

THINKING AUTONOMOUS SYSTEMS

Fernando Figueroa

Autonomous Systems Laboratory
NASA Stennis Space Center

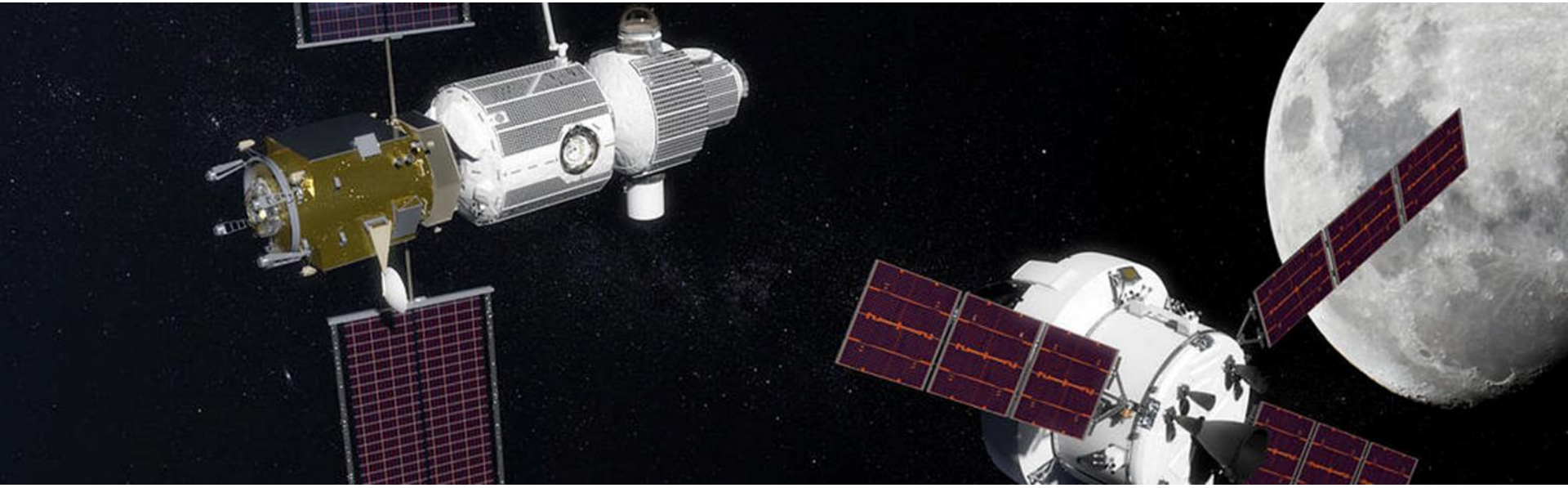
FLC

MIDWEST & SOUTHEAST REGIONAL MEETING

September 21-23, 2021 (Virtual)

Acknowledgements

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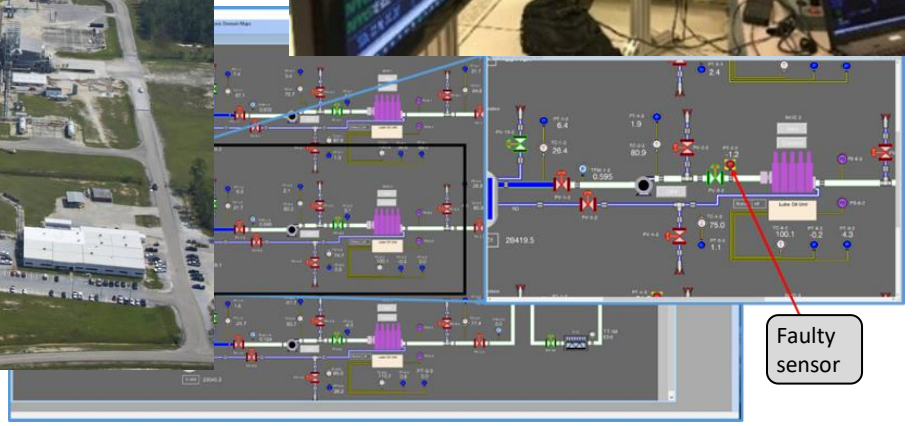


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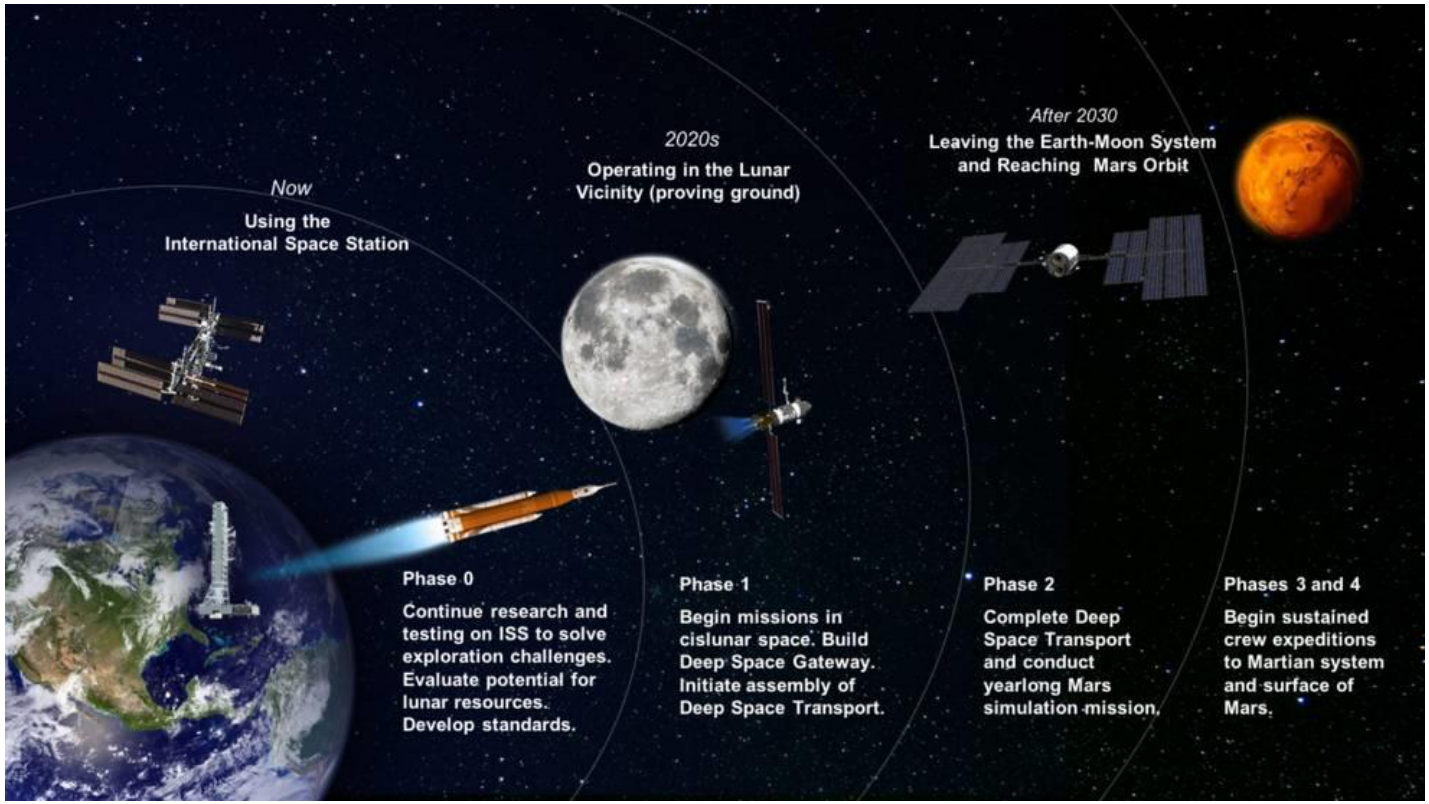
- Supports NASA's rocket engine test mission with sustainable facilities that produce reliable measurements, affordably.
- Develops and implements advanced technologies, expertise, and processes for ground and space Autonomous Operations and Systems







