Packaging and Fitting the System to the Aircraft
Objectives

• LRU
• Standards
  – ARINC 600
  – MIL-STD-1788
• Cooling
  – Active cooling
  – Passive cooling
Packaging and Fitting the system to the aircraft

- One of the toughest parts of building a good digital avionics system is fitting the system into the aircraft.
  - The most common image of avionics is the familiar "black box," more formally known as an LRU.
  - Every digital avionics system usually ends up packaged in one or more LRUs.
  - Descriptions of standardized LRUs for both civil and military avionics are given in this presentation.

- These standard LRU designs offer many advantages to both the designer and the operator in the form of
  - interchangeability,
  - easier maintenance
Packaging and Fitting the system to the aircraft

• In the opinion of many experts, keeping the avionics cool is the secret to highly reliable operation.
  – This presentation discusses some avionics cooling methods and LRU design techniques that reduce thermal stress on the components.

• The final section of this presentation interprets interfaces in two parts:
  – what the aircraft provides to the avionics and
  – what the avionics impacts on the aircraft are.
Packaging and Fitting the system to the aircraft

- The avionics units have to be packaged in ATR or Austin Trumbull Racking
- ARINC 600 for Civil Aircraft
- MIL-STD-1788 for Military Aircraft
- These have some commonality, as many manufacturers make both types
- ARINC 600 establishes the form factor, external design, and environmental interfaces with the aircraft.
- It facilitates exchange of LRU manufactured by one company to perform one function with one made by another vendor.
- (ARINC 700 Form, Fit, Function)
Typical LRUs
ARINC 600

- All LRUs are 194mm (7.64”) high, 324mm (12.76”) length which is the same as ARINC 404 ATR short case
- MCU as the basic width of LRU
- 8 MCU = one ATR as defined by ARINC 404
- ARINC 404 established Air Transport Racking (ATR), but on April 11, 1967, the Airlines Electronic Engineering Committee corrected ARINC 404 so that ATR Came to mean Austin Trumbull radio as was originally intended to honor the founder of the concept of standardized packaging and interfaces for air transport avionics.
- Width = (Nx33)-8 mm or
  Width = (Nx1.30) - 0.32 inches,
  where N = number of MCUs
- Electrical Connections are located at the back panel
- Cooling Air, if provided, flows from bottom to top
ARINC 600

- Electrical power must meet the requirements of RTCA (Radio Technical Commission for Aeronautics) document DO-160E or its equivalent EUROCAE document ED-14.
- Allowable power dissipation is a function of the LRU width.
- For LRUs without forced air cooling, power is limited to \((5 + 2.5N)\) W.
- Thus, for a one-MCU-wide LRU without forced air cooling, power dissipation is limited to 7.5 W and for a five-MCU-wide LRU to 17.5 W.
For LRUs with **forced air cooling**, power dissipation is much higher and can reach 25 W/MCU.

Regardless of the allowable power dissipation, the exterior vertical surfaces of the LRU must not exceed 60°C (140°F) average.

The temperature of cooling air for continuous operation can range from -15°C (5°F) to 55°C (131°F).

The air must not contain particles larger than 400 micrometers, or μm (0.016 in).
ARINC 600

- Cooling air openings, if used, are on the top and bottom of the LRU.
- The weight of an ARINC 600 LRU is limited to 2.5 kg (5.5 lb)/MCU, not to exceed 20 kg (44 lb).
- Thus, a four-MCU-wide LRU could weigh up to 10 kg (22 lb) and a ten-MCU-wide LRU, up to 20 kg (44 lb).
- ARINC 600 has been adapted, with some changes, for use on military aircraft as DOD-STD-1788 Avionics Interface Design Standard.
ARINC 600 LRU
Military Packaging Standards

