Overview of the GT/NIA ASDL Capabilities
"Design Methods for the Next Generation of Advanced Concepts"

Prof. Dimitri Mavris

Director, Aerospace Systems Design Laboratory (ASDL)
Langley Distinguished Professor
Endowed Chaired Regents Professor for Advanced Systems Analysis,
School of Aerospace Engineering

Georgia Tech | Aerospace Systems Design Laboratory

ASDL INTRODUCTION

Georgia Tech Program Organization

Other Departments …

Aerospace Engineering

Center for Aerospace Systems Engineering (CASE)

Academic Units

Mechanical Engineering

Georgia Tech Research Institute

Aerospace, Transportation & Advanced Systems Lab

ITTL ELSYS

Electronic Systems Lab

Sensors & Electromagnetic Application Lab

Huntsville Research Lab

Electro-Optica Systems Lab

Signature Technology La

- Founded in 1992, ASDL was created to bridge the gap between academia and industry's research perspectives
  - 200 MS and PhD Students, 50 Undergrads, 40 Research Staff Members and over $14M in sponsored research
- School of AE was one of the seven original Guggenheim Aeronautics schools, founded in 1930
- GT consistently ranked 3rd or 4th best college of engineering in the country based on US News & World Report

ASDL At A Glance

Aerospace Systems Design Laboratory, at a glance:

- 250 researchers
- Over $180 million in funding over 20 years
- State of the art facilities
- Strong ties with government agencies
- Partnerships with industry leaders around the globe

Aerospace Systems Design Laboratory
ASDL
Est. 1992

Government

Department of the Navy ONR Science & Technology
NASA
Federal Aviation Administration
DARPA Bridging the Gap Powered by Ideas

U.S. Sponsors

Northrop Grumman
GE
Boeing
Lockheed Martin
Pratt & Whitney A United Technologies Company
Gulfstream A General Dynamics Company
Sikorsky A United Technologies Company

International Sponsors

Thales
Siemens
DLR
EADS
Safran Hispano-Suiza
Airbus
Rolls-Royce
Dassault Aviation

Institute Resources

NLR National LambdaRail

ASDL Organization

Academic Manager
Allison Hill

International Program Manager
Elena Garcia

Chief Engineer
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Senior Advisor
Robert Loewy

Director
Dimitri Mavris
Assoc. Director
Brian German

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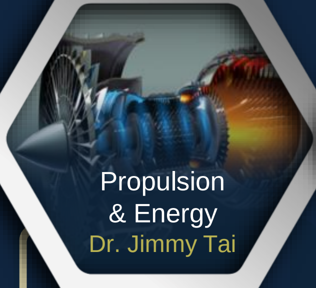

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- Space Systems *(Stephen Edwards)*
- Naval Systems *(Charles Domercant)*
- Ground Systems *(Blaine Laughlin)*
- C4ISR *(Charles Domercant)*

ASDL Affiliated Academic Faculty

Prof. Robert Loewy
- Senior Technical Advisor

Prof. Mark Costello
- Sikorsky Professor
  - Flight Mechanics & Controls
  - Autonomous Control
  - Rotorcraft Design

Prof. Brian German
- Associate Professor
  - Propulsion Design
  - Design Theory

Prof. Graeme Kennedy
- Assistant Professor
  - Structural Optimization
  - Multi-disciplinary Optimization

Prof. George Vachtsevanos
- Professor Emeritus
  - Autonomy
  - Intelligent, Fault-Tolerant Control

Prof. Daniel Schrage
- Professor, CASA Director
  - Rotorcraft Design
  - Certification

Prof. Massimo Ruzzene
- Professor
  - Smart Structures
  - Structural Health Monitoring
  - Vibration & Noise Control

Prof. Carlos “Santiago” Grijalva
- Associate Professor in ECE
  - Power Systems Security and Monitoring
  - Electricity Information Systems

Prof. Julian Rimoli
- Assistant Professor
  - Multiphysics
  - Multiscale Modeling of Solids

Centers of Excellence

University Strategic Alliance (USA) in partnership with General Electric General Electric Aircraft Engines and presently Energy in Systems Design and Optimization

Boeing Strategic Partnership for 21st Century Aerospace Manufacturing.

National Aeronautics and Space Administration University Research Engineering Technology Institute (URETI) on Aero-propulsion and Power Technology (UAPT)

PEGASAS

Partnership to Enhance General Aviation Safety, Accessibility and Sustainability

Pratt & Whitney Center of Excellence in Aeropropulsion

Member of the FAA's Aviation Sustainability Center

Our Sponsors – Worldwide Support

Sikorsky
A United Technologies Company

BOEING

SAIC
From Science to Solutions

Department of Energy
United States of America

Raytheon

RICARDO

BAE SYSTEMS

Air Force Office of Scientific Research
United States Air Force

Department of the Navy
ONR
Science & Technology

Gulfstream®
A GENERAL DYNAMICS COMPANY

DASSAULT
AVIATION

SAAB

EADS

NAVSEA
NAVAL SEA SYSTEMS COMMAND

AEROJET

NASA

NSF

Rolls-Royce®

Federal Aviation Administration

Department of Transportation
United States of America

NORTHROP GRUMMAN

Orbital

ARL

GE

Pratt & Whitney
A United Technologies Company

THALES

National Institute of Aerospace

Science to Shape the Future of the Army
Army Research Office
1951

U.S. Naval Research Laboratory
Washington, D.C.

Booz | Allen | Hamilton

Vought®
Aircraft Industries, Inc.

Bridging the Gap
DARPA
Powered by Ideas

LOCKHEED MARTIN

Department of Defense
United States of America

SIEMENS

SAFRAN
Hispano-Suiza

FedEx®
Express

AIRBUS

Strategic Alliances - Software Development

DASSAULT SYSTEMES

PHOENIX INTEGRATION

GVU

GEORGIA TECH

Georgia Tech School of Interactive Computing Graphics, Visualization, Usability (**GVU**) Center

sas THE POWER TO KNOW.

jmp™

Statistical Discovery.™ From SAS.

Pace

ASDL Graduate Courses

Fall Semester

- SWARMING
- Introduction to Grand Challenges

AE 6383
Applied Design Lab

- Probabilistic Design
- Design of Experiments & Surrogates

AE 6373
Advanced Design Methods I

- Problem Formulation
- Systems Engineering

AE 6372
Aerospace Systems Engineering

- Sizing & Synthesis
- Performance Analysis

AE 6343
Fixed-Wing Design I

Grand Challenges

Spring Semester

AE 8803 GER
Optimization Methods

- Optimization Techniques
- Numerical Methods

AE 8803 GRI
Introduction to SoS Engineering Principles

- System of Systems Engineering
- Stochastic Simulation

AE 6344
Fixed-Wing Design II

- Disciplinary Analysis
- Grand Challenge Continued

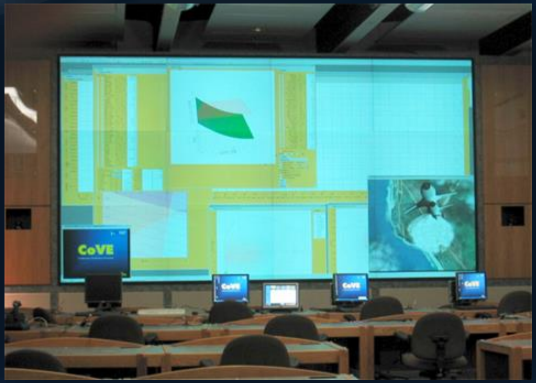
AE 6361
Propulsion Systems Design I

- Gas Turbine Fundamentals
- Engine Cycle Analysis

What are Grand Challenge Projects?

- Open-ended, relevant, realistic research problems
- Part of the ASDL core academic and research methods training
- Exercised over two entire academic semesters (Fall & Spring)
- Requires a very deep understanding of the problem, underlying theory and assumptions
- Requires practical implementation of advanced methods beyond traditional senior design problems
- Represent a significant contribution to the field

ASDL Facilities



Collaborative Visualization
Environment (CoVE) 2004

Collaborative Design
Environment (CoDE) 2009

Adaptive Design, Prototyping, and Testing
(ADePT) Facility 2013

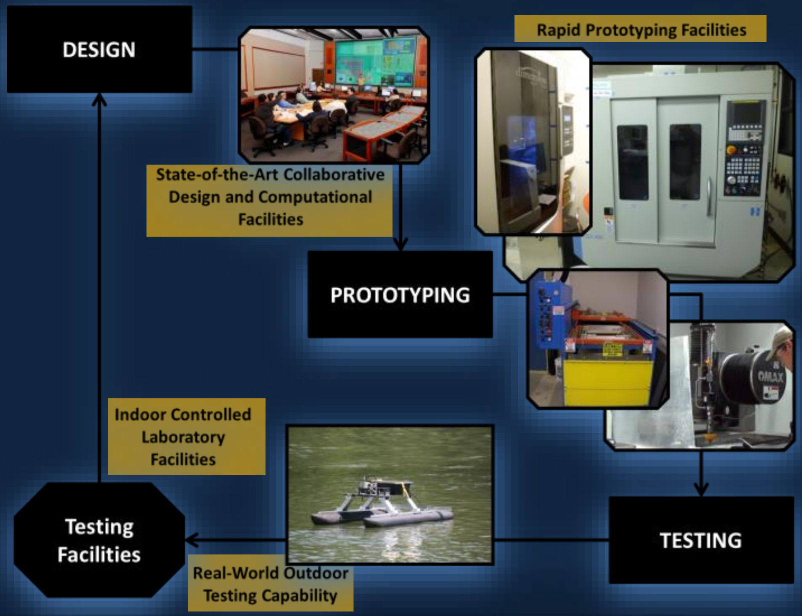
High Powered 256 Processor
Computing Cluster 2005

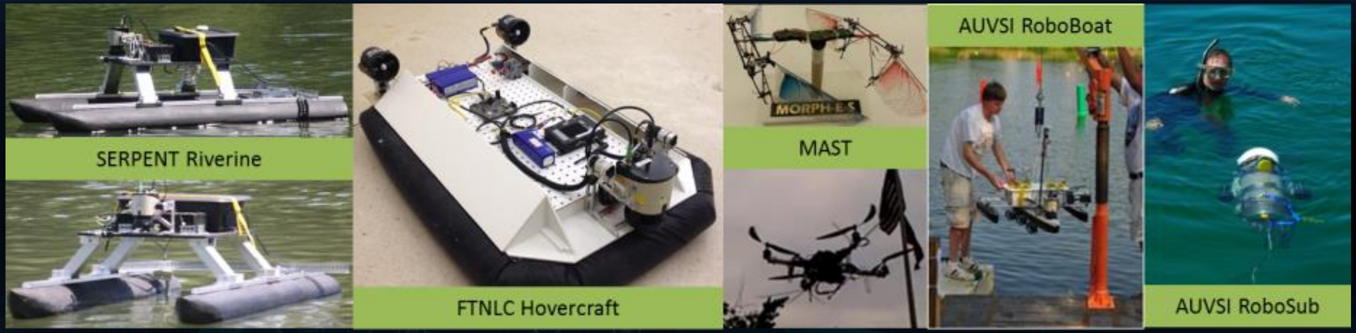
Design, Build, Fly Laboratory

Classified CoVE Facility
In GCATT Building (Atlanta)
2006

ADePT Laboratory

- Adaptive Design Prototyping and Testing Laboratory
  - Micro Autonomous System Technologies
  - Design, Build, Fly
  - AUVSI Roboboat
  - SERPENT Riverine Vehicle
  - Hydrogen Fuel Cell UAV





VIRTUAL EXPERIMENTATION: THE ASDL EDUCATION AND RESEARCH MODEL FOR ADVANCED CONCEPTS DESIGN

Virtual Experimentation

A game-changing, cyber-physical initiative that will enable the capability to seamlessly integrate and deploy

collaborative, networked, computational, human performance, cutting-edge, operations

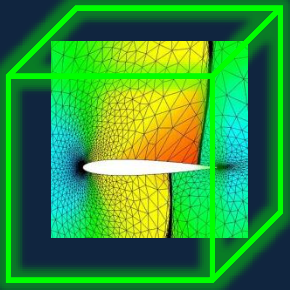
technologies into the analysis, design, testing, validation, discovery, and manufacturing processes

Ingredients:

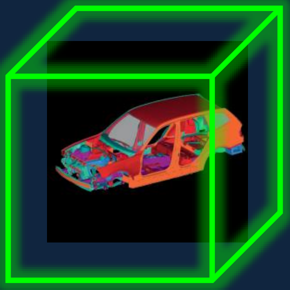
Physics-Based Computational Engineering Methods

