405	SAC305		SAC405	Flux Only	
CLCC-20	SnPb	SAC305				
CSP-100	SnPb	SAC305				
CSP-100	SAC405	SAC305				
CSP-100	SAC105	SAC305		SAC105	Flux Only	
CSP-100	SAC105	SAC305		SAC105	SnPb	
PDIP-20	Sn		SN100C			
PDIP-20	Sn		SN100C	Sn	SN100C	
QFN	SnPb	SAC305				
TQFP-144	NiPdAu	SAC305				
TQFP-144	SAC 305 Dip	SAC305				
TSOP-50	SnBi	SAC305				
TSOP-50	SnPb	SAC305				
TSOP-50	Sn	SAC305		Sn	SnPb	
TSOP-50	SnBi	SAC305		SnBi	SAC305	

Profiles used during initial assembly

Reflow Profile = SAC305
Preheat = 60-120 seconds @150-190°C
Peak temperature target = 243°C
Reflow:~20 seconds above 230°C
~30-90 seconds above 220°C

Wave Profile = SN100C
Solder Pot Temperature = 265°C
Preheat Board T = 134°C
Peak Temperature = 157°C
Speed: 90 cm/min

Testing Activities

Specific testing details can be found in the Joint Test Protocol (JTP)
http://www.teerm.nasa.gov/reports.html

Thermal Cycling: -20°C to +80°C BOEING	Thermal Cycling: -55°C to +125°C Rockwell Collins	Drop Testing CELESTICA
Vibration BOEING	Mechanical Shock BOEING	Interconnect Stress Testing Interconnect PWB Solutions Inc.
Combined Environments Testing Raytheon	Copper Dissolution Rockwell Collins CELESTICA	

NAVSEA Crane Rework Effort

- Build 30 test vehicles (sub-set of the 193 assembled)
  - Test vehicles will be built with Lead-Free solder and Lead-Free component finishes only = similar to Manufactured test vehicles for Mechanical Shock, Vibration and Drop Testing
  - Lead-Free alloys, SAC305 and SN100C
  - Rework will be done using only SnPb solder
  - Perform multiple pass rework 1 to 2 times on random Pb-free DIP, TQFP-144, TSOP-50, LCC and QFN components
  - Testing
    - Thermal Cycling -55°C to +125°C
    - Vibration Testing
    - Drop Testing

Thermal Cycle -20/+80°C

Parameters	- -20 to +80°C - Cycles: The project consortia will review the data and determine when the test is complete - Decision point 10,000 cycles - 5 to 10°C/minute ramp - 30 minute high temperature dwell - 10 minute low temperature dwell

Number of Test Vehicles Required

Manufactured		Rework		
Mfg. SnPb	Mfg. LF	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	5	1	5

Trials per Specimen 1

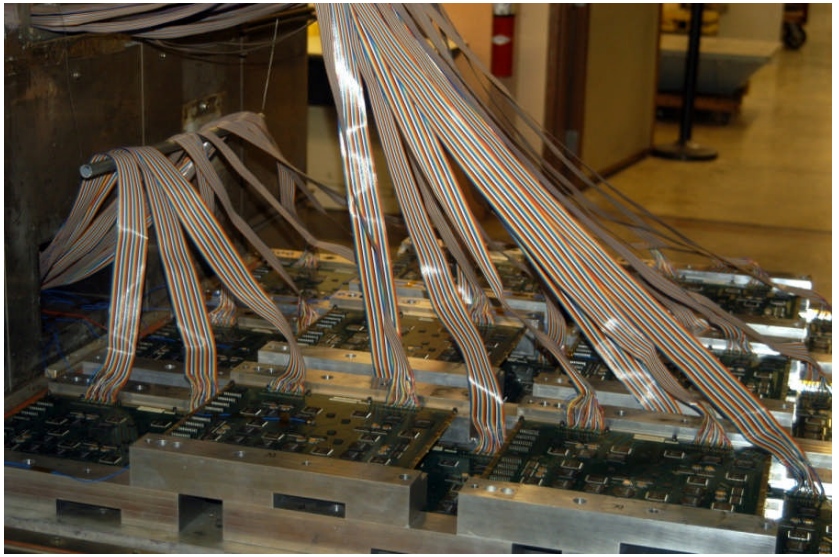
Phase 1 = JCAA/JGPP Lead Free Solder Project Test Results

- **27,135 thermal cycles**
  - All of the ceramic leadless chip carriers (CLCC's) and TSOP's had failed
  - Most of the BGA's had failed (SnPb solder/SnPb balls; SAC solder/SAC balls; SACB solder/SAC balls; and mixed technologies)
  - Most of the TQFP-144's had failed

