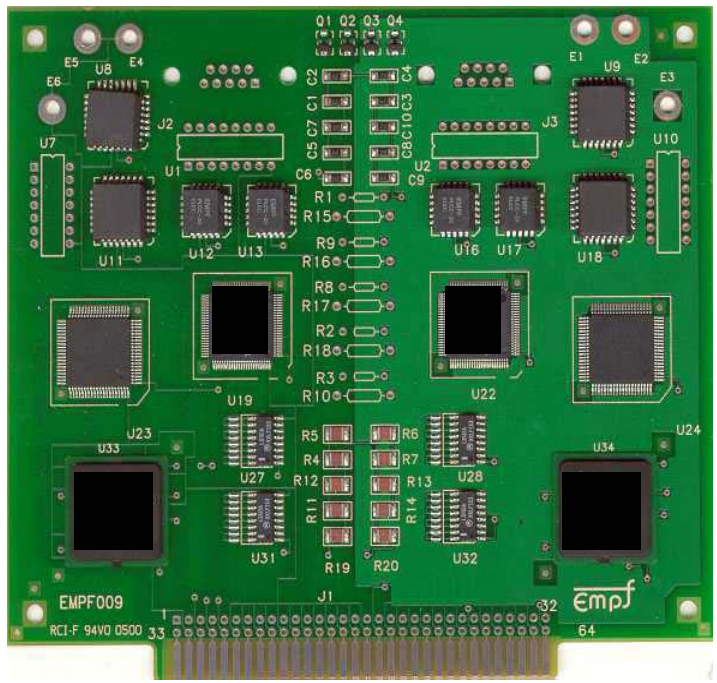
# C3P-NASA Technical Workshop

**Lisbon, Portugal**
**September 19, 2003**

# Project Area #5
# Lead-Free Solder

**Dr. Robert Hill**
**C3P and NASA Program**
**Integration Support**



# Issues/Drivers

- **Use of conventional tin-lead solders in circuit card manufacturing is threatened by**
  - **Environmental concerns**
  - **Increasing regulations**
- **U.S. Environmental Protection Agency has lowered reporting thresholds to 100 pounds for lead and lead compounds**
  - **Lead in waste water limits reduced by over 85 percent**
  - ***Starts this year!*** **2001 numbers must be reported in 2002**
- **European Union also regulating lead uses/processes through WEEE and RoHS**
- **Aerospace less than 2 percent of market share**
- **Suppliers responding to market demands**

# System and Facility Supportability Issues

- **Over 40 military and NASA specifications require tin-lead solder alloy for electronics manufacturing and maintenance**

- **DoD and NASA procurement practices have increased dependence on Commercial Off-the-Shelf technology (COTs) to reduce costs.**

- **U.S. industry for both military and space experiencing lead-free component deliveries, even when specifications call for lead components**

**Reductions or elimination of lead solder in future industrial base, increases possibility of lead versus lead-free component and solder cross contamination in delivered and repaired parts.**

# Lead-Free Surface Finishes and Low-VOC Conformal Coatings

## Objective:

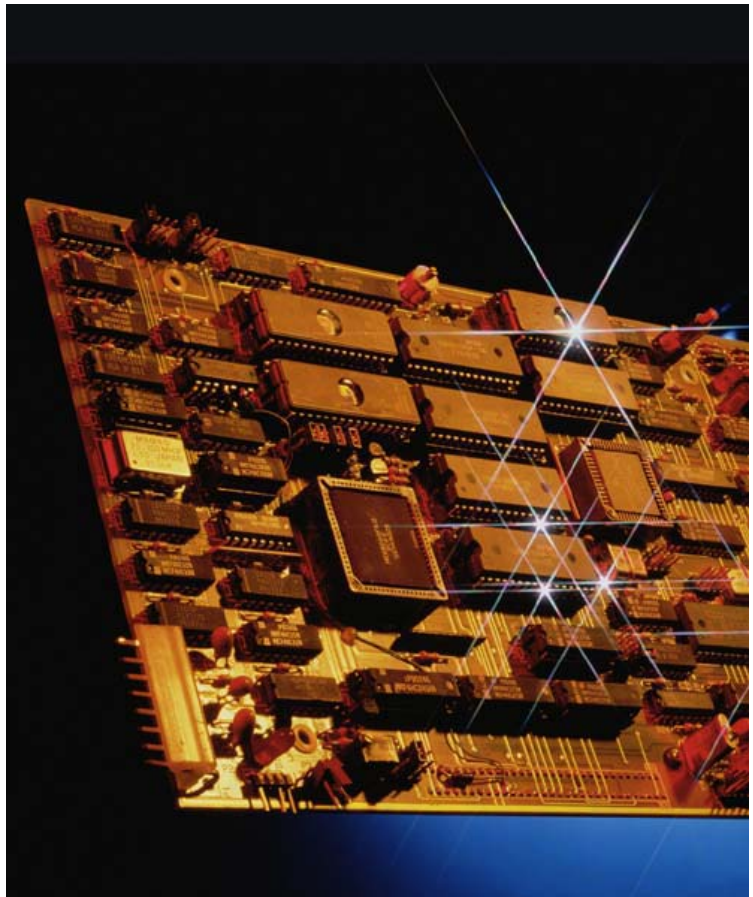
- Identify and qualify environmentally acceptable replacements to surface finishes and conformal coatings currently used in circuit card manufacturing reducing VOC emissions and waste management costs.