Virtual Manufacturing

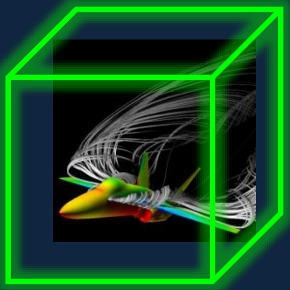
Activity-Based Costing



Computational Mesh Generation



Probabilistic FEM



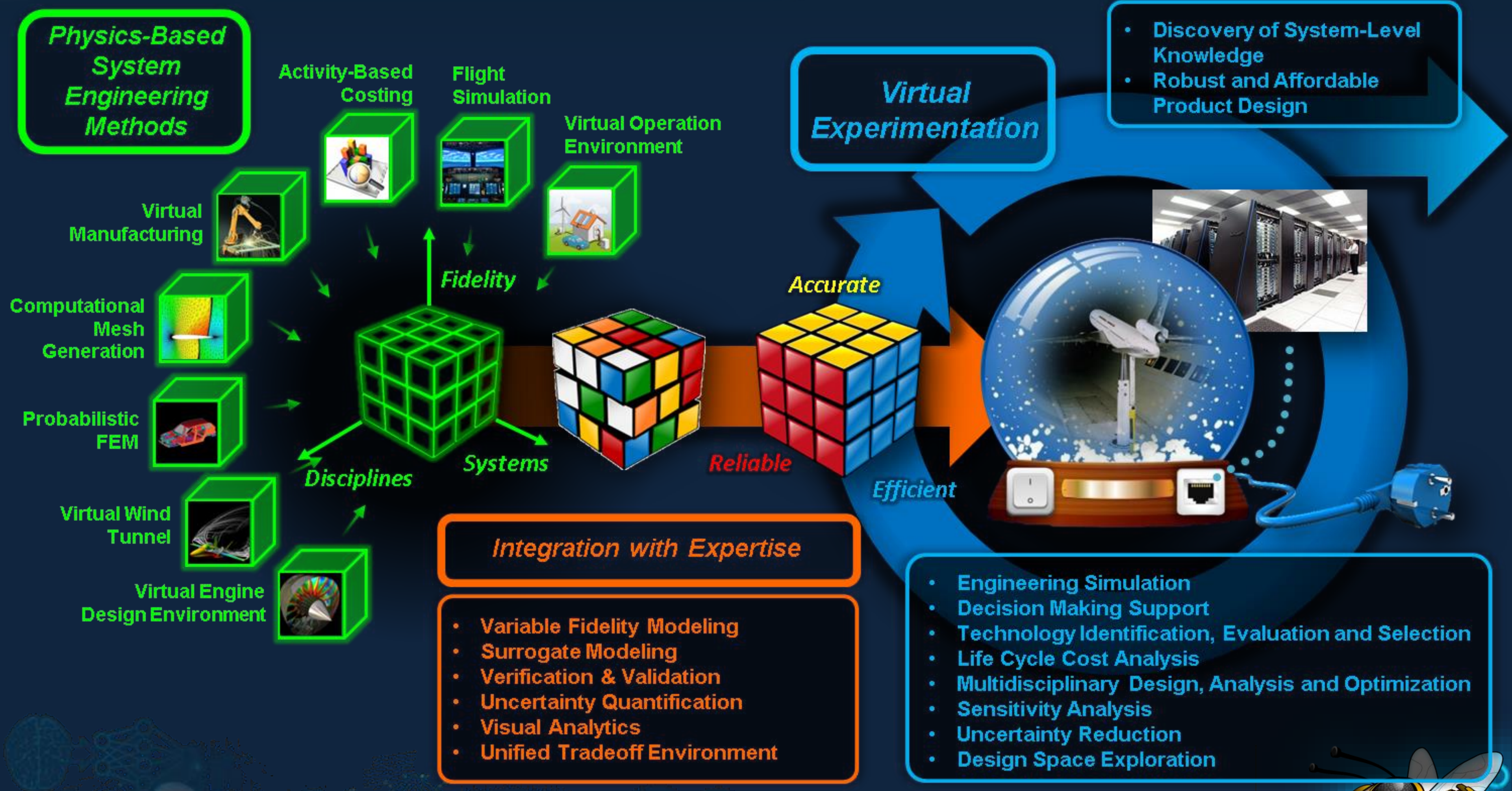
Virtual Wind Tunnel

Flight Simulation

Virtual Operation Environment

Virtual Engine Design Environment

Vision of Virtual Experimentation



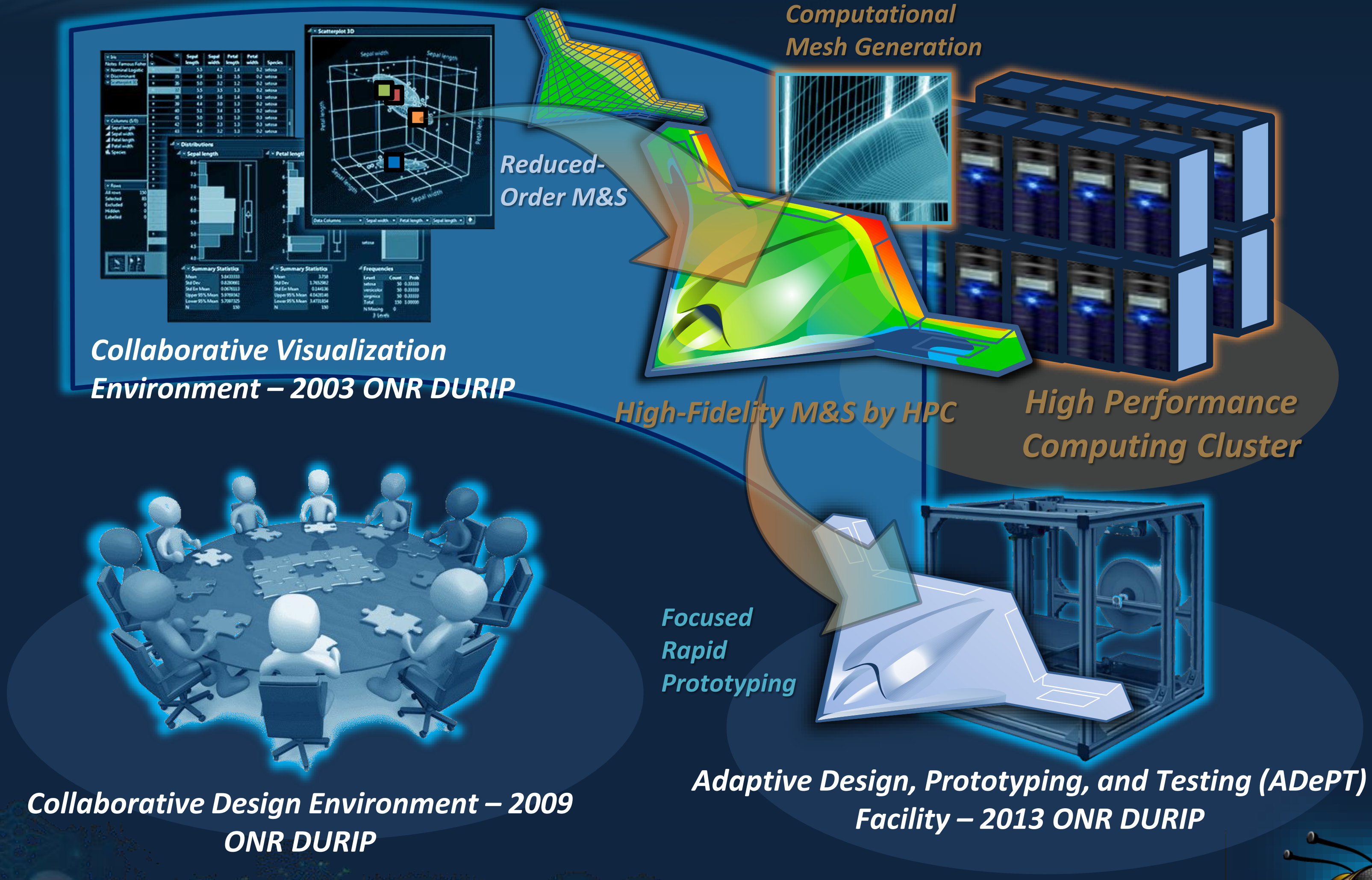
- Discovery of System-Level Knowledge
- Robust and Affordable Product Design

Integration with Expertise

- Variable Fidelity Modeling
- Surrogate Modeling
- Verification & Validation
- Uncertainty Quantification
- Visual Analytics
- Unified Tradeoff Environment

- Engineering Simulation
- Decision Making Support
- Technology Identification, Evaluation and Selection
- Life Cycle Cost Analysis
- Multidisciplinary Design, Analysis and Optimization
- Sensitivity Analysis
- Uncertainty Reduction
- Design Space Exploration

DURIP Facilities for Virtual Experimentation



Collaborative Visualization Environment – 2003 ONR DURIP

Reduced-Order M&S

Computational Mesh Generation

High-Fidelity M&S by HPC

High Performance Computing Cluster

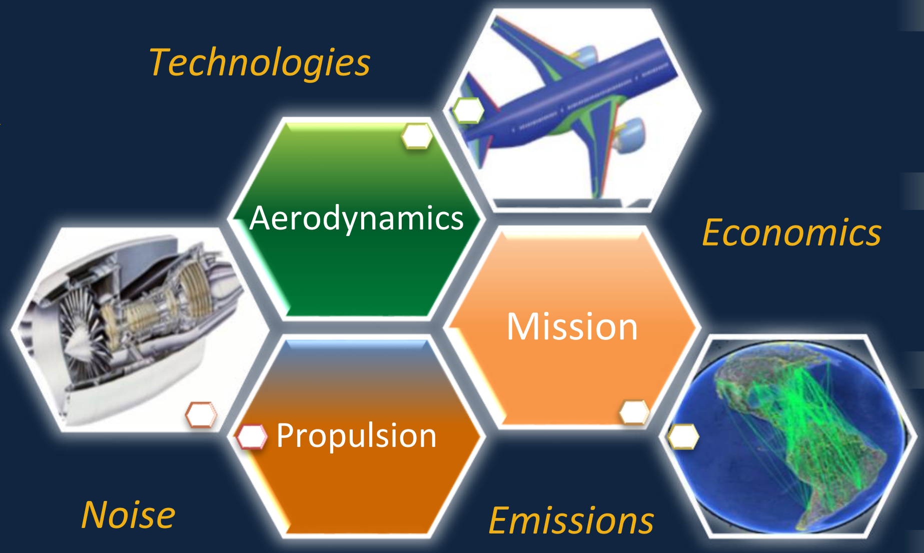
Focused Rapid Prototyping

Collaborative Design Environment – 2009 ONR DURIP

Adaptive Design, Prototyping, and Testing (ADePT) Facility – 2013 ONR DURIP

Prototype: Environmental Design Space

PARTNER



Technologies

Aerodynamics

Economics

Mission

Propulsion

Noise

Emissions

CLEEN

ERA N+2

SFW N+3

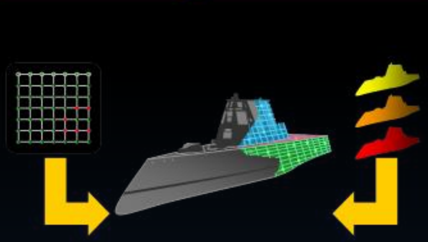
SUGAR

- Multi-stakeholder physics-based simulation for future aircraft concepts
- FAA tasked ASDL to piece together models from NASA to interface with legacy codes from the government

Prototype: Integrated Reconfigurable Intelligent Systems

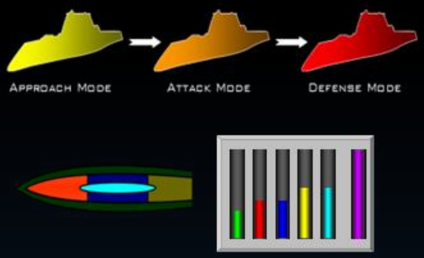
ASDL seeks to develop a virtual experimentation environment that allows for the effective design and analysis of the complex systems that consist of interdependent, heterogeneous subsystems.

Integrated



- The design of the system is shaped by the integration of multi-level heterogeneous systems
- Integration helps to reduce manpower, and increase survivability and reliability of the overall system

Reconfigurable

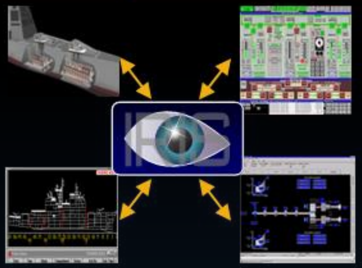


- The current situation is assessed based on incoming information collected from sensors
- Then the system is able to transform itself to the "best" mode to effectively deal with the situation at hand

Intelligent

- With the implementation of sensors and smart sensor technologies in the system
- The system can accurately sense and assess situations, make decisions autonomously or defer the decision to a human operator

Systems



- It is an integrated System of Systems (SoS) solution
- Integrate many subsystems into a single system where they communicate amongst themselves to coordinate their activities

Perpetual Cycle of Improvement

Grand Challenges

New Tool Sets

Ph.D Dissertation Research

New Methods

Virtual Experimentation

Launching Customers

Leaders from the below organizations were approached and verbally confirmed their interest in the corresponding VX environments.

Space Environment	Military Environment	Aero Environment	Emission Environment	Energy Environment	Strategic Decision Making Environment	Engine Environment	Hypersonic Environment
NASA Marshall	Raytheon	NASA Langley	FAA	GE	Northrop Grumman	Pratt & Whitney	Boeing
	ONR	Airbus	Alstom	GT	USNTPS	Siemens	AFRL
	ARL	EADS North America	GE	Cox Enterprises	Parsons Brinckerhoff	GE	
			PW	TAG			

Celebrating our 23rd year!

ASDL CAPABILITIES

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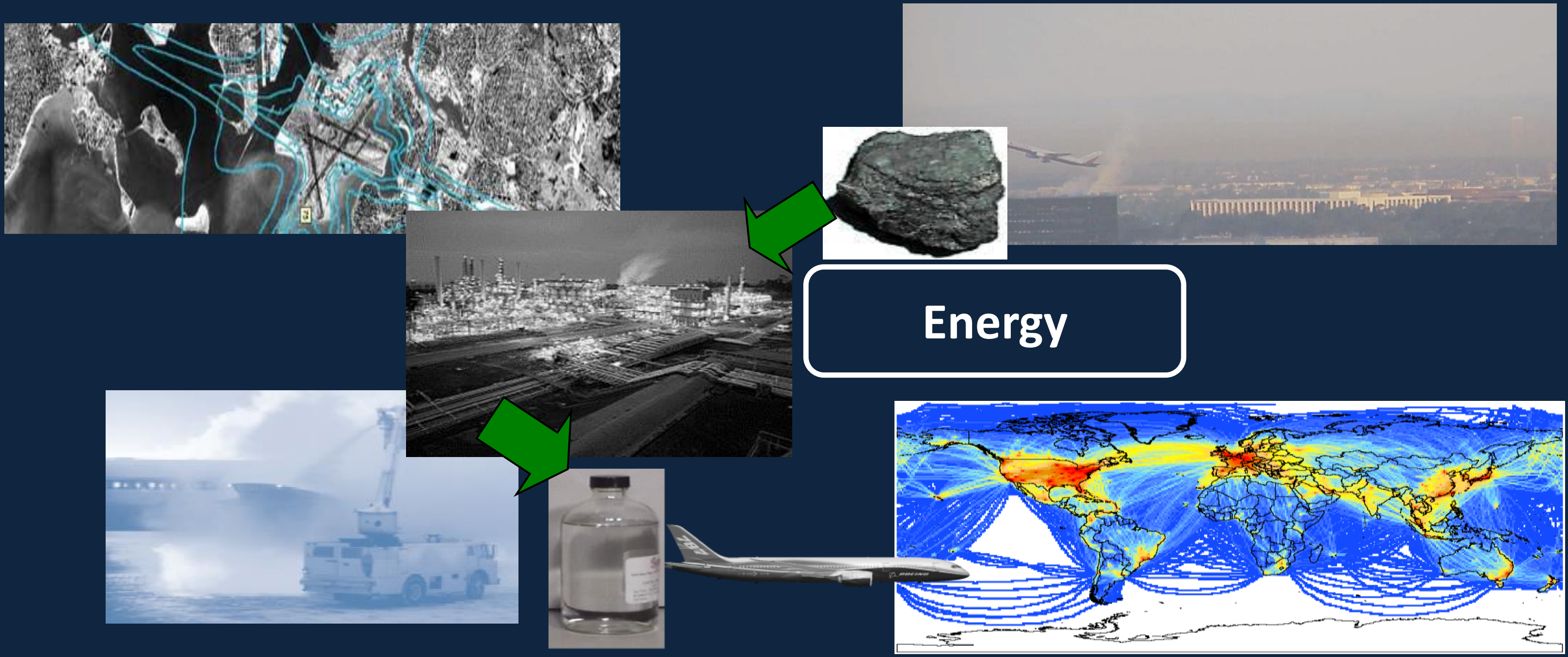
Be a leader in civil aviation research that will benefit society, government, and industrial decision makers with respect to aviation impacts on communities, global climate, economics, operations, and R&D investments while educating the next generation of engineers

– Provide relevant stakeholders with the tools, knowledge, and information to make well informed decisions
– Develop strong partnerships with experts in the field to enable accurate and comprehensive insight
– Develop and advance techniques to better serve stakeholder needs
– Be recognized as the entity for which expert opinion is solicited
– Promote academic excellence while educating and developing the next generation of engineers

Aviation Environmental Issues



Community Noise Impacts

Air Quality

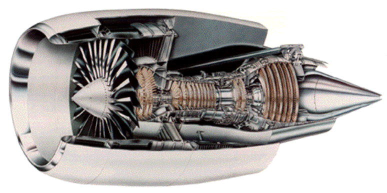
Energy

Water Quality

Global Climate

* Burleson, C., "Aviation and the Environment - Managing the Challenge of Growth," Presentation at Georgia Tech, 16 May 2008

Potential Solutions

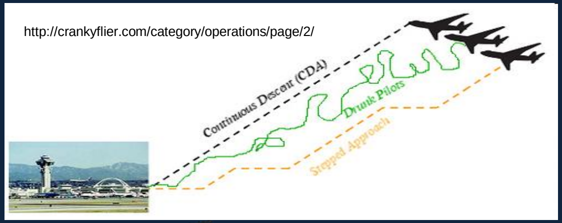

http://www.turbokart.com

Vehicle Technologies

Alternative Fuels


http://www.teagasc.ie/agfood2006/picturegallery/biofuel_9594.jpg
http://www.mecheng.ucl.ac.uk
http://sitemaker.umich.edu/section4group1/files/hydrogen.jpg

Operational Procedures


http://crankyflier.com/category/operations/page/2/

images.amazon.com

http://www.flightglobal.com

Operational Technologies

Advanced Concepts


http://www.youngscientists.co.uk


www.boeing.com

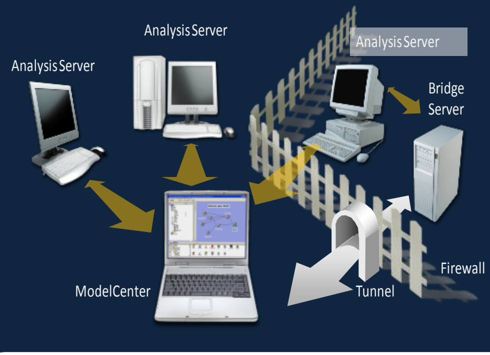
www.boeing.com

Types of Environmental Analysis Support

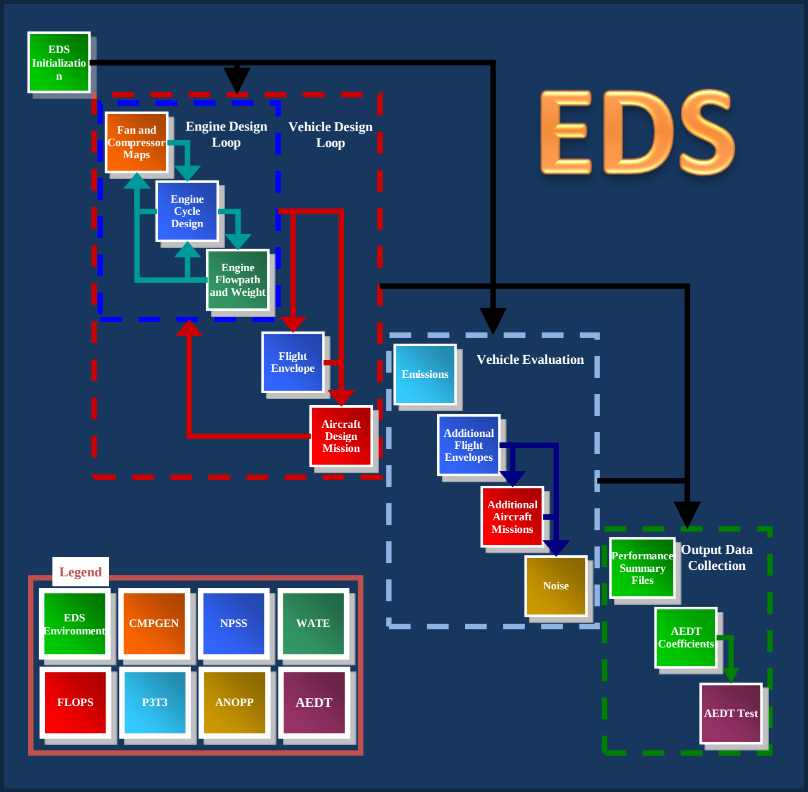
- ASDL has the capability to support each type of environmental analysis and is actively engaged in a number of projects that are addressing these issues

