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ROLLS ROYCE

Economic Benefits of Vertical Alignment

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"Good teams become great ones, when the members trust each other enough to surrender the 'me' for the 'we'."

Phil Jackson

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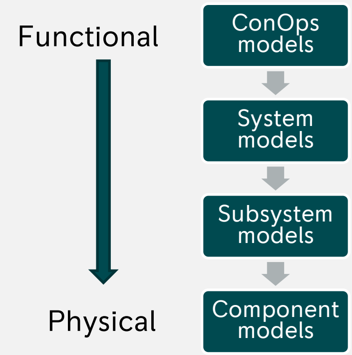
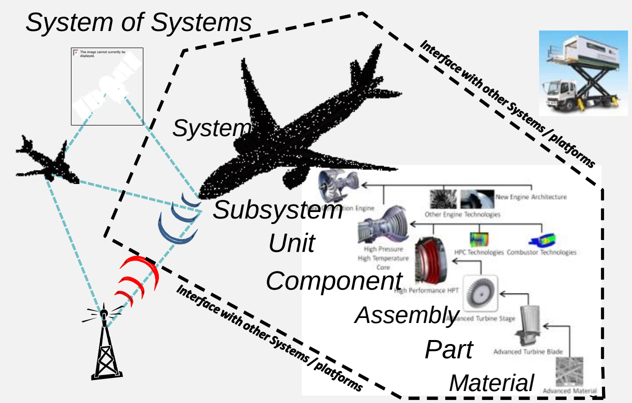
19 October 2018

Agenda

Context for presentation



Functional system decomposition allocated to physical system



Physical allocations from multi-disciplinary team spanning multiple organizations (e.g. vertical alignment)*

Source:
*Jimenez, French. "SE_CoS_for_G135_Face_to_Face_Meeting." AIAA Aerospace Systems Integration Working Group, PowerPoint Presentation, January 2012

Costs Increase Across a Full Life Cycle

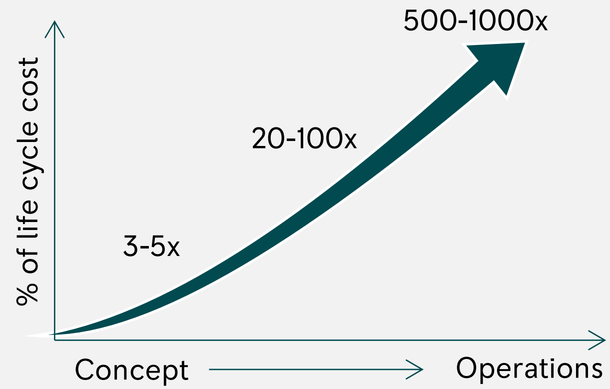
Defects are not like wine; they don't get better with age

Program costs can be reduced by:

- Making early decisions with good information and analysis
- Removing errors early in the life cycle
- Quickly managing impacts downstream to conceptual changes
- Representation from all skillsets in early life cycle phases

Program costs will be increased through:

- Hasty conceptual commitments without stakeholder buy-in through concurrent design
- Insufficient planning for incremental improvement (plan for requirements to evolve)
- Unaccounted uncertainties due to long development periods

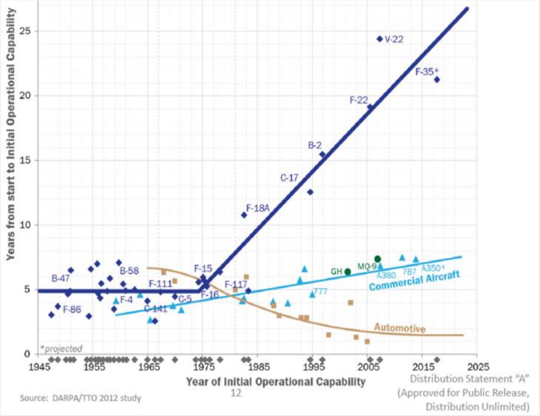


The time value of money is demonstrated by the increase in the amount of late life cycle dollars to fix problems; a dollar's value decreases the later a defect is found