NASA's Need for Autonomy



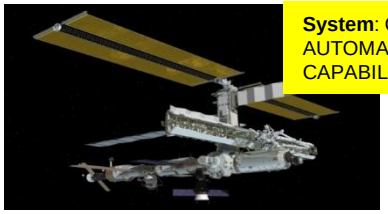


Spacecraft and systems will need to operate unattended for long periods of time or with minimal astronaut on-board participation.

Ground Support will be limited and delayed

People-Based ISHM/Operations Today

MOVE CAPABILITY TOWARD LEVELS 2 AND 1
DECREASE NEED FOR SUPPORT FROM LOWER LAYERS

	International Space Station	Rocket Engine Test Stand	
Layer 1 Vehicle/ Test Stand	 **System**: ON BOARD AUTOMATED ANALYSIS CAPABILITY		Signal threshold violation detection, some model-based methods
Layer 2 Astronaut/ Test Conductor	 **Operator**: FASTER, MORE ACCURATE ANALYSIS		Added DIaK from on-board users.
Layer 3 Control Room	 **Support:** FASTER, MORE ACCURATE ANALYSIS Decreased Need		Added DIaK from broad group of experts.
Layer 4 Back Control Room	 **More Support**: FASTER, MORE ACCURATE ANALYSIS Decreased Need		Added DIaK resources from larger communit y

Autonomy

Autonomy (*2015 NASA Technology Roadmaps*) is the ability of a system to achieve goals while operating independently of external control.

Requires

- ✓ **self-directedness (achieve goals)**
- ✓ **self-sufficiency (operate independently)**



Functional attributes associated with spaceflight

- Concepts of operations for autonomy
- Strategies for autonomy
- Software architecture
- Avionics architecture
- Strategies for Integrated System Health Management (ISHM)
- Anomaly Detection, diagnostics, prognostics and health awareness
- Plan creation and validation
- Plan scheduling
- Plan execution
- Flight software and hardware

Autonomy is not usually implemented as intelligent/thinking capability

Implementing intelligent/thinking autonomy

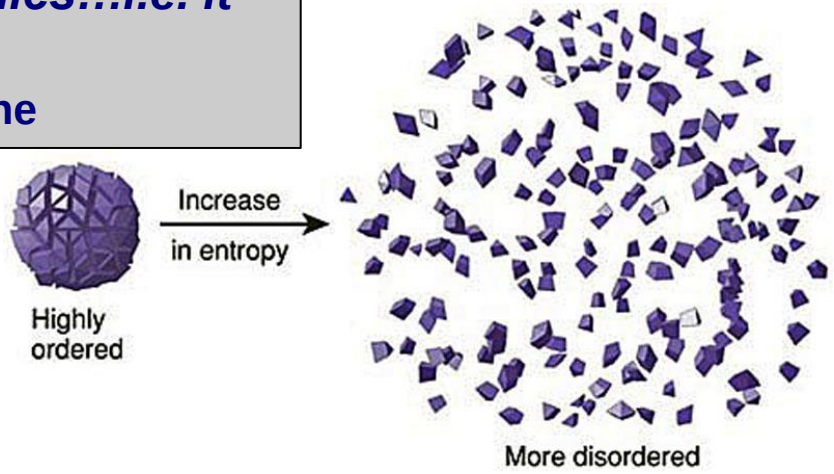
Requires a paradigm for capturing models and operations of complex systems:

- ✓ A software architecture that enables and integrates all autonomy functional attributes
- ✓ Systems engineering processes and methods



Software is like entropy. It is difficult to grasp, weighs nothing and obeys the Second Law of Thermodynamics…i.e. it is always increasing.