Analysis	Example	Input Needs	Output results for decisions	Fidelity
Policy	CAEP	Datum ops and forecast	Change in policy scenario and baseline	Initial: Medium to low Final: High
JPDO	NextGen	Datum ops and forecast	Change in policy scenario and baseline	Initial: Medium to low Final: High
Inventories		Radar tracks and tail matching	Absolutes	High
Regulatory	Part 150, EIS	Radar tracks and tail matching	Absolutes	High
Goal setting	CAEP, FAA	Datum ops and forecast	Change in policy scenario and baseline	Initial: Medium to low Final: High
Technology assessment	CLEEN, NASA, Industry	Datum ops and forecast	Change in policy scenario and baseline	Initial: Medium to low Final: High

Vehicle System Modeling and Simulation



Integration tool can link codes in different machines of different platforms



Modeling & Simulation Environment

Distributed Computing

Environmental Design Space

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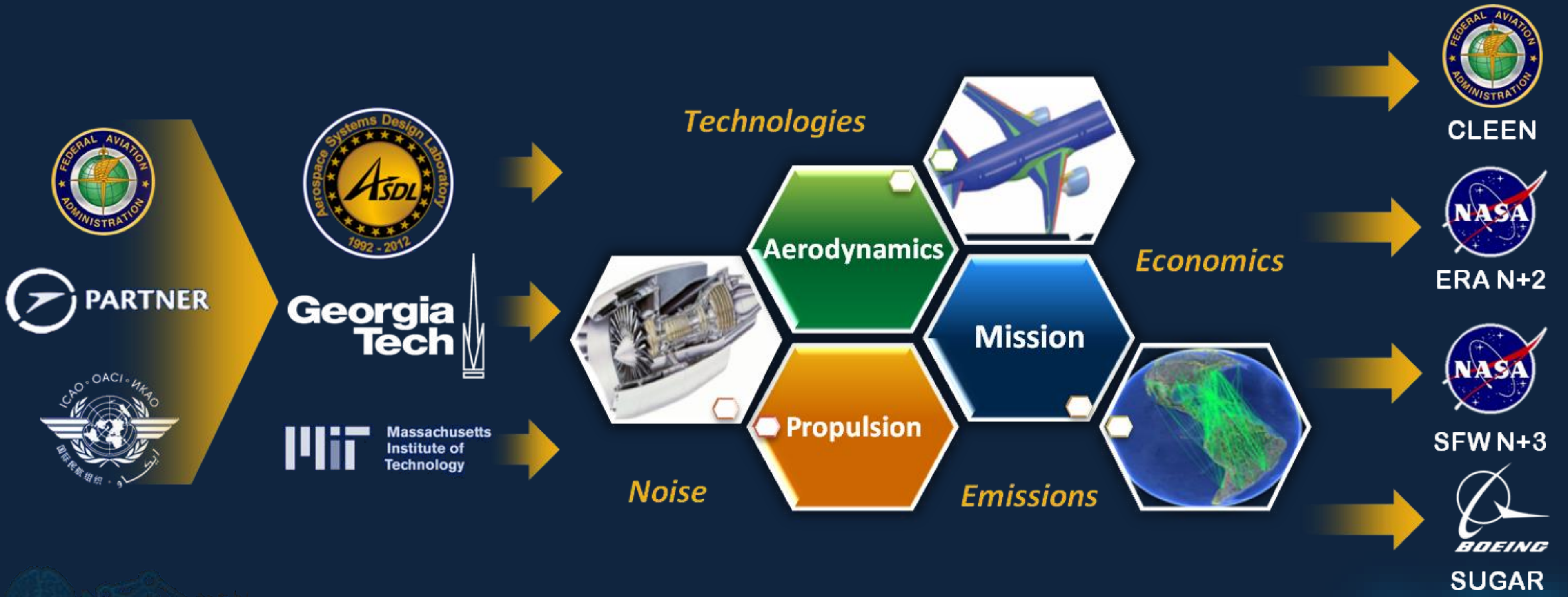

PARTNER

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Massachusetts Institute of Technology

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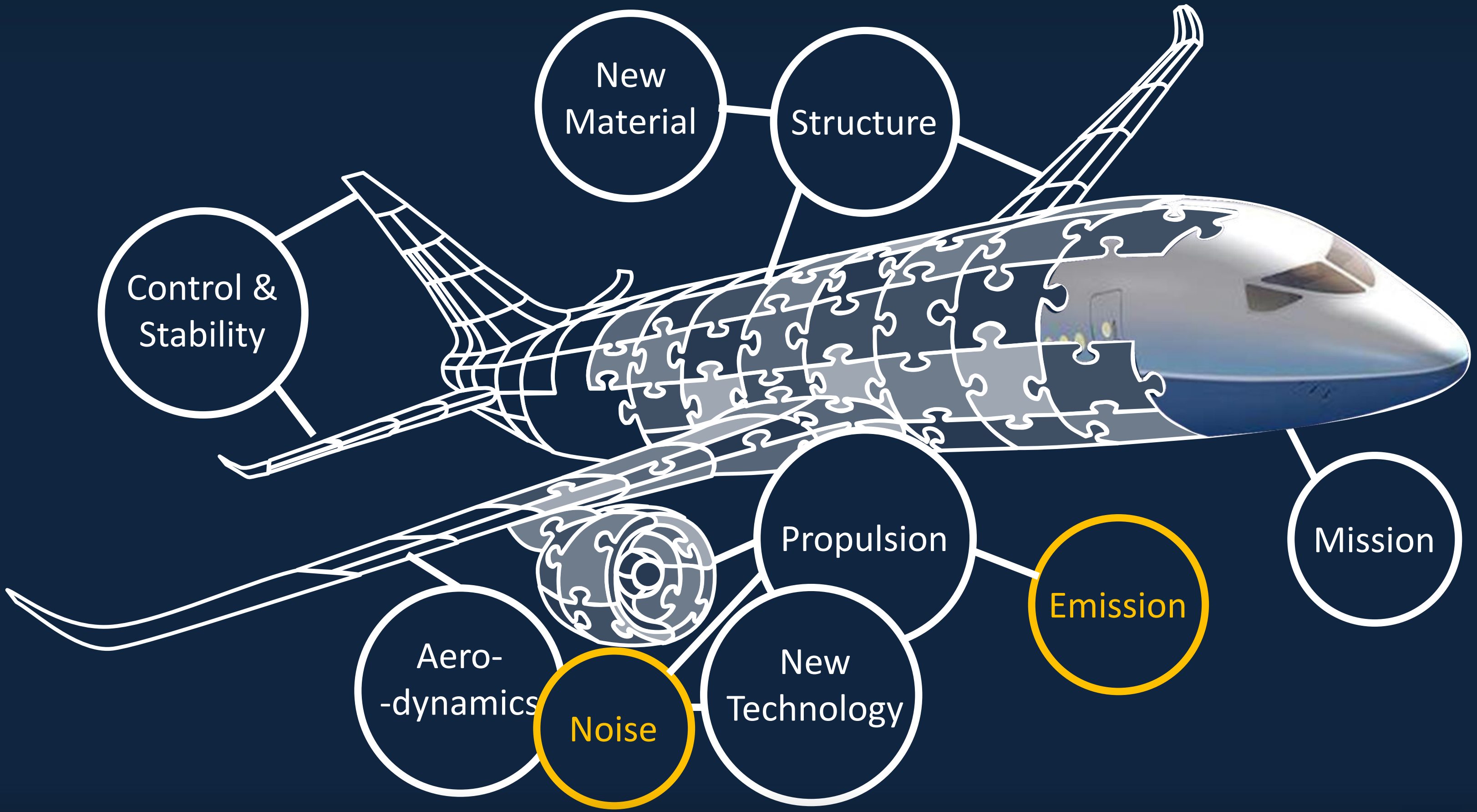
ERA N+2

SFW N+3

SUGAR

Environmental Design Space



New Material

Structure

Control & Stability

Propulsion

Emission

Mission

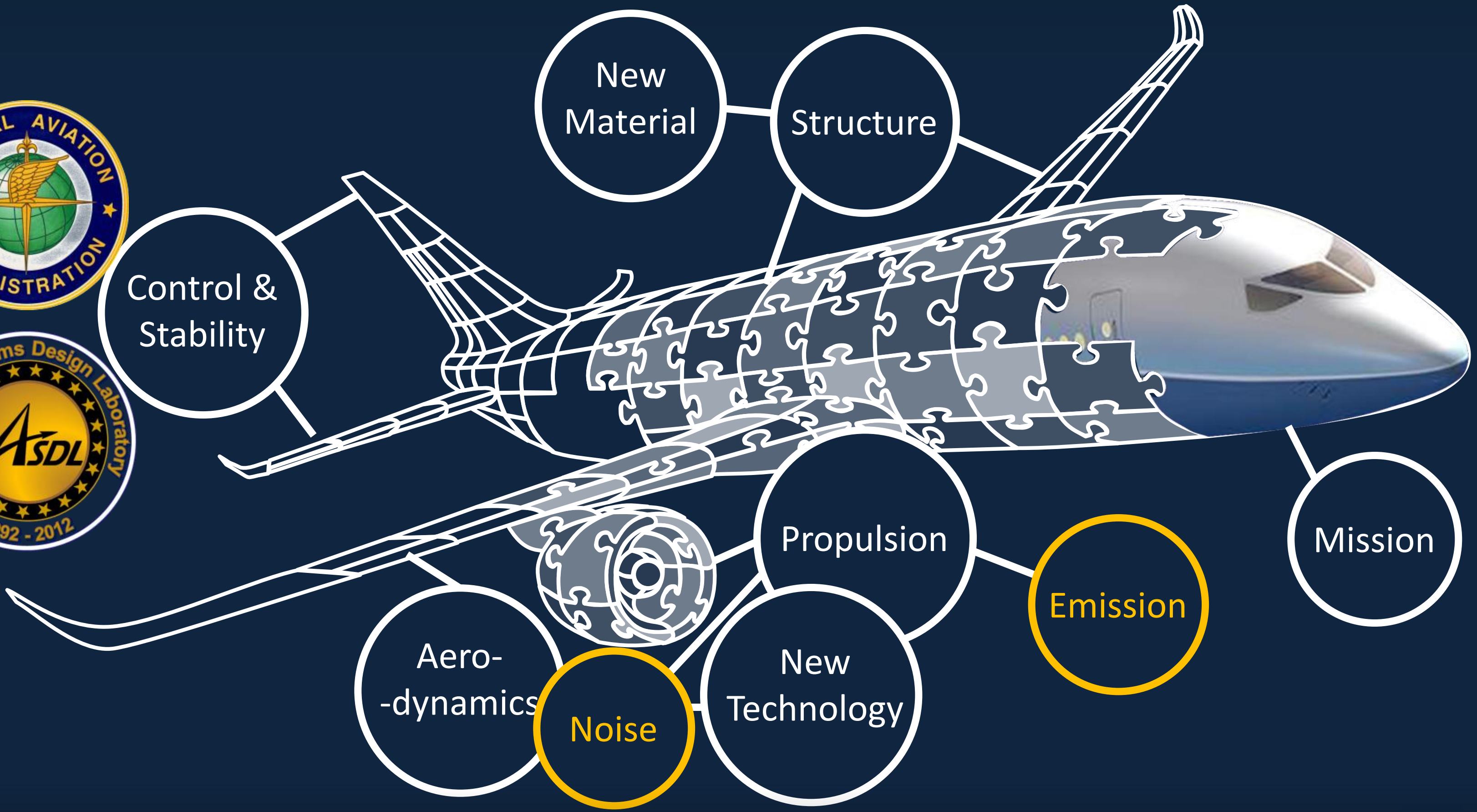
Aero-
-dynamics

Noise

New Technology

Challenging Problem

Environmental Design Space



New Material

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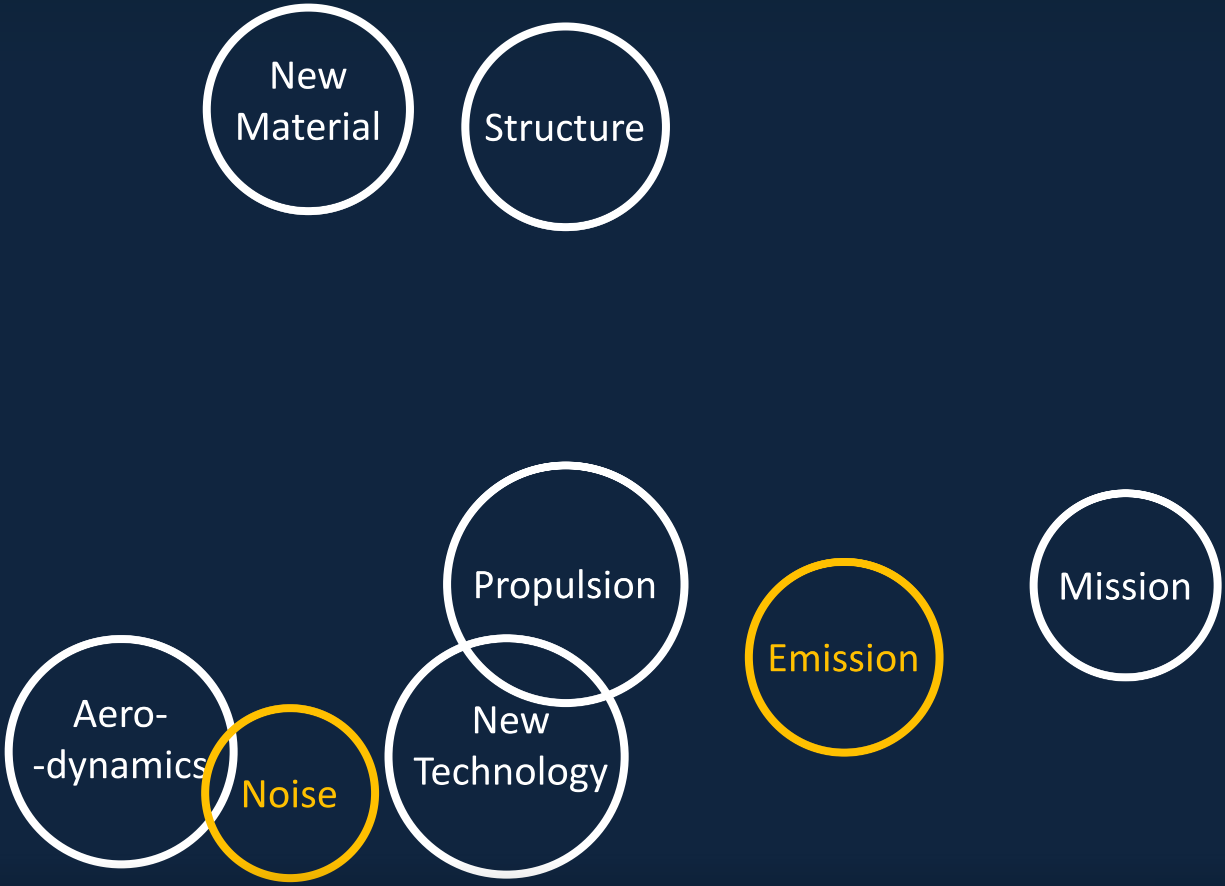
Aero-dynamics