## Benefits:

- Reduced regulatory financial liabilities
- Improved manufacturing and maintenance processes

## Technology:

- Three lead-free surface finishes were tested:
  - Benzimidazole
  - Immersion gold/palladium/copper (Au/Pd/Cu)
  - Immersion silver (Ag)
- Four low-/no-VOC conformal coating options were tested:
  - Silicone
  - Parylene
  - Urethane
  - No conformal coating



# Lead-Free Surface Finishes and Low-VOC Conformal Coatings (continued)

## Technology (continued):

- Circuit card test vehicles coated and subjected to various accelerated environmental conditions from vibration to corrosive environments, and then tested for electrical performance, reliability, and conformal coating adhesion
- All surface finishes evaluated appear to be viable choices
- All surface finishes and conformal coatings tested have advantages dependent on individual situations
- Application specific testing may be needed before making any process modifications if performance requirements used do not meet your applications

## Accomplishments:

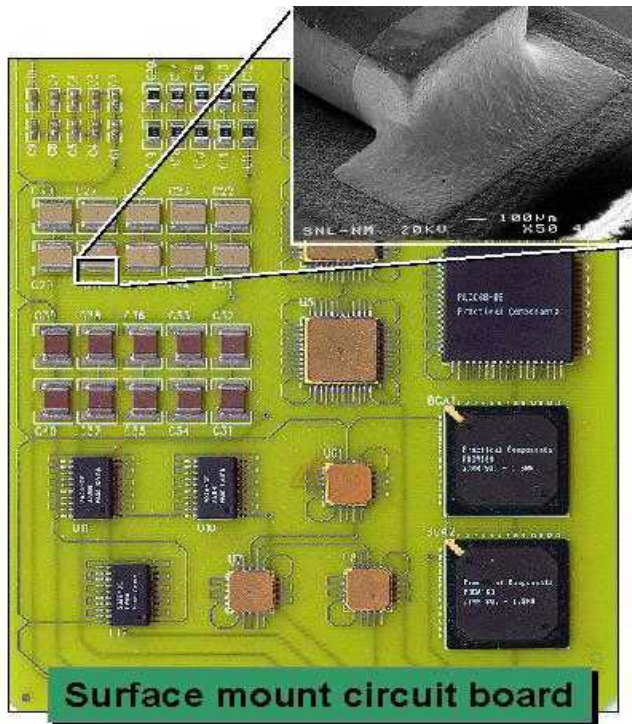
- Project completed with implementation at Rockwell Collins
- Stakeholders proposed lead-free solder as follow-on project to meet emerging European and Japanese legislation and market pressures

# Lead-Free Solder Project Overview

- **Joint project to qualify and validate lead free alternative solders for use in manufacture and repair of electronic equipment**

- **Project focus areas**
  - **New manufacture of electronic equipment**
  - **Overhaul and repair**