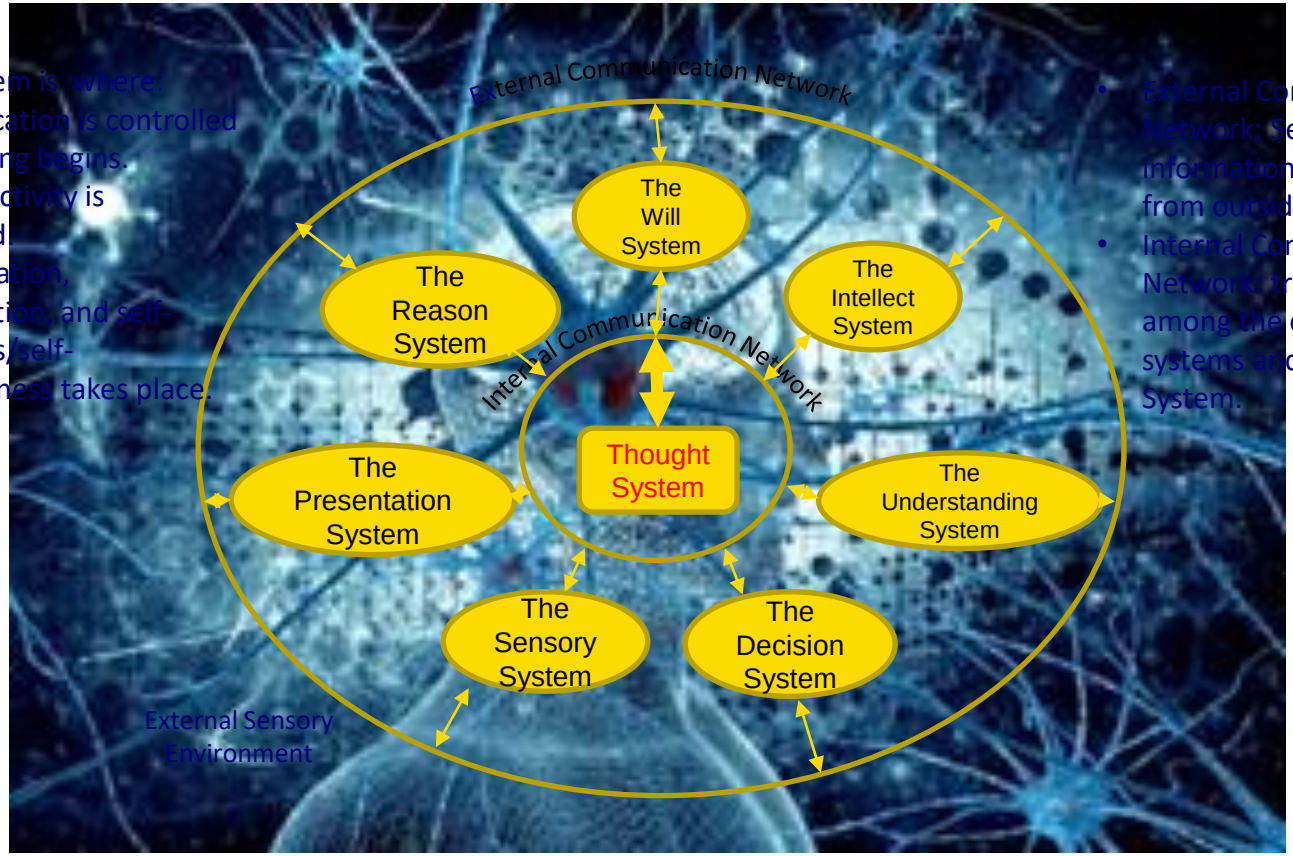
-Norman Ralph Augustine



Autonomous Systems Constellation Architecture

Thought System is where:

- communication is controlled
- The thinking begins.
- Thought activity is monitored
- Contemplation, consideration, and self-awareness/self-consciousness takes place.

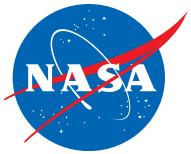


- External Communication Network: Sensory and information input coming from outside the system.
- Internal Communication Network: transactions among the constellations systems and the Thought System.

Autonomous Systems Architecture

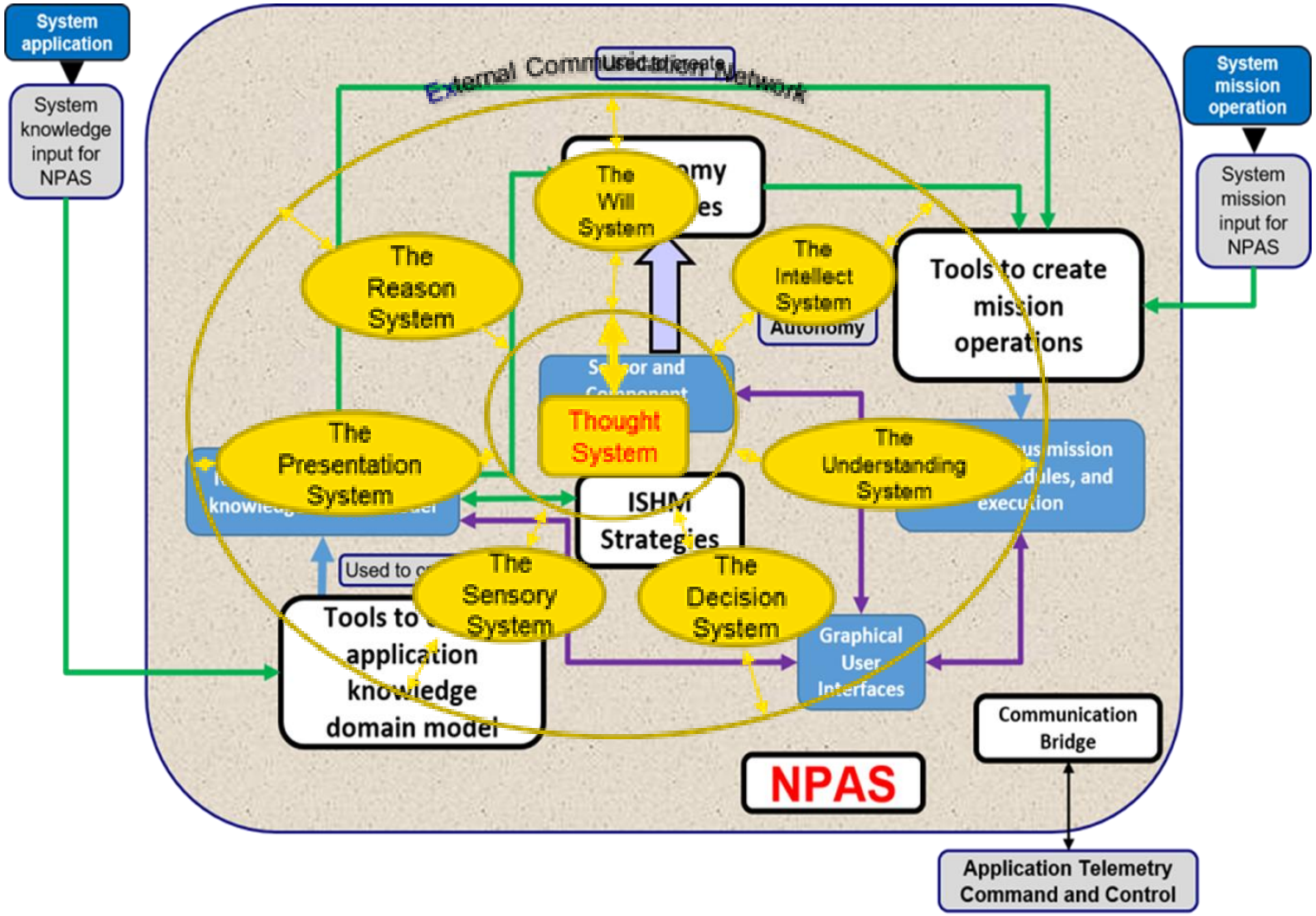
- The architecture is not a system with subsystems, but a constellation of nearly independent unique systems.
- Functionality that must be supported by the architecture:
  - The Intelligent Autonomous System (IAS)
    - Must be able to think and contemplate
    - Must receive instructions, learn, be receptive to orders, and carry them out
    - Must be able to make rational decisions without human input, and act upon those decisions
    - Must be able to communicate in the HUMAN LANGUAGE with people and other autonomous systems; and among its own internal systems.

