National Aeronautics and Space Administration

Systems Engineering Using Models – EFT-1 Case Study

Presentation to NASA PM Challenge 2012

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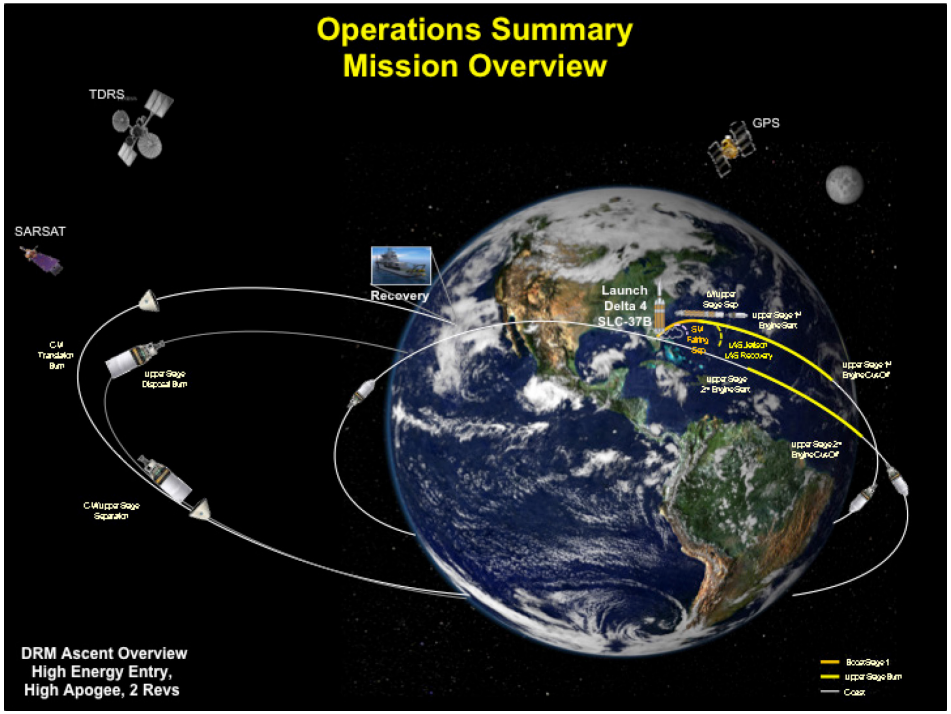
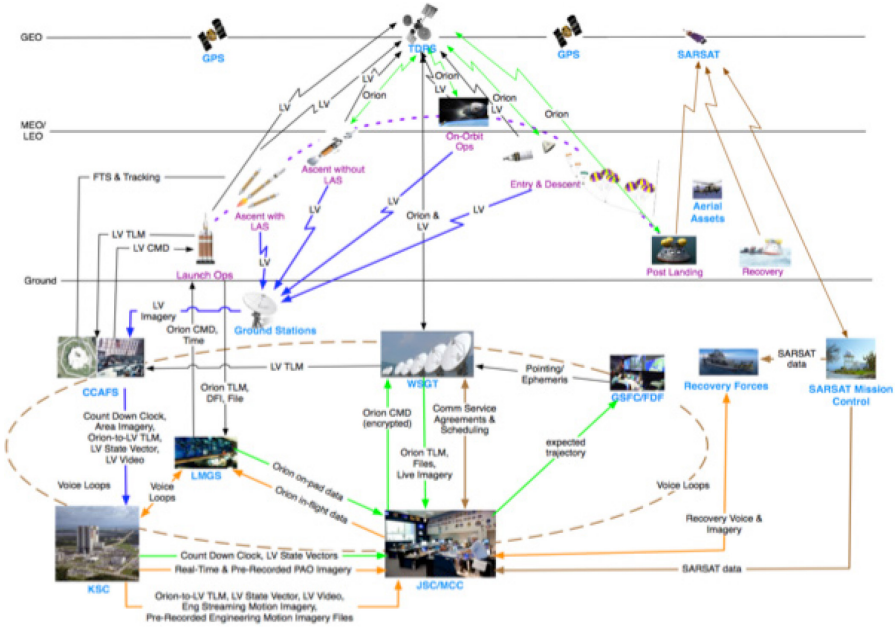
EFT-1 Mission Overview

- **Mission Overview:**
  - Reduced Block 0 Orion Configuration
  - Launch FY14 from CCAFS aboard Delta 4H
  - 2 orbits to high apogee
  - High Energy Re-entry
  - Water Landings & Recovery
- **Purpose: test & observe key characteristics of the Orion spacecraft**
  - Key Functions:
    - Nominal jettison/separations
    - Parachute performance
    - Attitude Control/Guided Entry
    - Water up-righting & recovery systems
  - Environments
    - Aerodynamic, Aerothermal, Acoustic, Vibration, Loads, etc.
- **Team**
  - Lockheed Martin (Mission Lead)
  - NASA (supporting – KSC, JSC, MSFC, SN)



EFT-1 Mission Overview (continued)

