HIL Integration

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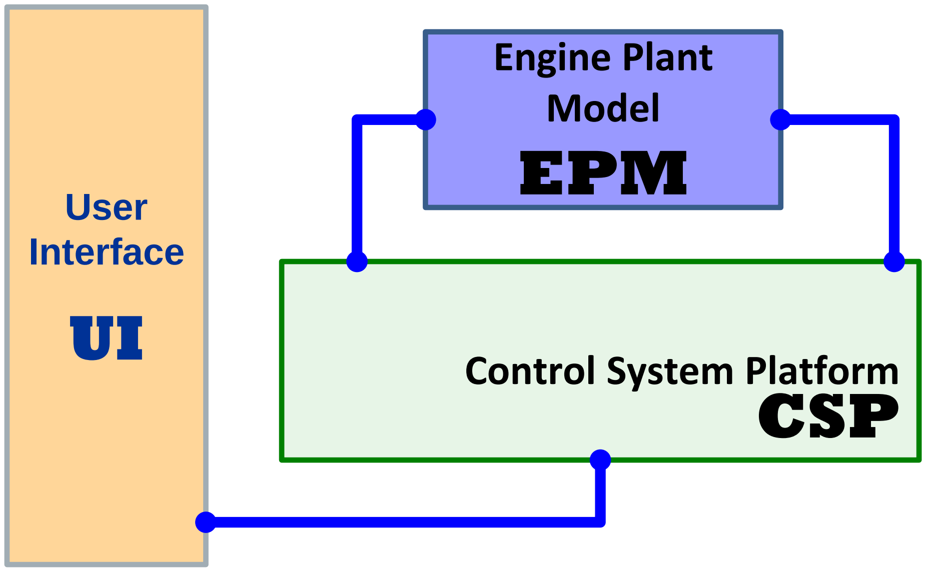


Why Hardware-in-the-Loop?

Question: How do you solve a system problem if you don’t have system knowledge?

- Hardware-in-the-Loop is a natural focal point for collaboration in that it enables the exploration of many of the underlying technologies necessary for Distributed Engine Control.

Wide range of focus from component through engine system

- HIL provides a means of quantifying the effect of controls on the system thereby providing a means to communicate capability based on new or existing technology

Ultimately, customers are interested in *capability*, not technology

Outline

- Goals and Objectives
- Design Decisions in the HIL System
    - Virtual Test Cell
    - Engine Plant Model
    - Control System Platform
    - User Interface
- Opportunities for Collaboration

Goals and Objectives

Objectives

Develop tools that enable the controls community to:

1. Analyze the effect of control systems on turbine engines
2. Analyze the effects engine systems have on the control system
3. Quantify the benefits of new control technologies in order to impact the design of future turbine engine systems