Defense Aerospace Trends are Unsustainable

Programs are becoming less efficient

- New Program Introduction (NPI) to Initial Operating Capacity (IOC) time duration increases program schedule
- Program schedule increases directly impact program costs
- Defense aerospace programs need to implement costly mitigations to late life cycle defects
- Need to address early phases of a programs life cycle to establish architecture capable of incremental change across multiple skillsets
- Multiple skillsets found within multi-disciplinary team spanning multiple organizations



"Hockey stick chart" showing unsustainable military aerospace costs[1]

[1]Source: Patt; DARPA/TTO Study; 2012

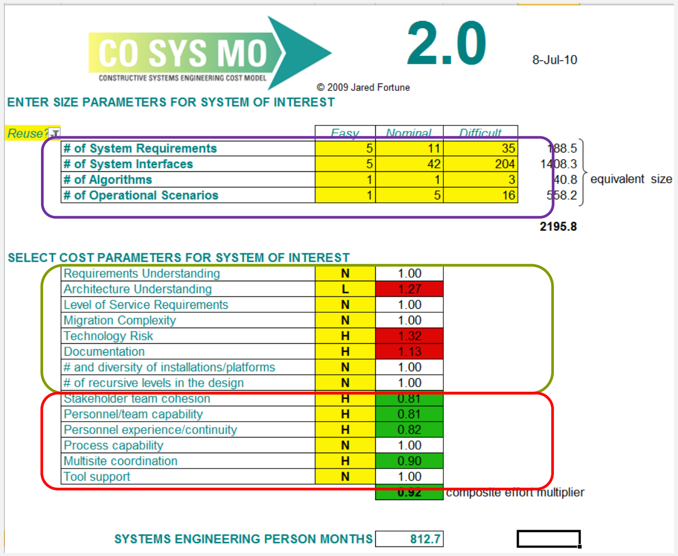
Team Dynamics Contribute to Inefficiencies

Program efficiency possible through systems engineering team effectiveness

COSYSMO addresses first four phases of a programs life cycle by estimating systems engineering scope through two categories of parameters

1. Size drivers → additive & incremental
2. Effort multipliers → multiplicative and system-wide
   - 8 of 14 multipliers require <u>team understanding</u>
   - 6 of 14 multipliers are <u>team dynamics</u>
   - Directly impact program cost parameters as <u>effort multipliers</u>

Assessing systems engineering effectiveness shows direct correlation to program cost overruns[1]



CO SYS MO 2.0 — CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL — 8-Jul-10 — © 2009 Jared Fortune

ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

Reuse?	Easy	Nominal	Difficult	
# of System Requirements	5	11	35	188.5
# of System Interfaces	5	42	204	1408.3
# of Algorithms	1	1	3	40.8
# of Operational Scenarios	1	5	16	558.2
				2195.8 equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	N	1.00
Architecture Understanding	L	1.27
Level of Service Requirements	N	1.00
Migration Complexity	N	1.00
Technology Risk	H	1.32
Documentation	H	1.13
# and diversity of installations/platforms	N	1.00
# of recursive levels in the design	N	1.00
Stakeholder team cohesion	H	0.81
Personnel/team capability	H	0.81
Personnel experience/continuity	H	0.82
Process capability	N	1.00
Multisite coordination	H	0.90
Tool support	N	1.00
		0.92 composite effort multiplier

SYSTEMS ENGINEERING PERSON MONTHS 812.7

COSYSMO model estimates amount of systems engineering effort needed[2]

Sources:
1. Honour, E.; Systems engineering ROI; 2004
2. Fortune, J.; Academic COSYSMO 2.0 tool; 2009