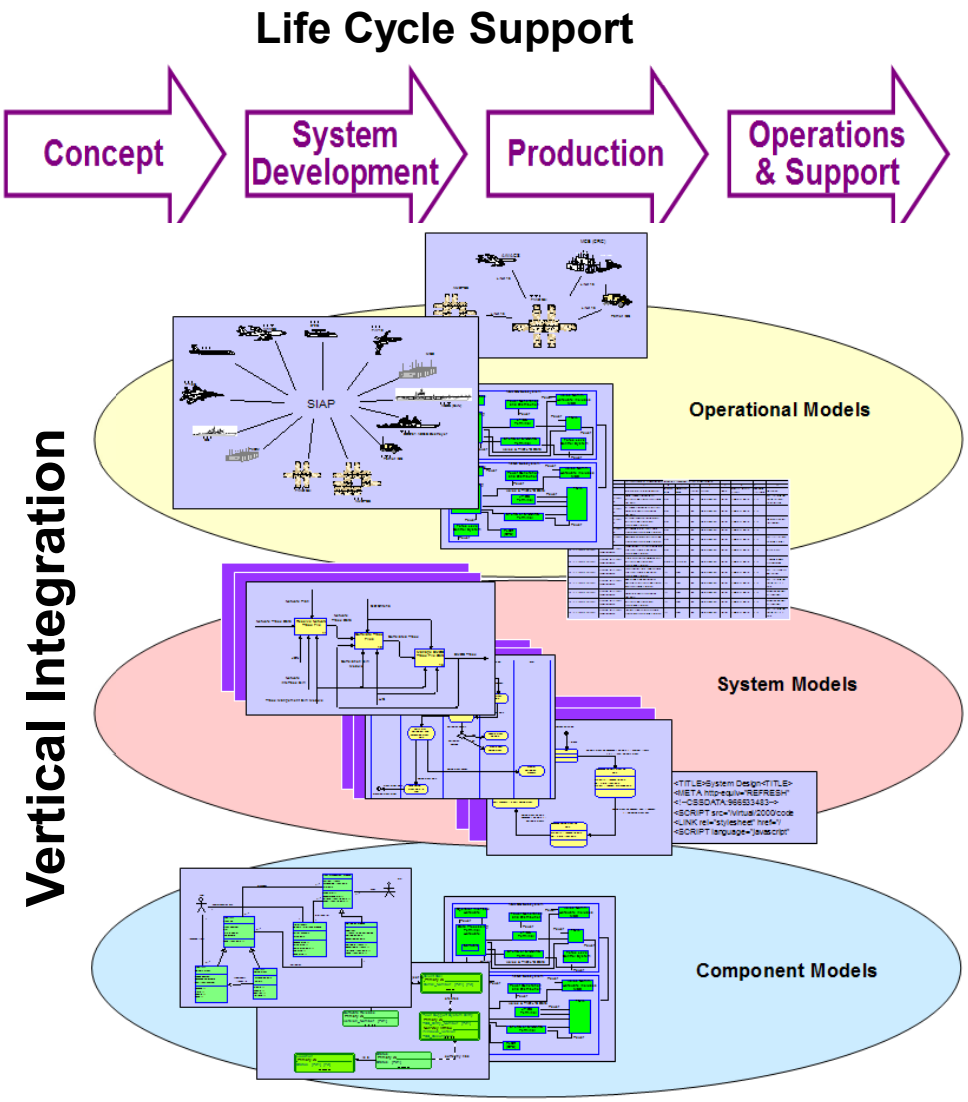
- **Need to ENSURE that we are able to control the spacecraft and gather all of the data needed to meet the flight test objectives.**
- **Particularly confusing given the large number of different organizations and required vs desired data flows**
- **Raised by MPCV as a significant risk**
- **Spawned a joint NASA/LM effort to understand (for all phases):**
  - What resources do we need to record/observe the flight?
  - What data needs to be collected
  - What needs to be live vs recorded
  - How will data be distributed/archived/shared?
  - What data is proprietary or sensitive and needs to be protected?



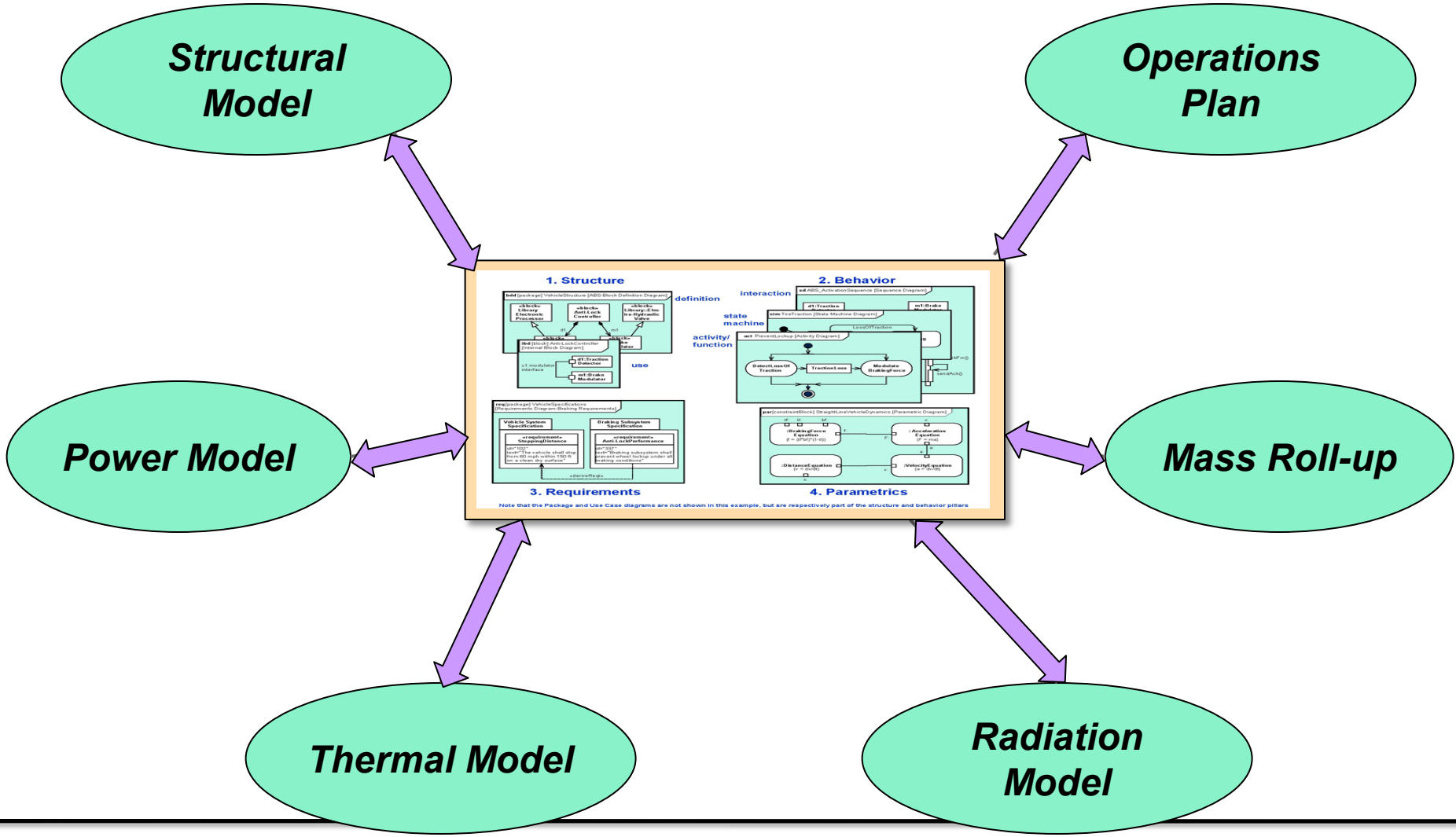
- **Systems Engineering team chose to a model-based approach to augment regular systems engineering approaches**

Systems Engineering using Models

- **Formalizes the practice of systems engineering through the use of models**
- **Broad in scope**
  - Integrates with multiple modeling domains across life cycle
- **Results in quality/productivity improvements & lower risk**
  - Rigor and precision
  - Communications among system/project stakeholders
  - Management of complexity



