Use of Digital Radiography for Final Part Acceptance of Aerospace Castings

Presented to Three Rivers Technical Conference

August 2009

Dave Brayshaw, Jim Barrett
PCC Structurals, Inc.
Metals Affordability Initiative

- MAI is a **national initiative** involving AFRL and the Specialty Aerospace Metals (SAM) industrial base
  - Project participation also includes 75 Companies (including more than 45 small businesses), 18 Universities and 3 National Laboratories in 35 States

- Processes:
  - **Competitive bidding** of projects assures participation by “the best of the best”
  - Competitors are comfortable with terms and participate on teams with each other

- Government value:
  - Demonstrated **high return on government investment** (ROI ≈ 15:1) Accomplished 50+ insertions to date

- Government/industry collaboration:
  - Allows **leveraging** of limited developmental funding and technical resources
  - **Technology is pervasive** and applicable to other military systems.

PCC-1 is a 2 year - $2.3 Million Dollar program includes a 25% Industry cost share and builds on work funded previously by: American Metal Casting Consortium, University of Alabama – Birmingham, and the Next Generation Manufacturing Technology Initiative.

This presentation has been cleared and authorized for public distribution under case number 88ABW-2009-3248
This project is collaboratively supported by:

- **Air Force**
- **Airframe Builders**
- **Gas Turbine OEMs**
- **Foundries**
- **Leading Digital Equipment Manufacturers**
  - Fuji, GEIT, Northstar Imaging, VJ Technologies, Yxlon
Current Situation

• Many Prime aerospace manufacturers have not established requirements for digital radiography of castings
• Where they do exist they vary widely between manufacturers
• This uncertainty and variability is preventing adoption of digital radiography in the casting supplier base

Pratt & Whitney 2007 supplier Meeting Finding:
The lack of available & common requirements among the prime manufacturers is the number one impediment to the use of digital radiography for aerospace suppliers
Program Objectives

• Establish digital based radiography as an approved method for final part acceptance of aerospace castings.
  – Direct Radiography (DR) – rigid detectors
  – Computed Radiography (CR) – imaging plates

• DR/CR promises:
  – Faster cycle times (lean)
  – Improved acquisition costs (sustainment)
  – Environmentally friendly inspections (green)
  – Pervasiveness across the industrial supply base
### Work Breakdown Structure

<table>
<thead>
<tr>
<th>Task 3</th>
<th>Task 4</th>
<th>Task 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical &amp; Business Investigation</td>
<td>Testing &amp; Validation</td>
<td>Implementation Planning &amp; Final Report</td>
</tr>
<tr>
<td>Technical</td>
<td>Technical</td>
<td>Technical</td>
</tr>
<tr>
<td>- Digital Standards</td>
<td>- Identify Parts List</td>
<td>- Report</td>
</tr>
<tr>
<td>- Titanium Standards Production</td>
<td>- Digital Technique Development of selected component</td>
<td></td>
</tr>
<tr>
<td>- Image Acquisition</td>
<td>- Requirements</td>
<td></td>
</tr>
<tr>
<td>- Round Robin Testing (Steel &amp; Titanium)</td>
<td>- System Identification</td>
<td></td>
</tr>
<tr>
<td>- ASTM document submitted</td>
<td>- Side by Side Trial for Final Part</td>
<td></td>
</tr>
<tr>
<td>- Side by Side Trials</td>
<td>- OEM Specifications Detailing</td>
<td></td>
</tr>
<tr>
<td>- Identify Issues</td>
<td>- Information Required for Acceptance</td>
<td></td>
</tr>
<tr>
<td>- Discussion</td>
<td>- Approved Technique for Final Acceptance to Customer Requirements</td>
<td></td>
</tr>
<tr>
<td>- Guidelines document</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business</td>
<td>Business</td>
<td>Business</td>
</tr>
<tr>
<td>- Film vs. Digital unit price comparison today and in future</td>
<td>- Refine Task 3 business case</td>
<td>- Finalize Overall Business Plan</td>
</tr>
<tr>
<td>- Capital Investment of unit(s)</td>
<td>- Capital investment of Unit(s)</td>
<td></td>
</tr>
<tr>
<td>- Lean differences</td>
<td>- Lean verification</td>
<td></td>
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<tr>
<td>- Environmental Benefits</td>
<td>- Cost savings determination</td>
<td></td>
</tr>
</tbody>
</table>

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To Produce Valid Standards:

- Produce reference images following the Boeing Process for aluminum - complete

- Draft documentation to support images – Editing in process

- Round Robin testing of images based on indications excised from castings using experienced personnel