Noise

New Technology

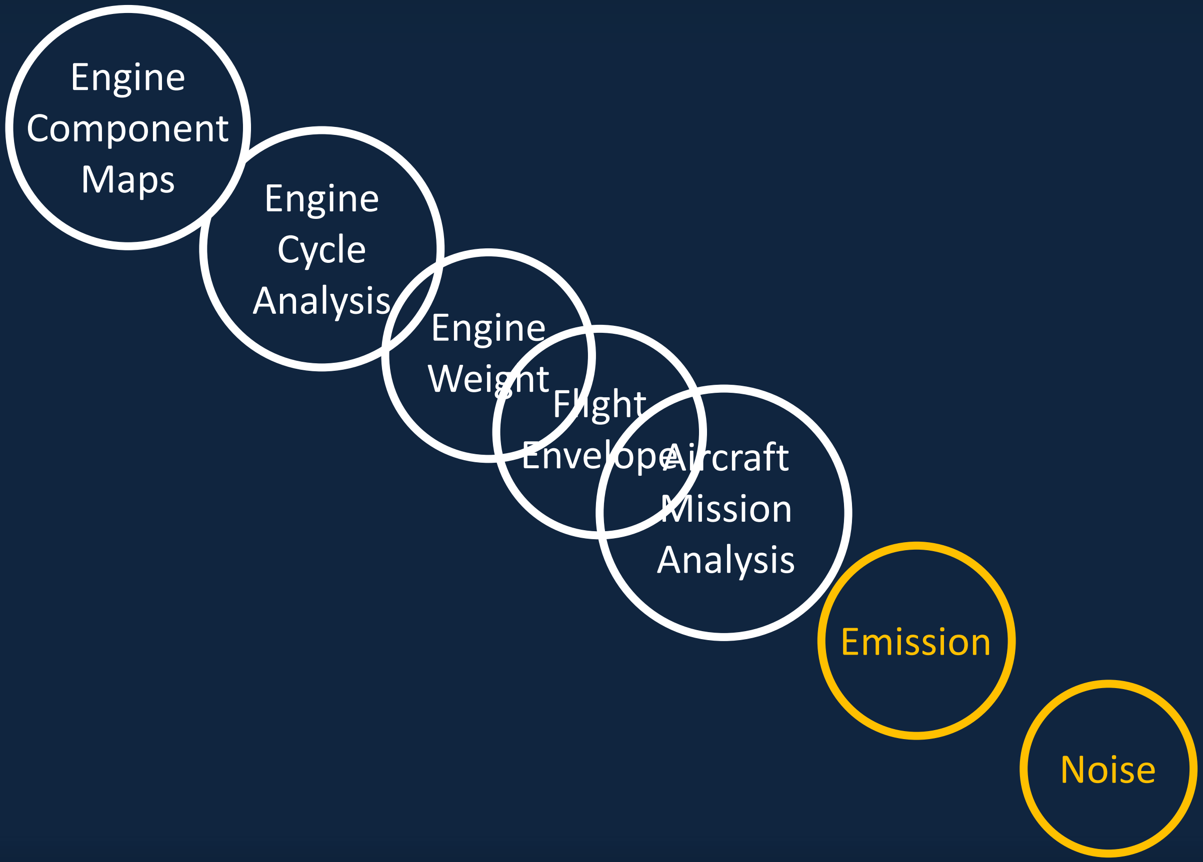
Challenging Problem

Environmental Design Space



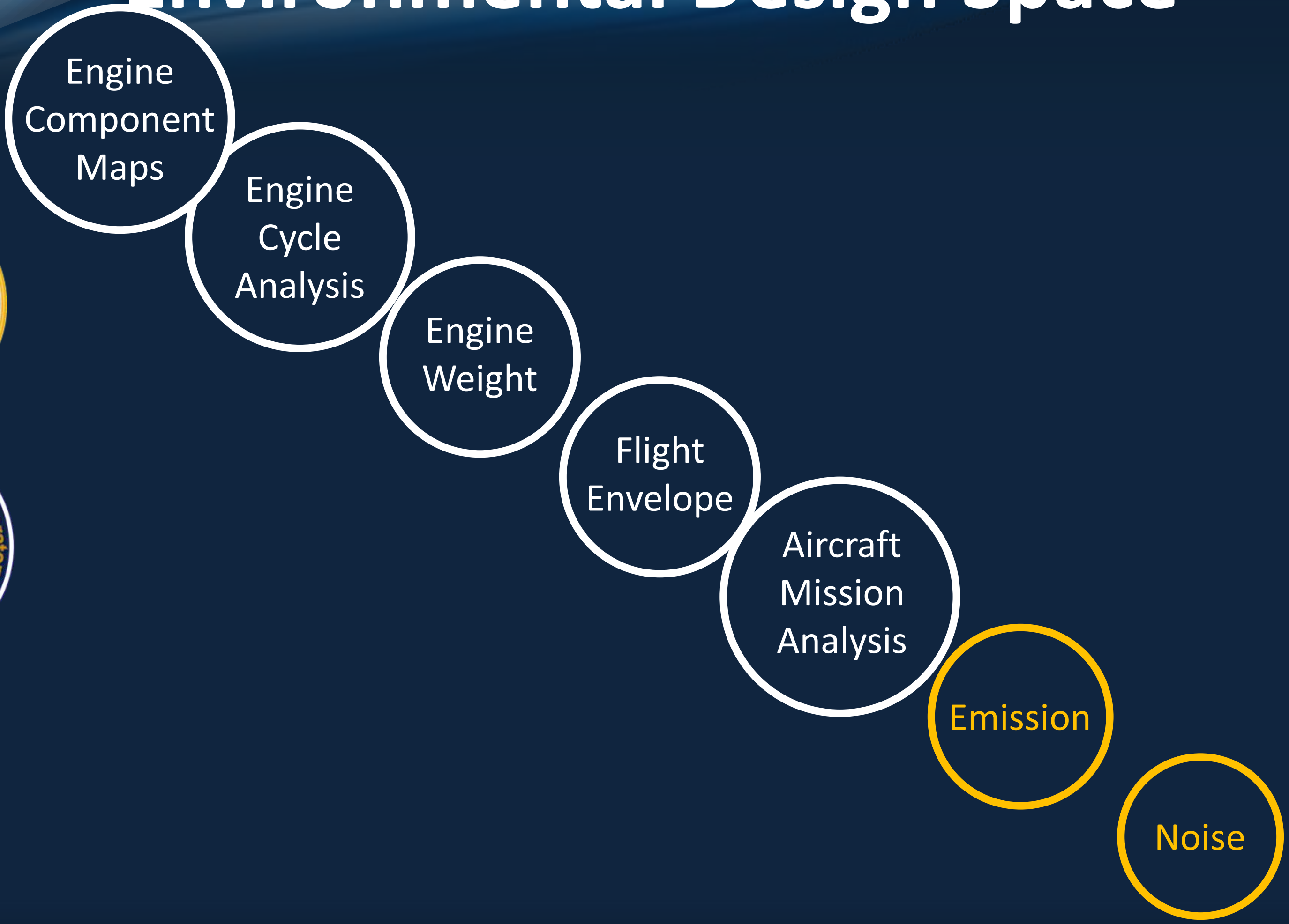
Challenging Problem

Environmental Design Space



Challenging Problem

Environmental Design Space



Engine Component Maps

Engine Cycle Analysis

Engine Weight

Flight Envelope

Aircraft Mission Analysis

Emission

Noise

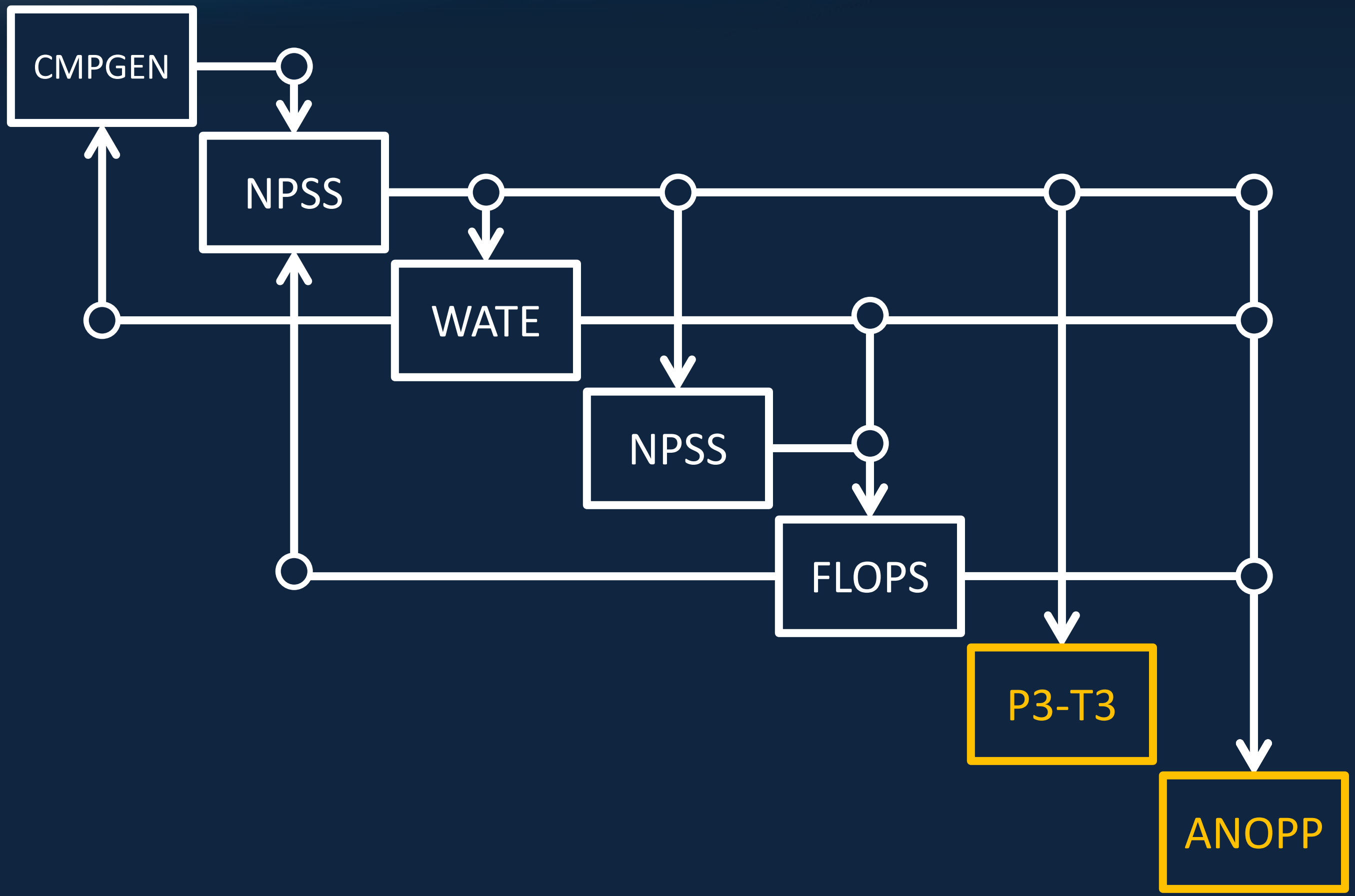
Challenging Problem

Environmental Design Space

Challenging Problem

Validated Modules

Environmental Design Space



CMPGEN

NPSS

WATE

NPSS

FLOPS

P3-T3

ANOPP

CLEEN

ERA N+2

SFW N+3

SUGAR

Challenging Problem

Validated Modules

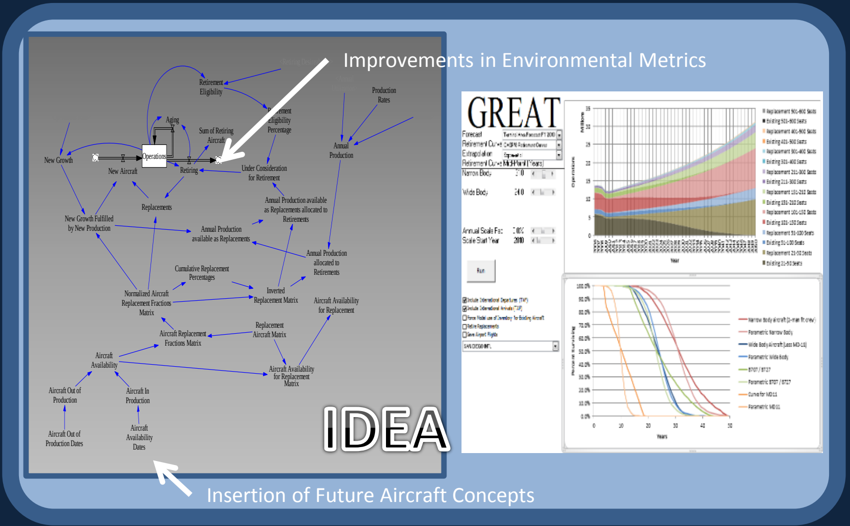
Integration with Expertise

EDS Capabilities and Value

- More than **16** years of V&V of predictive capability through national and international reviews by SMEs
- Seamless connectivity to high fidelity fleet-wide environmental tool
- Extensive library of aircraft configurations, including advanced configurations
  - Large library of engine/airframe architectures from existing to N+3 aircraft types
- Multi-level fidelity with a plug and play framework
- Realistic interdependency capability for current and future aircraft types:
  - Cost estimations
  - In-line noise estimation
  - CO2 (fuel burn), NOx, and noise
- Dynamic tool with continuous evolution of capability through industry and government SME input and a large team of disciplinary experts at GT
- Common tool for all commercial US R&D programs: CLEEN, ERA, and FW

Fleet Modeling and Simulation

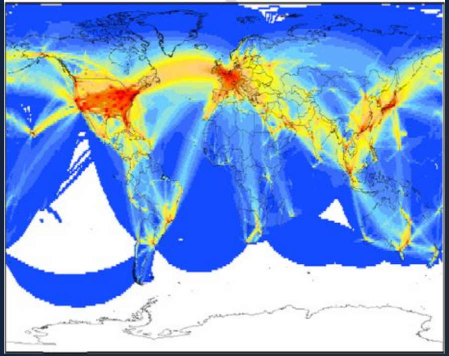
Research and Tool Development for Fleet Level Analysis

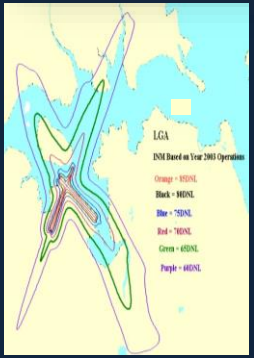


Improvements in Environmental Metrics

Insertion of Future Aircraft Concepts

Global Fuel Burn



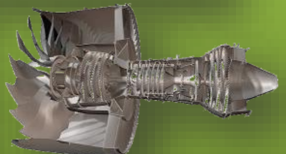


Global and Local Emissions

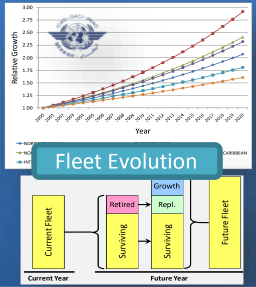
Airport Noise

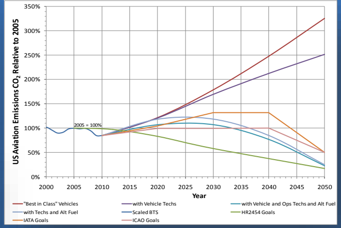
NASA ERA project

System Level Assessment of Advanced Concepts and Technologies

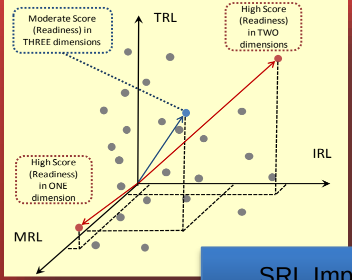


Parametric Fleet Assessment of Environmental Metrics





Methodology Development and Implementation



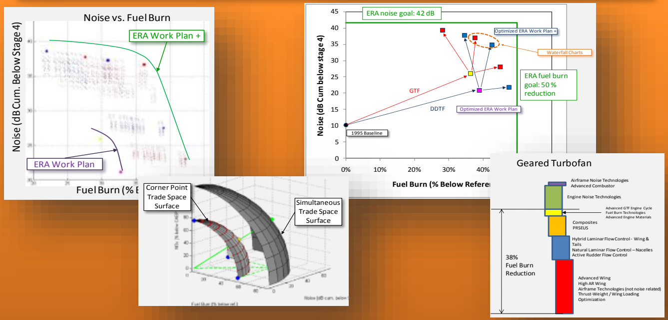
TRL	Criteria
1	...
2	...
3	...
4	...
5	...
6	...
7	...
8	...
9	...

MRL	Criteria
1	...
2	...
3	...
4	...
5	...
6	...
7	...
8	...
9	...

IRL	Criteria
1	...
2	...
3	...
4	...
5	...
6	...
7	...
8	...
9	...