- **International partnering**



# Lead-Free Solder Project

## Objective:

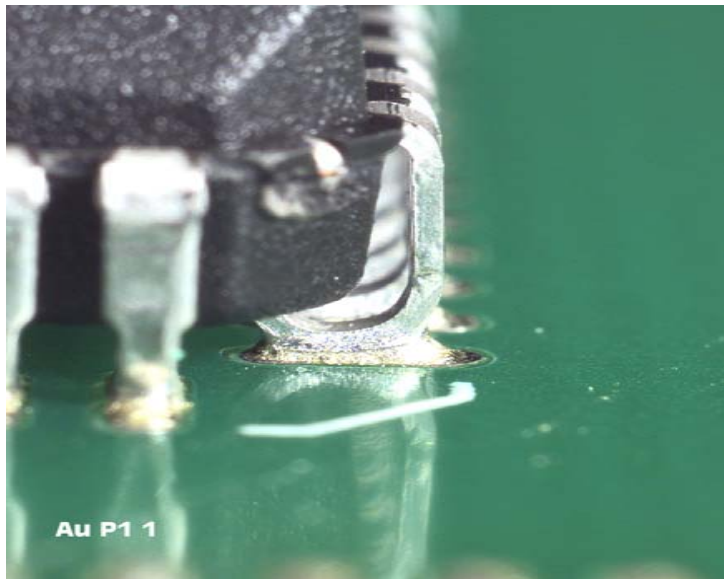
- Identify and qualify lead-free solders to replace conventional tin-lead solders used on circuit card assemblies, cannon plugs, connectors, and other electronics.

## Potential Benefits

- Reduce pollution without degrading electronics performance
- Reduce manufacturing and sustaining maintenance costs
- Reduce regulatory reporting (e.g., SARA 313 Toxic Chemical Release)
- Comply with pending U.S. environmental regulations
- and European/Japanese directives)
- Maintain mission readiness

## Solder Application Types:

- Wave Process
- Reflow Process
- Manual Process



# Lead-Free Solder (continued)

## Accomplishments:

- Established stakeholders group involving joint service, NASA, depots, weapon systems, flight centers, and electronics industry
  - Effecting aerospace, space, communications, and ground support equipment
- Completed PAR to identify and down-select alternatives for testing
- Completed JTP containing technical and performance requirements for both manufacturing and rework
- Prepared test plans and Printed Wiring Assembly test board design
- Project lead is now Joint Group on Aging Aircraft (JGAA) and NASA
- Current funding requirements available to cover cost of testing

# Project Participants

**U.S. Government**

- ***Army***
  - U.S. Army Missile Command (AMCOM)
  - U.S. Army Armaments Research, Development and Engineering Center (ARDEC)
  - Research Development & Engineering Center-Redstone Army Arsenal
  - U.S. Army Communications Electronic Command (CECOM)
  - U.S. Army Tank-Automotive and Armaments Command (TACOM)
- ***Navy/Marine Corps***
  - Chief of Naval Operations, Environmental
  - Naval Air Systems Command (NAVAIR)
  - Naval Sea Systems Command (NAVSEA)
  - Potomac Hudson Engineering/U.S. Marine Corps
- ***Air Force***
  - Air Force Research laboratory
  - ICBM (TRW), F-15 and F-35 Joint Strike Fighter Programs
  - Hill, Randolph, Tinker, Hanscom, Robins Air Force Bases
- ***NASA***
  - NASA Acquisition P2 Office
  - NASA-Ames Research Center and Jet Propulsion Lab
  - NASA-Goddard Space Flight Center
  - NASA-Kennedy Space Center
  - NASA-Marshall Space Flight Center
  - United Space Alliance/Solid Rocket Boosters

**U.S. Manufacturers**

- Alliant Tech Systems
- The Boeing Company
- Goodrich
- Harris
- Honeywell
- ITT
- Lockheed Martin
- Lucent Technologies
- Motorola
- Northrop Grumman
- Raytheon
- Rockwell-Collins
- Texas Instruments

**U.S. Industry and Academic Associations**

- American Competitiveness Institute
- IPC
- National Center for Manufacturing Sciences
- NIST
- University of Tennessee

**Vendors**

- Amkor
- Ensil
- Intersil
- Mitsui Comtek/Senju Metals Co.