<table>
<thead>
<tr>
<th></th>
<th>Film</th>
<th>Digital</th>
<th>Documents</th>
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<tbody>
<tr>
<td>Steel</td>
<td>E-192</td>
<td>E-2660</td>
<td>WK17855</td>
</tr>
<tr>
<td>Titanium</td>
<td>E-1320</td>
<td>E-2669</td>
<td>WK 21603</td>
</tr>
</tbody>
</table>
Round Robin Validation Testing

Procedure

- 115 Investment cast samples from PCC Airfoils and Structurals
  - Steel 61
  - Titanium 54
- Indications shot with film (parameters recorded)
- One indication marked per film
- Category identified
- Indications spread roughly equally between 5 digital equipment manufacturers
- Equivalent digital images were acquired (parameters recorded)
- Two test sites:
  - Round Robin #1: PCC Structurals Inc.- Portland, Oregon
  - Round Robin #2: Howmet Castings - Whitehall, Michigan
  - Readers from production and team member companies
  - Seven workstations brought in to facilitate the testing, with multiple film reading stations
  - Scoring sheets picked up after reading on each machine

- Data Analysis
  - Data collected by site and analyzed using Minitab by: Alloy, Defect, Thickness, Vendor for test for means and variability

<table>
<thead>
<tr>
<th>Readers</th>
<th>PCC Level II</th>
<th>PCC Level III</th>
<th>Howmet Level II</th>
<th>Howmet Level III</th>
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<tbody>
<tr>
<td>Steel</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>6</td>
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<tr>
<td>Ti</td>
<td>6</td>
<td>1</td>
<td>1</td>
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</tr>
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</table>

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Defect Matrix

- Defects spread across discontinuity types and thicknesses

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### Defect Matrix

**Defect Collection Matrix**

<table>
<thead>
<tr>
<th>Material Capable of being read to E-192</th>
<th>0.125 Thicknesses</th>
<th>0.375 Thicknesses</th>
<th>0.750 Thicknesses</th>
<th>1&quot;</th>
<th>2&quot;</th>
<th>3&quot;</th>
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<tbody>
<tr>
<td>Gas Holes</td>
<td>3 1 2</td>
<td>3 1 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage Cavity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sponge Shrinkage</td>
<td>1 1 2</td>
<td></td>
<td></td>
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<tr>
<td>Dendritic Shrinkage</td>
<td></td>
<td>2 1 2</td>
<td></td>
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<tr>
<td>Filamentary Shrinkage</td>
<td></td>
<td></td>
<td>3 2 1</td>
<td></td>
<td></td>
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<tr>
<td>Foreign Material Less Dense</td>
<td>1 2 1</td>
<td></td>
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</tr>
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</table>

**Additional Defect Types**
- Welding Defects
- Cracking/Cold Shot
- Lack of Fusion
- Porosity
- Positive Metal
- Shell Crack/Fins
- Hot Tears
- Cracks

---

<table>
<thead>
<tr>
<th>Material Capable of being read to E-1320</th>
<th>0.250 Thicknesses</th>
<th>0.500 Thicknesses</th>
<th>0.750 Thicknesses</th>
<th>N/A</th>
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<tbody>
<tr>
<td>Gas Holes</td>
<td>1 2 3</td>
<td>1 2 3</td>
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<tr>
<td>Clustered Gas Holes</td>
<td></td>
<td></td>
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<tr>
<td>Scattered Gas Holes</td>
<td>1 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage Cavity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scattered Shrinkage Cavity</td>
<td>1 5 4</td>
<td>1 5 1</td>
<td></td>
<td></td>
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<tr>
<td>Centerline Shrinkage</td>
<td>2 1 2</td>
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<td></td>
<td></td>
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<tr>
<td>Less Dense Inclusions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More Dense Inclusions</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Additional Defect Types**
- Welding Defects
- Cracking
- Lack of Fusion
- Porosity
- Positive Metal
- Shell Crack/Fins
- Hot Tears
- Cracks
How the Analysis was Conducted:
CR/DR/Film ASTM Average Plate Callouts

CR/DR/Film ASTM Average Plate Callouts

ΔCR/DR from Film

+ Higher ASTM Plate Callout for Digital
  “Reject Good Parts”

- Lower ASTM Plate Callout for Digital
  “Accept Bad Parts”
Round Robin #1 and #2 Analysis of Steel without Contrast Normalization - Summary

- No statistically significant difference in Means
- One value significant for variability – sample size issue
- Delta to ASTM plate shows no practical significance (less than a full plate)