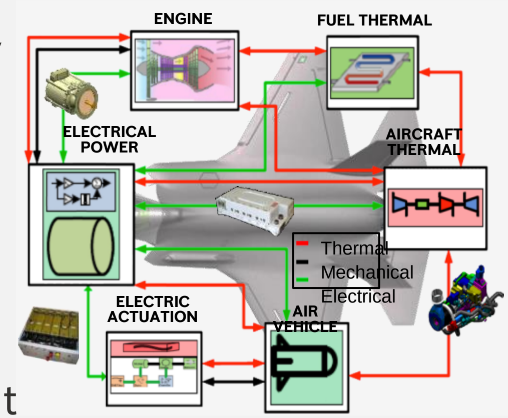
Case Study Introduction

Prediction that conventional 'cut & try' approaches add cost & delays

New design process required for identification and down-select of promising alternative architectures for increased aircraft complexity found in Energy Optimized Aircraft (EOA)

Process shall account for EOA attributes[1]:

- Revolutionary capabilities / architectures
- Multi-level modeling and simulation (M&S)
- Collaborative working environment
- Concurrent efforts on advanced component and subsystem development
- Must account for "entire" energy picture[2]
- Flexibility to support emerging capabilities[2]
- Vehicle level system assessment and optimization requires complex highly integrated models[2]
- Open design space for supporting technologies and architectures
- Full system architecture exploration requires significant resources



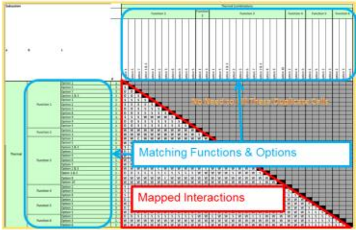
Tri-Service depiction of EOA subsystem interfaces[3]

Sources:
1. EOA Steering Committee Charter; 2011
2. Wolff, M.; "Tip-to-Tail" Energy/Engine/Power/Thermal MS&A; AFRL; 2010
3. Greek, C.; Air Force Overview, EOA Steering Committee; 2016

Case Study Estimates

Two types of team approaches

Estimated ~5x benefit through team changes only



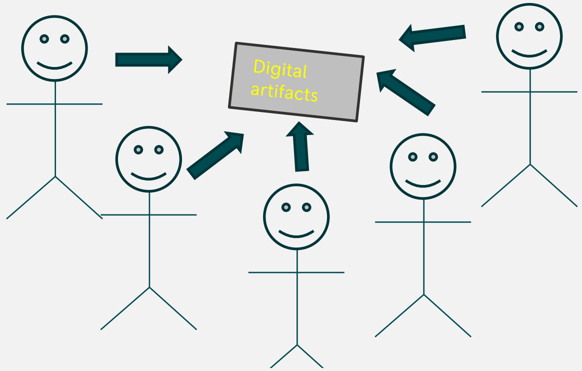
Correlation matrix sample*

Traditional 'cut & try' approach

"Throw it over the wall"

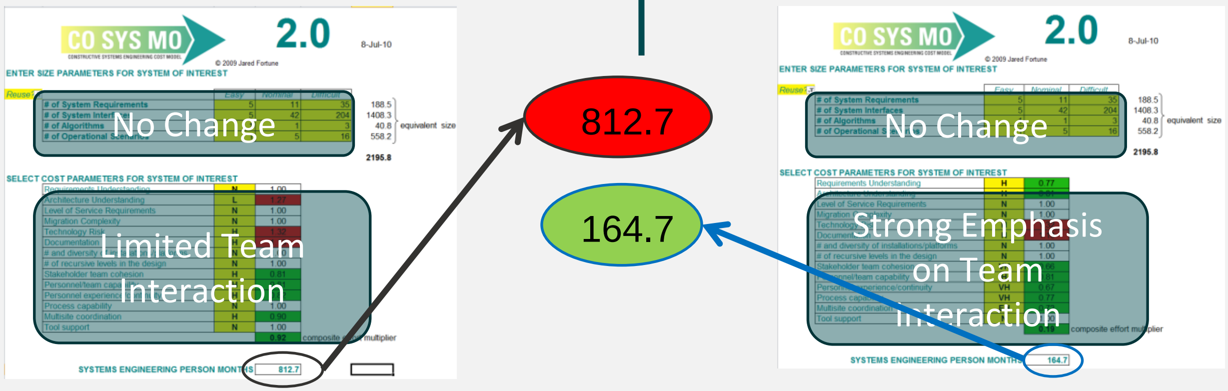
- Federated subsystems
- Organizational silo's
- Discipline silo's
- Limited horizontal cross-talk
- Limited vertical visibility
- IP Restricted
- Incremental arch development