Combine Environments Testing

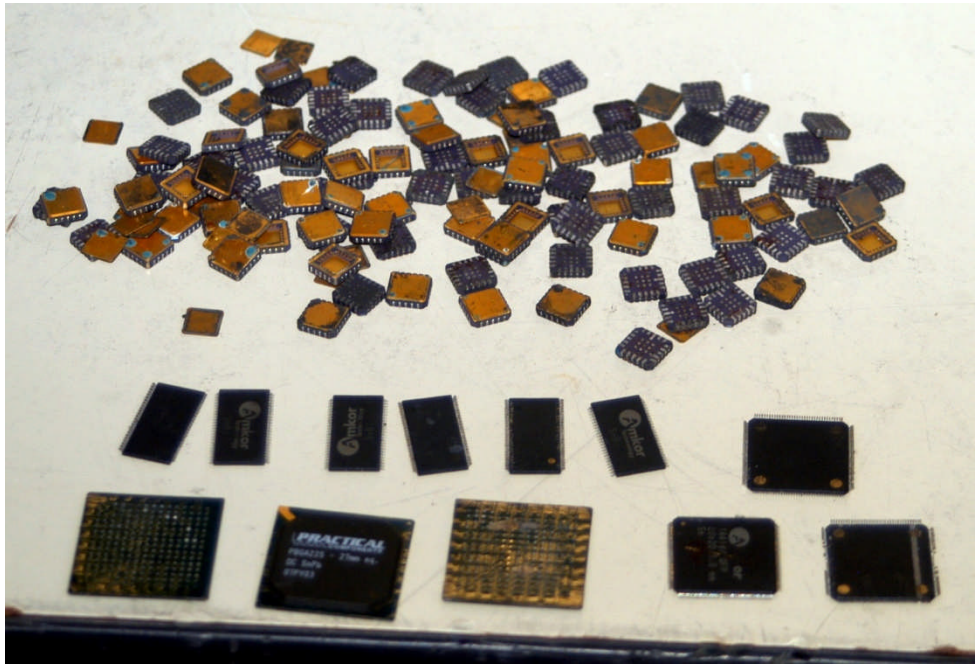
Parameters	- -55°C to +125°C - Number of cycles ≥ 500 - 20°C/minute ramp - 15 minute soak - Vibration for duration of thermal cycle - 10 G_{rms}, initial - Increase 5 Grms after every 50 cycles - 55 G_{rms}, maximum					
Number of Test Vehicles Required						
Manufactured				Rework		
Mfg. SnPb	Mfg. LF	Mfg. LF SN100C	Mfg. LF ENIG	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	5	1	5	1	5
Trials per Specimens	1					

