26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

Insights from Large Scale Model Based Systems Engineering at Boeing

Robert Malone, Brittany Friedland, John Herrold and Daniel Fogarty

The Boeing Company


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Agenda

1. Why is Model Based Systems Engineering Important at Boeing?
2. What Benefit Does Boeing Derive from System Architecture Modeling?
3. What Insight Has Boeing Gained from Large Scale System Architecture Modeling?
4. What Support Does Boeing Require from Standards Associations, Industry and Academia?
5. Conclusion

Boeing at a Glance

- Customers and customer support in 150 countries
  - Total revenue in 2012: $81.7 billion
  - 70 percent of commercial airplane revenue from customers outside the United States
- Manufacturing, service & technology partnerships with companies around the world
  - Contracts with 22,000 suppliers and partners globally
- Research, design & technology-development centers & programs in multiple countries
- More than 170,000 Boeing employees in 50 states and 70 countries

A Sample of Diverse Boeing Products

Why is Model Based Systems (MBSE) Engineering Important at Boeing?

MBSE Comprises More Than One Type of Model

1. System Architecture Models

   - which feed and interact with -

2. Analytic Models
3. Verification Models

(John C. Watson, INCOSE IW 2012 MBSE Workshop, Systems Modeling)

MBSE Comprises More Than One Type of Model

1. System Architecture Models

   - Used to capture the system's behavior, structure, constraints, interfaces and requirements
   - Repository-based to define product entities and their inter-relationships
   - A vehicle to define the needed analysis task including the task's goals, imposed constraints, and assumptions

(John C. Watson, INCOSE IW 2012 MBSE Workshop, Systems Modeling)

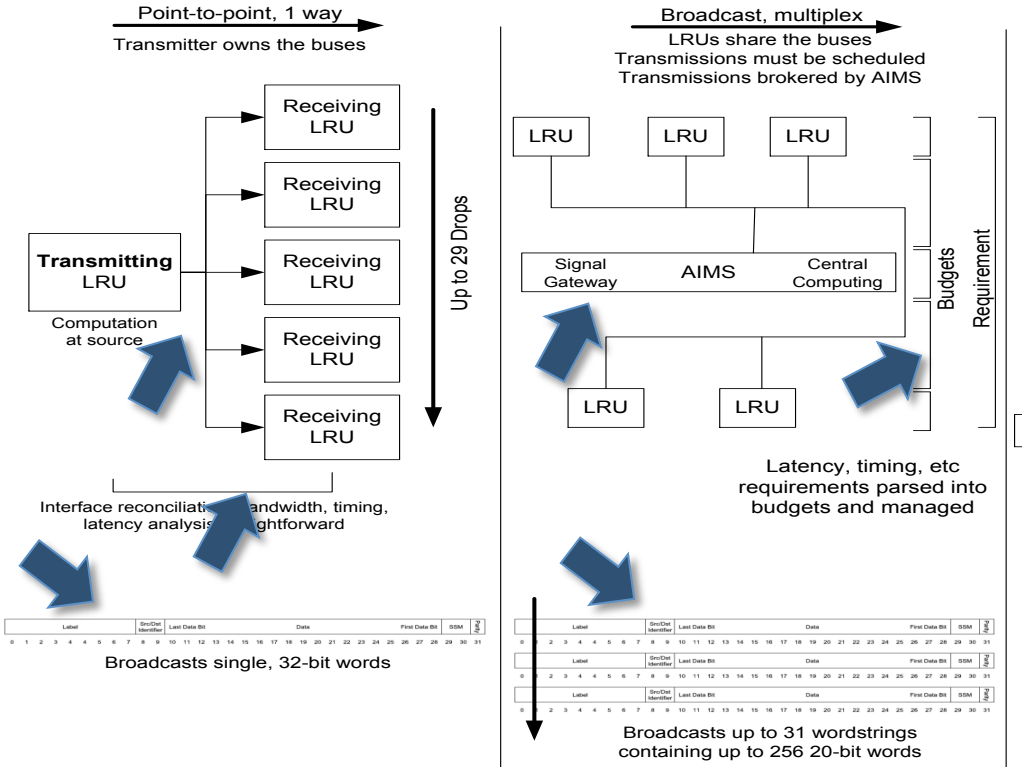
MBSE Comprises More Than One Type of Model