SRL Implementation

Data Analysis, Optimization and Visualization



> “**NASA** ERA continues to **rely upon EDS** to study and quantify the potential "environmental-based" impacts of promising technology at the aircraft system level and at the fleet level, for current and future aircraft configurations. I have heard it said that flight experiments separate the real from the imagined. I believe thorough **systems studies using EDS has allowed NASA to differentiate realism from excessive optimism** as we perform due diligence in [the] development of efficient research portfolios that have the greatest positive impacts on both the environment and aircraft performance.
>
> *Dr. Fayette Collier- Manager, Environmentally Responsible Aviation (ERA) Project , NASA*

NASA FW N+3 Vehicle Modeling

Our goal is to develop 3 N+3 Advanced Concept configurations and assess the potential fleet wide environmental impacts of the NASA SFW portfolio

* Image created by Rich Wahls, NASA

FAA CO_2 Projects

- FAA’s highest priority research
- Multiple projects under this umbrella
  - Assessing the implications of imposing CO2 stringency levels to in production aircraft, not only future aircraft
  - Assessing the cost-benefit of imposing a CO2 standard of total CO2 production at what cost to the manufacturers
  - Assessing the implications of CO2 metrics for US policy analysis for different future fleet scenarios
- Our research contributions to the development of the standard was just reported on Aviation Week and Space Technology (Aug 12)

This research is changing the world!

VERY high profile research to develop both a U.S. and an international certification standard for aviation CO2 emissions

What difference has ASDL made?

- ASDL has supported CAEP9/WG3/CO2Task Group in assessing aircraft CO2 certification metric systems for >4 years
- On 11 July, 2012, CAEP Steering Group “reached unanimous agreement on a CO2 metric system to underpin the CO2 standard”
- ASDL contributed to CAEP decision by showing that the basis of a CO2 metric system we defined in 2010 will meet an agreed upon set of criteria
- ASDL is the only academic entity supporting all N+1, N+2 and N+3 system level technology assessments
- Partner to NASA LaRC and GRC since 1990

STRATEGIC PORTFOLIO PLANNING

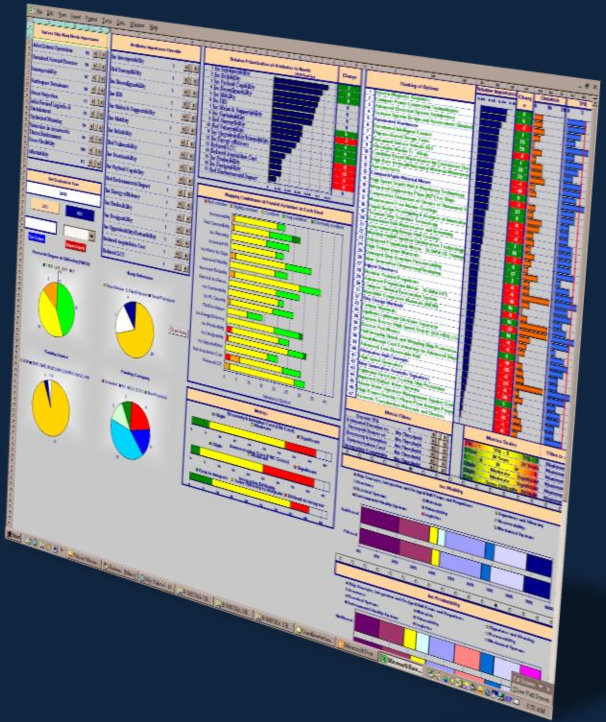
"SUBJECT MATTER EXPERT AND MODEL DRIVEN PROCESSES"

Georgia Tech Aerospace Systems Design Laboratory

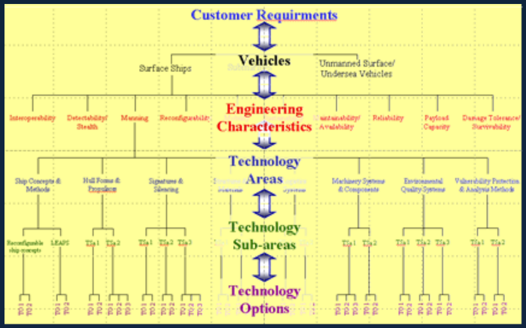
Strategic Prioritization and Planning (SP2)

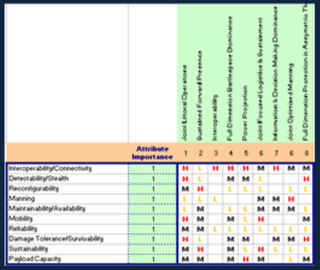
- An expert-based series of decision (or planning) matrices that are related qualitatively through different levels of abstraction and is the detailed process for program planning

1. Definition of top level needs or requirements
2. Description of the information desired to facilitate decision making, which may include: Schedule, annual or total budgets, source of funding, sensitivity level of abstraction, risk, specific time frames, rack and stack of priorities, etc.
3. Decomposition of the needs to the appropriate level of abstraction
4. Qualitatively relate each level of the decomposition through a series of planning matrices
5. Definition of a quantitative scale for each level of decomposition and translation to quantitative scales
6. Identification of the appropriate domain area experts for each level of the decomposition to provide necessary information

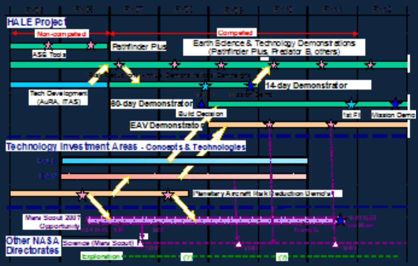


From Vision To Roadmap





	Attribute Importance	1 Joint Littoral Operations	2 Sustained Forward Presence	3 Interoperability	4 Full Dimension Battlespace Dominance	5 Power Projection	6 Joint Focused Logistics & Sustainment	7 Information & Decision Making Dominance	6 Joint Optimized Manning	8 Full Dimension Protection in Asymmetric Th
Interoperability/Connectivity	1	H	L	H	H	H	M	H	M	M
Detectability/Stealth	1	H	L		M	M	L			H
Reconfigurability	1	M	H		L	L	L		L	L
Manning	1	L	L	L			M	M	H	
Maintainability/Availability	1	L	M		L	L	M	M	M	L
Mobility	1	H	M		M	L	H			M
Reliability	1	M	M	L	L	L	L	L	L	L
Damage Tolerance/Survivability	1	H	L		M	M		M	M	H
Sustainability	1	M	H		M	L	H	L	L	L
Payload Capacity	1	M	M		M	H	M		L	M



Program Vision

Customer Requirements Definition

Engineering Characteristics Definition

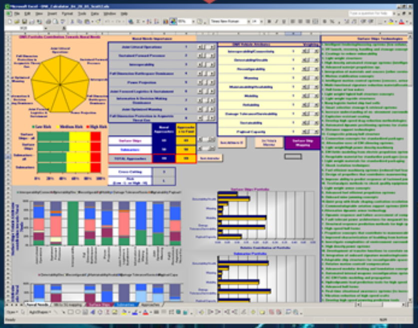
Data Call

Technology Presentation

Validation of Mappings

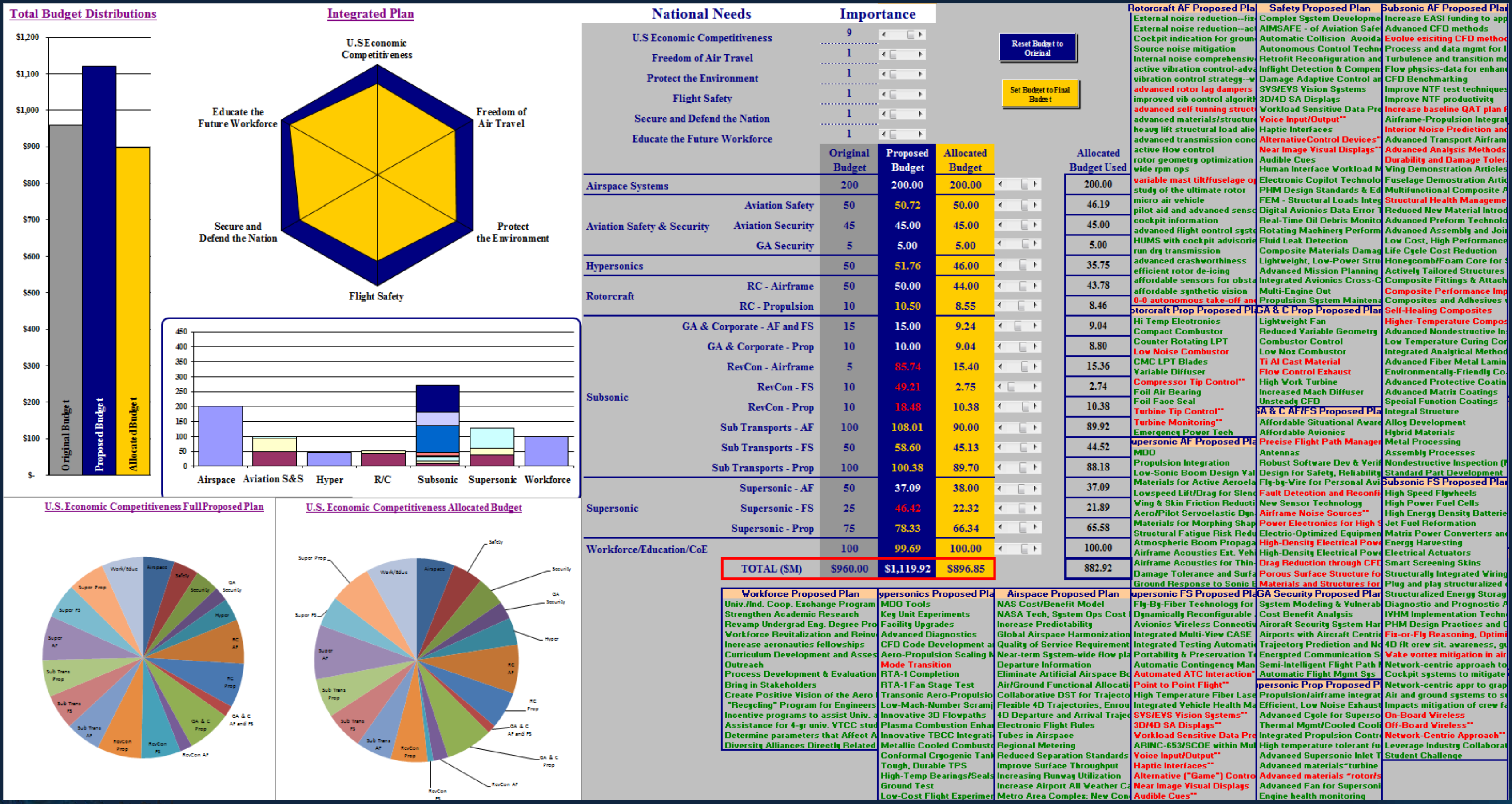
Execute Calculator

Create Strategic Roadmap



Organizational Planning, Technology Prioritization

NIA SP2



National Needs	Importance
U.S Economic Competitiveness	9
Freedom of Air Travel	1
Protect the Environment	1
Flight Safety	1
Secure and Defend the Nation	1
Educate the Future Workforce	1

Reset Budget to Original

Set Budget to Final Budget

		Original Budget	Proposed Budget	Allocated Budget	Allocated Budget Used
Airspace Systems		200	200.00	200.00	200.00
Aviation Safety & Security	Aviation Safety	50	50.72	50.00	46.19
	Aviation Security	45	45.00	45.00	45.00
	GA Security	5	5.00	5.00	5.00
Hypersonics		50	51.76	46.00	35.75
Rotorcraft	RC - Airframe	50	50.00	44.00	43.78
	RC - Propulsion	10	10.50	8.55	8.46
Subsonic	GA & Corporate - AF and FS	15	15.00	9.24	9.04
	GA & Corporate - Prop	10	10.00	9.04	8.80
	RevCon - Airframe	5	85.74	15.40	15.36
	RevCon - FS	10	49.21	2.75	2.74
	RevCon - Prop	10	18.48	10.38	10.38
	Sub Transports - AF	100	108.01	90.00	89.92
	Sub Transports - FS	50	58.60	45.13	44.52
	Sub Transports - Prop	100	100.38	89.70	88.18
Supersonic	Supersonic - AF	50	37.09	38.00	37.09
	Supersonic - FS	25	46.42	22.32	21.89
	Supersonic - Prop	75	78.33	66.34	65.58
Workforce/Education/CoE		100	99.69	100.00	100.00
	TOTAL ($M)	$960.00	$1,119.92	$896.85	882.92

Rotorcraft AF Proposed Pla
External noise reduction--fix
External noise reduction--act
Cockpit indication for groun
Source noise mitigation
Internal noise comprehensiv
active vibration control-adva
vibration control strategy--w
advanced rotor lag dampers
improved vib control algorith
advanced self tunning struct
advanced materials/structur
heavy lift structural load alle
advanced transmission conc
active flow control
rotor geometry optimization
wide rpm ops
variable mast tilt/fuselage o
study of the ultimate rotor
micro air vehicle
pilot aid and advanced sens
cockpit information
advanced flight control syste
HUMS with cockpit advisorie
run dry transmission
advanced crashworthiness
efficient rotor de-icing
affordable sensors for obsta
affordable synthetic vision
0-0 autonomous take-off an

otorcraft Prop Proposed Pl
Hi Temp Electronics
Compact Combustor
Counter Rotating LPT
Low Noise Combustor
CMC LPT Blades
Variable Diffuser
Compressor Tip Control""
Foil Air Bearing
Foil Face Seal
Turbine Tip Control""
Turbine Monitoring""
Emergency Power Tech

upersonic AF Proposed Pla
MDO
Propulsion Integration
Low-Sonic Boom Design Val
Materials for Active Aeroela
Lowspeed Lift/Drag for Slend
Wing & Skin Friction Reducti
Aero/Pilot Servoelastic Dyn
Materials for Morphing Shap
Structural Fatigue Risk Redu
Atmospheric Boom Propaga
Airframe Acoustics Ext. Vehi
Airframe Acoustics for Thin-
Damage Tolerance and Surfa
Ground Response to Sonic B

upersonic FS Proposed Pla
Fly-By-Fiber Technology for
Dynamically Reconfigurable
Avionics Wireless Connectiv
Integrated Multi-View CASE
Integrated Testing Automati
Portability & Preservation T
Automatic Contingency Man
Automated ATC Interaction""
Point to Point Flight""
High Temperature Fiber Lase
Integrated Vehicle Health Ma
SVS/EVS Vision Systems""
3D/4D SA Displays""
Workload Sensitive Data Pre
ARINC-653/SCOE within Mul
Voice Input/Output""
Haptic Interfaces""
Alternative ("Game") Contro
Near Image Visual Displays
Audible Cues""

Safety Proposed Plan
Complex System Developme
AIMSAFE - of Aviation Safe
Automatic Collision Avoida
Autonomous Control Techn
Retrofit Reconfiguration and
Inflight Detection & Compen
Damage Adaptive Control an
SVS/EVS Vision Systems
3D/4D SA Displays
Workload Sensitive Data Pre
Voice Input/Output""
Haptic Interfaces
AlternativeControl Devices"
Near Image Visual Displays""
Audible Cues
Human Interface Workload M
Electronic Copilot Technolo
PHM Design Standards & Ed
FEM - Structural Loads Integ
Digital Avionics Data Error T
Real-Time Oil Debris Monito
Rotating Machinery Perform
Fluid Leak Detection
Composite Materials Damag
Lightweight, Low-Power Stru
Advanced Mission Planning
Integrated Avionics Cross-C
Multi-Engine Out
Propulsion System Maintena

GA & C Prop Proposed Plan
Lightweight Fan
Reduced Variable Geometry
Combustor Control
Low Nox Combustor
Ti Al Cast Material
Flow Control Exhaust
High Work Turbine
Increased Mach Diffuser
Unsteady CFD

GA & C AF/FS Proposed Pla
Affordable Situational Aware
Affordable Avionics
Precise Flight Path Manager
Antennas
Robust Software Dev & Verif
Design for Safety, Reliability
Fly-by-Wire for Personal Avi
Fault Detection and Reconfi
New Sensor Technology
Airframe Noise Sources""
Power Electronics for High S
Electric-Optimized Equipmen
High-Density Electrical Powe
High-Density Electrical Powe
Drag Reduction through CFD
Porous Surface Structure fo
Materials and Structures for

GA Security Proposed Plan
System Modeling & Vulnerab
Cost Benefit Analysis
Aircraft Security System Har
Airports with Aircraft Centric
Trajectory Prediction and No
Encrypted Communication S
Semi-Intelligent Flight Path M
Automatic Flight Mgmt Sys

upersonic Prop Proposed Pl
Propulsion/airframe integrat
Efficient, Low Noise Exhaust
Advanced Cycle for Superso
Thermal Mgmt/Cooled Cooli
Integrated Propulsion Contr
High temperature tolerant fu
Advanced Supersonic Inlet T
Advanced materials~turbine
Advanced materials ~rotor/s
Advanced Fan for Supersoni
Engine health monitoring