Current State → Future State



Technical Approach

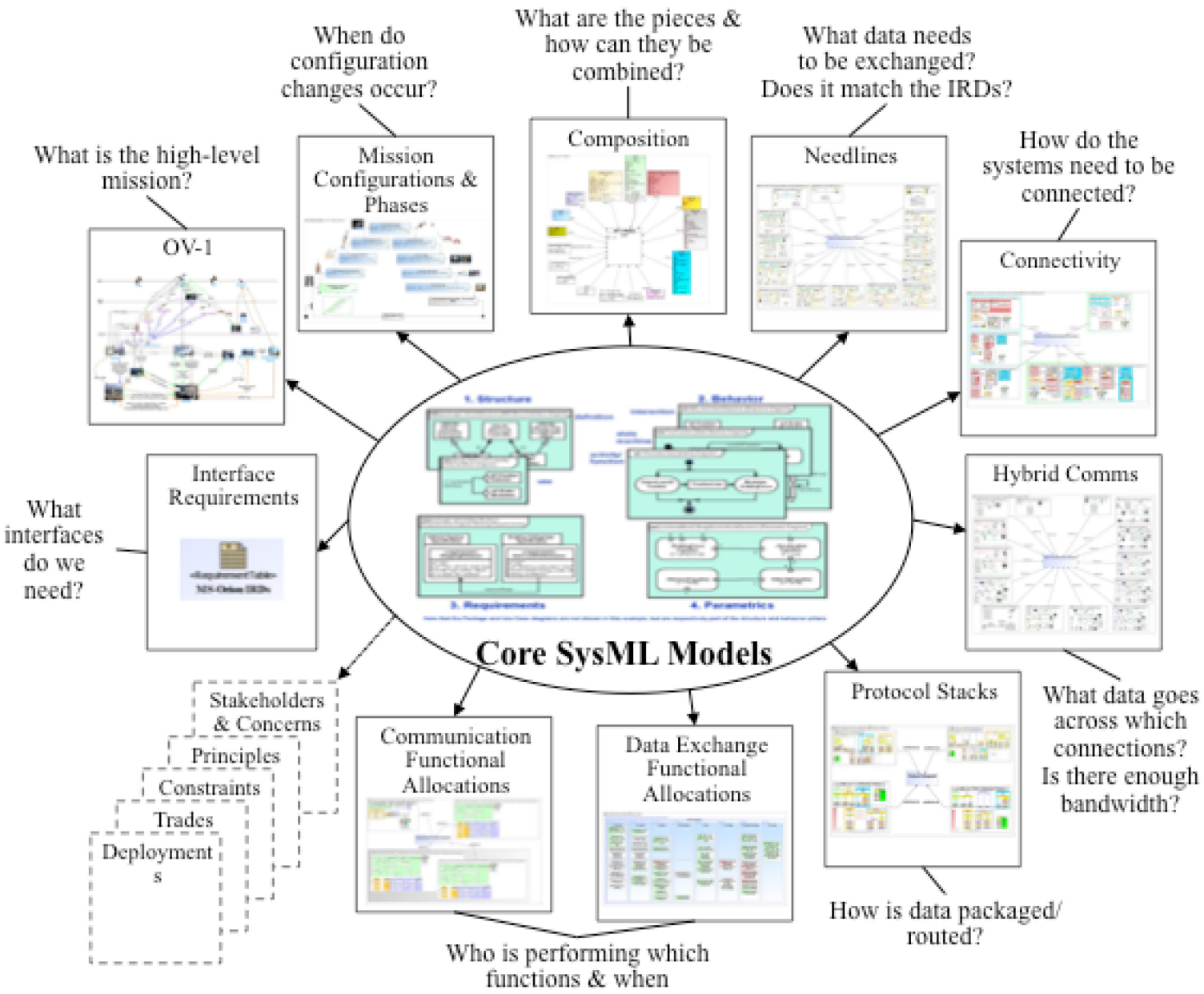
- **Work with the distributed NASA/LM team to understand mission needs, trade options, and establish baseline architecture.**

- **Use the Systems Engineering Markup Language (SysML) to define the models needed to capture relevant information**
  - Intent is to have a single authoritative source of information
  - Suitable for driving analysis/simulations (often via external tools) and capture results

- **Understand Key Stakeholder Concerns/Questions and address by defining Custom viewpoints (which also drives definition of model parameters.)**
  - What imagery will be available and when?
  - How will data be retrieved from Orion?
  - Who will have access to mission voice loops?
  - When will a command path to Orion be available?

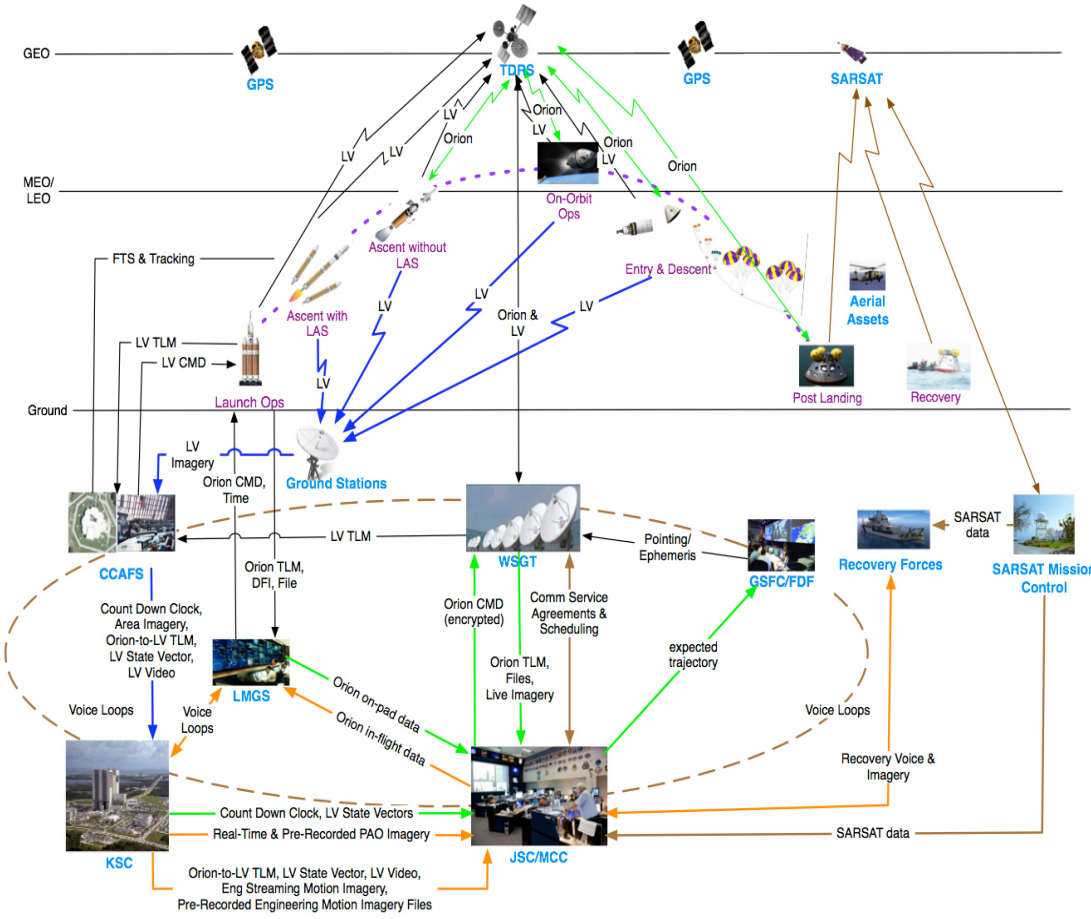
- **Tools**
  - MagicDraw/Teamwork for the complex modeling and visualization
    - Viewpoints, diagrams, defining the models & relationships
  - Web-based forms less technical interaction & wider access for engineers & manage