1. System Architecture Models

Address three major data management challenges:

- Bounding expanding data management effort resulting from integration of complex systems
- Coordination of data management activities within a global supplier base
- Schedule and cost risk imposed by the above

Evolution of Aerospace Systems Integration



Benefits of IMA:

- ***Performance***
- ***Weight Reduction***
- ***System Stability***

Importance of MBSE

A429 Network

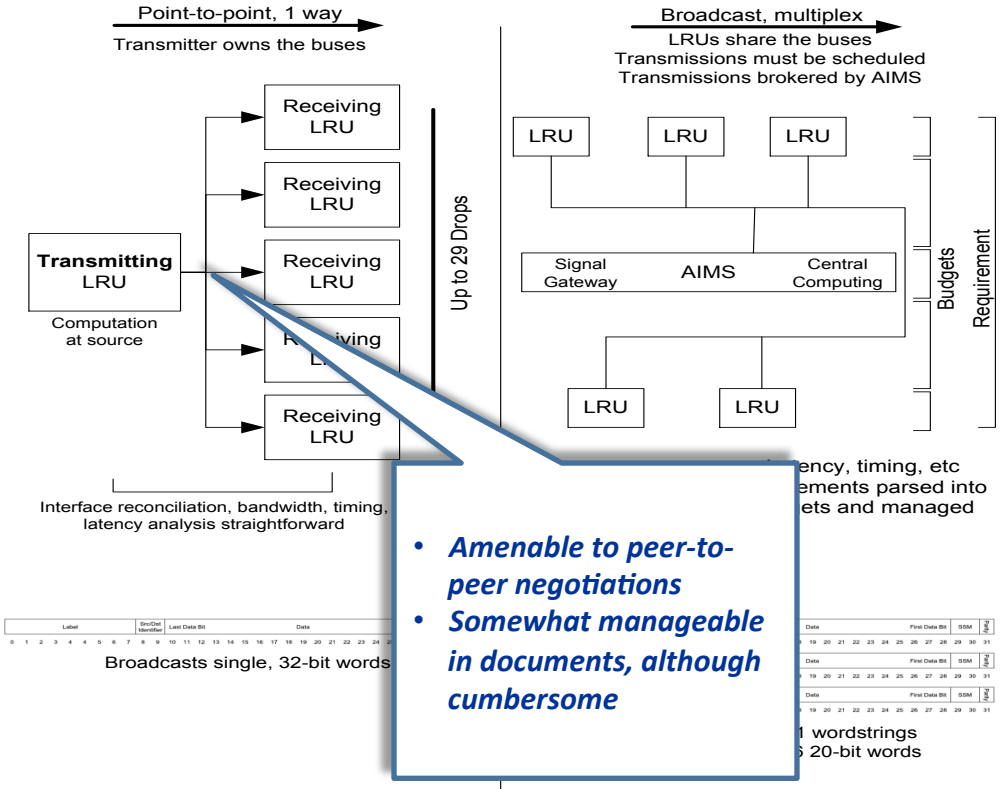
A629 Network

Integrated Modular Architecture (IMA)
A664 Network

Acronyms

AIMS - Airplane Information Management System
CAN - Controller Area Network
CCS - Common Core System
IMA - Integrated Modular Architecture
LRU - Line Replaceable Unit
RDC - Remote Data Concentrator

Evolution of Aerospace Systems Integration



- ***Amenable to peer-to-peer negotiations***
- ***Somewhat manageable in documents, although cumbersome***

- ***Peer-to-peer negotiations impossible***
- ***Management in documents untenable, modeling necessary***

A429 Network | **A629 Network** | **Integrated Modular Architecture (IMA) A664 Network**