Subsonic AF Proposed Plan
Increase EASI funding to app
Advanced CFD methods
Evolve exisiting CFD metho
Process and data mgmt for I
Turbulence and transition m
Flow physics-data for enhan
CFD Benchmarking
Improve NTF test technique
Improve NTF productivity
Increase baseline QAT plan
Airframe-Propulsion Integra
Interior Noise Prediction an
Advanced Transport Airfram
Advanced Analysis Methods
Durability and Damage Toler
Wing Demonstration Articles
Fuselage Demostration Artic
Multifunctional Composite A
Structural Health Manageme
Reduced New Material Intro
Advanced Preform Technolo
Advanced Assembly and Joi
Low Cost, High Performance
Life Cycle Cost Reduction
Honeycomb/Foam Core for
Actively Tailored Structures
Composite Fittings & Attach
Composite Performance Imp
Composites and Adhesives
Self-Healing Composites
Higher-Temperature Compo
Advanced Nondestructive In
Low Temperature Curing Co
Integrated Analytical Metho
Advanced Fiber Metal Lamin
Environmentally-Friendly Co
Advanced Protective Coatin
Advanced Matrix Coatings
Special Function Coatings
Integral Structure
Alloy Development
Hybrid Materials
Metal Processing
Assembly Processes
Nondestructive Inspection (
Standard Part Development

Subsonic FS Proposed Plan
High Speed Flywheels
High Power Fuel Cells
High Energy Density Batterie
Jet Fuel Reformation
Matrix Power Converters an
Energy Harvesting
Electrical Actuators
Smart Screening Skins
Structurally Integrated Wiring
Plug and play structuralized
Structuralized Energy Storag
Diagnostic and Prognostic A
IVHM Implementation Techn
PHM Design Practices and
Fix-or-Fly Reasoning, Optimi
4D flt crew sit. awareness, g
Wake vortex mitigation in ai
Network-centric approach to
Cockpit systems to mitigate
Network-centric appr to grap
Air and ground systems to s
Impacts mitigation of crew f
On-Board Wireless
Off-Board Wireless""
Network-Centric Approach""
Leverage Industry Collabora
Student Challenge

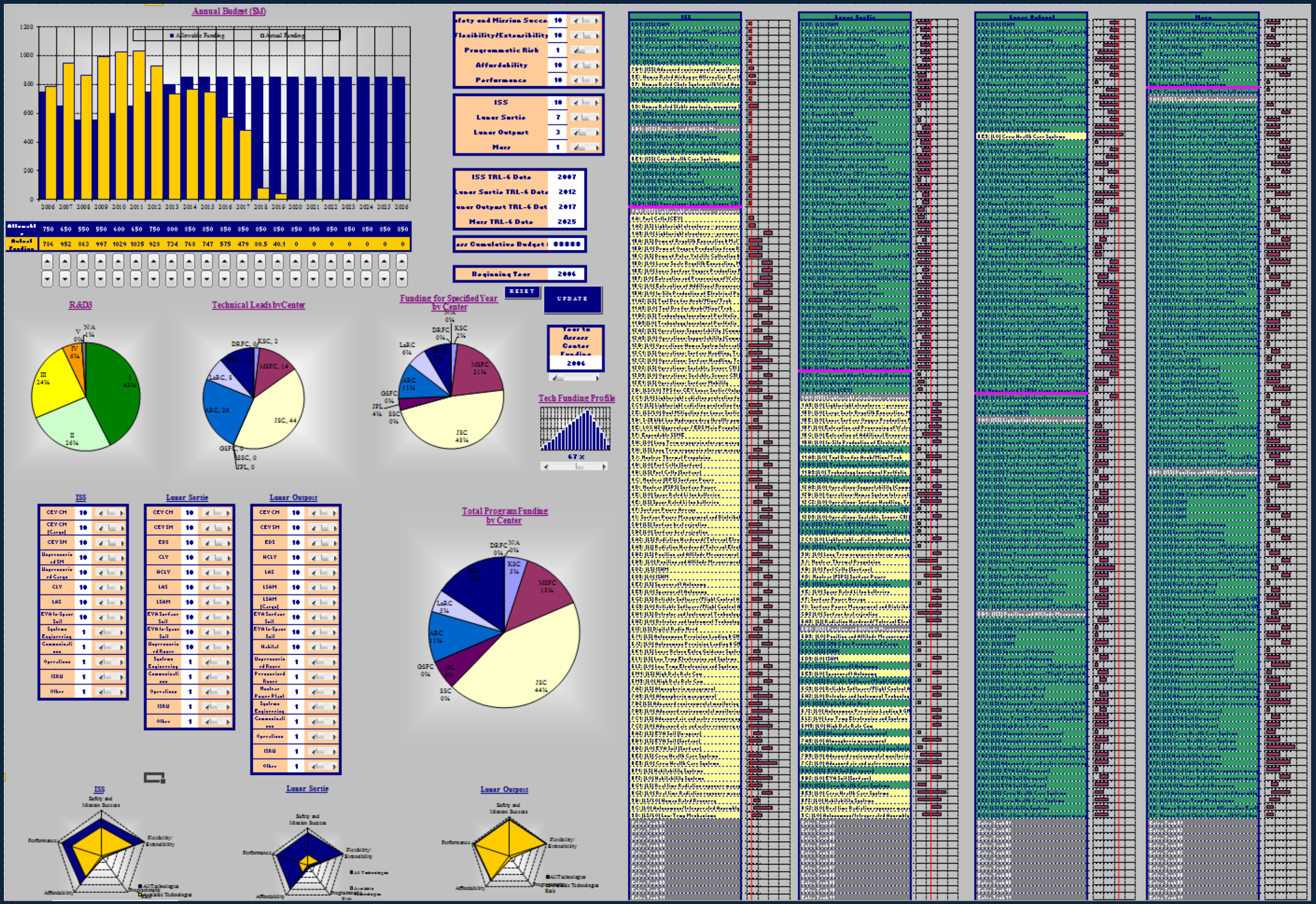
Workforce Proposed Plan
Univ./Ind. Coop. Exchange Program
Strengthen Academic Research
Revamp Undergrad Eng. Degree Pro
Workforce Revitalization and Reinv
Increase aeronautics fellowships
Curriculum Development and Asses
Outreach
Process Development & Evaluation
Bring in Stakeholders
Create Positive Vision of the Aero
"Recycling" Program for Engineers
Incentive programs to assist Univ. a
Assistance for 4-yr univ. VTCC stud
Determine parameters that Affect A
Diversity Alliances Directly Related

ypersonics Proposed Pla
MDO Tools
Key Unit Experiments
Facility Upgrades
Advanced Diagnostics
CFD Code Development a
Aero-Propulsion Scaling M
Mode Transition
RTA-1 Completion
RTA-1 Fan Stage Test
Transonic Aero-Propulsio
Low-Mach-Number Scramj
Innovative 3D Flowpaths
Plasma Combustion Enha
Innovative TBCC Integrati
Metallic Cooled Combust
Conformal Cryogenic Tan
Tough, Durable TPS
High-Temp Bearings/Seals
Ground Test
Low-Cost Flight Experime

Airspace Proposed Plan
NAS Cost/Benefit Model
NASA Tech, System Ops Cost
Increase Predictability
Global Airspace Harmonization
Quality of Service Requirement
Near-term System-wide flow pla
Departure Information
Eliminate Artificial Airspace Bo
Air/Ground Functional Allocati
Collaborative DST for Trajecto
Flexible 4D Trajectories, Enrou
4D Departure and Arrival Traje
Electronic Flight Rules
Tubes in Airspace
Regional Metering
Reduced Separation Standards
Improve Surface Throughput
Increasing Runway Utilization
Increase Airport All Weather Ca
Metro Area Complex: New Con

Operational/Mission Planning

SPACE SP2



Annual Budget ($M)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Allowable	750	650	550	550	600	650	750	800	850	850	850	850	850	850	850	850	850	850	850	850	850
Actual Funding	786	952	863	997	1029	1035	928	734	768	747	575	479	80.5	40.1	0	0	0	0	0	0	0

afety and Mission Succe	10	◀ ▶
Flexibility/Extensibility	10	◀ ▶
Programmatic Risk	1	◀ ▶
Affordability	10	◀ ▶
Performance	10	◀ ▶

ISS	10	◀ ▶
Lunar Sortie	7	◀ ▶
Lunar Outpost	3	◀ ▶
Mars	1	◀ ▶

ISS TRL-6 Date	2007
Lunar Sortie TRL-6 Date	2012
unar Outpost TRL-6 Dat	2017
Mars TRL-6 Date	2025

ars Cumulative Budget | #####

Beginning Year | 2006

RESET

UPDATE

Year to Assess Center Funding: 2006

ISS

CEV CM	10	◀ ▶
CEV CM (Cargo)	10	◀ ▶
CEV SM	10	◀ ▶
Unpressurized SM	10	◀ ▶
Unpressurized Cargo	10	◀ ▶
CLV	10	◀ ▶
LAS	10	◀ ▶
EVA In-Space Suit	10	◀ ▶
Systems Engineering	1	◀ ▶
Communication	1	◀ ▶
Operations	1	◀ ▶
ISRU	1	◀ ▶
Other	1	◀ ▶

Lunar Sortie

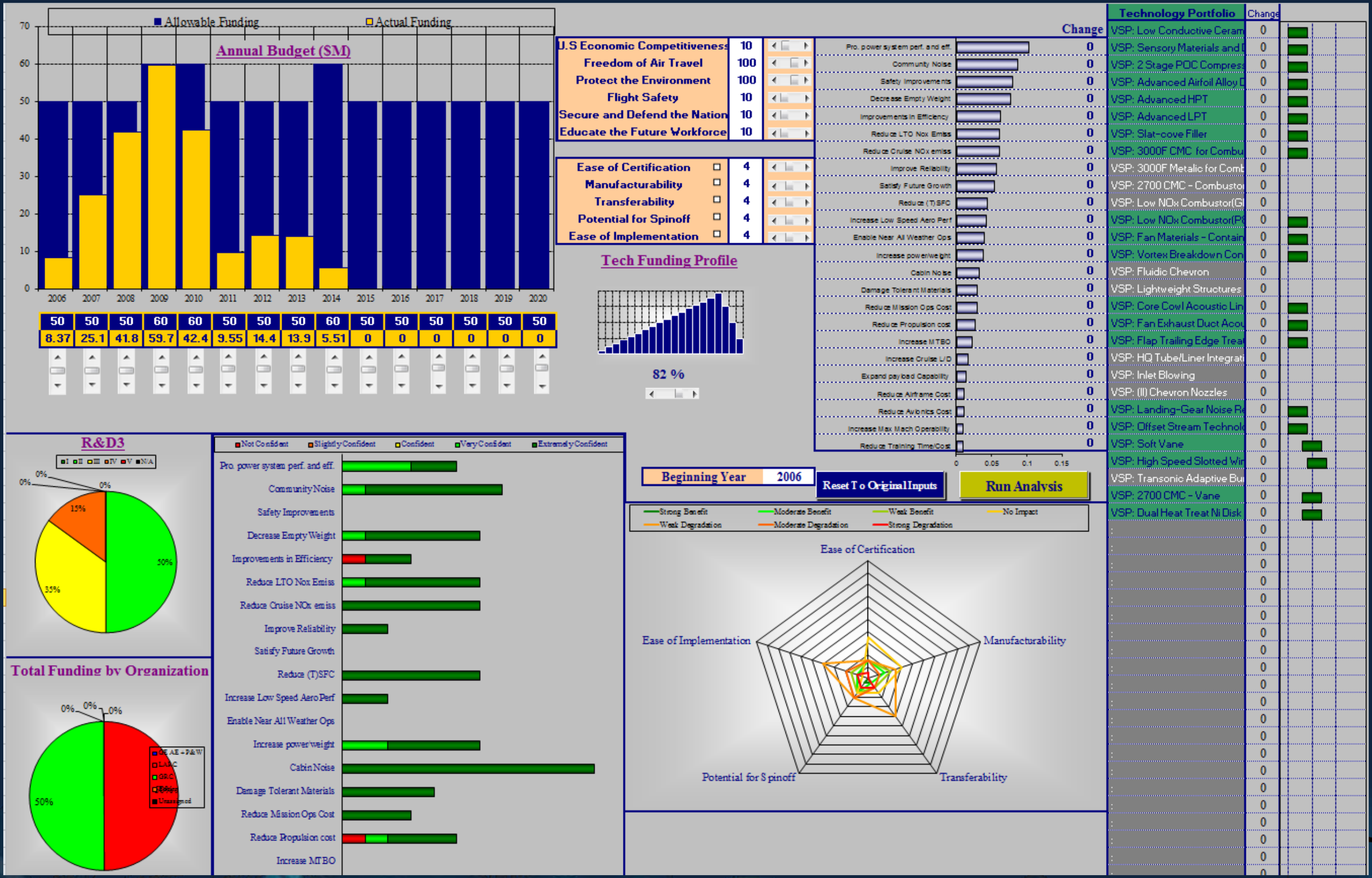
CEV CM	10	◀ ▶
CEV SM	10	◀ ▶
EDS	10	◀ ▶
CLV	10	◀ ▶
HCLV	10	◀ ▶
LAS	10	◀ ▶
LSAM	10	◀ ▶
EVA Surface Suit	10	◀ ▶
EVA In-Space Suit	10	◀ ▶
Unpressurized Rover	10	◀ ▶
Systems Engineering	1	◀ ▶
Communication	1	◀ ▶
Operations	1	◀ ▶
ISRU	1	◀ ▶
Other	1	◀ ▶

Lunar Outpost

CEV CM	10	◀ ▶
CEV SM	10	◀ ▶
EDS	10	◀ ▶
HCLV	10	◀ ▶
LAS	10	◀ ▶
LSAM	10	◀ ▶
LSAM (Cargo)	10	◀ ▶
EVA Surface Suit	10	◀ ▶
EVA In-Space Suit	10	◀ ▶
Habitat	10	◀ ▶
Unpressurized Rover	1	◀ ▶
Pressurized Rover	1	◀ ▶
Nuclear Power Plant	1	◀ ▶
Systems Engineering	1	◀ ▶
Communication	1	◀ ▶
Operations	1	◀ ▶
ISRU	1	◀ ▶
Other	1	◀ ▶

Technology Prioritization

VSP ROI Calculator



2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
50	50	50	60	60	50	50	50	60	50	50	50	50	50	50
8.37	25.1	41.8	59.7	42.4	9.55	14.4	13.9	5.51	0	0	0	0	0	0

U.S Economic Competitiveness	10
Freedom of Air Travel	100
Protect the Environment	100
Flight Safety	10
Secure and Defend the Nation	10
Educate the Future Workforce	10

Ease of Certification	☐	4
Manufacturability	☐	4
Transferability	☐	4
Potential for Spinoff	☐	4
Ease of Implementation	☐	4

	Change
Pro. power system perf. and eff.	0
Community Noise	0
Safety Improvements	0
Decrease Empty Weight	0
Improvements in Efficiency	0
Reduce LTO Nox Emiss	0
Reduce Cruise NOx emiss	0
Improve Reliability	0
Satisfy Future Growth	0
Reduce (T)SFC	0
Increase Low Speed Aero Perf	0
Enable Near All Weather Ops	0
Increase power/weight	0
Cabin Noise	0
Damage Tolerant Materials	0
Reduce Mission Ops Cost	0
Reduce Propulsion cost	0
Increase MTBO	0
Increase Cruise L/D	0
Expand payload Capability	0
Reduce Airframe Cost	0
Reduce Avionics Cost	0
Increase Max Mach Operability	0
Reduce Training Time/Cost	0