**Non U.S. Organizations**

- BAe Systems (UK)
- Institute of Welding and Quality (ISQ) (Portugal)

# Lead-Free Solder Project Overview

- **Scope:**
- **The interconnection of components to substrates with a lead free solder alloy**
- **Test for functional (electrical) reliability, not integrity**
- **Indirectly test effectiveness of repairing lead-containing Printed Wiring Boards with lead-free solder**
- **Test board to reflect many of circuits now on defense/space systems**
- **Select the best lead-free solders—and tests—that, upon completion of testing, will help stakeholders better ascertain risks to their programs/ systems**

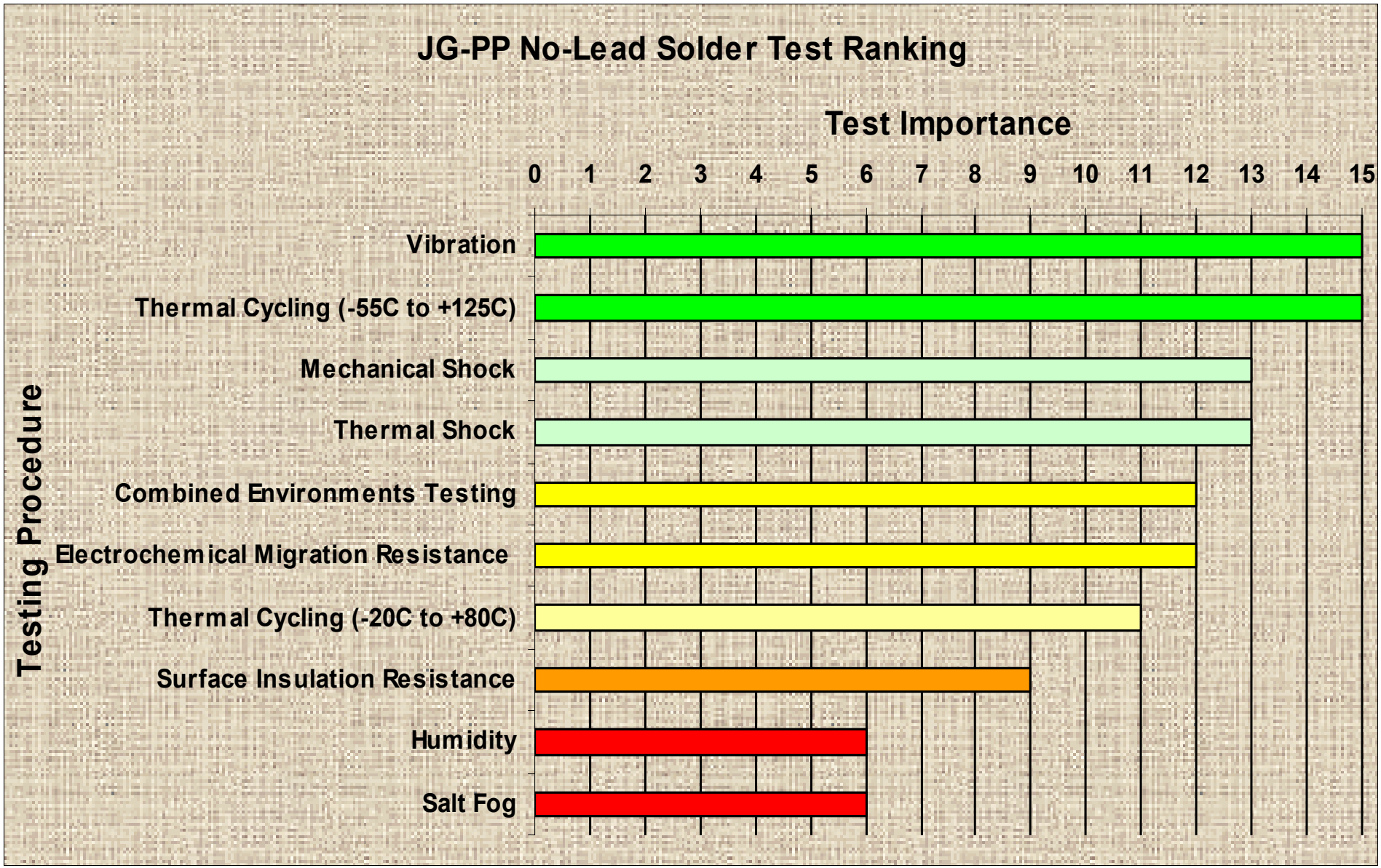
# Selected Lead-Free Solder Alloys

- **Consensus of the project stakeholders is to test the following lead-free solder alloys:**
- **Tin-copper (99.3Sn-0.7Cu) for wave soldering**
- **Tin-silver-copper (95.5Sn-3.9Ag-0.6Cu) for wave, reflow and manual soldering**
- **Tin-silver-copper-bismuth (92.3Sn-3.4Ag-1.0Cu-3.3Bi) for wave, reflow and manual soldering**
- **Solder Application Types:**
  - **Wave Process**
  - **Reflow Process**
  - **Manual or Hand-solder Process**