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AIMS - Airplane Information Management System
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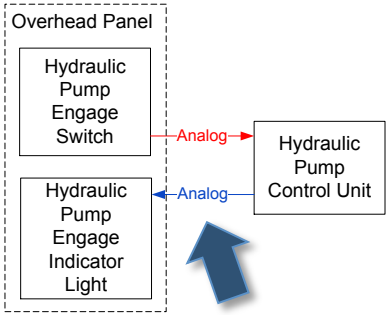
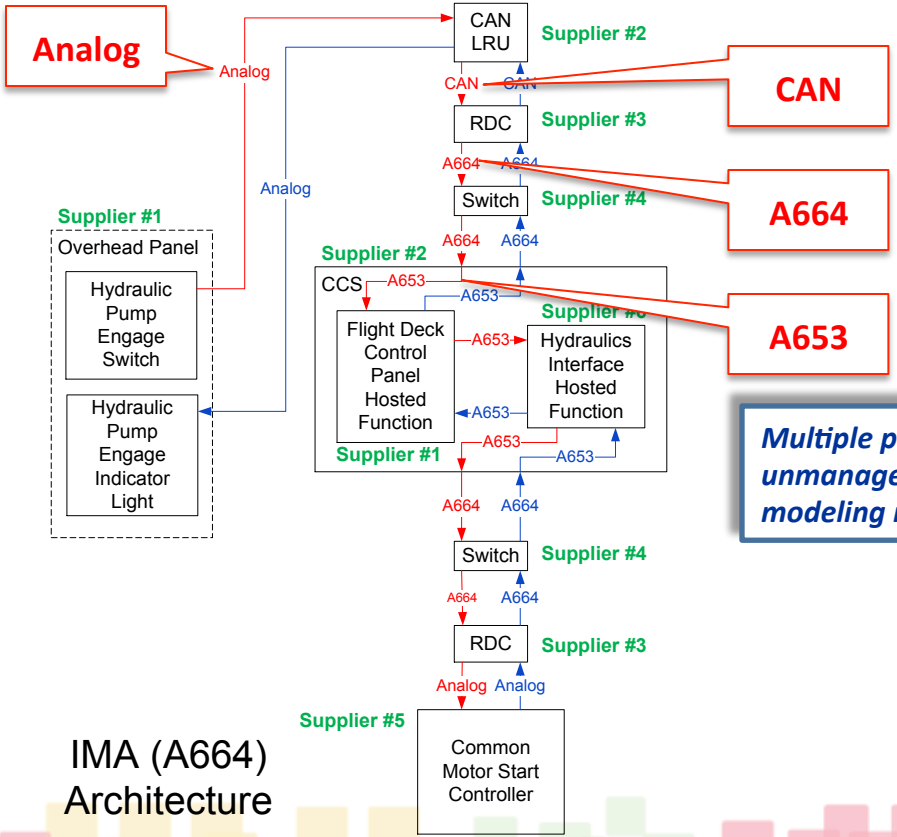
Importance of MBSE