Vertically aligned 'IPT' approach



"Collaborative Discussion"

- Multiple correlations matrices
- Co-located teams
- No IP barriers – team wins
- Better first time
- Multi-organizational team
- Multi-disciplinary team
- Concurrent team approach



Source: One of 14 linked correlation matrices described in AIAA 2013-0882

Case Study Results – Concept Phase Only

Results confirm estimates and show ~5x cost savings ratio through vertical alignment

	Cost per model ($M)	# of models needed using Cut & Try Approach	# of models needed using Integrated team Approach
Conceptual models	1.4	9	2†
Detailed models	2.9	3	1
NPW ($M)		-21.4	-4.3
FW ($M)‡*		-29.3	-5.9

Case study baseline:

- Limited to architecture development in Concept Phase
- Assumed no future iterations needed
- Assumed no forecasted interest rate changes
- FW estimates limited to today's architecture modeling expenditures

Significant performance improvement:

- Team achieved >100% improvement over baseline aircraft
- USAF expected ~40% improvement
- Two independent teams achieved similar results with differing costs

†Provided 2 conceptual level models, of which the second built off the first with cost equal to 1 conceptual model
‡Used 10 year DoD life cycle from NPI to EIC per USC SAE560[1]
*Used 3.2% interest rate per Deloitte forecast[2]

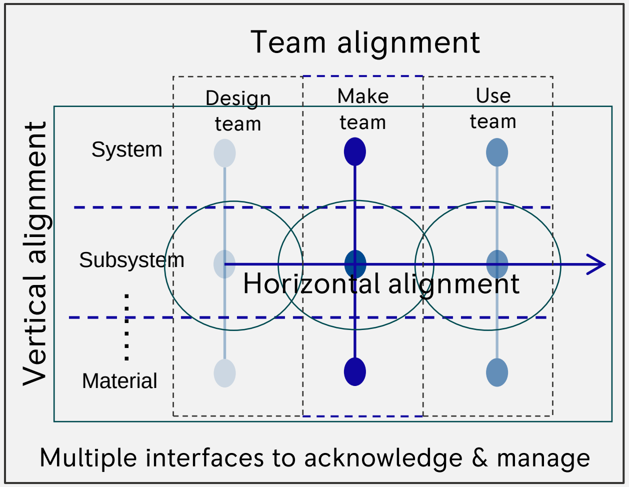
Sources:
1. Hihn, J.; USC SAE560
2. Deloitte; Global aerospace and defense sector outlook; 2017

Future Work – Horizontal Alignment

Product validation through vertical & horizontal alignment

Horizontal alignment spans:

- Conceptual phase
- Design phase
- Development phase
- Production / test phase
- Operations phase
- Disposal phase