Raytheon

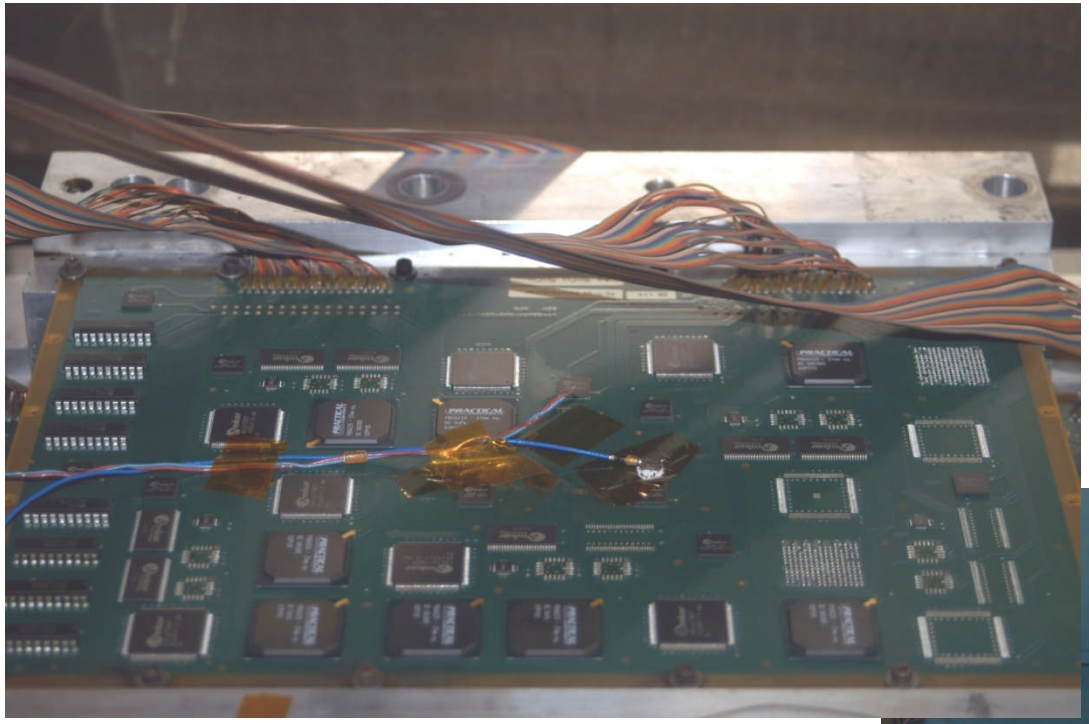


Combine Environments Testing Status

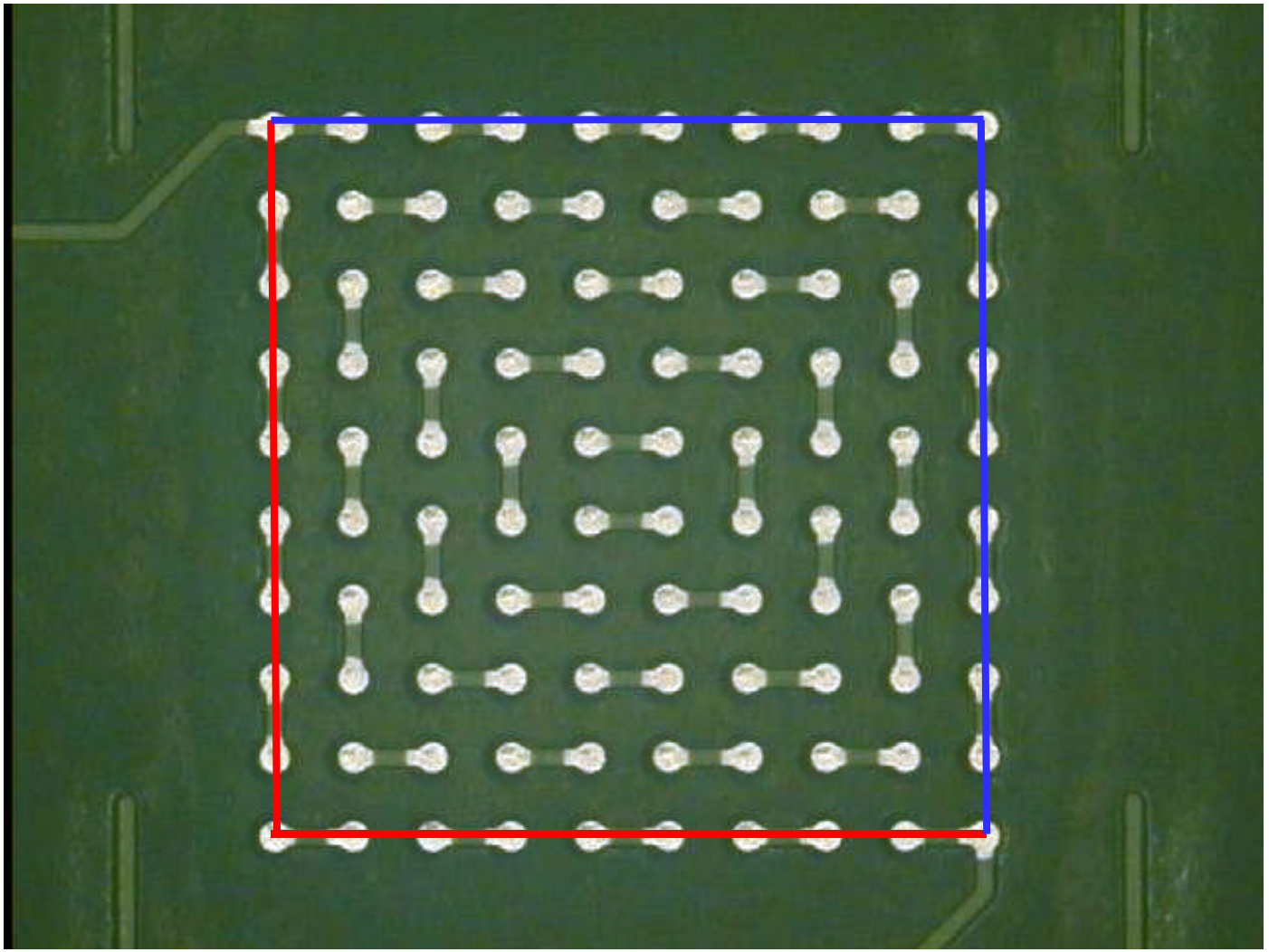
- Manufactured Test Vehicles
- 650 cycles completed on April 1, 2009
- Results
  - 121 of 150 BGA's failed (81%)
  - 139 of 150 CLCC's failed (93%)
  - 57 of 150 CSP's failed (38%)
  - 3 of 60 Sn PDIP's failed (5%)
  - 2 of 60 NiPdAu PDIP's failed (3%)
  - 20 of 75 QFN's failed (27%)
    - includes component U15
  - 44 of 150 TQFP's failed (29%)
  - 36 of 150 TSOP's failed (24%)



Combine Environments Testing
Test Vehicle Wiring



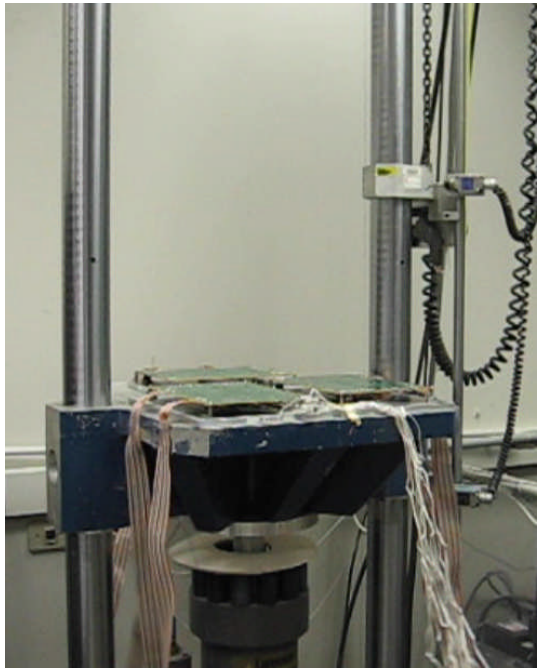
When reviewing the CSP data, please note that the CSP components on all test vehicles only have continuity in the outside solder balls.