Goals

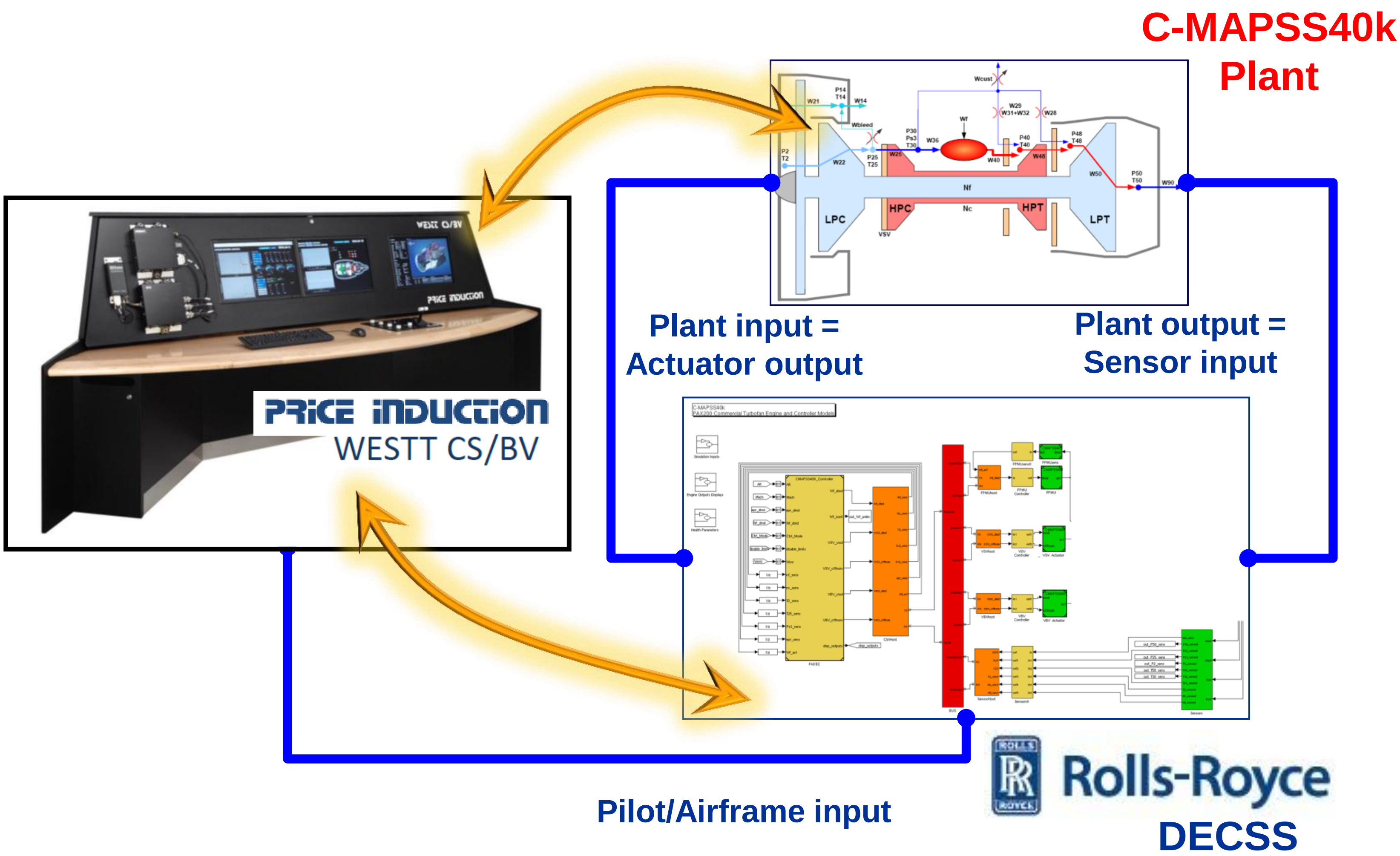
1. Simplify the process of collaboration and information sharing
2. Protect intellectual property of collaborators

System Design Choices

There are a multitude of ways to design a HIL system. Rolls Royce is providing the core functionality and expertise in dealing with hardware. We are choosing to extend this functionality to emulate a virtual test cell.

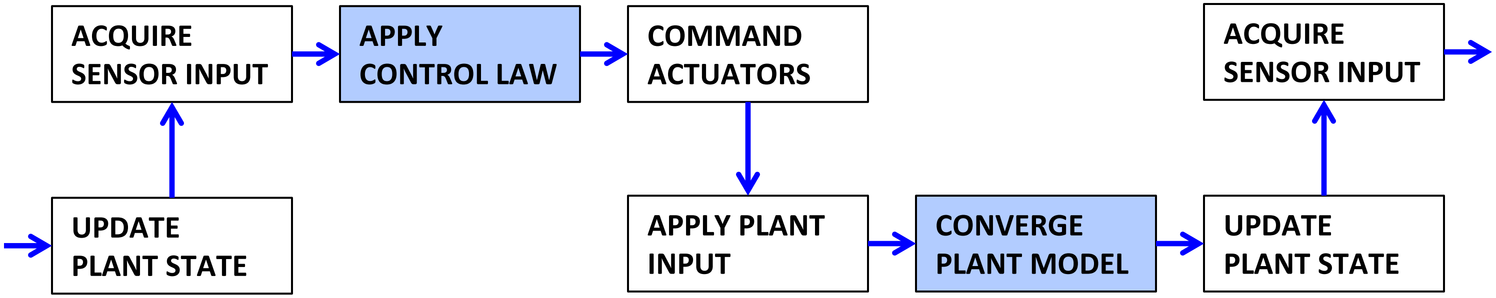
- Replicate the natural interfaces that exist between the mechanical engine system, the electronic control system, and the operator
- Decouple the HIL system functions so that they are modular, i.e., independent of each other – emphasize interfaces
- Modularity enables the system to scale depending on the complexity of the investigation and invites collaboration by providing additional means to protect IP