Beginning Year 2006

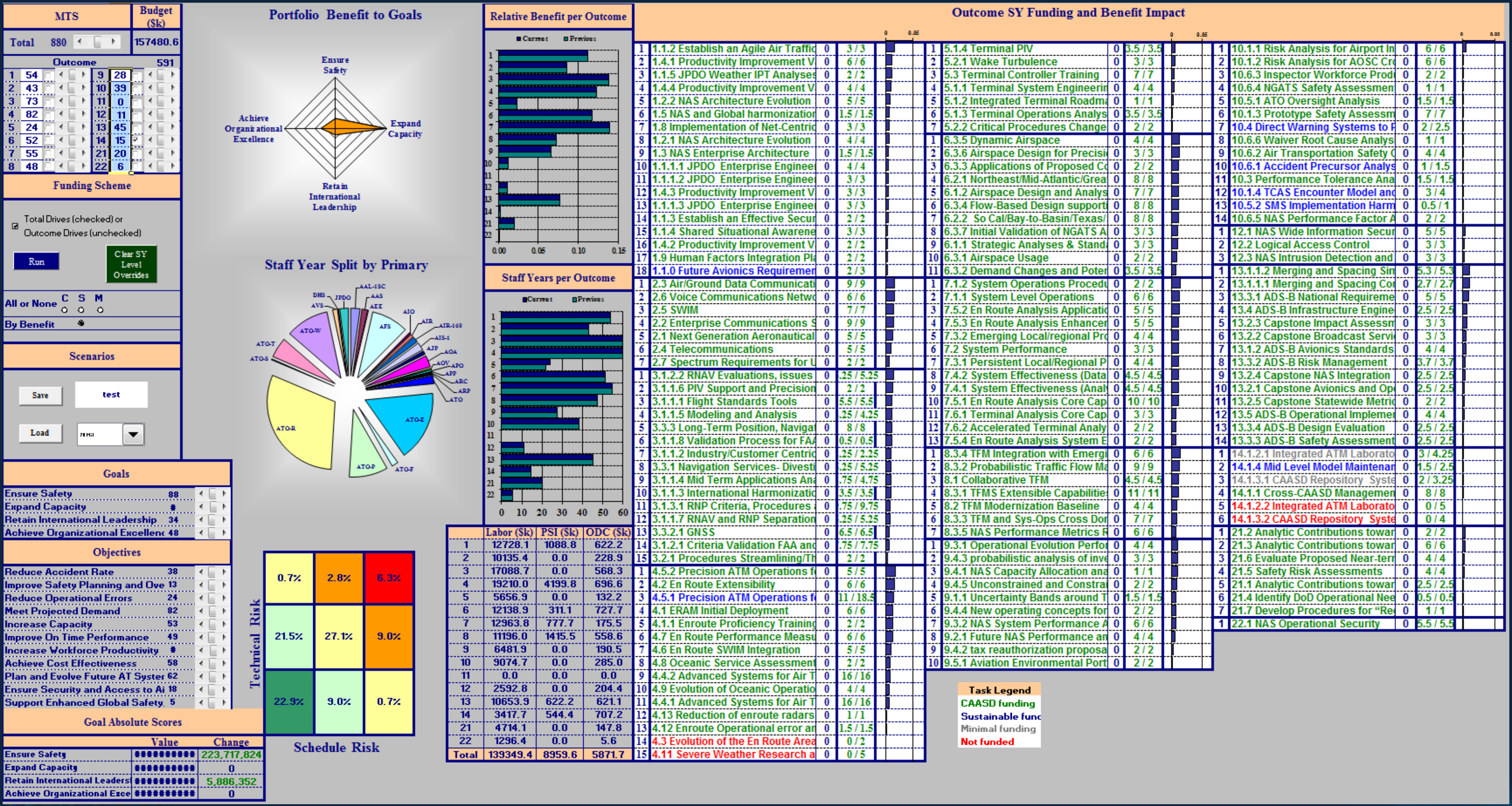
Reset To Original Inputs

Run Analysis

Technology Portfolio	Change
VSP: Low Conductive Ceram	0
VSP: Sensory Materials and	0
VSP: 2 Stage POC Compress	0
VSP: Advanced Airfoil Alloy	0
VSP: Advanced HPT	0
VSP: Advanced LPT	0
VSP: Slat-cove Filler	0
VSP: 3000F CMC for Combu	0
VSP: 3000F Metalic for Comb	0
VSP: 2700 CMC - Combusto	0
VSP: Low NOx Combustor(G	0
VSP: Low NOx Combustor(P	0
VSP: Fan Materials - Contain	0
VSP: Vortex Breakdown Con	0
VSP: Fluidic Chevron	0
VSP: Lightweight Structures	0
VSP: Core Cowl Acoustic Lin	0
VSP: Fan Exhaust Duct Acou	0
VSP: Flap Trailing Edge Trea	0
VSP: HQ Tube/Liner Integrati	0
VSP: Inlet Blowing	0
VSP: (II) Chevron Nozzles	0
VSP: Landing-Gear Noise R	0
VSP: Offset Stream Technol	0
VSP: Soft Vane	0
VSP: High Speed Slotted Wi	0
VSP: Transonic Adaptive Bu	0
VSP: 2700 CMC - Vane	0
VSP: Dual Heat Treat Ni Disk	0

Technology Prioritization, Risk Analysis

MITRE SP2



MTS		Budget ($k)
Total	880	157480.6

Outcome 591

1	54 ☐	9	28 ☐
2	43 ☐	10	39 ☐
3	73 ☐	11	0 ☐
4	82 ☐	12	11 ☐
5	24 ☐	13	45 ☐
6	52 ☐	14	15 ☑
7	55 ☐	21	20 ☐
8	48 ☐	22	6 ☐

Funding Scheme

☑ Total Drives (checked) or Outcome Drives (unchecked)

Run

Clear SY Level Overrides

All or None C ○ S ○ M ○

By Benefit ●

Scenarios

Save test

Load

Goals

Ensure Safety	88
Expand Capacity	#
Retain International Leadership	34
Achieve Organizational Excellenc	48

Objectives

Reduce Accident Rate	38
Improve Safety Planning and Ove	13
Reduce Operational Errors	24
Meet Projected Demand	82
Increase Capacity	53
Improve On Time Performance	49
Increase Workforce Productivity	#
Achieve Cost Effectiveness	58
Plan and Evolve Future AT Syster	62
Ensure Security and Access to Ai	18
Support Enhanced Global Safety	5

Goal Absolute Scores

	Value	Change
Ensure Safety	##########	223,717,824
Expand Capacity	##########	0
Retain International Leaders	##########	5,886,352
Achieve Organizational Exce	##########	0

Technical Risk	0.7%	2.8%	6.3%
	21.5%	27.1%	9.0%
	22.9%	9.0%	0.7%
	Schedule Risk		

	Labor ($k)	PSI ($k)	ODC ($k)
1	12728.1	1088.8	622.2
2	10135.4	0.0	228.9
3	17088.7	0.0	568.3
4	19210.0	4199.8	696.6
5	5656.9	0.0	132.2
6	12138.9	311.1	727.7
7	12963.8	777.7	175.5
8	11196.0	1415.5	558.6
9	6481.9	0.0	190.5
10	9074.7	0.0	285.0
11	0.0	0.0	0.0
12	2592.8	0.0	204.4
13	10653.9	622.2	621.1
14	3417.7	544.4	707.2
21	4714.1	0.0	147.8
22	1296.4	0.0	5.6
Total	139349.4	8959.6	5871.7

Outcome SY Funding and Benefit Impact

1	1.1.2 Establish an Agile Air Traffic	0	3 / 3
2	1.4.1 Productivity Improvement V	0	6 / 6
3	1.1.5 JPDO Weather IPT Analyses	0	2 / 2
4	1.4.4 Productivity Improvement V	0	4 / 4
5	1.2.2 NAS Architecture Evolution	0	5 / 5
6	1.5 NAS and Global harmonization	0	1.5 / 1.5
7	1.8 Implementation of Net-Centric	0	3 / 3
8	1.2.1 NAS Architecture Evolution	0	4 / 4
9	1.3 NAS Enterprise Architecture	0	1.5 / 1.5
10	1.1.1.1 JPDO Enterprise Engineer	0	4 / 4
11	1.1.1.2 JPDO Enterprise Engineer	0	3 / 3
12	1.4.3 Productivity Improvement V	0	3 / 3
13	1.1.1.3 JPDO Enterprise Engineer	0	3 / 3
14	1.1.3 Establish an Effective Secur	0	2 / 2
15	1.1.4 Shared Situational Awarene	0	3 / 3
16	1.4.2 Productivity Improvement V	0	2 / 2
17	1.9 Human Factors Integration Pla	0	2 / 2
18	1.1.0 Future Avionics Requiremen	0	2 / 3
1	2.3 Air/Ground Data Communicati	0	9 / 9
2	2.6 Voice Communications Netwo	0	6 / 6
3	2.5 SWIM	0	7 / 7
4	2.2 Enterprise Communications S	0	9 / 9
5	2.1 Next Generation Aeronautical	0	5 / 5
6	2.4 Telecommunications	0	5 / 5
7	2.7 Spectrum Requirements for U	0	2 / 2
1	3.1.2.2 RNAV Evaluations, issues	0	.25 / 5.25
2	3.1.1.6 PIV Support and Precision	0	2 / 2
3	3.1.1.1 Flight Standards Tools	0	5.5 / 5.5
4	3.1.1.5 Modeling and Analysis	0	.25 / 4.25
5	3.3.3 Long-Term Position, Navigat	0	8 / 8
6	3.1.1.8 Validation Process for FAA	0	0.5 / 0.5
7	3.1.1.2 Industry/Customer Centric	0	.25 / 2.25
8	3.3.1 Navigation Services- Divesti	0	.25 / 5.25
9	3.1.1.4 Mid Term Applications Ana	0	.75 / 4.75
10	3.1.1.3 International Harmonizatio	0	3.5 / 3.5
11	3.1.3.1 RNP Criteria, Procedures a	0	.75 / 9.75
12	3.1.1.7 RNAV and RNP Separation	0	.25 / 5.25
13	3.3.2.1 GNSS	0	6.5 / 6.5
14	3.1.2.1 Criteria Validation FAA and	0	.75 / 7.75
15	3.2.1 Procedures Streamlining/Th	0	2 / 2
1	4.5.2 Precision ATM Operations fo	0	5 / 5
2	4.2 En Route Extensibility	0	6 / 6
3	4.5.1 Precision ATM Operations fo	0	11 / 18.5
4	4.1 ERAM Initial Deployment	0	6 / 6
5	4.1.1 Enroute Proficiency Training	0	2 / 2
6	4.7 En Route Performance Measu	0	6 / 6
7	4.6 En Route SWIM Integration	0	5 / 5
8	4.8 Oceanic Service Assessment	0	2 / 2
9	4.4.2 Advanced Systems for Air T	0	16 / 16
10	4.9 Evolution of Oceanic Operatio	0	4 / 4
11	4.4.1 Advanced Systems for Air T	0	16 / 16
12	4.13 Reduction of enroute radars	0	1 / 1
13	4.12 Enroute Operational error an	0	1.5 / 1.5
14	4.3 Evolution of the En Route Area	0	0 / 2
15	4.11 Severe Weather Research a	0	0 / 5

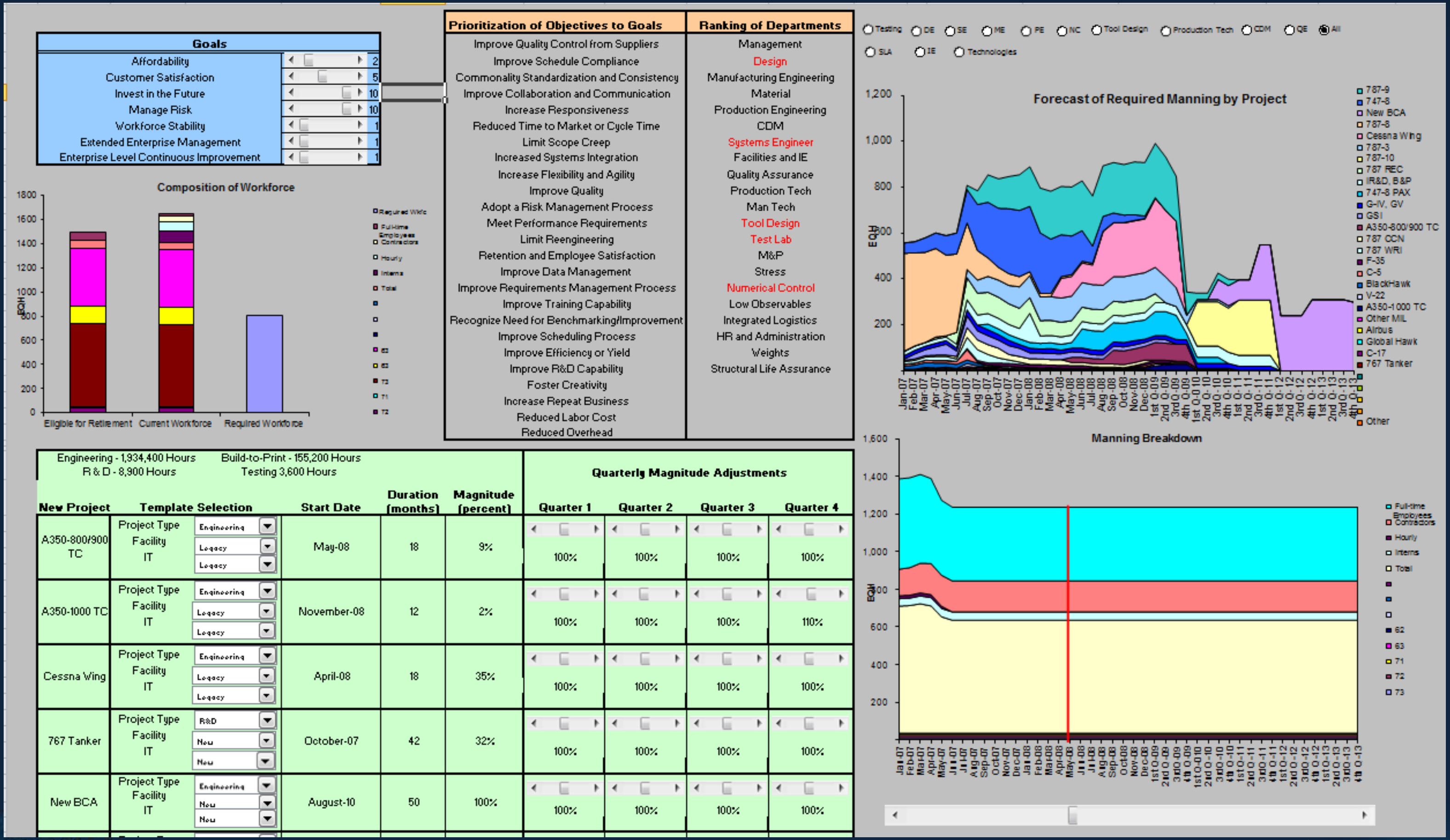
1	5.1.4 Terminal PIV	0	3.5 / 3.5
2	5.2.1 Wake Turbulence	0	3 / 3
3	5.3 Terminal Controller Training	0	7 / 7
4	5.1.1 Terminal System Engineerin	0	4 / 4
5	5.1.2 Integrated Terminal Roadma	0	1 / 1
6	5.1.3 Terminal Operations Analys	0	3.5 / 3.5
7	5.2.2 Critical Procedures Change	0	2 / 2
1	6.3.5 Dynamic Airspace	0	4 / 4
2	6.3.6 Airspace Design for Precisi	0	3 / 3
3	6.3.3 Applications of Proposed Co	0	2 / 2
4	6.2.1 Northeast/Mid-Atlantic/Great	0	8 / 8
5	6.1.2 Airspace Design and Analys	0	7 / 7
6	6.3.4 Flow-Based Design supporti	0	8 / 8
7	6.2.2 So Cal/Bay-to-Basin/Texas/	0	8 / 8
8	6.3.7 Initial Validation of NGATS A	0	3 / 3
9	6.1.1 Strategic Analyses & Standa	0	3 / 3
10	6.3.1 Airspace Usage	0	2 / 2
11	6.3.2 Demand Changes and Poter	0	3.5 / 3.5
1	7.1.2 System Operations Procedu	0	2 / 2
2	7.1.1 System Level Operations	0	6 / 6
3	7.5.2 En Route Analysis Applicatio	0	5 / 5
4	7.5.3 En Route Analysis Enhancer	0	5 / 5
5	7.3.2 Emerging Local/regional Pro	0	4 / 4
6	7.2 System Performance	0	3 / 3
7	7.3.1 Persistent Local/Regional P	0	4 / 4
8	7.4.2 System Effectiveness (Data	0	4.5 / 4.5
9	7.4.1 System Effectiveness (Analy	0	4.5 / 4.5
10	7.5.1 En Route Analysis Core Cap	0	10 / 10
11	7.6.1 Terminal Analysis Core Cap	0	3 / 3
12	7.6.2 Accelerated Terminal Analy	0	2 / 2
13	7.5.4 En Route Analysis System E	0	2 / 2
1	8.3.4 TFM Integration with Emergi	0	6 / 6
2	8.3.2 Probabilistic Traffic Flow Ma	0	9 / 9
3	8.1 Collaborative TFM	0	4.5 / 4.5
4	8.3.1 TFMS Extensible Capabilities	0	11 / 11
5	8.2 TFM Modernization Baseline	0	4 / 4
6	8.3.3 TFM and Sys-Ops Cross Dor	0	7 / 7
7	8.3.5 NAS Performance Metrics R	0	6 / 6
1	9.3.1 Operational Evolution Perfor	0	4 / 4
2	9.4.3 probabilistic analysis of inve	0	3 / 3
3	9.4.1 NAS Capacity Allocation ana	0	1 / 1
4	9.4.5 Unconstrained and Constrai	0	2 / 2
5	9.1.1 Uncertainty Bands around T	0	1.5 / 1.5
6	9.4.4 New operating concepts for	0	2 / 2
7	9.3.2 NAS System Performance A	0	6 / 6
8	9.2.1 Future NAS Performance an	0	4 / 4
9	9.4.2 tax reauthorization proposa	0	2 / 2
10	9.5.1 Aviation Environmental Port	0	2 / 2