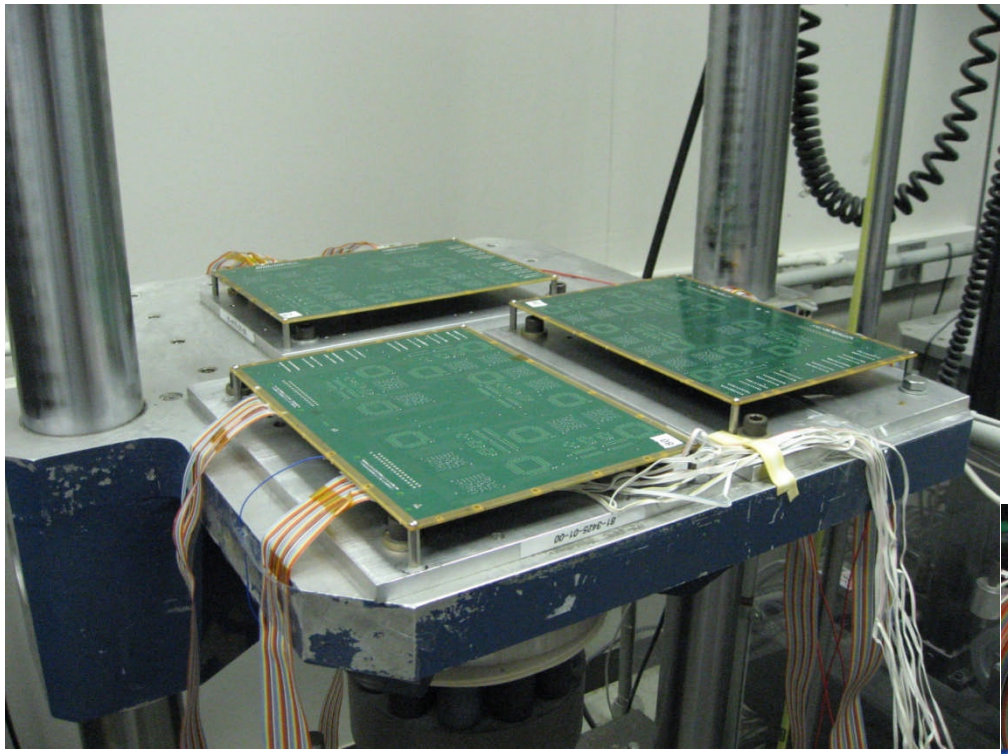
Drop Testing

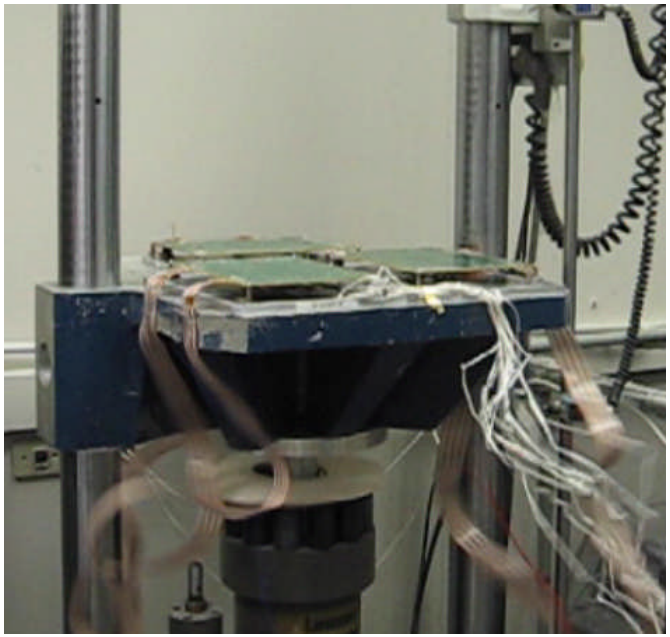
Parameters	- Shock testing will be conducted in the -Z direction - 340Gpk input, 2ms pulse duration - Test vehicles will be dropped until all monitored components fail or 10 drops have been completed				
Number of Test Vehicles Required					
Manufactured		Rework			
Mfg. SnPb	Mfg. LF	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF	
5	5	5	1	5	
Trials per Specimen	A maximum of 10 drops				

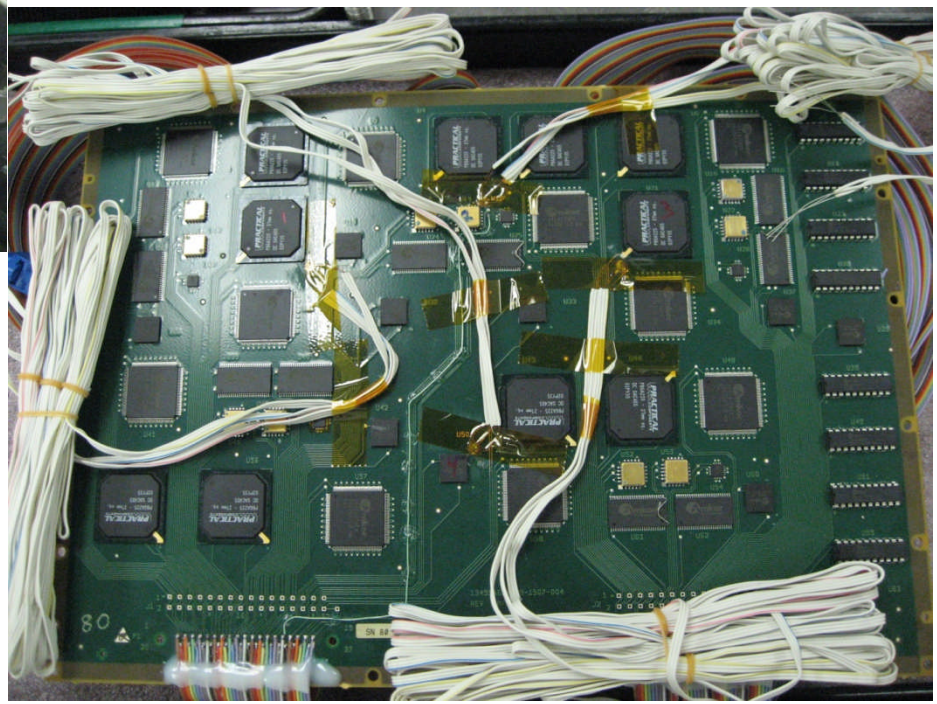
CELESTICA.