HIL System Architecture
Virtual Test Cell

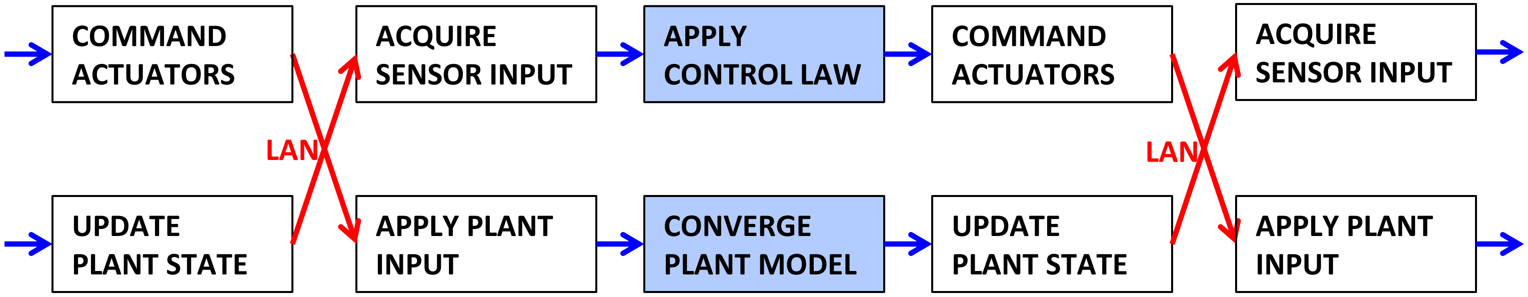


Parallel Operation

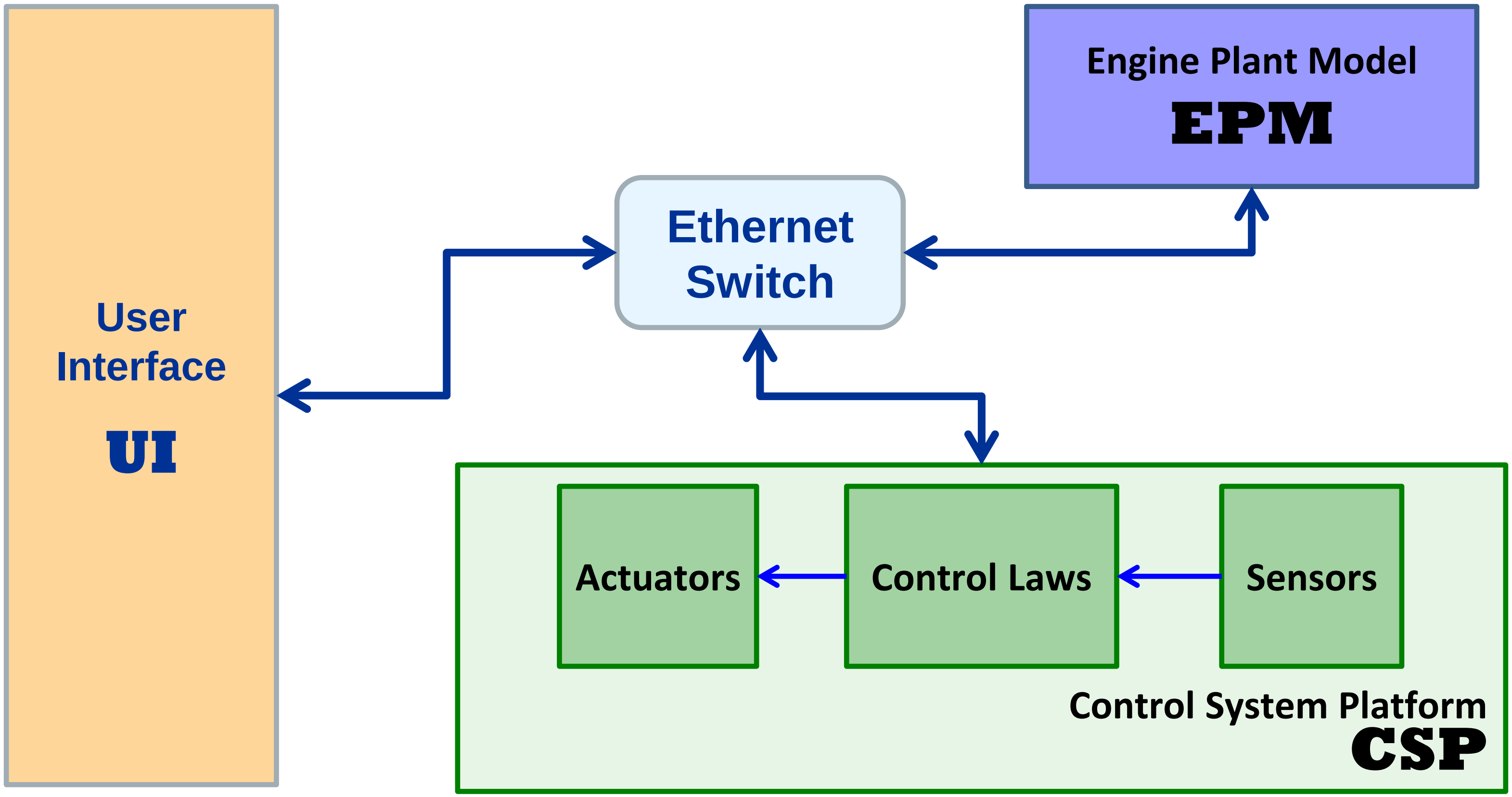
- Baseline CMAPSS40k - Sequential Model, One Machine, One Processor