Key Questions and Viewpoints



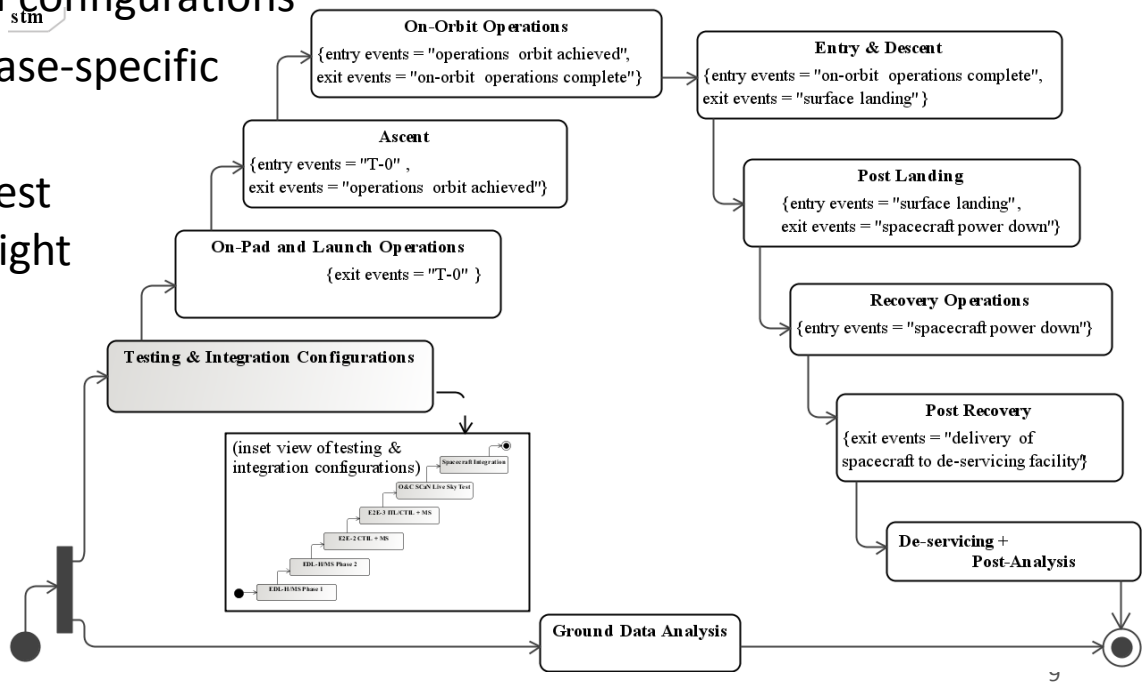
Viewpoint: Mission Overview

- **Key Questions:**
  - What is the big picture?
- **Viewpoint Features:**
  - Major: phases, assets, communications links, data flows, and deployments.
  - Object attributes drive color coding.
- **Uses:**
  - Single view that can be used as a high level description of almost everything else
  - Helps management understand the major players, how they interact, and the issues that need to be worked (color coded).



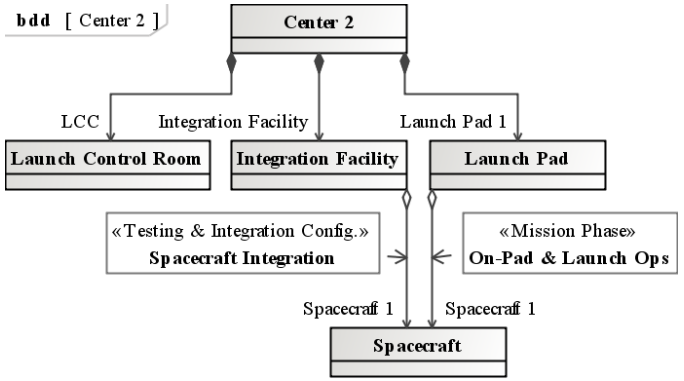
Viewpoint: Mission Configuration and Phases

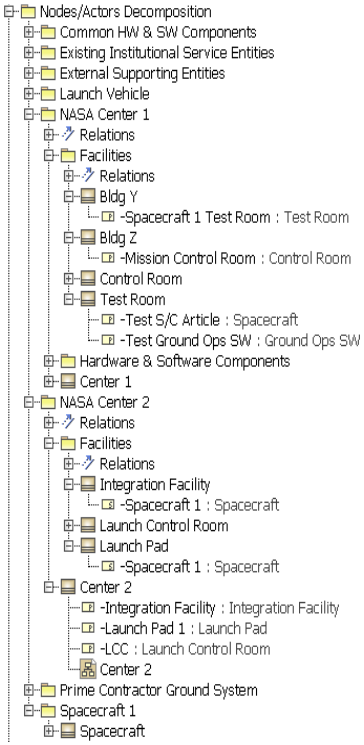
- **Key Questions:**
  - What are the major testing, integration and mission phases,
  - How does the configuration change between each of these?
- **Viewpoint Features:**
  - key phases and transition events
- **Uses:**
  - Provides a consistent vocabulary for talking about the mission phases and configurations
  - Basis for defining all other phase-specific configurations
    - E.g., connections during test vs on-pad operations vs flight