# Test Selection Process

| JTP Test | NASA | Boeing | Rockwell Collins | Air Force | Raytheon | TOTAL |
|---|---|---|---|---|---|---|
| Vibration | 3 | 3 | 3 | 3 | 3 | 15 |
| Thermal Cycling (-55C to +125C) | 3 | 3 | 3 | 3 | 3 | 15 |
| Mechanical Shock | 2 | 3 | 3 | 3 | 2 | 13 |
| Thermal Shock | 2 | 3 | 3 | 3 | 2 | 13 |
| Combined Environments Testing | 1 | 2 | 3 | 3 | 3 | 12 |
| Electrochemical Migration Resistance | 2 | 3 | 2 | 2 | 3 | 12 |
| Thermal Cycling (-20C to +80C) | 2 | 3 | 3 | 1 | 2 | 11 |
| Surface Insulation | 2 | 1 | 2 | 3 | 1 | 9 |
| Humidity | 1 | 1 | 1 | 2 | 1 | 6 |
| Salt Fog | 1 | 1 | 1 | 2 | 1 | 6 |

# Test Selection Process cont.



# Development of the Test Vehicle

- **Surface finishes:**
  - **Immersion Ag & Pb HASL**
- **Component styles:**
  - **CLCC, PLCC, TSOP, TQFP, BGA, CSP, PDIP, chip capacitors (0402, 0805, 1206), resistor (1206), and hybrids**
- **Component finishes:**
  - **Four (4) Pb-free (Sn, Au/Pd/Ni, SnCu, & SnAgCu) & baseline (Sn/Pb)**
- **Component sizes: "typical" I/O size**
- **Flux: Non-aqueous (rely on vendor recommendation)**
- **Generally five (5) of each component per test vehicles (TV) and five (5) TV per test**
  - **⇨ 25 total of each component per test [7 tests]**

# Printed Wiring Assembly

## Manufacturing Test Vehicle Build

| Type | Laminate | Surface Finish | Reflow Solder | Wave Solder |
|---|---|---|---|---|
| Lead-Free | High Tg, Glass Fiber | Immersion Silver | Tin-Silver-Copper | Tin-Silver-Copper |
| | | | Tin-Silver-Copper-Bismuth | Tin-Copper |
| Base-line (control) | High Tg, Glass Fiber | Immersion Silver | Eutectic Tin-Lead | Eutectic Tin-Lead |

## Rework Test Vehicle Build

| Type | Laminate | Surface Finish | Reflow & Wave Solder Alloy | Repair Solder Alloy Surface Mount Technology | Repair Solder Alloy Plated Through Hole |
|---|---|---|---|---|---|
| Rework | Low Tg, Glass Fiber | Hot Air Solder Leveled (HASL) | Eutectic Tin-Lead | Tin-Silver-Copper-Bismuth | Tin-Copper |
| | | | | Tin-Silver-Copper | Tin-Silver-Copper |
| Repair Control | Low Tg, Glass Fiber | Hot Air Solder Leveled (HASL) | Eutectic Tin-Lead | Eutectic Tin-Lead | Eutectic Tin-Lead |

# Joint Test Protocol (JTP) Common Tests

| Validation Test | JTP Section | Reference | Electrical Test | Acceptance Criteria [a] |
|---|---|---|---|---|
| Vibration | 3.2.1 | MIL-STD-810F, Method 514.5, Procedure I | Electrical continuity failure | Better than or equal to tin/lead controls |
| Mechanical Shock | 3.2.2 | MIL-STD-810F, Method 516.5, Procedure I | Electrical continuity failure | Better than or equal to tin/lead controls |
| Thermal Shock | 3.2.3 | MIL-STD-810F, Method 503.4, Procedure I | Electrical continuity failure | Better than or equal to tin/lead controls at 10% Weibull cumulative failure |
| Thermal Cycling | 3.2.4 | IPC-SM-785 | Electrical continuity failure | Better than or equal to tin/lead controls at 10% Weibull cumulative failure |
| Combined Environments Test | 3.2.5 | MIL-STD-810F, Method 520.2, Procedure I | Electrical continuity failure | Better than or equal to tin/lead controls at 10% Weibull cumulative failure |

