The Boeing 777 has two inertia units, 
  – the ADIRU (Air Data Inertial Reference Unit) and 
  – the SAARU (Secondary Attitude and Arial Data Reference Unit) 
We will look at the ADIRU, based on the discussion in the paper 
  – A Fault-Tolerant Air Data/Inertial Reference Unit 
    » Michael L. Sheffels 
    » IEEE AES Systems Magazine, March 1993
Fault Tolerant ADIRU

- Main features
  - inertial and air data reference for ARINC 651 Integrated Modular Avionics distributed architecture
  - low life cycle cost
  - deferred maintenance
  - high reliability
  - high integrity fault detection
  - fault isolation
  - redundancy management
  - quad channel redundancy
  - robust partitioning
  - simple serial internal interfaces
  - simple voting
  - 3 ARINC 629 bus interfaces

Fault Tolerant ADIRU

- Architecture
  - 5 basic functions required for operation, referred to as *Fault Containment Areas* (FCA)
    - processor
    - gyro
    - accelerometer
    - ARINC 629 interface
    - power supply
  - Individual resources making up a FCA are referred to as *Fault Containment Models* (FCM)
    - each FCA can tolerate the loss of 2 FCMs
    - third failure will cause loss of the ADIRU
    - ARINC 629 interfaces differ
Fault Tolerant ADIRU

- Requirements

<table>
<thead>
<tr>
<th>FCA</th>
<th>Function</th>
<th>Dispatch</th>
<th>Deferred Maintenance</th>
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<tbody>
<tr>
<td>Processor</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Gyro</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Power Supply</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ARINC 629 Left</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>ARINC 629 Center</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>ARINC 629 Right</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Fault Tolerant ADIRU

- **Interconnections**
  - FCMs communicate via serial busses
    - this keeps hardware complexity to a minimum
  - Power distribution
    - there are 3 robust power busses
    - the power of all 3 power supplies is summed for each bus
    - each FCM has own regulator
    - fault isolation keeps regulator failures independent
  - ADIRU transmits on 2 of 3 channels (left, right)
  - ADIRU receives on all 3 channels
  - 3rd channel used for SAARU (Secondary Air data Attitude Reference Unit)

- **Processor FCA**
  - contains fault tolerant clock (FTC)
  - used for 100 Hz synchronization interrupts providing processor synchronization

- **ARINC 629**
  - failures in any ARINC 629 bus are independent
  - votes on processor output before transmitting on bus
  - watchdog timers and power monitors are used to assure graceful shutdown if processor control over ARINC 629 interface is lost.
Fault Tolerant ADIRU

- Power supply
  - 3 supplies
  - each has independent inputs for +28VDC primary power and +28VDC battery backup
  - outputs are summed to produce single source of power (used by the 3 power busses)
  - each supply employs
    - over-voltage monitoring
    - shut-down circuitry in case of power surge
    - under-voltage is not problem due to the power summing

Fault Tolerant ADIRU

- Redundancy management
  - Hardware data-consistency-checks used to provide same input to all processors.
  - Fault-tolerant detection and isolation software manages gyros and accelerometers.
    - tries to eliminate benign faults
  - Outputs from processors are voted on by the ARINC 629 interfaces.
  - Power supplies are mainly tested upon power-up and shut down for deferred maintenance.
Fault Tolerant ADIRU

**Fault Isolation**
- Design objectives are to maximize fault independence.
- Electrical fault isolation
  - important since time to repair might be long
- Mechanical fault isolation
  - shorts caused by foreign objects
- Occam's razor approach: keep things simple.
- Multiple methods (layers) of fault isolation
  - at least 2 levels to protect interfaces between FCMs
  - serial busses and discrete interconnections via isolation resistors on both ends

Fault Tolerant ADIRU

**Reliability**
- Typical Inertial Reference Unit
  - Mean Time Between Failure (MTBF)
    - typical 10,000 h
  - Mean Time to First Failure (MTFF)
    - typical 8,000 h
  - using TMR: MTBF = 10,000/3 = 3,333h
- Deferred Maintenance Approach
  - Mean Time to Dispatch Alert with no maintenance
    - > 25,000h
    - assuming 1 fault sustained in each FCA
  - With better maintenance, i.e. fix unit at convenient time after annunciation
    - Mean Time to Dispatch Alert = 300,000h