Drop Testing







CELESTICA

NAVSEA Crane Rework Effort - Drop Test Vehicles

- Perform multiple pass SnPb rework 1 to 2 times on random Pb-free DIP, TQFP-144, TSOP-50, LCC and QFN components

RefDes	Part	Number of Reworks					
		Drop Test Board (Lead-Free Manufactured Batch F)					
		SN80	SN82	SN84	SN85	SN86	SN87
U16	TSOP 50/SnBi	2	2	2	1	2	1
U24	TSOP 50/SnBi	0	0	0	0	0	0
U26	TSOP 50/SnBi	0	0	0	1	0	1
U40	TSOP 50/SnBi	1	1	1	2	1	2
U62	TSOP 50/SnBi	1	1	1	0	1	0
U12	TSOP 50/Sn	0	0	0	0	0	0
U25	TSOP 50/Sn	2	2	2	1	2	1
U29	TSOP 50/Sn	1	1	1	2	1	2
U39	TSOP 50/Sn	0	0	0	1	0	1
U61	TSOP 50/Sn	1	1	1	0	1	0
U9	CLCC-SAC305	2	2	2	1	2	1
U10	CLCC-SAC305	1	1	1	2	1	2
U13	CLCC-SAC305	0	0	0	0	0	0
U14	CLCC-SAC305	0	0	0	0	0	0
U17	CLCC-SAC305	2	2	2	1	2	1
U22	CLCC-SAC305	1	1	1	2	1	2
U45	CLCC-SAC305	0	0	0	1	0	1
U46	CLCC-SAC305	1	1	1	0	1	0
U52	CLCC-SAC305	0	0	0	1	0	1
U53	CLCC-SAC305	1	1	1	0	1	0
U1	TQFP-144/Sn	2	2	2	1	2	1
U3	TQFP-144/Sn	0	0	0	0	0	0
U7	TQFP-144/Sn	1	1	1	2	1	2
U20	TQFP-144/Sn	0	0	0	0	0	0
U31	TQFP-144/Sn	2	2	2	1	2	1
U34	TQFP-144/Sn	1	1	1	2	1	2
U41	TQFP-144/Sn	0	0	0	1	0	1
U48	TQFP-144/Sn	1	1	1	0	1	0
U57	TQFP-144/Sn	0	0	0	1	0	1
U58	TQFP-144/Sn	1	1	1	0	1	0
U08	PDIP-20/NiPdAu	1	1	1	2	1	2
U49	PDIP-20/NiPdAu	1	1	1	2	1	2
U23	PDIP-20/NiPdAu	1	1	1	0	1	0
U30	PDIP-20/Sn	0	0	0	1	0	1
U38	PDIP-20/Sn	1	1	1	0	1	0
U11	PDIP-20/Sn	1	2	2	1	2	1
U51	PDIP-20/Sn	1	2	2	1	2	1
U59	PDIP-20/Sn	0	1	1	0	1	0
U15	QFN/Sn	2	2	2	1	2	1
U27	QFN/Sn	1	1	1	2	1	2
U28	QFN/Sn	2	2	2	1	2	1
U47	QFN/Sn	0	0	0	1	0	1
U54	QFN/Sn	1	1	1	0	1	0

NAVSEA Crane Rework Effort - Drop Test Vehicles

- The test vehicles are LF Manufactured Batch F
  - LF Reflow (SAC305) / Wave (SN100C)
  - LF profiles
  - All BGA components have SAC405 balls.

- Perform multiple pass SnPb rework 1 to 2 times on random Pb-free DIP, TQFP-144, TSOP-50, LCC and QFN components

- Test vehicles 80, 82, 87 were subjected to 10 drops at 340G and then 10 drops at 500G

- Test vehicles 84, 85, 86; 83, 81, 60 were subjected to 20 drops at 500G only

NAVSEA Crane Rework Effort - Drop Test Vehicles

	PBGA 225								
	82	80	87	86	85	84	83	81	60
U18	12	17	15	10	2	6	9	17	0
U56	14	11	13	7	9	8	16	7	14
U55	19	11	19	7	6	3	9	6	15
U2	4	11	14	4	6	4	5	15	17
U4	10	11	6	3	2	4	2	9	6
U43	11	11	6	3	5	6	7	5	8
U21	8	8	10	5	5	3	5	4	5
U44	13	12	10	10	9	7	12	11	16
U5	5	7	5	4	3	2	5	4	4
U6	7	7	5	4	2	2	5	3	3

	CABGA 100								
	82	80	87	86	85	84	83	81	60
U32	0	0	0	0	0	0	0	0	0
U50	0	0	0	0	0	0	0	0	0
U33	0	0	0	0	0	0	0	0	0
U36	0	0	0	0	0	0	0	0	0
U19	0	0	0	0	0	0	0	0	0
U42	0	0	0	0	0	0	0	0	0
U37	0	0	0	0	0	0	0	0	0
U35	0	0	0	0	0	0	0	0	0
U63	0	0	0	0	0	0	0	0	0
U60	0	0	0	0	0	0	0	0	0

Number of Drops To Failure

NAVSEA Crane Rework Effort - Drop Test Vehicles

CLCC 20	82	80	87	86	85	84	83	81	60
U9	0	0	0	0	0	0	0	0	0
U13	0	0	0	0	0	0	0	0	0
U14	0	0	0	0	0	3	0	0	0
U17	0	0	0	0	0	0	0	0	0
U45	0	0	0	0	0	0	0	0	0
U46	0	0	0	0	0	0	0	0	0
U22	0	0	0	0	0	0	0	0	0
U52	0	0	0	0	0	0	0	0	0
U53	0	0	0	0	0	0	0	0	0
U10	0	0	0	0	0	0	0	0	0