- MIL-STD-1788 Avionics Interface Design Standard establishes the form factor, mounting, and environmental operating conditions for avionics to be installed in the avionics bay of large military aircraft.
- This standard is based on ARINC 600 and its predecessor, ARINC 404, and they share many similarities.
- Military avionics designers are required to use 1788 wherever possible to achieve the reliability, maintainability, and life cycle cost benefits promised from its application.
- Like its civil predecessor, DOD-STD-1788 Avionics Interface Design Standard establishes standard LRU case dimensions.
Military Packaging Standards

• All cases have a
  – standard height of 194 mm (7.64 in) and
  – a depth of 324 mm (12.76 in).
• MIL-STD-1788 describes the width of an LRU by a size number, N.
• The actual width of an LRU is determined by the formula
  \[ W = (N \times 33) - 8.0 \text{ mm} \]
  or
  \[ W = (N \times 1.30) - 0.32 \text{ in} \]
  where \( W \) = width and \( N \) = LRU size number.
• The rack space required in the avionics bay by an LRU is simply \( N \times 33 \) mm (or \( N \times 1.30 \) in).
Military Packaging Standards

- Long-standing terms used to describe the dimensions of civil avionics LRUs are:
  - MCU, as established by ARINC 600 Air Transport Avionics Equipment Interfaces, and
  - Austin Trumbull radio (ATR), as established in ARINC 404 Air Transport Equipment Cases and Racking.

- The size number, N, of a 1788 LRU matches the width of a civil LRU in MCUs.

- Thus, a 1788 LRU where \( N = 8 \) is identical in width to an ARINC 600 LRU where the width is 8 MCUs.

- The depth of a 1788 LRU is the same as the depth of an ARINC 600 LRU.

- Similar comparisons can be made between 1788 and ARINC 404.

- A 1788 LRU where \( N = 8 \) is equal in width to a one-ATR-wide ARINC 404 LRU. The standard 1788 LRU depth of 324 mm (12.76 in) equals a short ATR case and an alternate depth of 502 mm (19.76 in) equals a long ATR case.
MIL-STD-1788

Figure 1a. Front view.

Figure 1b. Side view.
MIL-STD-1788A

Figure 1c. Back view.

<table>
<thead>
<tr>
<th>LRU SIZE</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIM W</td>
<td>58.3</td>
<td>90.4</td>
<td>124</td>
<td>157.2</td>
<td>190.5</td>
<td>223.3</td>
<td>256.3</td>
<td>289.3</td>
<td>322.3</td>
<td>355.3</td>
<td>388.4</td>
</tr>
</tbody>
</table>

NOTES:
1. Dimensions are in millimeters. Unless otherwise specified, the tolerance is ± 1.0 mm.
2. Optional front holddown fasteners are for LRU sizes 2 through 5 only.
3. Front holddown fasteners shall be in accordance with MIL-F-85731 /2, or structurally and mechanical equivalent devices.
4. Lower corners rounded 1.3 RAD.
MIL-STD-1788A

COOLING AIR INLET PORTS (SEE FIGURE 4)

Connectors (See Figure 4)

194 ± 0.0 mm
- 1.0 mm
(7.64 in. ± 0.0
- 0.04)

DIM W

Figure 1c. Back view.

<table>
<thead>
<tr>
<th>LRU SIZE</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIM W</td>
<td>58.3</td>
<td>90.4</td>
<td>124</td>
<td>157.2</td>
<td>190.5</td>
<td>223.3</td>
<td>256.3</td>
<td>289.3</td>
<td>322.3</td>
<td>355.3</td>
<td>388.4</td>
</tr>
</tbody>
</table>

NOTES:
1. Dimensions are in millimeters. Unless otherwise specified, the tolerance is ± 1.0 mm.
2. Optional front holddown fasteners are for LRU sizes 2 through 5 only.
3. Front holddown fasteners shall be in accordance with MIL-F-85731 /2, or structurally and mechanically equivalent devices.
4. Lower corners rounded 1.3 RAD.
Military Packaging Standards