- Baseline HIL System - Parallel Model, Two Machines, Two or More Processors



HIL System Interfaces



- Gigabit Ethernet is used to implement a “reflective memory” between HIL components and to synchronize the system based on the CSP real-time clock.

UDP vs. TCP/IP in HARD Real-time Systems

UDP

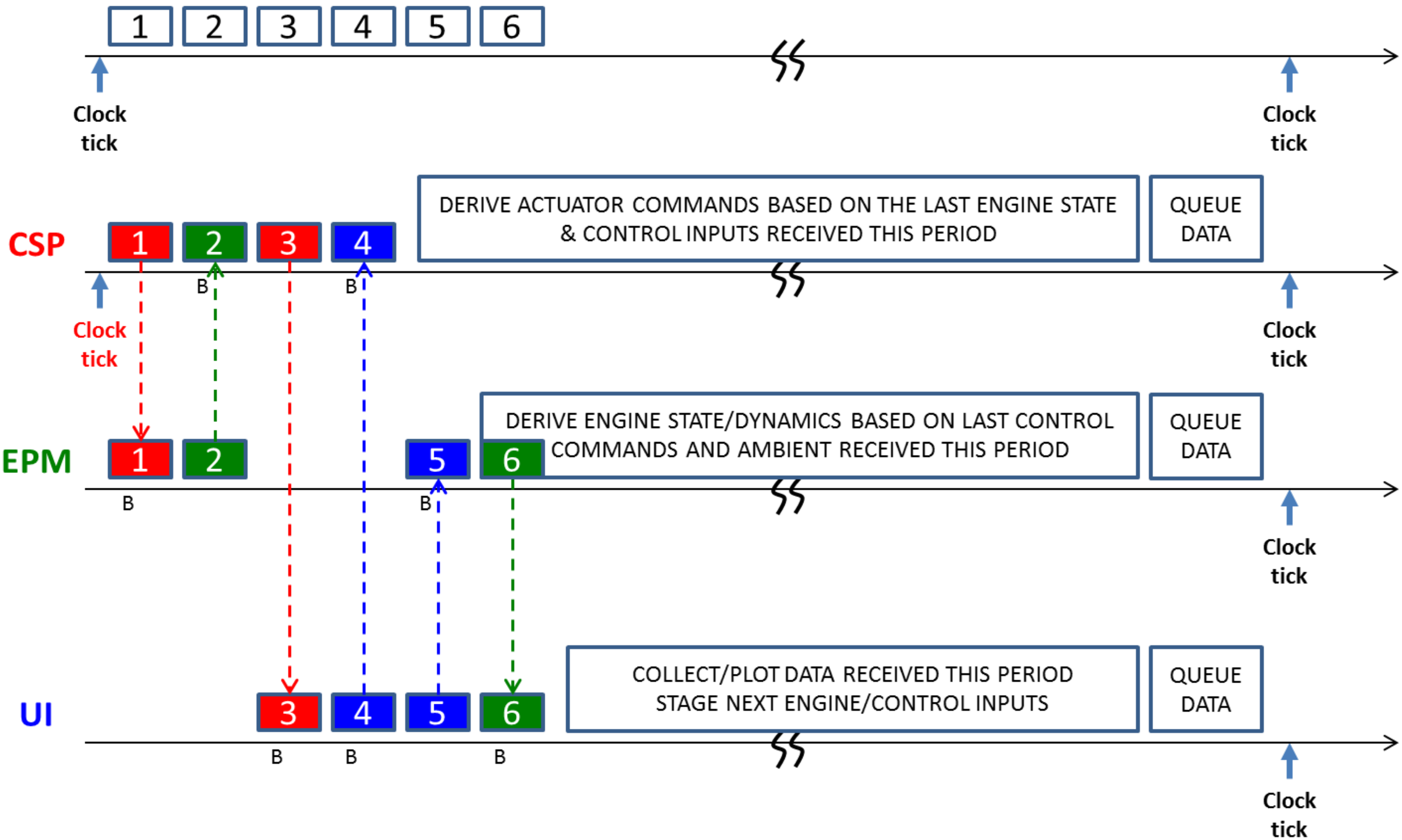
1) Small Application Layer
2) Dropped packets are not resent
3) No message receipt
4) Out of order delivery
5) Faster Data Rates