0 Rework

QFN 20	82	80	87	86	85	84	83	81	60
U27	0	0	0	0	0	0	0	0	0
U15	0	0	0	18	0	0	0	0	0
U47	0	0	0	0	0	0	0	0	0
U54	0	0	0	0	0	0	0	0	0
U28	0	0	0	0	0	0	0	0	0

2x Rework

PDIP 20	82	80	87	86	85	84	83	81	60
U11	0	0	0	0	0	0	0	0	0
U30	0	0	0	0	0	0	0	0	0
U38	0	0	0	0	0	0	0	0	0
U49	0	0	0	0	0	0	0	0	0
U51	0	0	0	0	0	0	0	0	0
U59	0	0	0	0	0	0	0	0	0
U8	0	0	0	0	17	0	0	0	0
U23	0	0	0	0	0	0	0	0	0

2x Rework

Number of Drops To Failure

NAVSEA Crane Rework Effort - Drop Test Vehicles

TQFP 144	82	80	87	86	85	84	83	81	60
U1	0	0	0	0	0	0	0	0	0
U41	0	0	0	0	0	0	0	0	0
U3	0	0	0	0	0	0	0	0	0
U57	0	0	0	0	7	0	0	0	0
U58	0	0	0	0	0	0	0	0	0
U31	0	0	0	0	0	0	0	0	0
U20	0	0	0	0	0	0	0	0	0
U48	0	0	0	0	0	0	0	0	0
U7	0	0	0	0	0	0	0	0	0
U34	0	0	0	0	0	0	0	0	0

1x Rework

TSOP 50	82	80	87	86	85	84	83	81	60
U26	0	0	0	0	0	0	0	0	0
U39	0	0	0	0	0	0	0	0	0
U40	0	0	0	0	0	0	0	0	0
U25	0	0	0	0	0	0	0	0	0
U12	0	0	0	0	0	0	0	0	0
U24	0	0	0	0	0	0	0	0	0
U61	0	0	0	0	0	0	0	0	0
U16	0	0	0	0	0	0	0	0	0
U62	0	0	0	0	0	0	0	0	0
U29	0	0	0	0	0	0	0	0	0

Number of Drops To Failure

Thermal Cycle -55/+125°C

Parameters	- -55 to +125°C - Cycles: The project consortia will review the data and determine when the test is complete - Decision point at 2,000 and 4,000 cycles - 5 to 10°C/minute ramp - 30 minute high temperature dwell - 10 minute low temperature dwell

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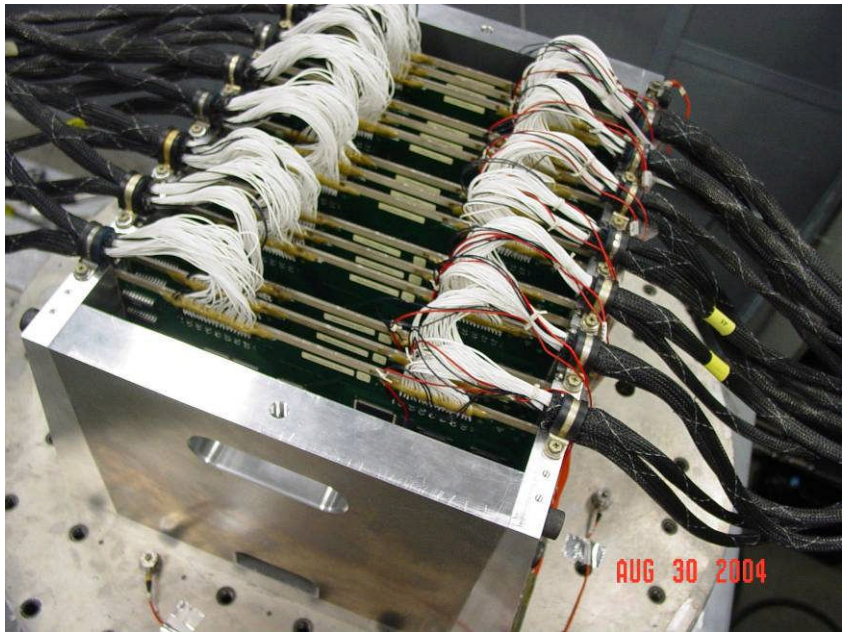
Number of Test Vehicles Required

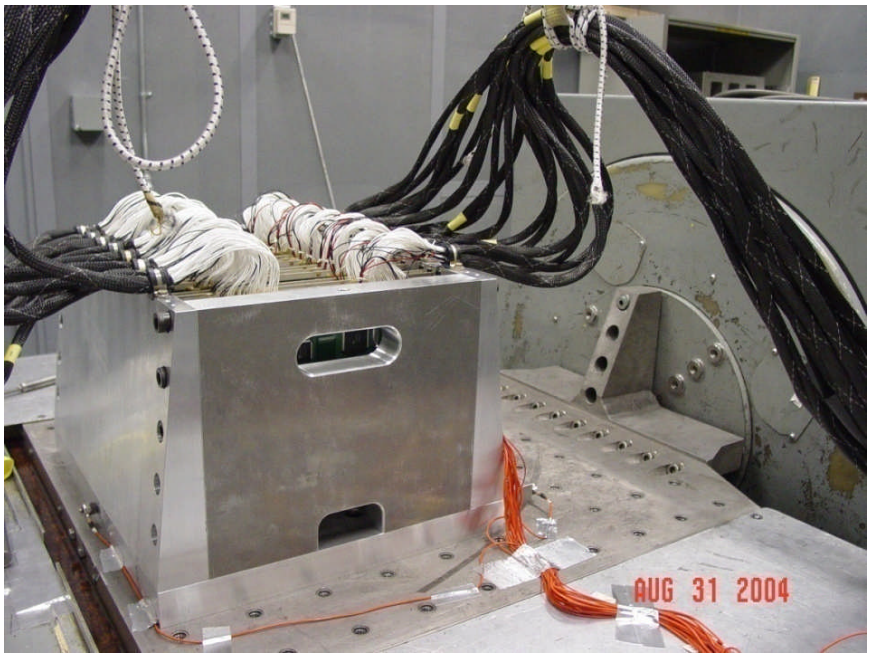
Manufactured				Rework		
Mfg. SnPb	Mfg. LF	Mfg. LF SN100C	Mfg. LF ENIG	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	5	1	5	1	5