Viewpoint: Composition

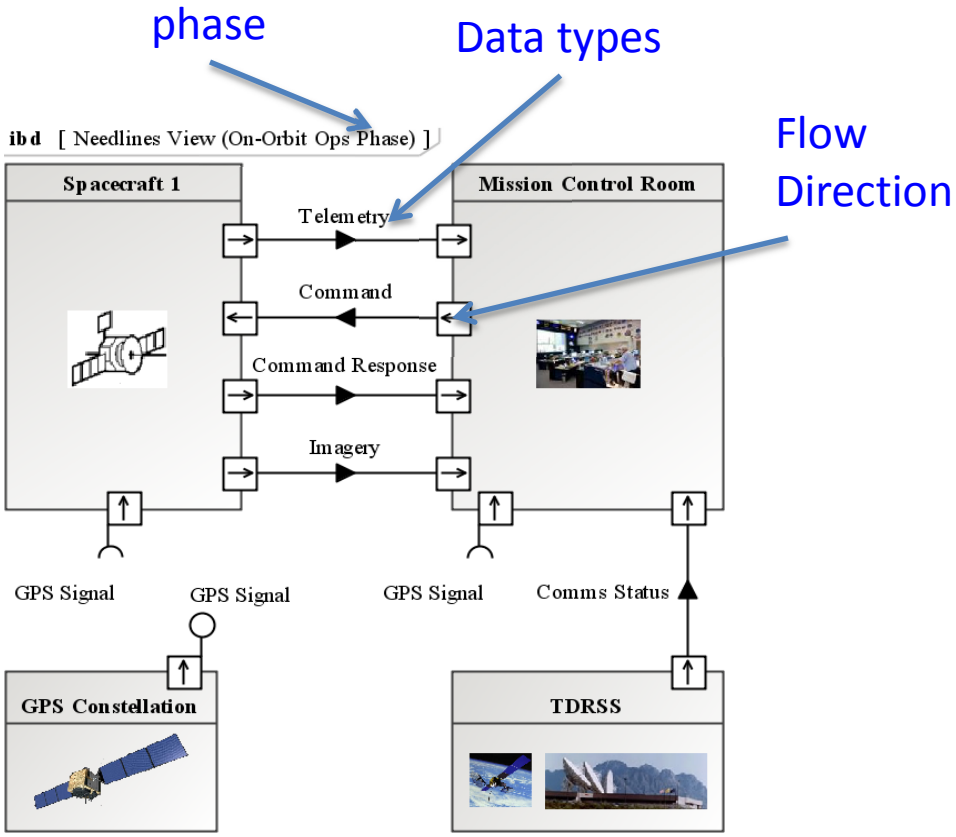
- **Key Questions:**
  - What are the major components?
  - How can they be combined?
  - What are the configurations during each mission phase?
- **Viewpoint Features:**
  - Hierarchical list of components (systems, hardware software, people, etc.)
  - Definition of how they are combined during each phases.
- **Uses:**
  - Clear definition of the components and how they are organized.
  - Understanding of components available/active in each mission configuration
  - Understanding of how components are composed into systems





Viewpoint: Needlines

- **Key Questions:**
  - What data needs to be exchanged between systems during each mission phase to meet the mission objectives?
  - What are its parameters (quantity, quality, security, etc)?
- **Viewpoint Features:**
  - key data exchange types and sources/destinations
- **Uses:**
  - Definition of data types,
  - Basis of Interface Requirements Documents (IRDs),
  - Understanding of what data will be exchanged during each mission phase

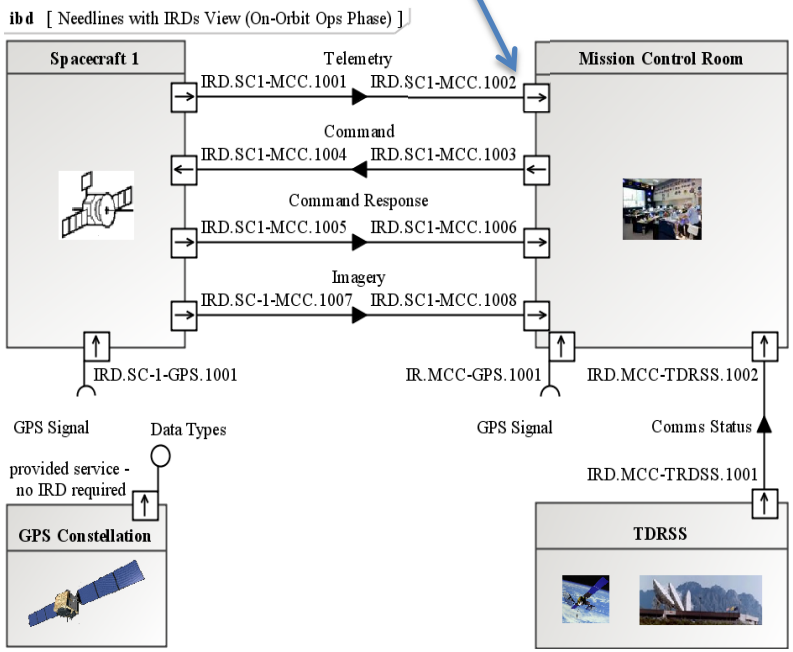


Needlines are also linked to :
* parameters about a particular flow during a specific phase.
* More precise definition of the data types.

Viewpoint: Requirements - IRDs

- **Key Questions:**
  - Are there gaps between the IRDs & the Needlines?
  - Which IRDs are on contract, funded, or <tbd>?
- **Viewpoint Features:**
  - Augments needlines with specific IRDs
  - Attributes of the IRDs (such as contract status) are used to color code the needlines/ports
- **Uses:**
  - Helps management understand the status of the IRDs versus operational data exchange needs
  - Provides an initial gap analysis
    - Needlines that don't have IRDs
  - Identifies exchanges we may not need to fund
    - IRDs with no corresponding needline

Ports are linked to IRDs

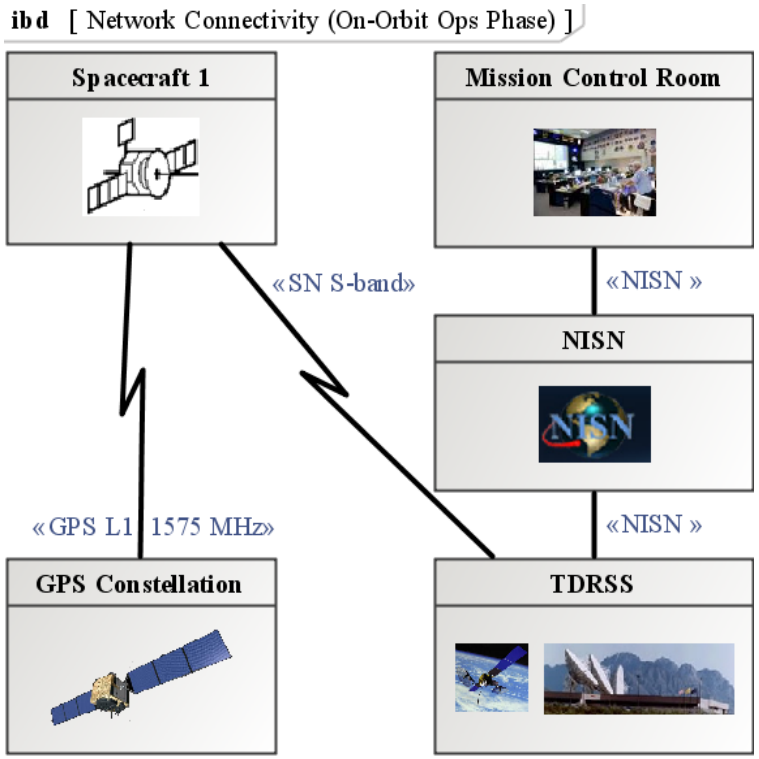


IRDs are managed in a data table which was imported from the IRD documents

* ideally the IRDs would be automatically generated from the needline models.