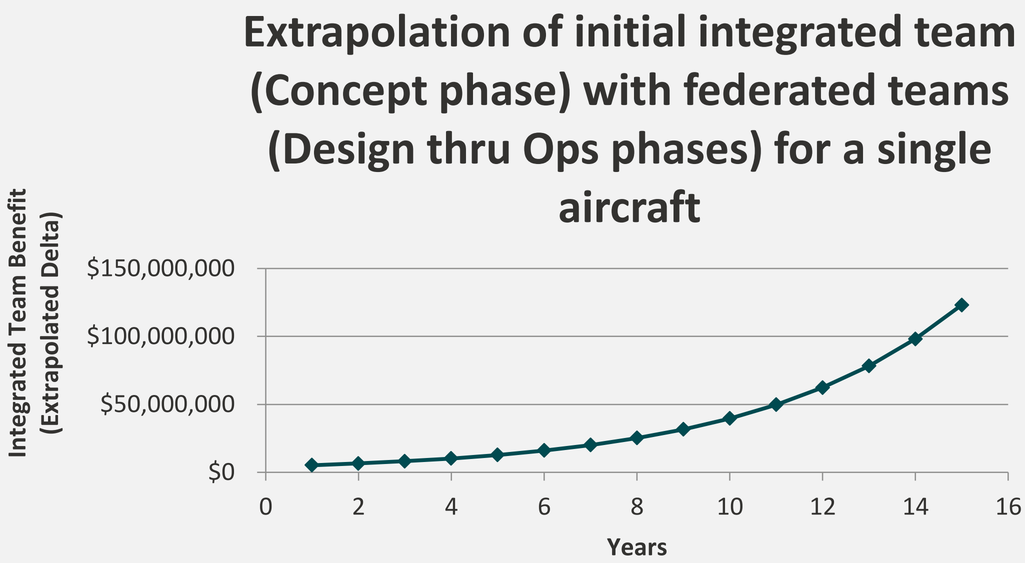


Team alignment needed to realize:

- System digital twin
- System digital threads
- Prognostic capability
- Understand impacts of uncertainties
- Aid ability to make good decisions
- Maintain engineered product validation

Aircraft Extrapolation – Integrated vs federated

- A little upfront investment in improving teamwork goes a long way
- More pre-work = less rework



- Projected economic benefits of extending the vertical alignment IPT approach to horizontal alignment across the entire life cycle can yield substantial economic benefits.
- Substantial cost savings are possible not by diluting the requirements but by “simple” team dynamics.
- By adopting the IPT approach in the concept phase can yield a ~17% ($123M) cost savings for a single aircraft ($132B for fleet)
- By adopting the IPT approach in the concept, design, development, and test phases can yield a ~47% ($560M) cost savings for a single aircraft ($604B for fleet)

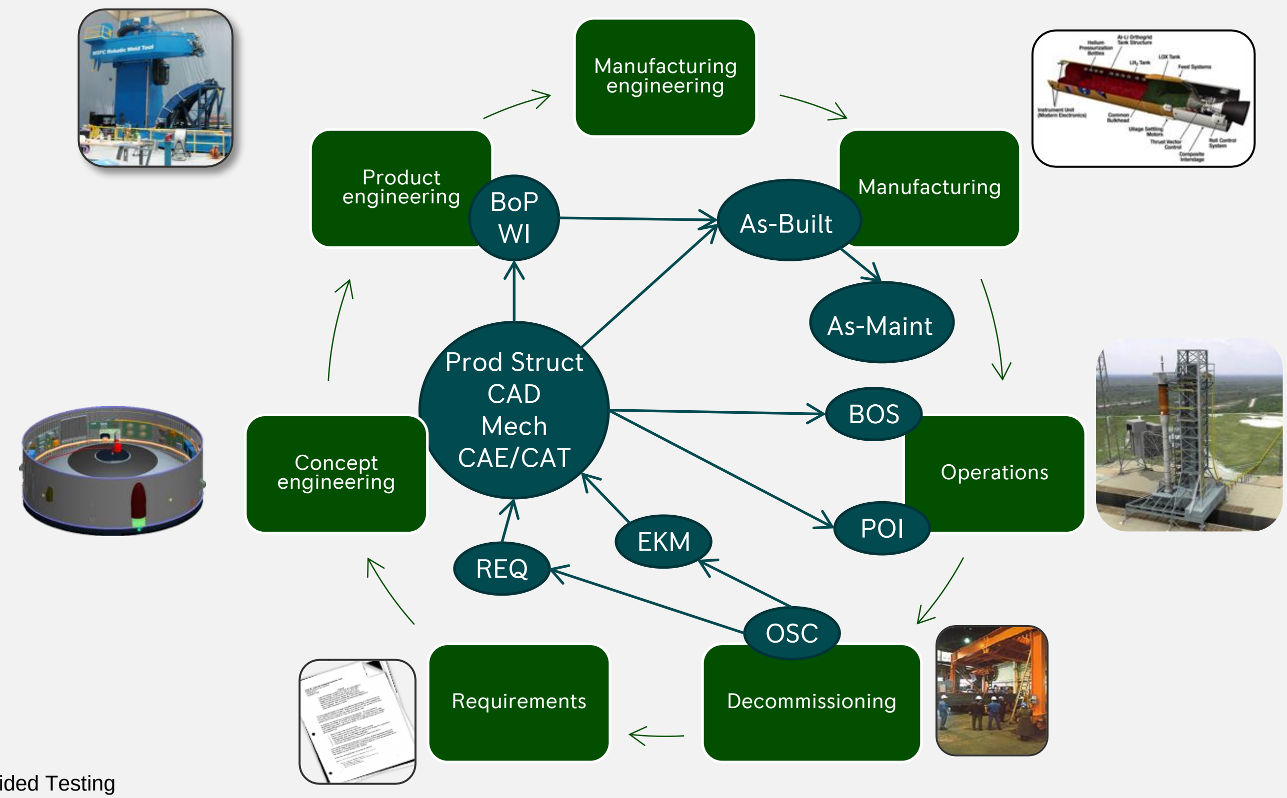
Better concept phase teamwork saves ~17% off total cost for a single aircraft