Intelligent Autonomous System (IAS)



- An IAS must be able to “think” and to be “self-aware.”
- Development of an IAS is not a trivial matter, it can’t be done by an individual or even by a small group of computer scientists. An IAS can only be achieved as a large-scale project.
- Must use an architecture model for a system that is able to think and be self-aware.

Autonomy Software Functional Architecture with Knowledge Domains



NPAS (NASA Platform for Autonomous Systems)

NPAS Infrastructure

Domain Object Library and knowledge

hydraulic



electrical



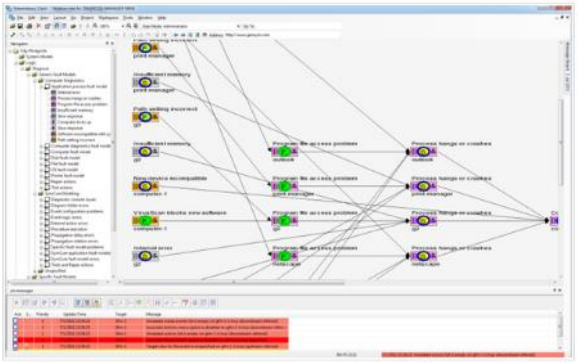
computing



mechanical

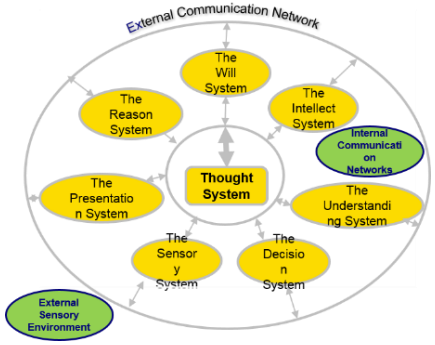


Health Management



FMEA/diagnosis, prognosis, anomaly detection

Functional relationships, constraints, concepts of operation



Autonomy



Plan, creation, scheduling & execution

Processes and event management





OODA loop

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Scripting Autonomy

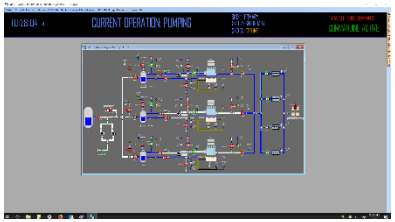
Brute Force **Minimal or no analysis and decisions by the System**	**Concept/Model Based Thinking Autonomy** **Most analysis and decisions by the System**
Problems solved by the expert off-line, and made available to computer code to make the most appropriate choice of solutions (lookup tables).	***Problems solved by the autonomous system that is able to apply generic models of processes taking place in the system, in real time***.
Solutions must be found for ***every possible case defined by every object, every process that involves the object, and every configuration of the system where the object belongs***; and for every process that may occur in the system (nominal and off-nominal).	The autonomous system analyses the system behavior at a high level of abstraction, by applying generic models (e.g. physics models) that employ definitions and concepts used in the models; Solutions are determined with a relatively small set of models.
Coverage is not comprehensive***; it is limited by the thoroughness of the analysis by expert off-line programmers***.	Coverage is comprehensive for each generic model used. So total comprehensive coverage is feasible, since first principles cover all behaviors.
The autonomous system does not “think” it merely makes use of what has been “thought” by humans.	***The autonomous system “thinks” to provide solutions that need not be solved off-line by humans.***

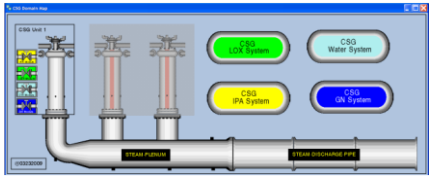
NPAS Development and Validation

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Autonomous Ground Operations
Nitrogen System Management for use in rocket engine testing

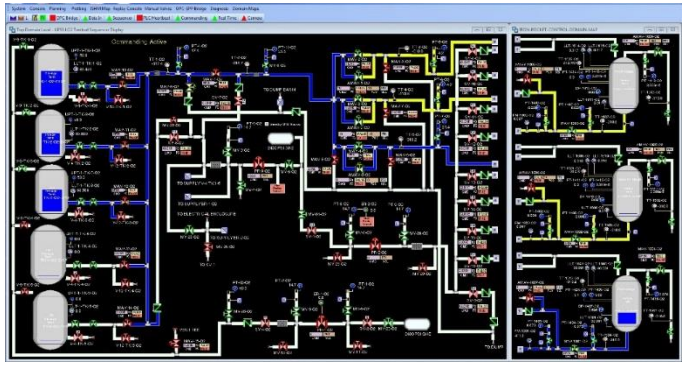




Integrated System Health Management (**ISHM**) of CSG (Chemical Steam Generator and Test Facility Systems)

Orion Capsule EFT-1 ISHM using recorded telemetry data







Integrated Power Avionics and Software (**iPAS**) Testbed at JSC





Universal Propellant Servicing System (**UPSS**) physics-simulated Autonomous Propellant Loading (**APL**) at KSC





Cryogenic Testbed Lab's (**CTL**) Integrated Ground Operations Demonstration Unit track progress of an autonomous propellant loading operation at KSC

Habitat Module Autonomy
Partnering with Northrop Grumman









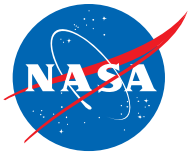
NORTHROP GRUMMAN

Autonomous Habitat User Interface

Stennis Space Center

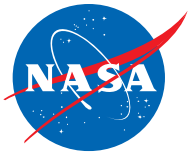


Clarifying Autonomy



- A hardwire system cannot think, contemplate, communicate, evaluate, learn, design, plan, execute, or make decisions, because it cannot perform the fluid, self-reflective dynamic logic that is required for an autonomous system.
- A hardwired “autonomous” system is a contradiction in terms.
- The process of generating an Idea is considered the most important and unique attribute of the mind of a human being. It is the one that separates it from the purely biological animals, and as such is the first prime mover of the thought process.