Viewpoint: Connectivity

- **Key Questions:**
  - How do the systems need to be connected?
  - What types of connections do we need (umbilical, RF, discrete, WAN, etc.)?
  - What are the parameters of each connection (data rate, security, completeness, reliability, etc)?
- **Viewpoint Features:**
  - Identifies Communications Providers
  - Major communications links and configurations between system.
- **Uses:**
  - Defines the high-level communications architecture (can be decomposed into lower level models)

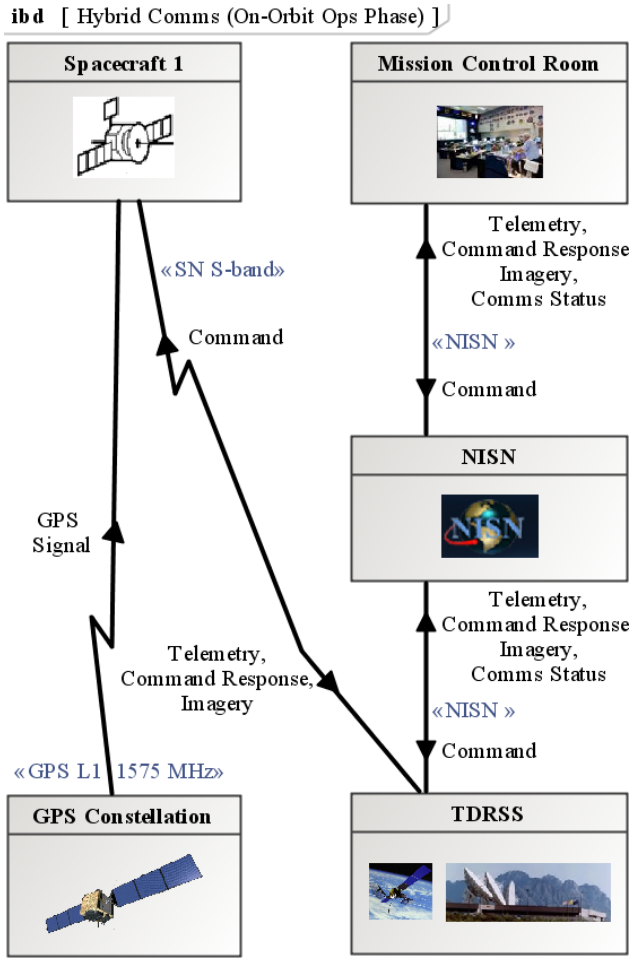


Each connection is linked to a configuration table that defines its unique parameters

* RF – frequency, modulation, framing protocol, SNR, BER, security, etc.
* WANs – bandwidth, reliability, security, routing, address allocations, etc

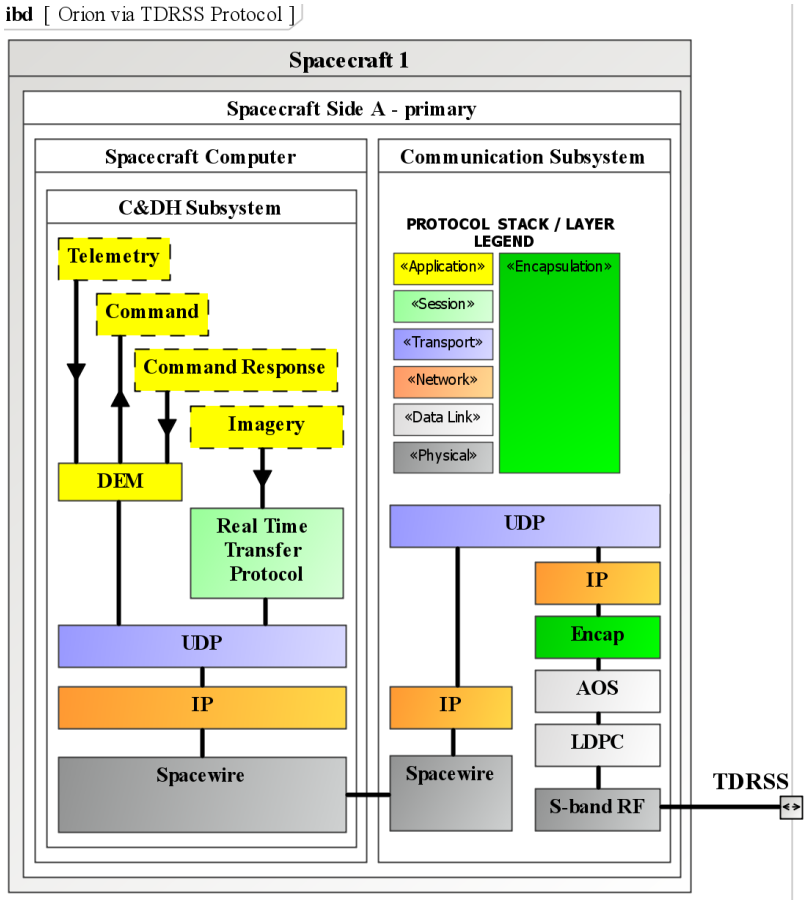
Viewpoint: Hybrid Needline-Connectivity

- **Key Questions:**
  - Which connections are used by which needlines?
  - Do the connections provide the needed capabilities?
    - Bandwidth, data reliability, latency, etc.
    - Security
- **Viewpoint Features:**
  - Overlays the needline flows on top of the connectivity views
    - Still linked to all the same information
- **Uses:**
  - Reasoning about the impact of the communications architecture on data exchange.
  - Allows high level modeling of the communications/data exchange architecture