[a] Failure of a test board in a specific test does not necessarily disqualify a lead-free solder alloy for use in an application for which that test does not apply. Electrical performance requirements for a particular circuit apply only to parts containing that circuit.

# Additional (Extended) Tests

- **Salt Fog: (Manufactured PWAs) Determine effects of salt deposits on the physical and electrical aspects of solder joints.**

- **Humidity: (Manufactured PWAs) Determine resistance to the deteriorative effects of high humidity and heat conditions.**

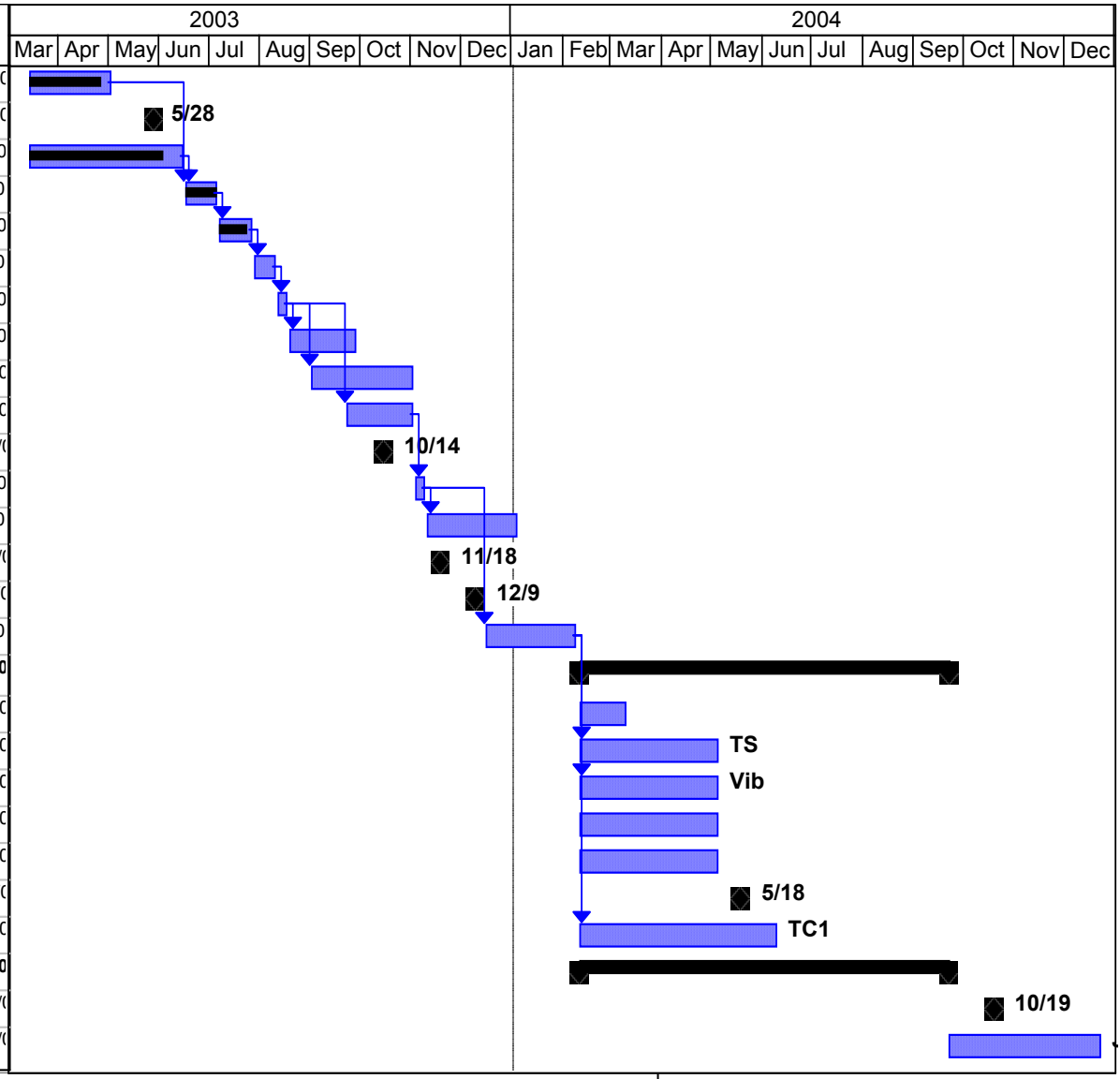
- **Surface Insulation Resistance: (B-24 coupons) Determine the degradation of electrical insulation resistance.**