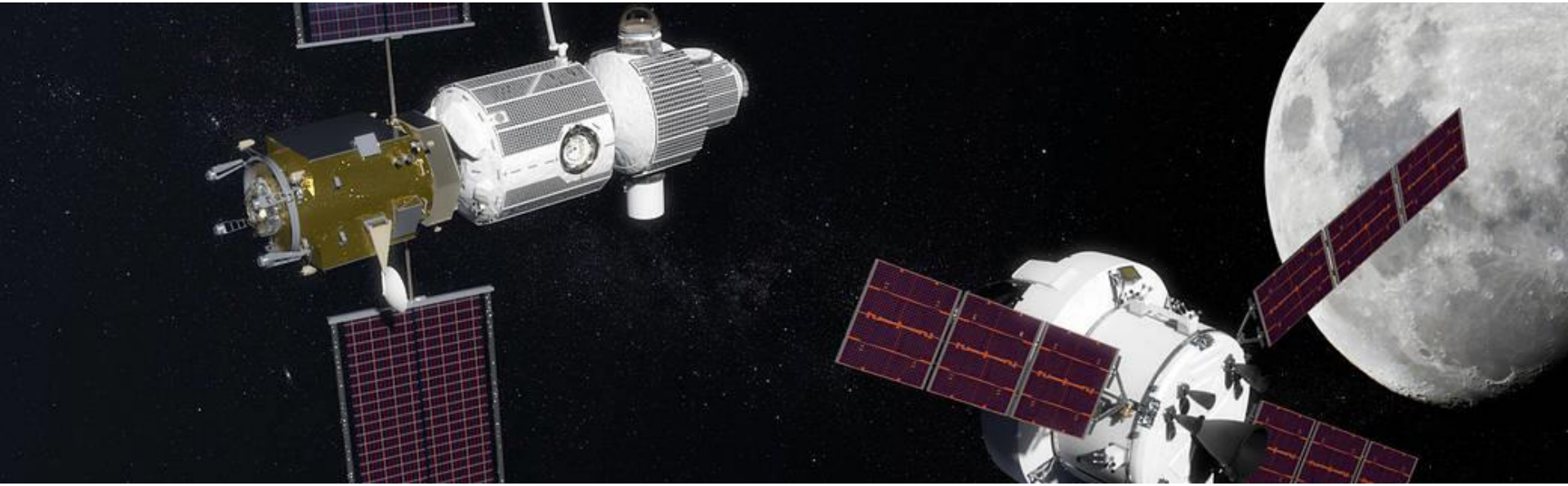
Clarifying Autonomy (Continued)



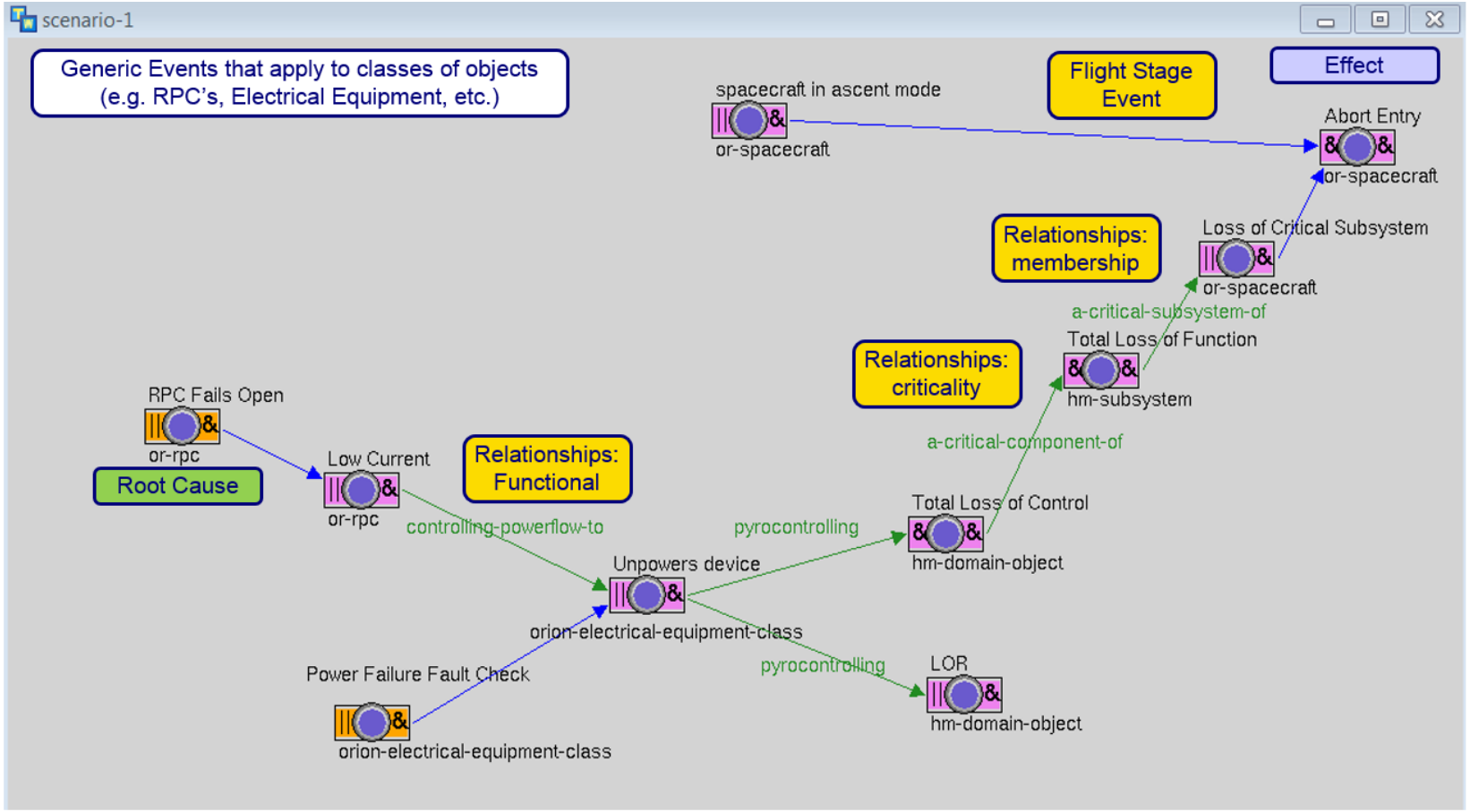
- The **Concept** is the other prime mover of the thought process. It is a processor and a mental design object in time and space. It is generated by the initial stimulation of the **Idea**, and indeed it is for our design purposes an extension of the Idea and often remains a mental image object.
- In human beings, this may happen only if the mind of the **thinker** is equipped with the **Intellect, Understanding, and Decision** necessary to complete the substantiation process.
- For our purposes, the Idea can originate in any of the Will, Reason, or Understanding systems, but it is up to the **Thought Process** (nucleous) to develop it into a Concept.