Viewpoint: Protocol Stacks

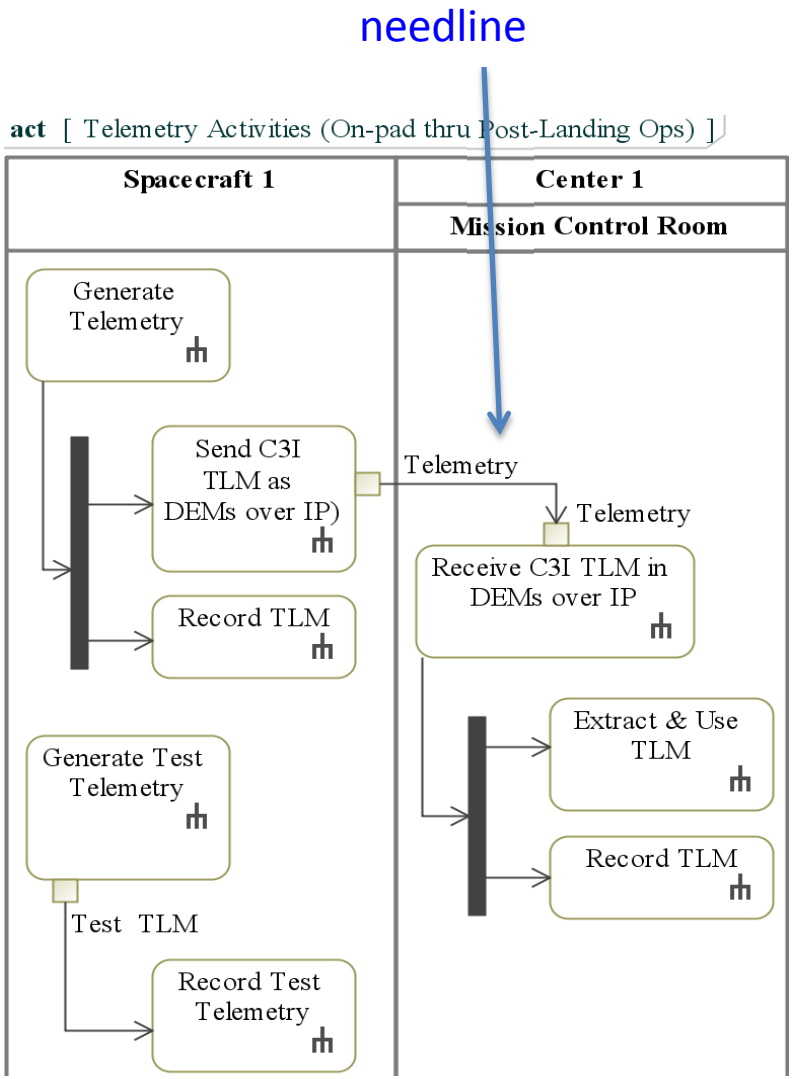
- **Key Questions:**
  - What communications protocols are used by the data exchanges and connections?
  - How are the protocols related?
  - What headers and overhead do they add?
- **Viewpoint Features:**
  - Relationship between data exchanges and protocols.
  - Relationship between protocols
    - Buffering, encapsulation, routing, etc.
- **Uses:**
  - Reasoning about the impact of the communications architecture on data exchange.
  - More precise modeling of the communications/data exchange architecture
  - Impact of integrating with other protocols



Currently the model only has high level parameters of the protocols (e.g., header size). We're working on modeling the behavior of the protocols (say retransmit on loss of packet)

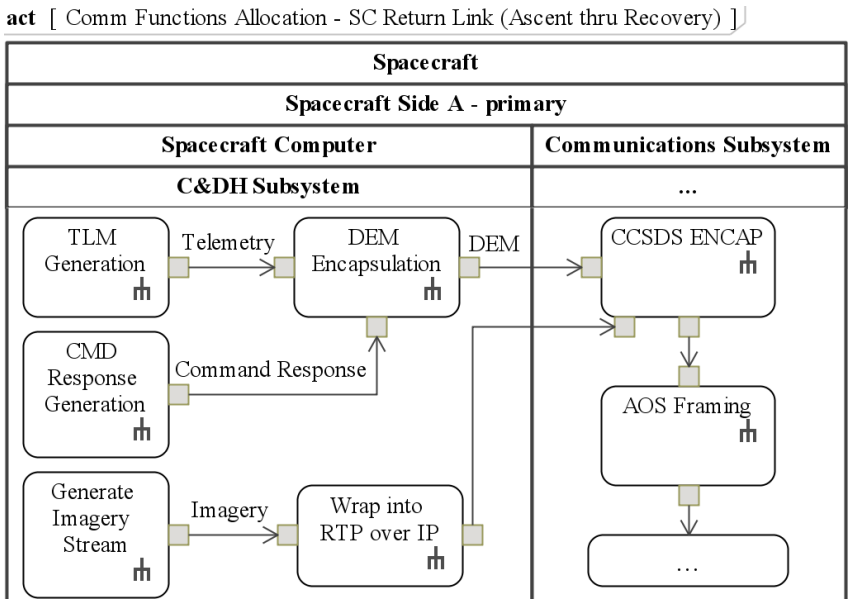
Viewpoint: Data Exchange Functions

- **Key Questions:**
  - What are the key functions for each type of data exchange and who is responsible for providing them?
  - Where are the authoritative & secondary data stores?
- **Viewpoint Features:**
  - Key functions and allocations to systems
  - Identifies the functions that are producing and consuming the needlines.
- **Uses:**
  - Common understanding of who is doing what and when.
  - Identifies all data exchanges and where data is stored (useful in planning for contingencies and showing that the architecture supports the analysis plan)



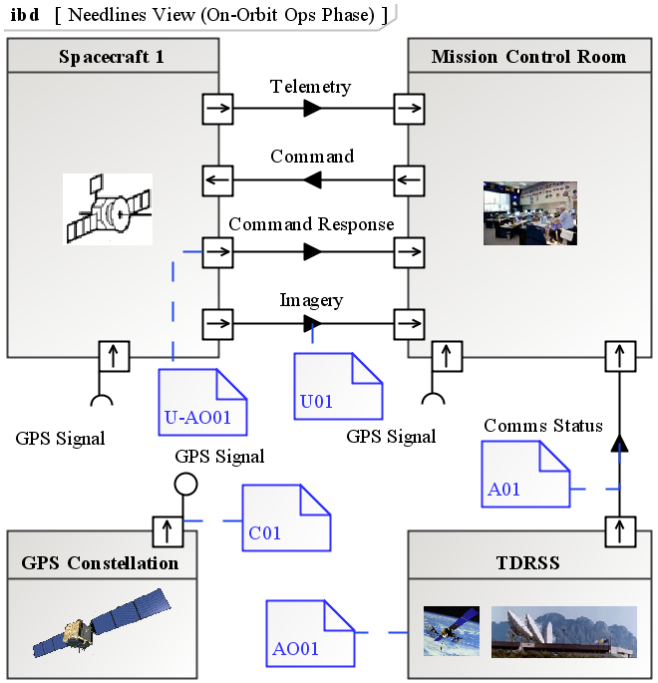
Viewpoint: Communications Functions

- **Key Questions:**
  - What are the communications functions for each connection?
- **Viewpoint Features:**
  - Key functions and allocations to systems
- **Uses:**
  - Common understanding of how the communication system functions.
  - During integration and test, also helped us understand which portions of the communications system were being emulated, simulated, or provided by actual systems.