• The rear panel has cooling air inlets at the top and bottom and also contains the electrical connector(s).
• An alternate case design, referred to as the low-profile tray, but never discussed further in the standard, limits the case height to 170 mm (6.7 in) and places the cooling air inlets on the side of the rear panel.
• For either case design, the cooling air exits the LRU through slots in the front panel.
• However, if a closed cooling system is used, there are no front openings; the rear panel top slot is the air inlet and the bottom slot is the return.
• DOD-STD-1788 goes beyond specifying the dimensions of an LRU case to present many other important design considerations.
Military Packaging Standards

- They include constraints on the weight and cooling air consumption as a function of the width of the LRU.
- **The weight is limited to 3.5 kg (7.71b)/N, not to exceed a maximum of 27.5 kg (60.5 lb).**
- In other words, LRUs where N <= 8 cannot weigh more than 27.5 kg (60.5 lb).
- **Power dissipation for LRUs with cooling air is limited to 125 W/N.**
- Thus, an LRU for which N = 2 can dissipate up to 250 W and an LRU for which N = 12 can dissipate up to 1500 W.
- LRU power dissipation without cooling air is limited to 10 + 2.5 x (N - 2) W.
Military Packaging Standards

- In designing the LRU, cooling air is not permitted to flow directly over electronic component to keep it at normal operating temperatures.
- The maximum temperature of an LRU side panel is limited to 76°C (169°F) to minimize radiative or convective heat transfer to adjacent LRUs.
- MIL-STD-1788 requires the LRU design to be "thermally optimized within appropriate design constraints to minimize the LRU life cycle cost (LCC) and optimize the LRU reliability (based on the predicted reliabilities of the individual parts)."
- The results of the analysis should be used to optimize the location of piece parts to improve their reliability.
Military Packaging Standards

- A comparison of selected LRU parameters in ARINC 600 and MIL-STD-1788 is given in Table.
- Note the relatively short operating time and substantially higher maximum external case temperatures, without cooling air, for 1788 when compared to ARINC 600.
- Thus, a source of cooling air that can be brought on line quickly is required for military avionics.
### ARINC 600 and MIL-STD-1788

<table>
<thead>
<tr>
<th>Case Dimensions</th>
<th>ARINC 600</th>
<th>DOD-STD-1788</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height</strong></td>
<td>194 mm (7.64”)</td>
<td>194 mm (7.64”)</td>
</tr>
<tr>
<td><strong>Depth</strong></td>
<td>324 mm (12.76”)</td>
<td>324 mm (12.76”)</td>
</tr>
<tr>
<td><strong>Width</strong></td>
<td>(Nx33)-8 mm or (Nx1.30) - 0.32 in *</td>
<td>(Nx33)-8 mm or (Nx1.30) - 0.32 in *</td>
</tr>
<tr>
<td><strong>Cooling airflow rate 30°C</strong></td>
<td>136 kg/hr/KW</td>
<td>58 kg/hr/KW</td>
</tr>
<tr>
<td><strong>Cooling airflow °C 30 40</strong></td>
<td>Bottom to top 136/5 # 220/8.1</td>
<td>Rear to front 88/3.2# 117/4.2</td>
</tr>
<tr>
<td><strong>Emergency operation without cooling air</strong></td>
<td>90 min</td>
<td>5 min</td>
</tr>
<tr>
<td><strong>Max Ext case temperature</strong></td>
<td>60°C (140°F)</td>
<td>76°C (169°F)</td>
</tr>
<tr>
<td><strong>Max weight</strong></td>
<td>20 Kg (44 lbs)</td>
<td>27 Kg (60 lbs)</td>
</tr>
<tr>
<td><strong>Max power dissipation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With cooling air</td>
<td>25W per N 5+2.5xN W</td>
<td>125W per N</td>
</tr>
<tr>
<td>Without cooling air</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* N= No of MCUs for ARINC 600 and Size No for DOD-STD-1788
# xxx/y where xxx is in kg/h.kw and y. y is in lb/min.kw
Conventional wisdom says that all electronics should be kept cool to achieve long life.