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Round Robin #1 and #2 Analysis of Titanium without System E for Cavity Shrink - Summary

### Titanium

- **Cavity Shrink**
  - Centerline Shrink
    - $p_{mean} = 0.484$
    - $p_{var} = 0.382$
    - $CR \Delta = 0.022$
    - $DR \Delta = 0.218$
  - $3/4"$
  - $1/4"$
  - $3/4"$
  - N/A
  - $p_{mean} = 0.290$
  - $p_{mean} = 0.172$
  - $p_{mean} = 0.794$
  - $p_{mean} = 0.231$
  - $p_{mean} = 0.375$
  - $p_{mean} = 0.207$
  - $p_{mean} = 0.207$
  - $p_{mean} = 0.669$
  - $p_{mean} = 0.593$
  - $p_{mean} = 0.530$
  - $p_{mean} = 0.539$
  - $p_{mean} = 0.539$
- **FMMD**
  - $p_{mean} = 0.187$
  - $p_{mean} = 0.187$
  - $p_{mean} = 0.187$
  - $p_{mean} = 0.174$
  - $p_{mean} = 0.174$
  - $p_{mean} = 0.506$
  - $p_{mean} = 0.419$
  - $p_{mean} = 0.419$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.238$
  - $p_{mean} = 0.238$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.025$
- **Scattered Cavity Shrink**
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.042$
  - $p_{mean} = 0.042$
  - $p_{mean} = 0.042$
  - $p_{mean} = 0.042$
  - $p_{mean} = 0.042$
  - $p_{mean} = 0.042$
- **Gas Hole**
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.214$
  - $p_{mean} = 0.214$
  - $p_{mean} = 0.214$
  - $p_{mean} = 0.214$
  - $p_{mean} = 0.214$
  - $p_{mean} = 0.214$
- **Scattered Gas Holes**
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.002$
  - $p_{mean} = 0.000$
  - $p_{mean} = 0.000$
  - $p_{mean} = 0.000$
  - $p_{mean} = 0.000$
  - $p_{mean} = 0.000$
  - $p_{mean} = 0.000$

### Summary

- No statistically significant difference in Means
- One value significant for variability – No difference in vendor performance
- Delta to ASTM plate levels one significant difference at a full plate different; reason could not be identified

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**Technical Issues**

- **Contrast Normalization**
  - Should be an option, not a requirement in supporting text documents
  - Testing methods are needed to assure consistent contrast normalization results across vendor systems
  - Concern surrounds difficulty with varying densities (alloys) between the step blocks and part in our images, our round robin set was deemed equivalent by qualified readers

- **Reference Images:**
  - Opened on some systems with no contrast (completely white); this was determined to be a vendor software issue
  - Error in labeling; need to be corrected
  - Master disks sent to ASTM after correction

- **Training:**
  - Should not be overlooked (error in locking)
  - It will be addressed in our guidelines document
Guidelines Document

- Topics:
  - Image Viewing Protocol
  - Detector Qualification/Selection
  - Image Quality Control
  - Implementation Issues
Technical Progress