Epilogue

- Thinking— pure thinking —is considered a system of concepts.
- Logic is in turn the science of pure thinking.
- Thus, in the design of the autonomous system, we can originate concepts from the Reason, the Intellect, and even the Presentation.



Comprehensive Spacecraft FMEA

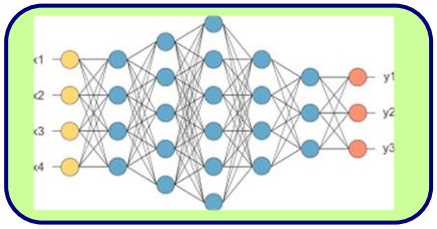


The system can send an event to any instance represented by a node. Causes and consequences will propagate upstream and downstream to assert status of all events (true, false, suspect).

NPAS Physics/Engineering Models and Reasoning

Modeling for consistency checking and predictive behavior

Models taught to artificial neural networks (ANN)

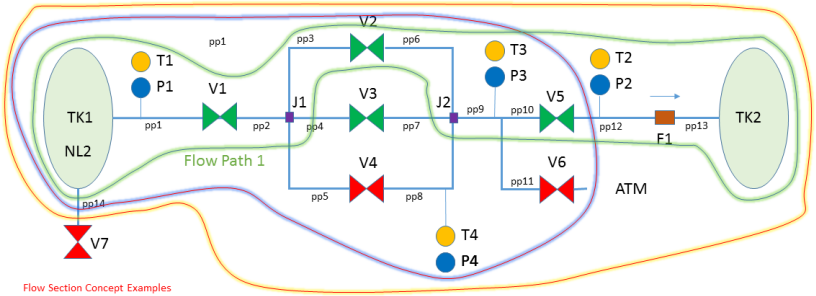


Resembles human synaptic activity



Very difficult to get from ANNs to this level of knowledge

Paramount to teaching scientific laws and how to apply them



Flow Section Concept Examples

Section 1: Part of (pp1, T1, P1) Bounding: (TK1, V1)

Section 2: Part of (pp2, J1, pp3, pp4, pp5) Bounding: (V1, V2, V3, V4)

Section 3: Part of (pp6, pp7, pp8, J2, pp9, T3, P3, T4, P4, pp10, pp11) Bounding: (V2, V3, V4, V5, V6)

Section 4: Part of (T2, P2, pp12, F1, pp13) Bounding: (V5, TK2)

Enabled Flow Subsystem Examples:

EFS 1: Collection of sections 1,2,3, and 4.

EFS 2: Collection of sections 1,2, and 3.

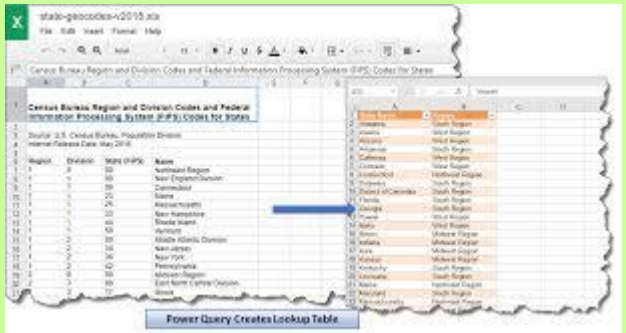
Flow Path Examples:

Flow Path 1: Collection including TK1, pp1, T1, P1, V1, pp2, J1, pp3, V2, pp6, J2, pp9, T3, P3, pp10, V5, T2, P2, pp12, F1, pp13, TK2.

Flow Path 2: Collection including TK1, pp1, T1, P1, V1, pp2, J1, pp4, V3, pp7, J2, pp9, T3, P3, pp10, V5, T2, P2, pp12, F1, pp13, TK2.