Trials per Specimen	1

Vibration

Parameters	- Start at 8.0 g_{rms} then step up in 2 g_{rms} increments in the axis perpendicular to the plane of the test vehicles until the 20.0 g_{rms} level is completed. Vibrate for 1 hour at each test level. Finish with 1 hour at 28.0 g_{rms}.					
Number of Test Vehicles Required						
Manufactured				Rework		
Mfg. SnPb	Mfg. LF	Mfg. LF ENIG	Mfg. LF SN100C	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	1	5	5	1	5
Trials per Specimen			1			



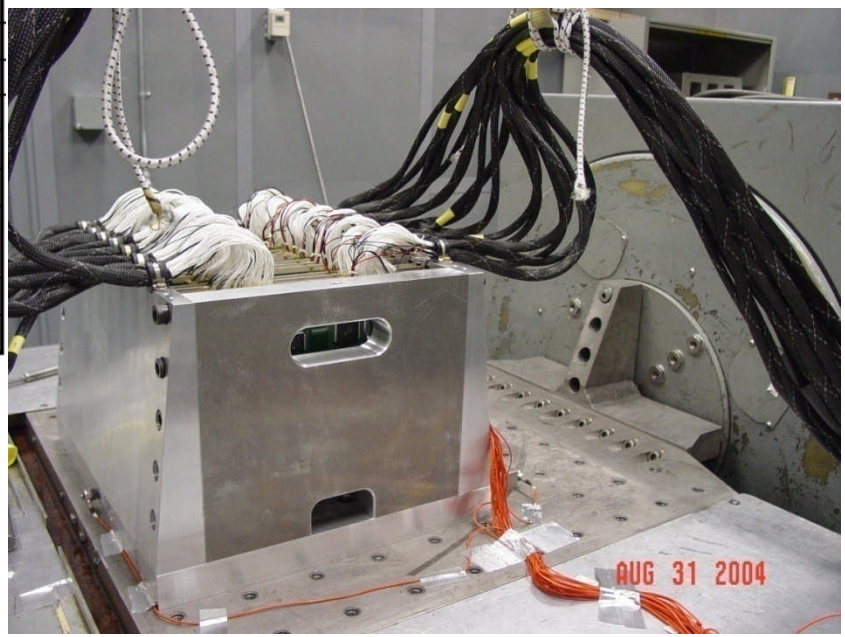


Mechanical Shock

Parameters	The shock transients will be applied perpendicular to the plane of the board and will be increased after every 100 shocks (i.e., a step stress test). Frequency range is 40 to 1000 Hz. SRS damping: 5%			
	Test Shock Response Spectra	Amplitude (G's)	Te (msec)	Shocks per Level
	Modified Functional Test for Flight Equipment (Level 1)	20	<30	100
	Modified Functional Test for Ground Equipment (Level 2)	40	<30	100
	Modified Crash Hazard Test for Ground Equipment (Level 3)	75	<30	100
	Level 4	100	<30	100
	Level 5	200	<30	100
	Level 6	300	<30	100
	Level 7	500	<30	100
	Level 8	700	<30	100

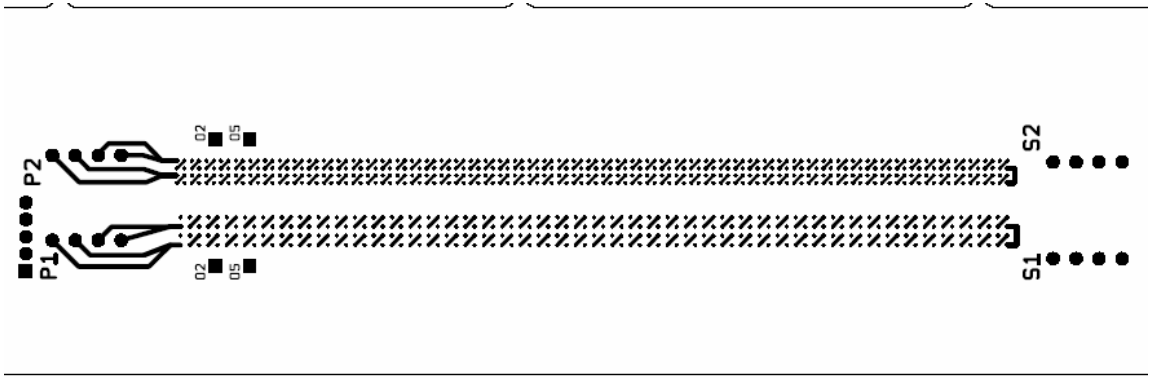
Number of Test Vehicles Required				
Manufactured		Rework		
Mfg. SnPb	Mfg. LF	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	5	1	5
Trials per Specimen		1		

BOEING



Interconnect Stress Test (IST)