• Digital reference images:
  – Round robin
    • Testing has been completed
    • Final report in process - to be issued July 2009
  – Steel and Titanium Reference images were accepted by ASTM E07
  – Supporting Document requires further editing-complete by October 9th
• Guidelines Document to be issued to team in July 2009
Program Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Titanium standards production</td>
<td>8.75 days</td>
<td>Mon 5/1/09</td>
<td>Fri 10/09</td>
</tr>
<tr>
<td>2</td>
<td>Main project award</td>
<td>0 days</td>
<td>Wed 1/1/09</td>
<td>Wed 1/1/09</td>
</tr>
<tr>
<td>3</td>
<td>Program Kickoff Meeting</td>
<td>1 day</td>
<td>Thu 10/2/09</td>
<td>Thu 10/2/09</td>
</tr>
<tr>
<td>4</td>
<td>Digital X-ray for Final Part Acceptance</td>
<td>566 days</td>
<td>Fri 10/2/09</td>
<td>Mon 8/27/10</td>
</tr>
<tr>
<td>5</td>
<td>Task 3 - Technical and Business Investigation</td>
<td>311 days</td>
<td>Fri 10/2/09</td>
<td>Thu 12/3/09</td>
</tr>
<tr>
<td>6</td>
<td>Gathering of Samples for Blind and Transparent</td>
<td>5.8 days</td>
<td>Fri 10/2/09</td>
<td>Fri 4/2/09</td>
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<tr>
<td>7</td>
<td>Image gathering (film and digital (DR or CR))</td>
<td>3 days</td>
<td>Fri 10/2/09</td>
<td>Thu 11/1/09</td>
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<td>8</td>
<td>Sound Reprof Testing (visual and digital)</td>
<td>4.05 days</td>
<td>Fri 1/1/09</td>
<td>Fri 3/2/09</td>
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<tr>
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<td>Presentation to ASTM</td>
<td>5 days</td>
<td>Sun 1/14/09</td>
<td>Thu 1/18/09</td>
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<td>Sub-task review</td>
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<td>Thu 7/23/09</td>
<td>Thu 7/26/09</td>
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<td>Guideline document Draft 1</td>
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<td>Wed 1/22/09</td>
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<tr>
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<td>CBMS mastery procedure</td>
<td>1.8 days</td>
<td>Thu 7/23/09</td>
<td>Thu 7/26/09</td>
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<td>13</td>
<td>System identification and Part Selection</td>
<td>5.8 days</td>
<td>Thu 7/23/09</td>
<td>Thu 7/26/09</td>
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<td>14</td>
<td>Digital and film side-by-side study (System Evaluation)</td>
<td>3 days</td>
<td>Thu 7/23/09</td>
<td>Wed 10/14/09</td>
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<tr>
<td>15</td>
<td>Business Issues</td>
<td>160 days</td>
<td>Mon 3/1/09</td>
<td>Thu 5/5/09</td>
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<td>16</td>
<td>Film vs. digital cost comparison</td>
<td>5 days</td>
<td>Mon 3/1/09</td>
<td>Thu 5/20/09</td>
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<td>Capital comparison</td>
<td>5 days</td>
<td>Mon 3/1/09</td>
<td>Thu 5/20/09</td>
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<td>18</td>
<td>Lean difference</td>
<td>5 days</td>
<td>Mon 3/1/09</td>
<td>Thu 5/20/09</td>
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<td>19</td>
<td>Environmental Benefits</td>
<td>5 days</td>
<td>Mon 3/1/09</td>
<td>Thu 5/20/09</td>
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<td>Game review</td>
<td>0 days</td>
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<td>Thu 12/3/09</td>
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<td>21</td>
<td>Task 4 - Testing and Validation</td>
<td>151 days</td>
<td>Fri 1/1/10</td>
<td>Fri 10/10</td>
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<td>22</td>
<td>Identify patient</td>
<td>3 days</td>
<td>Fri 1/1/10</td>
<td>Thu 3/25/10</td>
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<td>23</td>
<td>Digital technique development</td>
<td>3 days</td>
<td>Fri 3/26/10</td>
<td>Thu 8/17/10</td>
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<td>24</td>
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<td>1.5 days</td>
<td>Fri 5/11/10</td>
<td>Thu 7/26/10</td>
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<td>151 days</td>
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<td>Fri 10/10</td>
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<td>26</td>
<td>Refine Task 3 business information</td>
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<td>Thu 3/25/10</td>
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<td>27</td>
<td>Capital investment of unit(s)</td>
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<td>3 days</td>
<td>Fri 1/1/10</td>
<td>Thu 3/25/10</td>
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<td>Cost savings determination</td>
<td>3 days</td>
<td>Fri 1/1/10</td>
<td>Thu 3/25/10</td>
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<td>Fri 7/30/10</td>
<td>Fri 8/3/10</td>
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<td>31</td>
<td>Task 5 - Implementation Planning and Final Report</td>
<td>41 days</td>
<td>Mon 8/2/10</td>
<td>Mon 8/27/10</td>
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<td>1 mon</td>
<td>Mon 8/2/10</td>
<td>Fri 8/27/10</td>
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<tr>
<td>34</td>
<td>Finalize overall business plan</td>
<td>2 mon</td>
<td>Mon 8/2/10</td>
<td>Fri 8/27/10</td>
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<td>35</td>
<td>Game review</td>
<td>1 day</td>
<td>Mon 9/2/10</td>
<td>Mon 9/2/10</td>
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We Gratefully Acknowledge the following people for their help and support with this work

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- **Fuji**
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  - Fred Morro
  - Jim Neil
  - Paul Phillips
  - Clarence Wyland
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  - Joe Portaz
- **GEIT**
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  - Larry Lang
  - Curt Powell
  - Scott Wittkop
  - Matt Rademacher
  - Phil McDonough
  - Bruce Friswold
  - Mike Strokel
  - Bruce Daby
  - Doug Beaton
  - Rich LaPointe
  - Randy Grina
  - Josh Richards
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  - Hank Sikorski
  - Jack Schirra
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  - Bob Stusrud
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  - Chris Cherry
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