NPAS

Principled knowledge with scientifically derived models



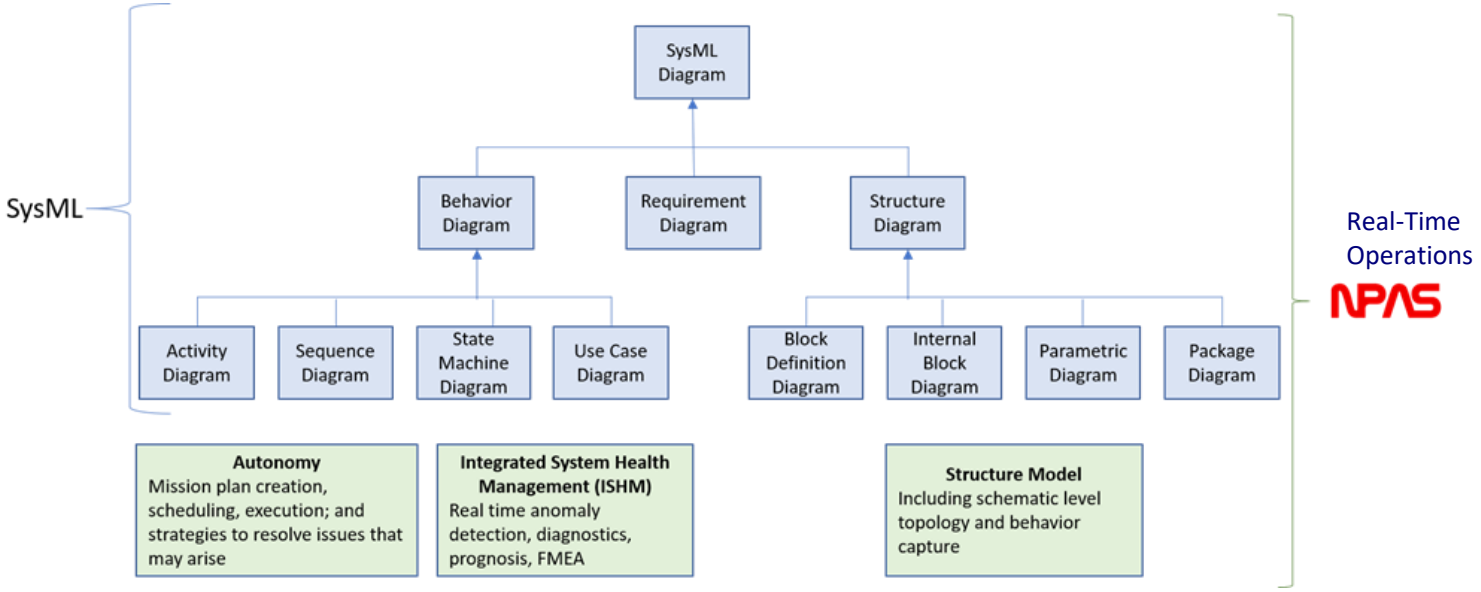
Look-up table of cases and solutions

Solutions based on models for all preconceived cases of an application

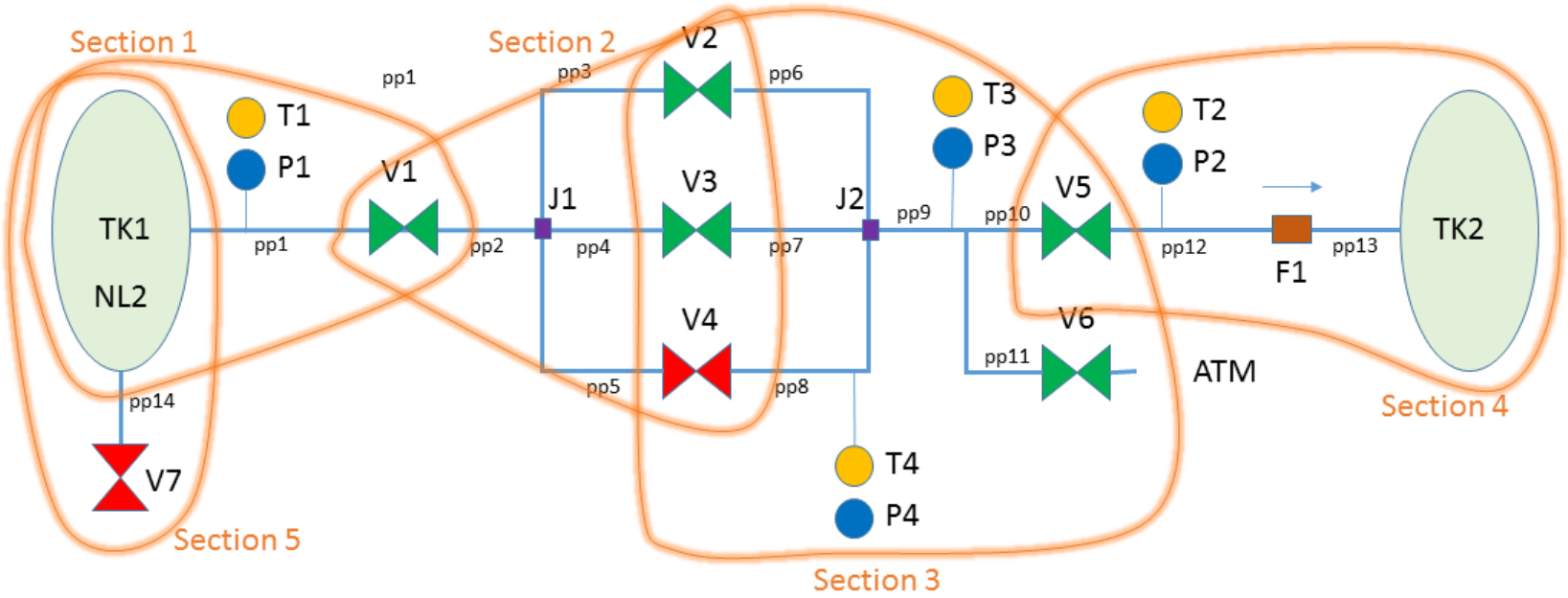
NPAS and SysML

G2/NPAS Model Development

- Includes content associated with all SysML diagrams
- Augments behavior content for ISHM and Autonomy
- Augments detail of structure diagrams by including schematic details



Concept: Flow-Section-and-Sensors



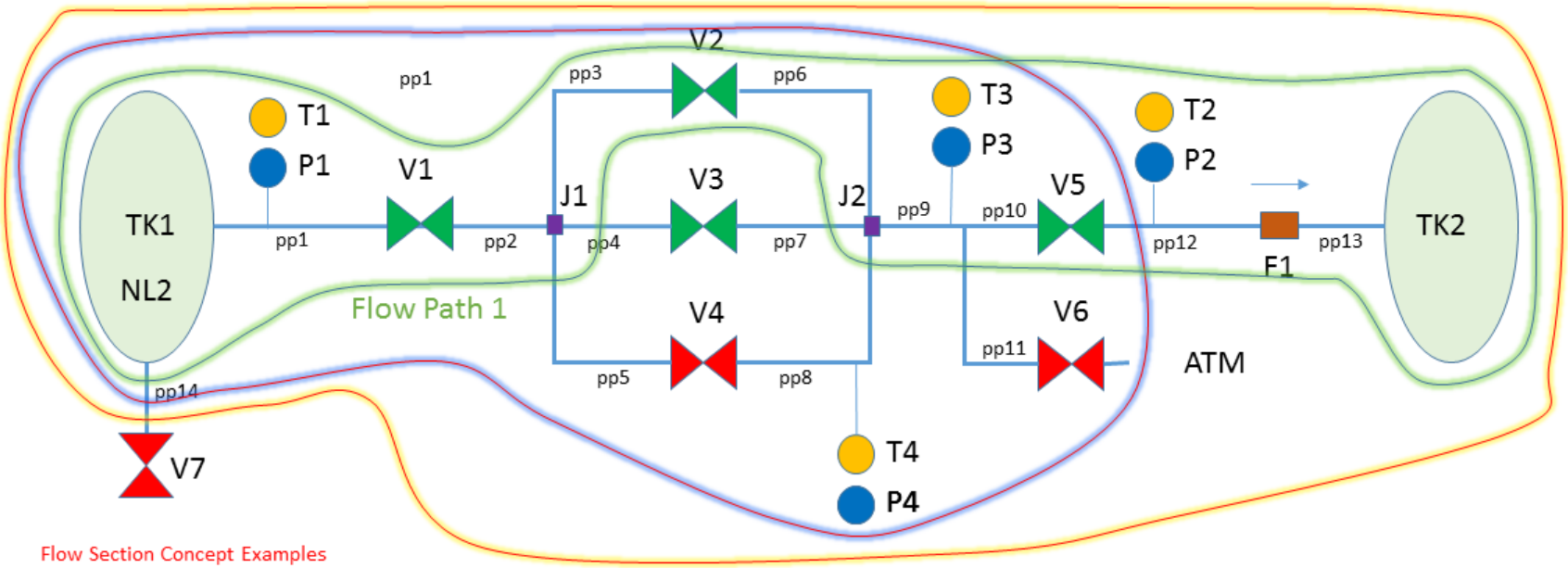
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Section 4: Part of (T2, P2, pp12, F1, pp13) Bounding: (V5, TK2)

Model: "Throughout each flow section there is one commodity, and some physical variables of the commodity such as temperature should be similar throughout the piping section"