This is especially true for avionics, which are frequently inconvenient and expensive to maintain.

Earlier standards for interfacing the avionics with the aircraft, including the need for cooling air were discussed.

Focus on the benefits of keeping the avionics cool and offer design techniques to reduce thermal stress on the components.

Many studies have demonstrated the value of reducing the temperature of electronic components to extend their lifetime.

Typical results from these studies are shown in Fig.

Honeywell Weather Radar Example
Failure Rate vs Temperature

![Graph showing the relationship between failure rate and temperature.](image-url)
Keeping the Avionics Cool

- This figure shows that a 10°C (18°F) rise in Junction temperature increases the device failure rate by about 50 percent for a component that matches curve A.
- Raising the temperature of a component that matches curve B by 10°C (18°F) raises the failure rate by only about 10 percent.
- Passive cooling is a simple and obvious way to keep the avionics cool.
- It has been used successfully in the past, but all modern avionics, especially in densely packed military LRUs, have required active cooling, that is, air being pulled over the avionics by fans.
- Reexamination of passive cooling by the Boeing Commercial Airplane Co. has shown that properly designed modules in a modular avionics architecture can be adequately cooled by passive means.
- Passive cooling saves weight and improves the overall reliability of the aircraft since there is no avionics cooling equipment to fail.
Keeping the Avionics Cool

• ARINC 600 and MIL-STD-1788 recommend the use of cooling air to keep the entire LRU at or below a selected operating temperature limit.

• The more competent and astute designers go beyond these recommendations and conduct analyses and tests to optimize the location of components on circuit boards to substantially reduce component and, therefore, LRU failure rates.

• The U.S. Air Force has established a Thermal Management Control (TMC) program as Task 106 of MIL-STD-785 Reliability Program for Systems and Equipment Development and Production.

• The objective of the TMC program is to allocate cooling capacity at the system level to minimize LCC.
Keeping the Avionics Cool

• A subsidiary program, Electronic Equipment Thermal Management, requires the avionics equipment design to be optimized for minimum avionics LCC, not just to obtain a simple reliability goal.

• If an LRU contained a circuit board with two components, one of which had a failure rate versus temperature that matched curve A in Fig. and the other component matched curve B, emphasis should be placed on reducing the operating temperature of the curve A type of component since a reduction in temperature for it will yield the largest reduction in the LRU failure rate.

• The most common ways to reduce the temperature of a component are
  – to relocate the component on the circuit board or
  – to relocate the circuit board within the LRU relative to the cooling air
Keeping the Avionics Cool

• Heat pipes are another promising method of cooling avionics.
• Heat pipes are closed containers with a working fluid and a capillary wick.
• As heat is absorbed in the hot end of the pipe, it vaporizes the working fluid, which is driven to the cold end where the heat is removed and the vapor returns to the liquid state.
• The liquid is then transported by capillary action back to the hot end of the pipe where the process is repeated.
• Tests were conducted with typical avionics circuit boards containing bulk memory device one board with an aluminum substrate and the other with a heat pipe substrate.
• The results showed a 16°C (29°F) case temperature variation among components at different locations on the aluminum substrate board but only a 3°C (5.4°F) case temperature variation among those components on the heat pipe substrate board.
• Those components on the heat pipe substrate board were also substantially cooler, which translated into an estimated 40 to 60 percent greater mean time between failure (MTBF).
Heat Pipe thermal cycle:
1) Working fluid evaporates to vapour absorbing thermal energy.
2) Vapour migrates along cavity to lower temperature end.
3) Vapour condenses back to fluid and is absorbed by the wick, releasing thermal energy.
4) Working fluid flows back to higher temperature end.
Capillary Effect
Keeping the Avionics Cool

• One major airline cools the entire avionics bay with a separate on-board air conditioner any time the avionics are operating on the ground and the bay temperature is higher than 26°C (80°F).

• The MTBF of the LRUs is improved by approximately 60 percent.
Questions !!!