Illustrative Example of Digital Networks Evolution



Legacy Architecture

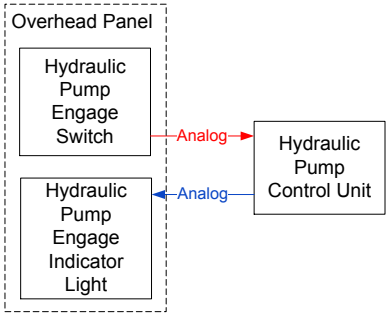


IMA (A664) Architecture

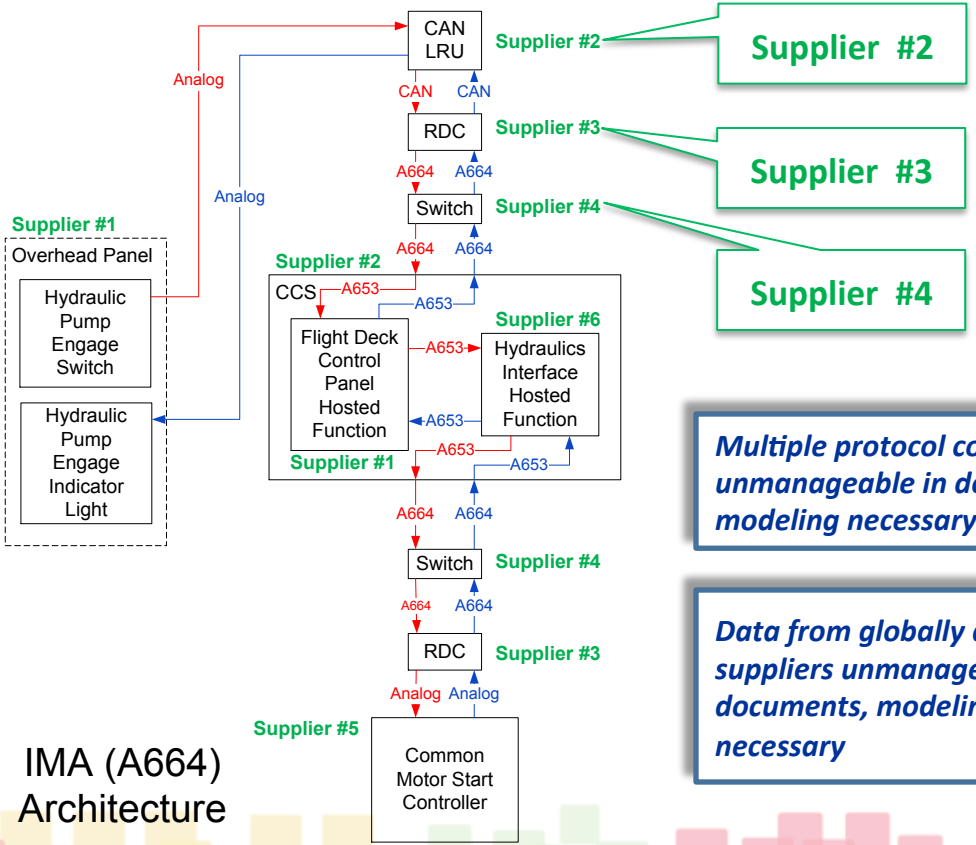
Multiple protocol conversions unmanageable in documents, modeling necessary

Importance of MBSE

Illustrative Example of Digital Networks Evolution



Legacy Architecture



IMA (A664) Architecture

Supplier #2

Supplier #3

Supplier #4

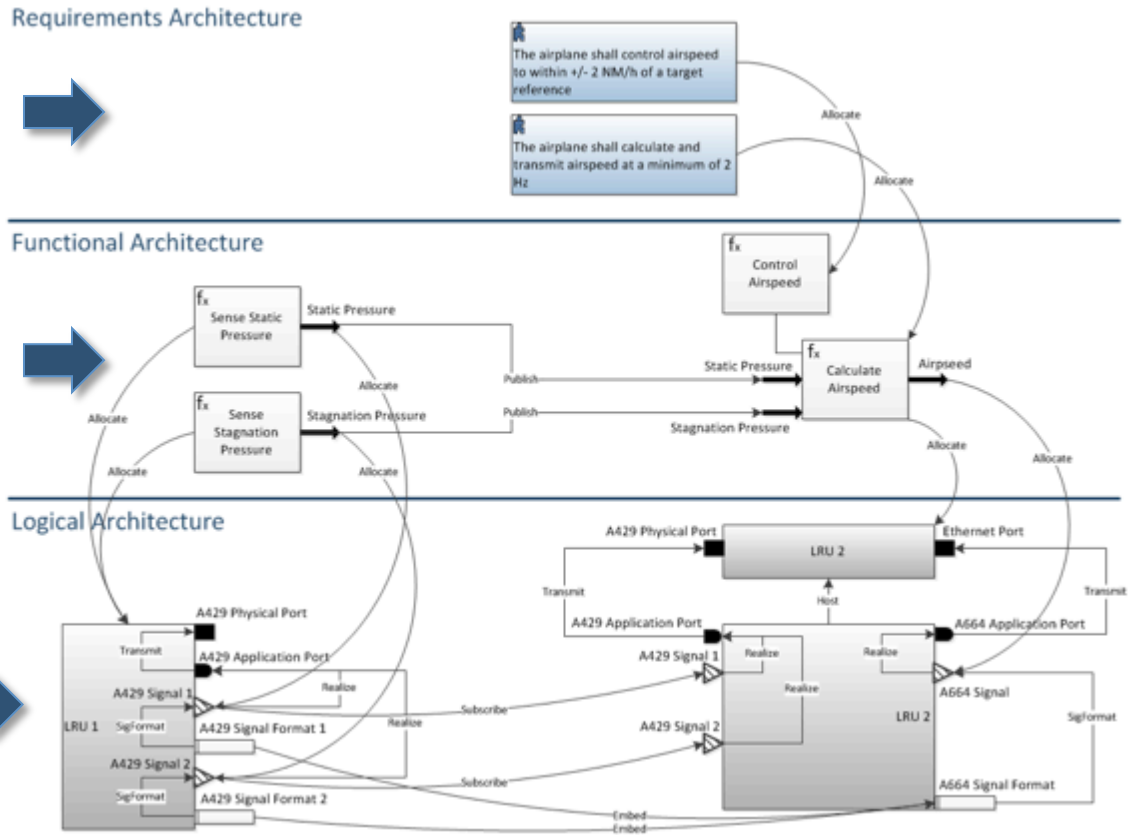
Multiple protocol conversions unmanageable in documents, modeling necessary