Rolls-Royce

Future State – Extended Depiction

A work in progress – future state depicted

Horizontal alignment with vertical alignment across the life cycle



BoP – Bill of Process
BOS – Base Operations Services - Bill of Service
CAD – computer-aided design
CAE – Computer-aided engineering
CAT – Computer assisted translation - Computer Aided Testing
EKM – Enterprise knowledge management
OSC – Operational Safety Case - Operational State Changes
POI – Point of Interest - Product Operational Instruction
REQ – Requirements
WI – Work Instruction

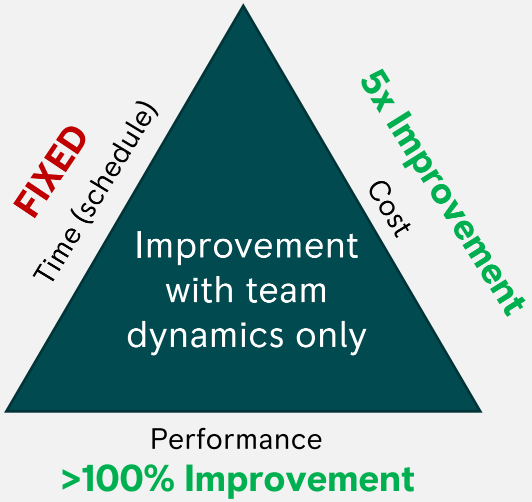
Note: Limited life cycle artifacts shown for brevity & clarity

Image used with permission courtesy of Dr. Mike Grieves, shown at AIAA CASE 2016

Summary

Cost & performance improvement achievable through team dynamics

- Defects are not like wine; they don't get better with age
- Programs are becoming less efficient
- Program efficiency through systems engineering team effectiveness
- Conventional 'cut & try' approaches add cost & delays
- COSYSMO estimates for 5x benefit through team changes only were validated
- Results show ~5x cost savings ratio through vertical alignment
- Better concept phase teamwork saves 6% off total cost
- Future work can show product validation through vertical & horizontal alignment
- Horizontal alignment is vertical alignment across the life cycle



Overview of project management[1]

