Design and Benchmarking of a Network-In-the-Loop Simulation for Use in a Hardware-In-the-Loop System

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Overview

• Background
• Motivation and goals
• Controller Models
• Test Results
• Conclusions
Background
Aircraft Engine Control Architecture

• Centralized control – analog data network to transfer information to/from sensors, analog to digital conversion inside central controller, some signals to the engine have less content

• Distributed Control – digital data network, analog to digital conversion at sensor source, control logic can executed outside of the central controller (e.g. fuel flow meter),
Motivation and Goals

- Develop C-MAPSS40k engine model to better represent a Hardware-In-The-Loop (HIL) system
- Conversion of C-MAPSS40k to a distributed model to enable exploration of distributed engine control
- Allows for the exploration of advanced engine control systems
  - Controls to compensate for information loss
  - Model based controls
  - Requirements exploration
Controller Models

• Baseline: C-MAPSS40k out of the box, 1 computer

**Baseline C-MAPSS40k**

Several configurations were compared to the original C-MAPSS40k:

- Ideal Network-in-the-Loop (Ideal NIL) – JPC 2016
- Network-in-the-Loop (NIL) – SciTech 2017
Smart Transducer Model (SXD)

- **Network Capable Application Processor (NCAP)**
  - Network communication
  - Application interface to STIM

- **Smart Transducer Interface Module (STIM)**
  - Analog to Digital and Digital to Analog converter
  - Signal conditioning
  - Interface to transducer
SXD As Implemented in Test Bed
Network-in-the-Loop (NIL) Control Network

- System that allows information to flow between the control logic and the engine simulation
- Traditional engine systems are analog (no latency, star topology)
- New engines are digital (latency, sample delay, many topologies)
EADIN Lite Control Network Details

• Major and Minor Frames

<table>
<thead>
<tr>
<th>Major Frame</th>
<th>Sampled sensors:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor Frame 1</td>
<td>Nc, Nf, T2</td>
</tr>
<tr>
<td>Minor Frame 2</td>
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• Frame Interval
• Major frame has 50 minor frames

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<tr>
<th>Node Type</th>
<th>Wf, VSV, VBV, P2, P25, Ps3, P50, Nc, Nf</th>
<th>T2, T25, T30, T50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Interval</td>
<td>10 minor frames</td>
<td>25 minor frames</td>
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</table>
EADIN Lite Control Network Details

- Master / Slave protocol
- Protocol based on Distributed Engine Control Working Group draft spec.
- Example packet shown below:
Test Setup

- Real flight profile used to evaluate fuel efficiency
- Burst and chop at various points in the flight envelope to study transients
Test Results

- Thrust Specific Fuel Consumption had changed negligibly
- No operability margins violated
- Fuel Flow (Wf) actuator ringing
- NIL system has communication delays, other systems assume instantaneous messaging
- C-MAPSS40k controller was not redesigned to compensate for network delays, SXD quantization, and signal conditioning
- No filtering was applied to the communication network sensor data to take care of aliasing to compensate for reduced sample rate
Successful tests indicate potential network speeds of 120Kbps to 450Kbps depending on security requirements. Additional requirements may create additional loads on the network. Health Monitoring Data, Fault Reporting Data, Authentication, and More Sensors / Actuators.

The diagram shows the bandwidth requirements for different types of data:
- **Overhead**: 22 Kbps
- **Control Data**: 18 Kbps
- **Health Data**: 10 Kbps
- **Fault Data**: 10 Kbps
- **Authentication**: 165 Kbps
Conclusions

• A real-time network was integrated into C-MAPSS40k engine model
• Impacts of the real-time network on control system performance were studied
• Network bandwidth requirements were estimated
• Results indicate that control logic should be redesigned to optimize networked systems
Questions?

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Future Work
Network-in-the-Loop with Analog I/O
Backup