Data from globally distributed suppliers unmanageable in documents, modeling necessary

Importance of MBSE

What Benefit Does Boeing Derive from System Architecture Modeling?

A Simple Integrated System Architecture Model



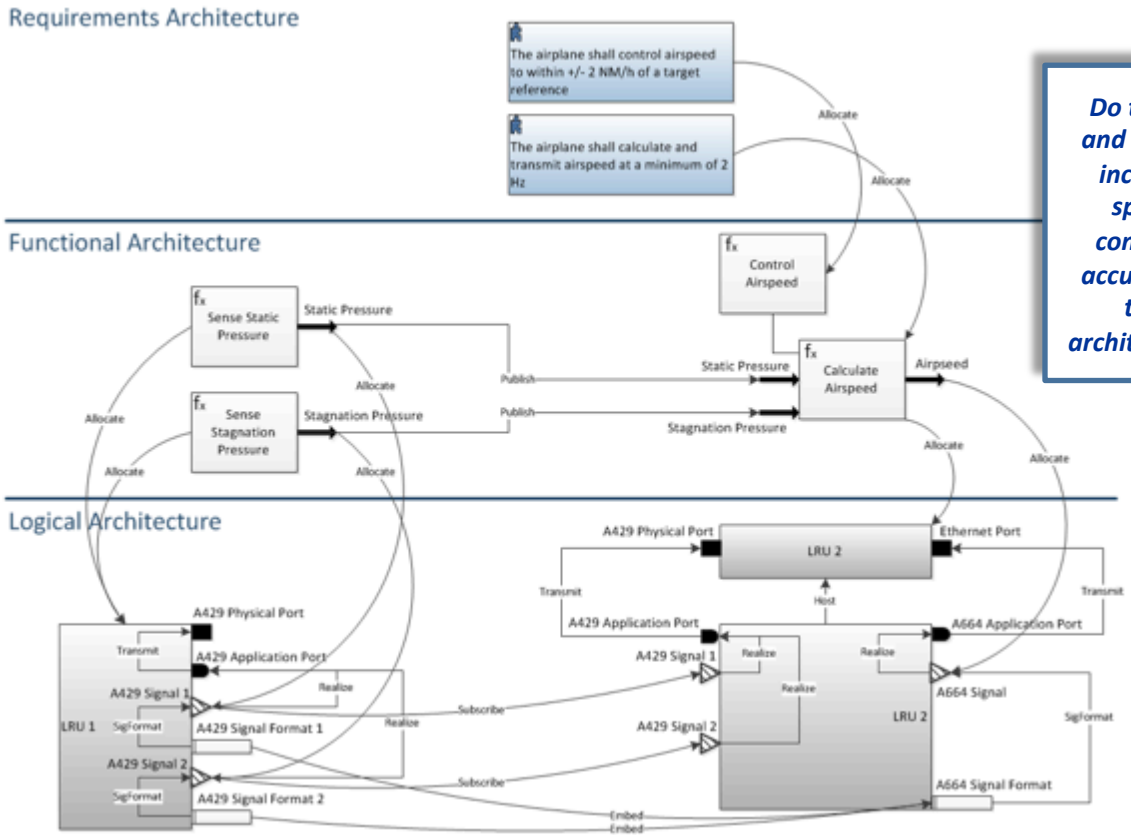
How Well

What Has to be Done

How it is Done

Benefit of MBSE

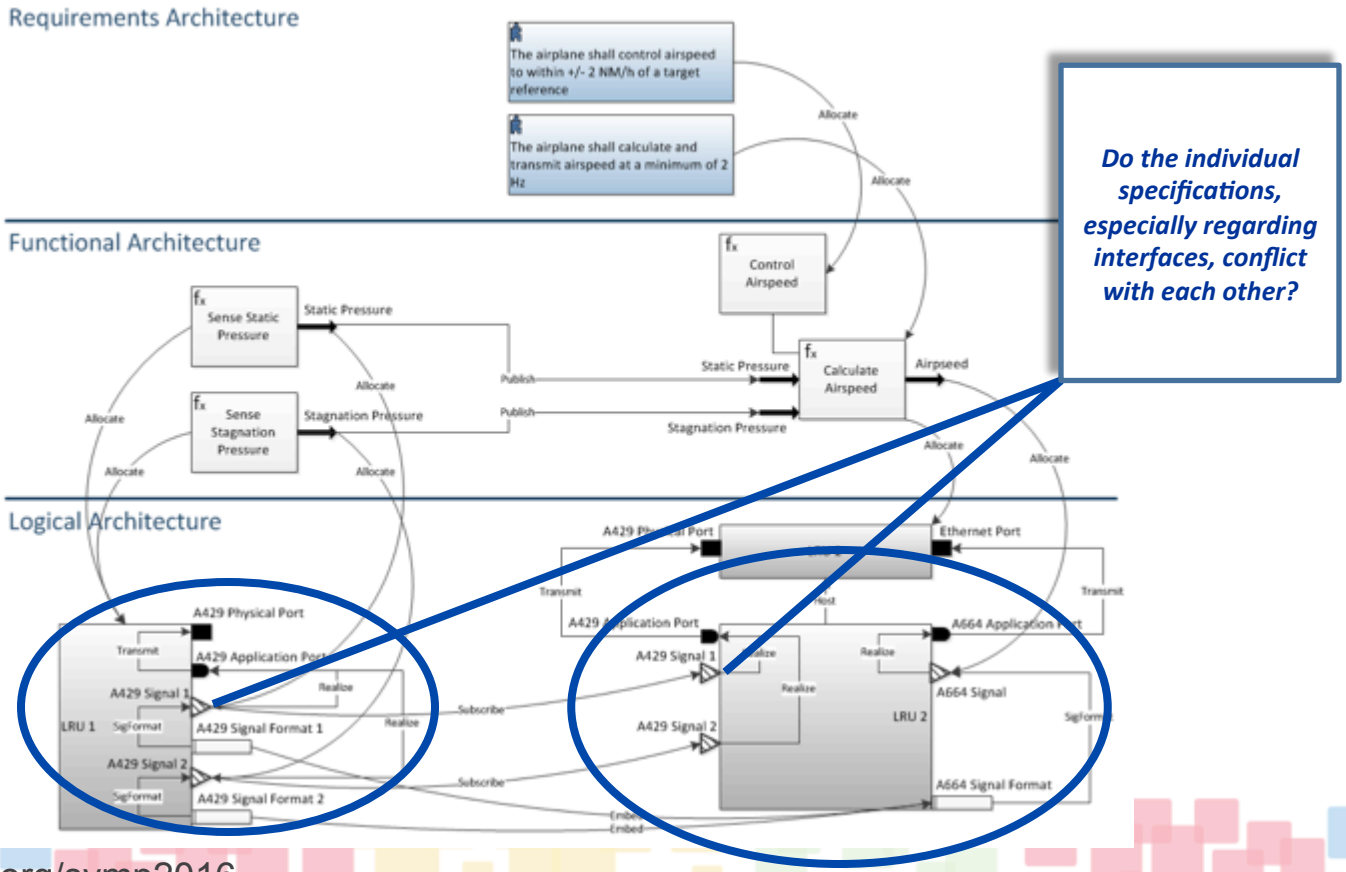
A Simple Integrated System Architecture Model