Adapted from Kerzner, H.; Project Management; 8 th Ed; 2003

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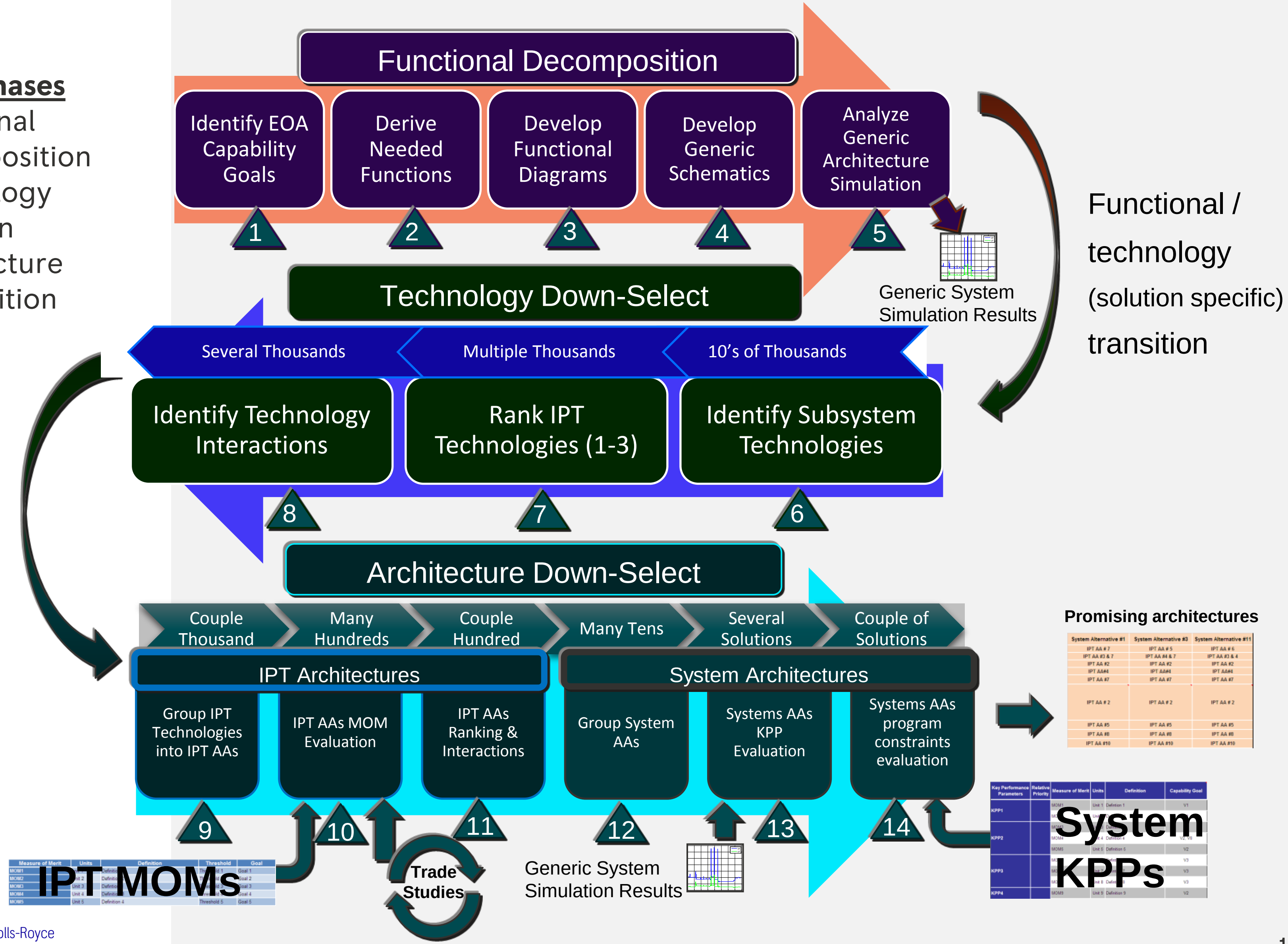
Vertical Alignment Process[1]

3 Distinct Phases

1. Functional decomposition
2. Technology selection
3. Architecture composition

Technology / architecture transition



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[1]Source: AIAA 2013-0882