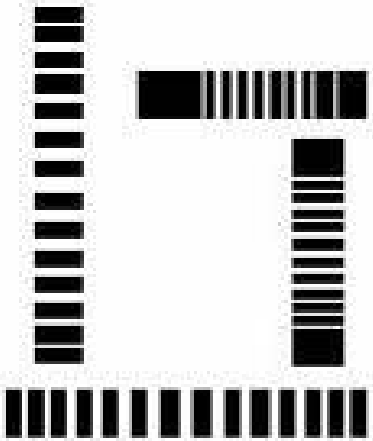
- Accelerates thermal cycling testing by heating a specifically designed test coupon to 150°C (higher temperatures in specific applications in exactly 3 minutes followed by cooling to ambient in approximately two minutes.
- Assembly and rework simulation is achieved by subjecting the coupon to heating to 230°C (260°C for lead-free applications) in three minutes followed by cooling to ambient in approximately 2 minutes.
  - Three thermal cycles simulate assembly
  - Six thermal cycles simulate assembly and rework

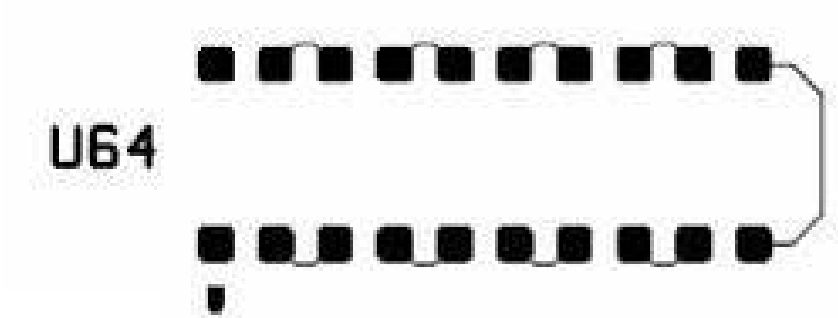


Copper Dissolution

Parameters	▪Mini-wave soldering versus manual soldering ▪Number of component removals: 1X versus 3X ▪PDIPS on break off coupon and QFP pad pattern ▪Metallographic Analysis: ▪As fabricated copper thickness ▪As assembled copper thickness ▪As reworked copper thickness

Number of Test Vehicles Break off Coupons Required					
Manufactured			Rework		
Mfg. SnPb	Mfg. LF	Mfg. LF SN100C	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	5	5	1	5





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CELESTICA

NASA-DoD Lead-Free Electronics Project

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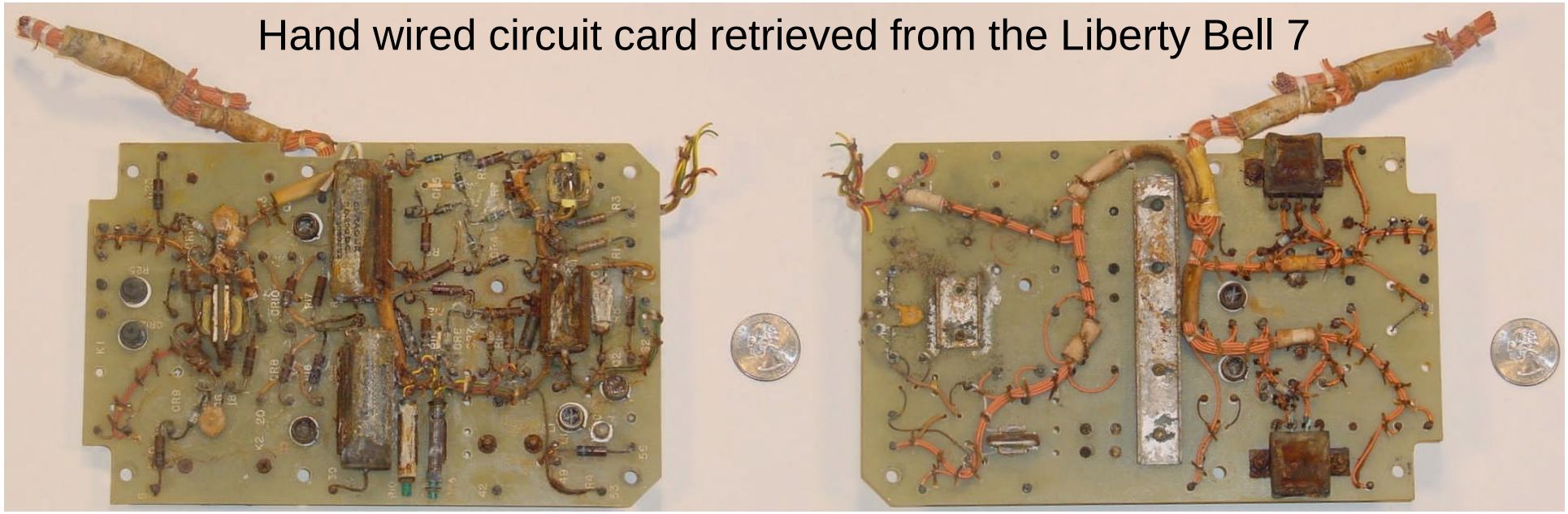
Web Links:

- **NASA-DoD Lead-Free Electronics Project:**
http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html

- **JCAA/JGPP Lead-Free Solder Testing for High Reliability**:
http://www.teerm.nasa.gov/projects/LeadFreeSolderTestingForHighReliability_Proj1.html

Questions

Hand wired circuit card retrieved from the Liberty Bell 7



(http://apollotribute.blogspot.com/2005/11/liberty-bell-7-circuit-card.html)

The Liberty Bell 7 was pulled from a depth of 15,000 feet -- 3,000 feet deeper than the Titanic