Do the functions and requirements included in the specification completely and accurately specify the logical architecture model

Benefit of MBSE

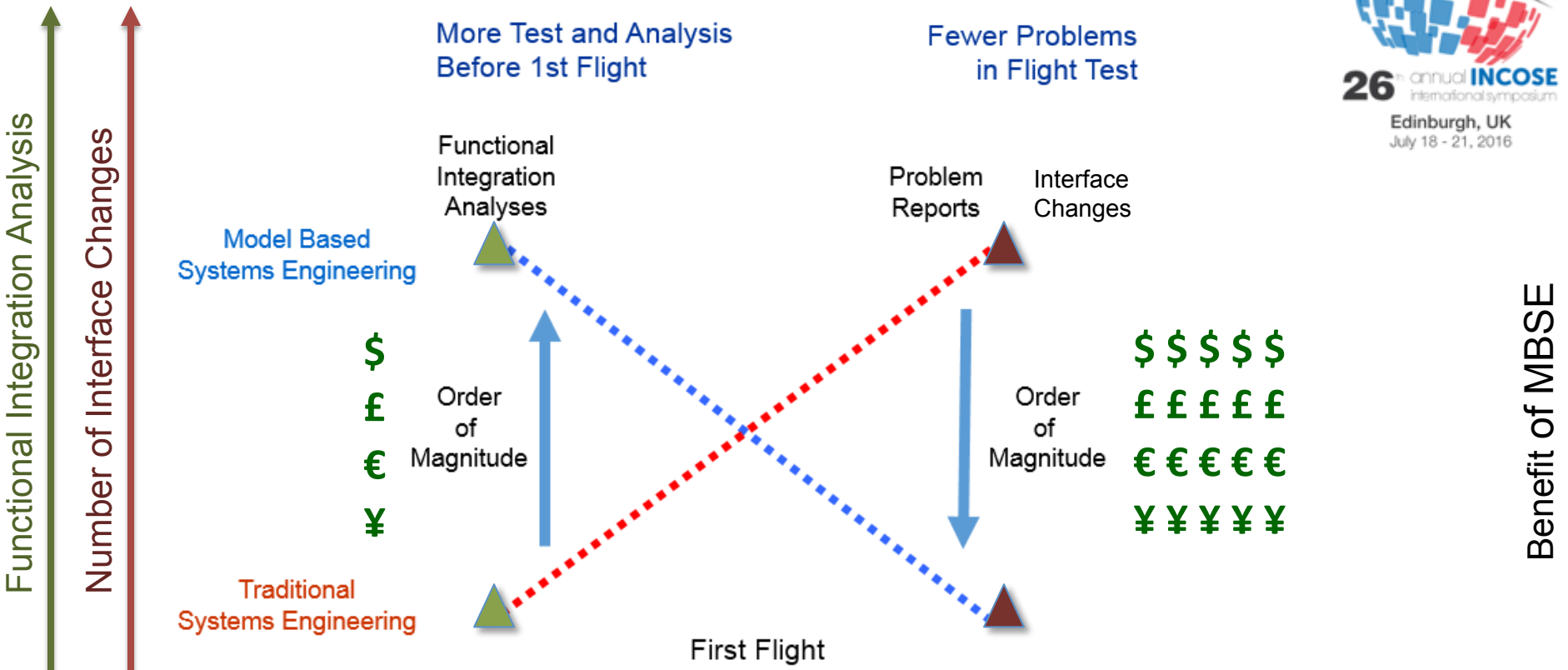
A Simple Integrated System Architecture Model



Do the individual specifications, especially regarding interfaces, conflict with each other?