Similar value set 1: T3, T4

Concept: Flow-Path



Flow Section Concept Examples
Section 1: Part of (pp1, T1, P1) Bounding: (TK1, V1)
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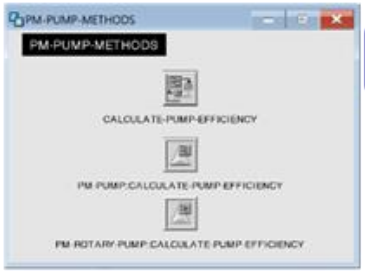
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NPAS Physics/Engineering Modeling



Definition of a class for a rotary pump

For every rotary pump instance

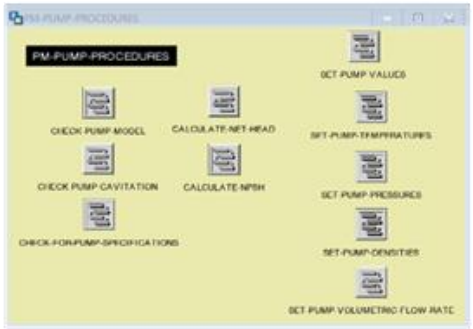


Calculating pump efficiency

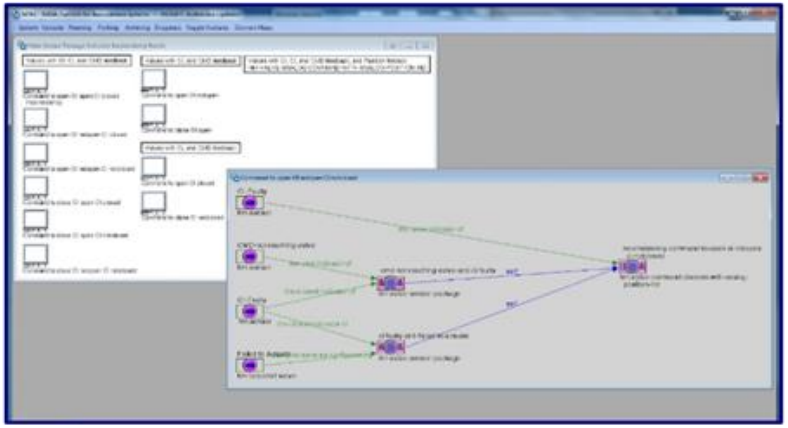


Example, of an inconsistency of a sensor, and this inconsistency is triggered by NPAS models being applied; physics, or other models in NPAS are detecting events; these events are used in root cause trees for diagnosis (as shown in example below)

Checking consistency of models against real-time data

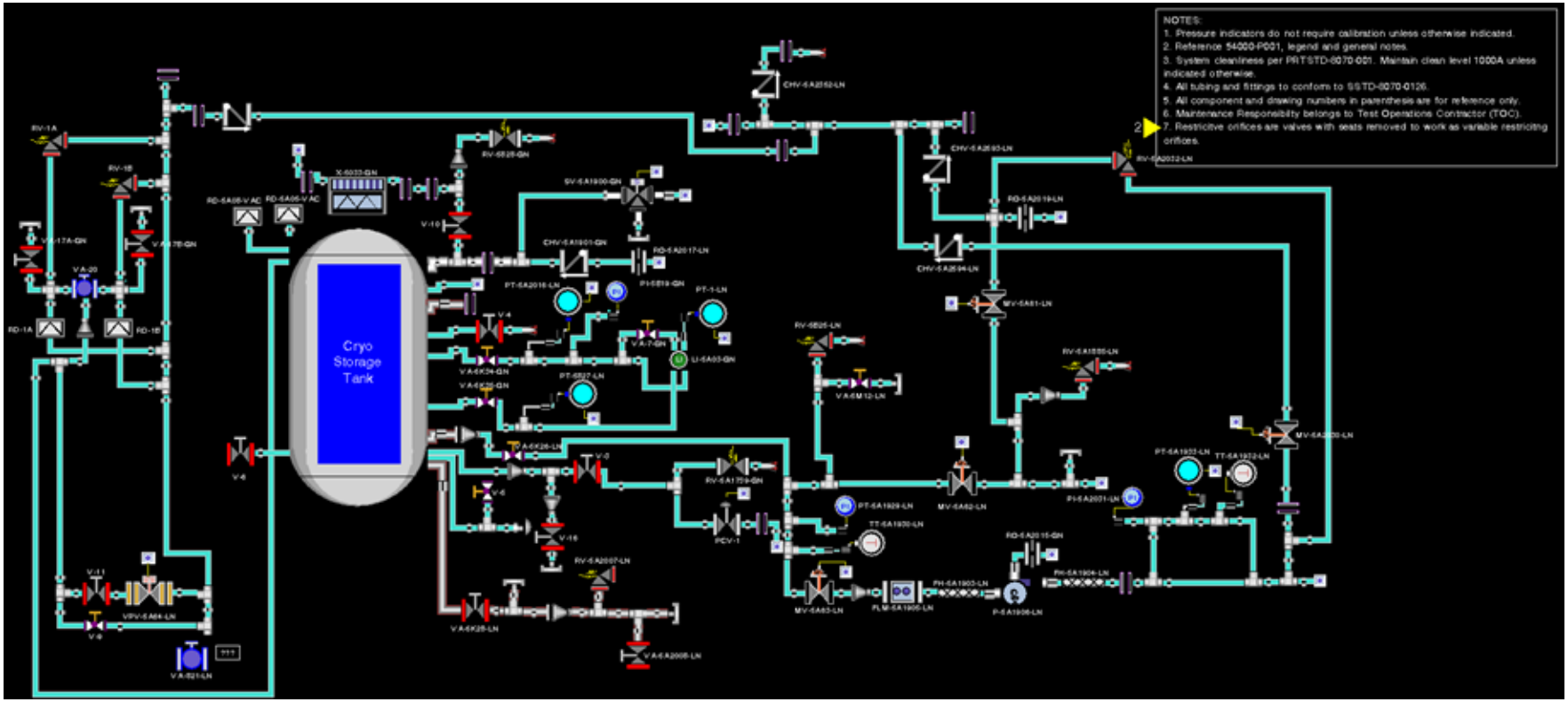


Execution of models (blocks above) generate truth values on events that form part of cause-effect trees (on the right), corresponding to FMEA and/or used for other reasoning as needed by autonomous operations activities



Root cause tree associated with a valve assessment model

Life schematics as part of the domain knowledge model of SSC's High Pressure Gas Facility



GUI of Commodity Management of a Launch and Rocket System

NPAS