Other Model Components: Comments

- **Features**
  - Objects are managed in a table and that can be associated with any part of the model and displayed on any of the views
- **Used to:**
  - Help clarify portions of the model or views
  - Identify areas where work needs to be done (questions, issues, discrepancies)



ID	Description
A01	Assumption is that TDRSS Comms Status updates will be provided same as on previous missions
C01	GPS is an existing service that S/C1 would use
U01	Unknown whether all of the on-board cameras will be sending imagery at the same time.
U-AO01	Unknown whether an entirely closed loop command and control loop is needed for all commands sent to the S/C. Alternatively, only mission critical commands should trigger command responses.
AO1	Alternatively, TDRSS could be supplemented by NEN ground stations.

Other Model Components & Viewpoints

- **Other Viewpoints (in the model, but not used in EFT-1)**
  - Stakeholders & Concerns
  - Constraints
  - Architecture Principles
  - Trades
  - Deployments

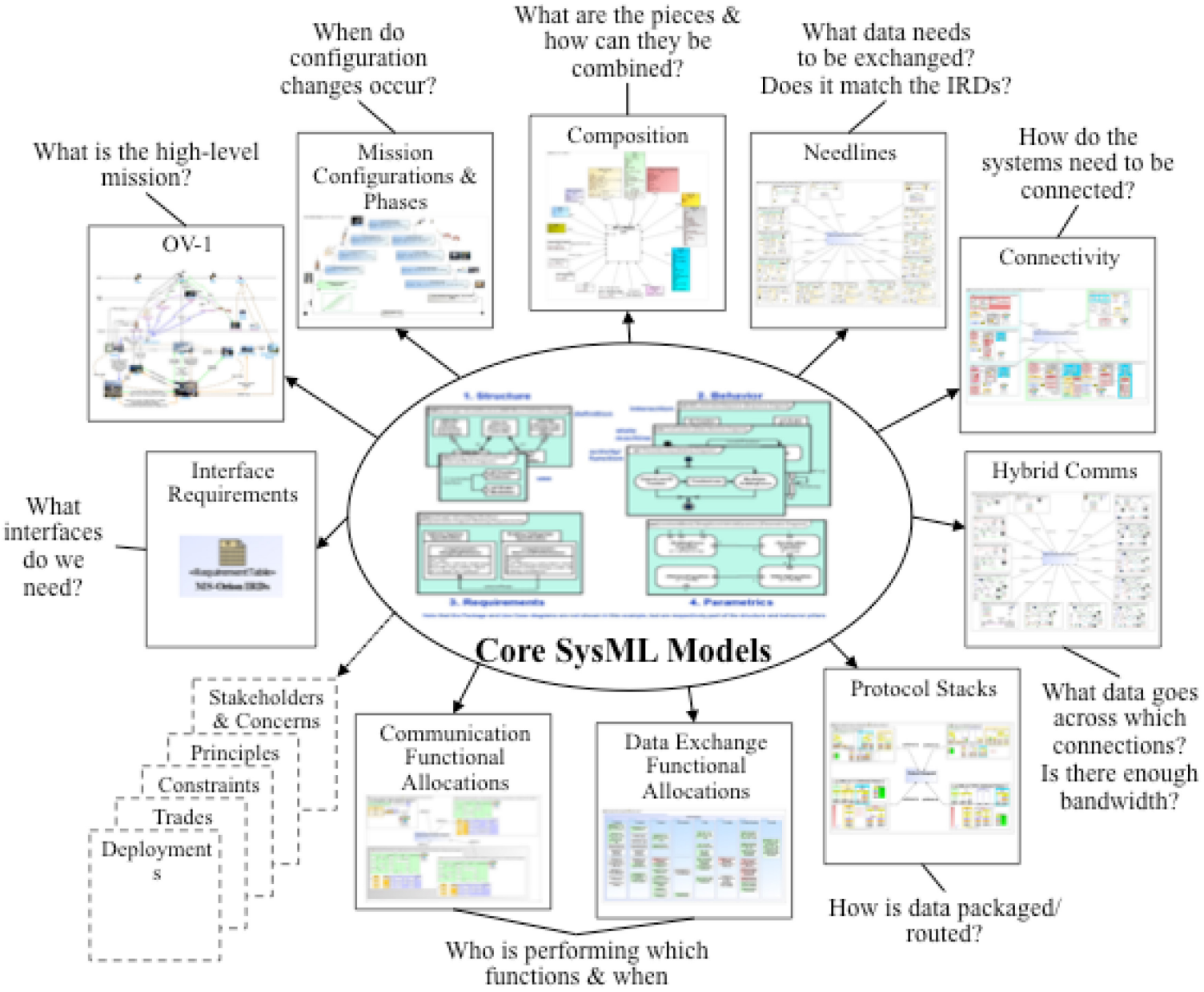
Advantages

- **Single Source of Truth (authoritative)**
  - Information is entered ONCE.
  - Consistent terminology, configurations, representations etc. across all products.
- **It's Alive!**
  - Model always reflects the latest/best information and decisions.
  - Updates are automatically applied across all products.
- **Shared Understanding**
  - Allows stakeholders to understand the system from "their perspective".
    - Addresses their concerns & understand how their pieces fit in.
  - Helps new users understand the system more quickly, and allows all users to explore/drill-down as needed.
- **Expressive but easy to understand.**
  - Can model complex relationships between systems (versus boxes and lines)
  - Produces products that are usable by both Humans and machine
    - Gate products for reviews
    - data and configurations to drive analysis and simulation
    - Promise of being able to support "what-if" trade analysis

Lessons Learned

- **Understanding stakeholders concerns is essential to designing the right viewpoints and capturing the right information**
- **The model-based approach must provide concrete value to the project, not just a different way of generating the same material.**
- **Teams more readily adopt the approach if (and only if)**
  - It directly helps them do their job – i.e., generates products they need in a format they can use, performs useful analysis, etc.
  - They have appropriate training & access to the tools.
  - They have support (a community of peers!) to resolve problems/questions.
- **Cross-pollination with other teams can be a big efficiency multiplier**
- **Modeling Tools are still catching up to the needs.**

Questions?


When do configuration changes occur?
What are the pieces & how can they be combined?
What data needs to be exchanged? Does it match the IRDs?
What is the high-level mission?
How do the systems need to be connected?
Mission Configurations & Phases
Composition
Needlines
OV-1
Connectivity
Interface Requirements
What interfaces do we need?
Hybrid Comms
Core SysML Models
Stakeholders & Concerns
Principles
Constraints
Trades
Deployments
Communication Functional Allocations
Data Exchange Functional Allocations
Protocol Stacks
What data goes across which connections? Is there enough bandwidth?
How is data packaged/ routed?
Who is performing which functions & when