Benefit of MBSE

Avoiding Test Errors Through Early System Architecture Modeling



What Insight has Boeing Gained from Large Scale System Architecture Modeling?

Large Scale, Highly Integrated Systems : Large, Highly Integrated Models

Typical Digital Networks System Architecture Model Data Volume (Tens of GBytes)

~1,000 modelers

Functions	~2,300
Functional Data Flows	~10,000
Equipment Installations	~5,000
Data Parameters Processed by Installed Equipment	~1,000,000
Electrical Connections Between Installed Equipment	~9,000
Objects in Model	~ 50,000,000 (~ 3 relationships (links) per 1 object)

Insights

Effective Modeling Requires Multiple Model Views

- Diagramming view impractical to create and view 50,000,000 objects and relationships
  - Time required to populate diagrams unacceptable
  - Number and size of diagrams untenable
- Diagramming view impractical to analyze 50,000,000 objects and relationships for integrity
  - Human analysis of drawings too slow and error prone
- Modeling tasks shift from structure (diagrams) to detail and analysis (querying) as model matures and grows.
- Need several model views to efficiently populate and review data:
  - Spreadsheet Views
  - Document Views
  - etc

Insights

Other Insights

- Extensibility of the Modeling Environment is Essential
  - Higher fidelity models allow more precise analysis
    - Precise analysis captures specific design problems/errors early
  - Higher fidelity models require more detailed underlying data models
  - Boeing digital avionics data model comprises several dozen object types, several hundred relationship types, several thousand object attributes
- Import/Export Utilities Are Critical
- The Dataset Is The Model
  - Artifacts are views of the model
  - Model sharing is dataset sharing

Other Insights

- A Standard Modeling Notation does not Achieve Data Integrity
  - A standard data model constrained by rules achieves integrity
- Model Analysis Utilities Are Critical (Query Engine)
  - Detecting modeling errors reduces schedule and cost risk
  - Takes longer to produce data in a database than in standard desktop applications (point of contention among users)
  - Payoff is the ability to analyze integrated model data for completeness and correctness
  - Well formed set of model analysis queries allow people not involved in system design nor model development to detect thousands of modeling errors daily

What Support Does Boeing Require from Standards Associations, Industry and Academia?

Support from Standards Associations, Industry and Academia

- Standards Associations
  - Standard MBSE data models, and accompanying composition/aggregation/construction rules
  - Data exchange and schema standards

- Boeing participating in INCOSE WGs
- Potential Boeing MBSE data model paper at IS 2017

Help Needed

Support from Standards Associations, Industry and Academia

- Industry
  - A suite of tools based on a robust, flexible hub that provides multiple data creation and manipulation views, with data exchange utilities
    - persistent, robust database that allows hundreds of users to modify the models simultaneously and globally
    - extensible data model that can be easily constrained by a rule set
    - extensible API to support customized data creation and manipulation utilities
    - rich, natural language query engine
    - industry standard import/export utility
- Potential Boeing trade study paper at IS 2017

Help Needed

Support from Standards Associations, Industry and Academia

- Academia
  - Architects: MBSE tool and process architecting established as a component of MBSE course curricula
    - Use case, process and task, data model, business rule development
  - Practitioners: Modeling principles taught as part of MBSE curricula, before the use of any particular modeling tool or language
    - Develop skills in extracting data and relationships from documents
    - Develop skills in effectively organizing data in terms of objects, relationships, attributes

Help Needed

Conclusion

Conclusion

- System architecture models indispensable at Boeing
- High fidelity modeling allows Boeing to accelerate development schedules
- Large model datasets bring data management challenges
- For large scale system architecture modeling, MBSE community should pursue:
  - standard data models and modeling rule sets
  - robust, capable tools; and,
  - education for tool and process architects and modeling practitioners

Questions?