- **Electrochemical Migration Resistance: (B-25A coupons) Assess surface electrochemical migration on the test PWAs.**

# U.S. Air-Force/NASA Lead-Free Solder Project

As of July 12, 2003

| Task Name | Start | Finish |
|---|---|---|
| Joint Test Protocol (JTP) Approval | Fri 3/14/0 | Wed 4/30/0 |
| Mtg. - Gov't Business | Wed 5/28/0 | Wed 5/28/0 |
| Determine Cost Shares (Subject to modific | Fri 3/14/0 | Fri 6/13/0 |
| Send out RFPs | Mon 6/16/0 | Fri 7/4/0 |
| OEM write RFPs | Mon 7/7/0 | Fri 7/25/0 |
| Proposals received and analyzed | Mon 7/28/0 | Fri 8/8/0 |
| Sign subcontract agreement. Distribute P | Mon 8/11/0 | Fri 8/15/0 |
| Order components (Collins) | Mon 8/18/0 | Fri 9/26/0 |
| Components received and characterized ( | Mon 9/1/0 | Fri 10/31/0 |
| Order test vehicles and solders (Collins) | Mon 9/22/0 | Fri 10/31/0 |
| Mtg. - View Test Matls. (Collins, Cedar Rap | Tue 10/14/0 | Tue 10/14/0 |
| Characterize printed wiring boards (Collin | Mon 11/3/0 | Fri 11/7/0 |
| Build Boards (Boeing-Irving) | Mon 11/10/0 | Fri 1/2/0 |
| Mtg. - Test Phase Kickoff (Boeing PW) | Tue 11/18/0 | Tue 11/18/0 |
| Mtg. - View PWA Assy. (Boeing-Irving) | Tue 12/9/0 | Tue 12/9/0 |
| Test vehicles and solders characterization | Mon 12/15/0 | Fri 2/6/0 |
| **Testing** | **Tue 2/10/0** | **Mon 9/20/0** |
| Extended Tests (TBD) | Tue 2/10/0 | Mon 3/8/0 |
| Thermal Shock (Boeing PW) | Tue 2/10/0 | Mon 5/3/0 |
| Vibration (Boeing PW) | Tue 2/10/0 | Mon 5/3/0 |
| Mechanical Shock (Boeing PW) | Tue 2/10/0 | Mon 5/3/0 |
| Combined Environments Testing (Raythe | Tue 2/10/0 | Mon 5/3/0 |
| Mtg. - Data Review (Collins, Cedar Rap | Tue 5/18/0 | Tue 5/18/0 |
| Thermal Cycle -55/+125C (Collins) | Tue 2/10/0 | Mon 6/7/0 |
| **Thermal Cycle -20/+80C (Boeing)** | **Tue 2/10/0** | **Mon 9/20/0** |
| Mtg. - Final Data Review (Raytheon, TX) | Tue 10/19/0 | Tue 10/19/0 |
| **Joint Test Report** | Tue 9/21/0 | Tue 12/21/0 |




Task Legend:

Maroon = task in progress — Green = task completed

Red = Planned meetings

Blue = task funded but not yet begun — Black = task presently unfunded

# Summary

- **Risks from continued sole reliance on tin-lead solders exist, or are unknown, to many applications**
- **Lead-Free Solder project is presently the only lead-free solder testing program focusing on answering many of the electronics reliability concerns of lead-free solders in military and space applications.**
  - **Variety of common and advanced components**
  - **Promising lead-free solder alloys**
  - **Comprehensive suite of tests**
- **To be prepared, companies & organizations need to develop projects partnerships and procedures to manage current and near-term risks**