TCP/IP

1) Large Application Layer
2) Dropped packets are resent
3) Message Receipt
4) Data deliver in order
5) Slower Data Rates

- Data in Hard Real-Time Systems is useful only when delivered before the deadline.

Current UDP Implementation



Engine Plant Model

- The engine plant model from C-MAPSS40k has been isolated and implemented in a model reference format to prevent race conditions.
- It is currently running on a low cost Windows 7 laptop as a stand alone executable derived from a Matlab/Simulink model using Simulink Coder
- The model runs on startup and converges to steady state in about 20 iterations where it idles awaiting new control inputs
- The control interval in C-MAPSS40k is 15 milliseconds

Engine Plant Model

- Advantages of decoupling the engine plant model:
  - inherently provides more processing capacity
  - can be implemented in any software technology
  - can be operated from any hardware platform
  - can be more secure if it exists as a binary code
  - can be more secure as a removable plug-in
- The assumption for any dynamic simulation of an engine plant model is that it runs *at least in real-time*.
- It is not necessary for the hardware to be hard real-time as long as it will be synchronized via the HIL network
- Any engine plant model conforming to the HIL network interface can be used in the system.
- NASA will be able to provide this interface definition once the system is released.

Control System Platform

- The control system platform (CSP) is being provided by Rolls Royce DECSS. It is based on ***hard real-time hardware*** and a ***real-time operating system***.
- It is important to understand that everything related to the control system is included in the CSP.
- The HIL UDP LAN is NOT the control system network.

- At the CSP interface to the HIL only **digital data** is exchanged with the other HIL components

TO CSP:
- Engine plant physical state (for sensor input)
- Pilot/airframe signals and control component health data

FROM CSP:
- Actuator outputs (for engine control surfaces)
- Internal CSP information (such as model variables and control metrics)

Control System Platform

- All control system functions exist within the CSP as **modeled elements** OR as **hardware** *connected to control networks originating from the control model*.
- All the complexity of analog interfaces to / from control hardware are contained within the real-time control platform.
- The CSP accommodates any analog I/O channels on a case-by-case basis driven by the data flow within the HIL and reflected to the CSP.

User Interface

- The User Interface is the primary means of operating the HIL system.
- The UI will provide a single system for software licensing where both the EPM and CSP operate as target computers.
- The User Interface is a source of considerable future development work. While the primary purpose of the UI is to operate the HIL, the primary purpose of the HIL is to analyze Control Metrics. The information flows in multiple directions:
  - The benefit of control applications and technologies needs to be conveyed to system designers
  - The requirements and constraints on control systems needs to be conveyed to component and control application developers.

User Interface

- Several modes of operation are defined for the User Interface including:
  - **Development** – where the operator develops models of control system components and/or control architectures.
  - **Simulation** – where the operator tests the interaction of a pure simulated control system with the engine plant model
  - **Programming** – where the operator creates source code and compiles and uploads code for smart control hardware targets and/or the real-time HIL control target
  - **Run** - where the operator performs a real-time test of a HIL architecture
  - **Analysis** – where the operator performs post analysis of data collected from simulated or real-time tests of control systems or hardware.

User Interface

A new system has been acquired from Price Induction as a training tool. It features an operator console and multiple displays. This system will be integrated into the HIL to function as a User Interface.

Opportunities for Participation

- We want to help you integrate our tools with your EPM or actuator / sensor model
- Our tools are designed to maintain the security of proprietary Sensor, Actuator, and Engine models.

Questions?

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