1	10.1.1 Risk Analysis for Airport In	0	6 / 6
2	10.1.2 Risk Analysis for AOSC Cro	0	6 / 6
3	10.6.3 Inspector Workforce Produ	0	2 / 2
4	10.6.4 NGATS Safety Assessmen	0	1 / 1
5	10.5.1 ATO Oversight Analysis	0	1.5 / 1.5
6	10.1.3 Prototype Safety Assessm	0	7 / 7
7	10.4 Direct Warning Systems to P	0	2 / 2.5
8	10.6.6 Waiver Root Cause Analysi	0	1 / 1
9	10.6.2 Air Transportation Safety C	0	4 / 4
10	10.6.1 Accident Precursor Analys	0	1 / 1.5
11	10.3 Performance Tolerance Ana	0	1.5 / 1.5
12	10.1.4 TCAS Encounter Model and	0	3 / 4
13	10.5.2 SMS Implementation Harm	0	0.5 / 1
14	10.6.5 NAS Performance Factor A	0	2 / 2
1	12.1 NAS Wide Information Secur	0	5 / 5
2	12.2 Logical Access Control	0	3 / 3
3	12.3 NAS Intrusion Detection and	0	3 / 3
1	13.1.1.2 Merging and Spacing Sin	0	5.3 / 5.3
2	13.1.1.1 Merging and Spacing Cor	0	2.7 / 2.7
3	13.3.1 ADS-B National Requireme	0	5 / 5
4	13.4 ADS-B Infrastructure Engine	0	2.5 / 2.5
5	13.2.3 Capstone Impact Assessm	0	3 / 3
6	13.2.2 Capstone Broadcast Servi	0	3 / 3
7	13.1.2 ADS-B Avionics Standards	0	4 / 4
8	13.3.2 ADS-B Risk Management	0	3.7 / 3.7
9	13.2.4 Capstone NAS Integration	0	2.5 / 2.5
10	13.2.1 Capstone Avionics and Ope	0	2.5 / 2.5
11	13.2.5 Capstone Statewide Metric	0	2 / 2
12	13.5 ADS-B Operational Implemer	0	4 / 4
13	13.3.4 ADS-B Design Evaluation	0	2.5 / 2.5
14	13.3.3 ADS-B Safety Assessment	0	2.5 / 2.5
1	14.1.2.1 Integrated ATM Laborato	0	3 / 4.25
2	14.1.4 Mid Level Model Maintenan	0	1.5 / 2.5
3	14.1.3.1 CAASD Repository Syste	0	2 / 3.25
4	14.1.1 Cross-CAASD Managemen	0	8 / 8
5	14.1.2.2 Integrated ATM Laborato	0	0 / 5
6	14.1.3.2 CAASD Repository Syste	0	0 / 4
1	21.2 Analytic Contributions towar	0	2 / 2
2	21.3 Analytic Contributions towar	0	6 / 6
3	21.6 Evaluate Proposed Near-term	0	4 / 4
4	21.5 Safety Risk Assessments	0	4 / 4
5	21.1 Analytic Contributions towar	0	2.5 / 2.5
6	21.4 Identify DoD Operational Nee	0	0.5 / 0.5
7	21.7 Develop Procedures for "Re	0	1 / 1
1	22.1 NAS Operational Security	0	5.5 / 5.5

Task Legend
- CAASD funding
- Sustainable func
- Minimal funding
- Not funded

Workforce Planning & Prioritization

Vought Calculator



Goals	
Affordability	2
Customer Satisfaction	5
Invest in the Future	10
Manage Risk	10
Workforce Stability	1
Extended Enterprise Management	1
Enterprise Level Continuous Improvement	1

Prioritization of Objectives to Goals	Ranking of Departments
Improve Quality Control from Suppliers	Management
Improve Schedule Compliance	Design
Commonality Standardization and Consistency	Manufacturing Engineering
Improve Collaboration and Communication	Material
Increase Responsiveness	Production Engineering
Reduced Time to Market or Cycle Time	CDM
Limit Scope Creep	Systems Engineer
Increased Systems Integration	Facilities and IE
Increase Flexibility and Agility	Quality Assurance
Improve Quality	Production Tech
Adopt a Risk Management Process	Man Tech
Meet Performance Requirements	Tool Design
Limit Reengineering	Test Lab
Retention and Employee Satisfaction	M&P
Improve Data Management	Stress
Improve Requirements Management Process	Numerical Control
Improve Training Capability	Low Observables
Recognize Need for Benchmarking/Improvement	Integrated Logistics
Improve Scheduling Process	HR and Administration
Improve Efficiency or Yield	Weights
Improve R&D Capability	Structural Life Assurance
Foster Creativity	
Increase Repeat Business	
Reduced Labor Cost	
Reduced Overhead	

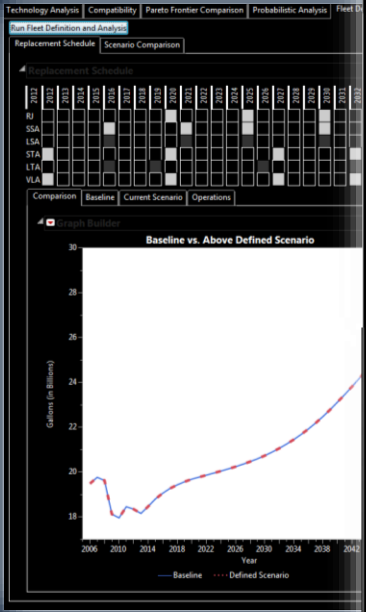
○ Testing ○ DE ○ SE ○ ME ○ PE ○ NC ○ Tool Design ○ Production Tech ○ CDM ○ QE ● All
○ SLA ○ IE ○ Technologies

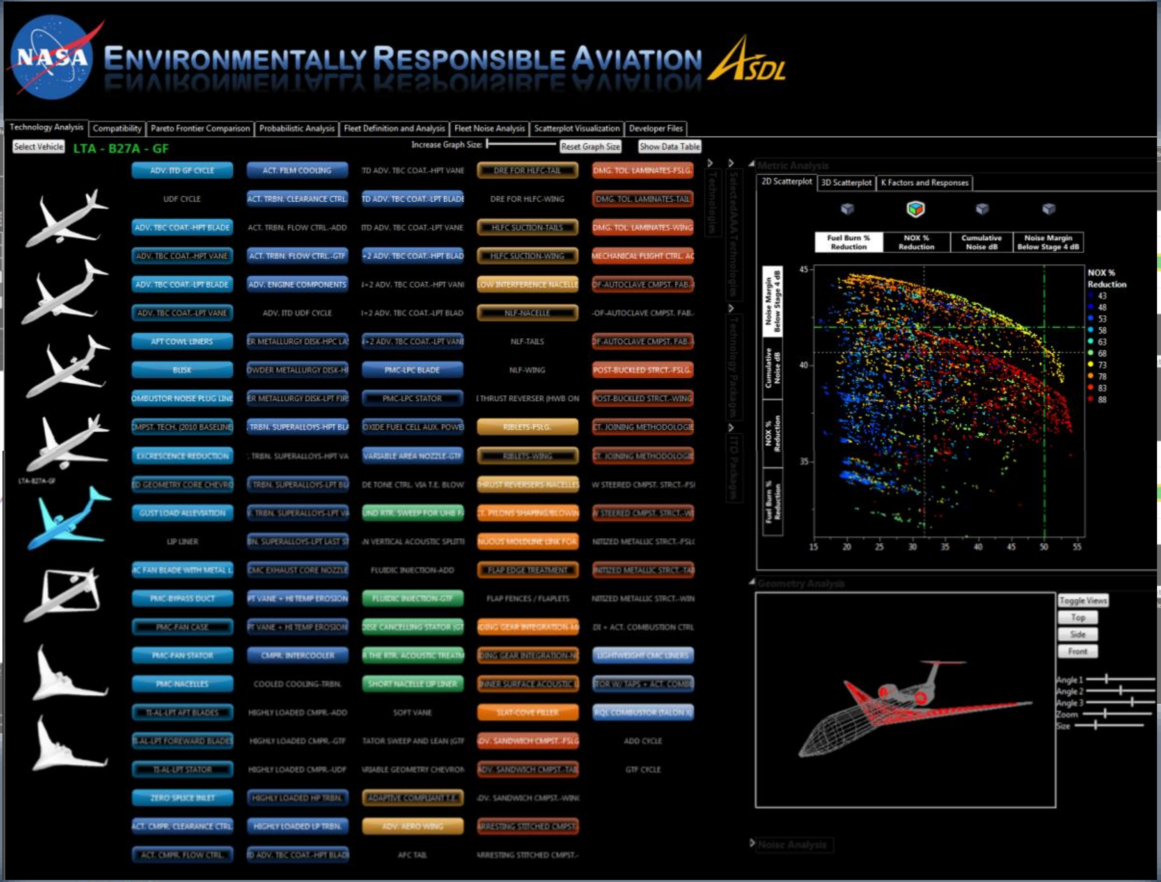
Engineering - 1,934,400 Hours Build-to-Print - 155,200 Hours
R & D - 8,900 Hours Testing 3,600 Hours

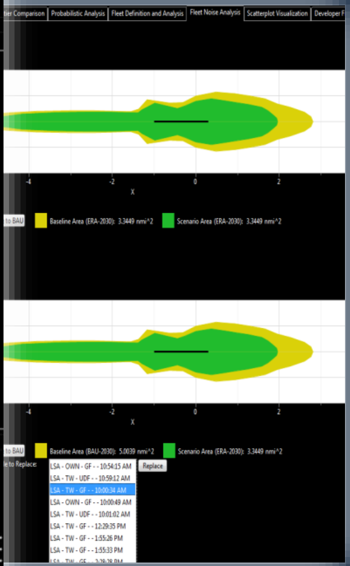
New Project	Template Selection		Start Date	Duration (months)	Magnitude (percent)	Quarterly Magnitude Adjustments Quarter 1	Quarter 2	Quarter 3	Quarter 4
A350-800/900 TC	Project Type Facility IT	Engineering Legacy Legacy	May-08	18	9%	100%	100%	100%	100%
A350-1000 TC	Project Type Facility IT	Engineering Legacy Legacy	November-08	12	2%	100%	100%	100%	110%
Cessna Wing	Project Type Facility IT	Engineering Legacy Legacy	April-08	18	35%	100%	100%	100%	100%
767 Tanker	Project Type Facility IT	R&D New New	October-07	42	32%	100%	100%	100%	100%
New BCA	Project Type Facility IT	Engineering New New	August-10	50	100%	100%	100%	100%	100%

Technology Analysis, Fleet, Environmental Modeling

NASA ERA Dashboard

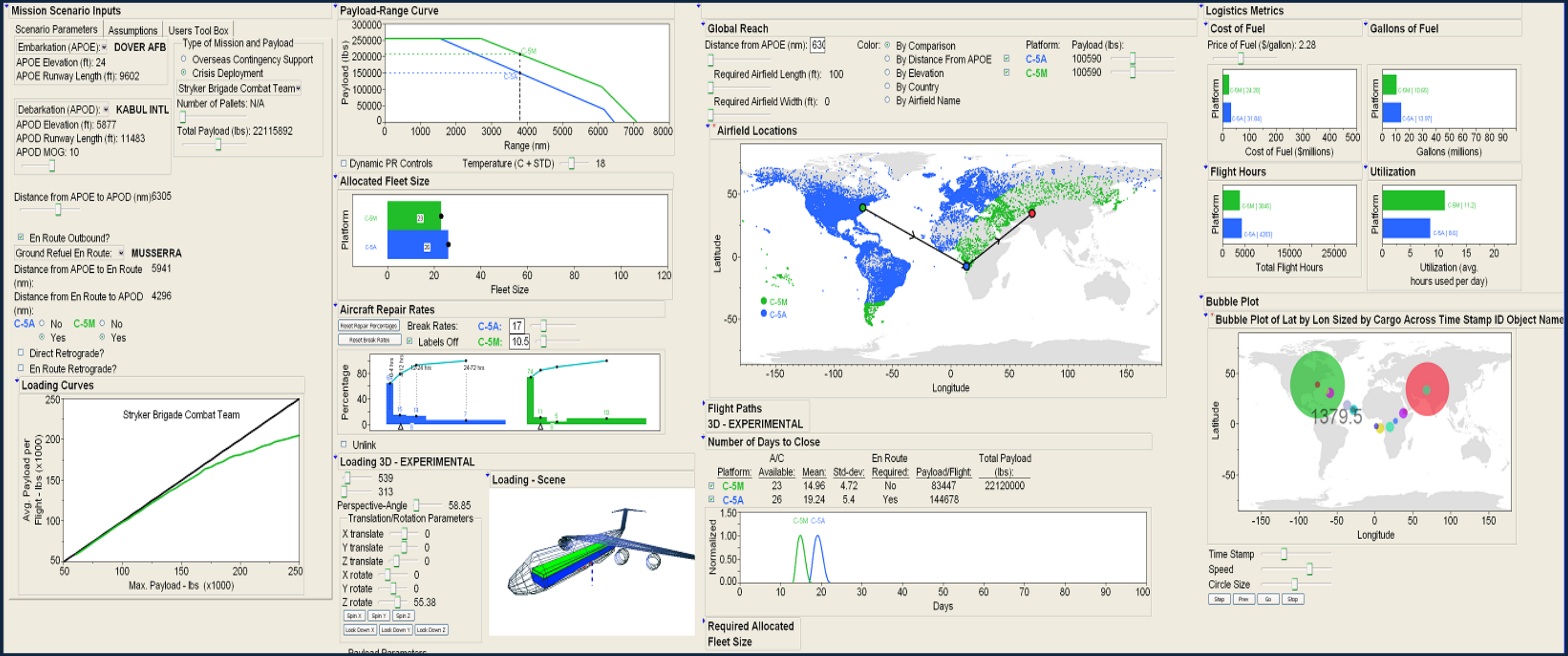






Logistics & Operations

SACT-Lockheed



Mission Scenario Inputs

Scenario Parameters | Assumptions | Users Tool Box

Embarkation (APOE): DOVER AFB
APOE Elevation (ft): 24
APOE Runway Length (ft): 9602

Type of Mission and Payload
○ Overseas Contingency Support
● Crisis Deployment
Stryker Brigade Combat Team
Number of Pallets: N/A
Total Payload (lbs): 22115892

Debarkation (APOD): KABUL INTL
APOD Elevation (ft): 5877
APOD Runway Length (ft): 11483
APOD MOG: 10

Distance from APOE to APOD (nm) 6305

☑ En Route Outbound?
Ground Refuel En Route: MUSSERRA
Distance from APOE to En Route (nm): 5941
Distance from En Route to APOD (nm): 4296
C-5A ○ No ● Yes C-5M ○ No ● Yes
☐ Direct Retrograde?
☐ En Route Retrograde?

Loading Curves

Payload-Range Curve

☐ Dynamic PR Controls
Temperature (C + STD) 18

Allocated Fleet Size

Aircraft Repair Rates

Reset Repair Percentages | Reset Break Rates
Break Rates: C-5A: 17 C-5M: 10.5
☑ Labels Off

☐ Unlink

Loading 3D - EXPERIMENTAL

539
313
Perspective-Angle 58.85
Translation/Rotation Parameters
X translate 0
Y translate 0
Z translate 0
X rotate 0
Y rotate 0
Z rotate 55.38
Spin X | Spin Y | Spin Z
Look Down X | Look Down Y | Look Down Z

Loading - Scene

Payload Parameters

Global Reach

Distance from APOE (nm): 630
Required Airfield Length (ft): 100
Required Airfield Width (ft): 0

Color: ● By Comparison ○ By Distance From APOE ○ By Elevation ○ By Country ○ By Airfield Name

Platform:	Payload (lbs):
☑ C-5A	100590
☑ C-5M	100590

Airfield Locations

Flight Paths

3D - EXPERIMENTAL

Number of Days to Close

Platform:	A/C Available:	Mean:	Std-dev:	En Route Required:	Payload/Flight:	Total Payload (lbs):
☑ C-5M	23	14.96	4.72	No	83447	22120000
☑ C-5A	26	19.24	5.4	Yes	144678	

Required Allocated Fleet Size

Logistics Metrics

Cost of Fuel

Price of Fuel ($/gallon): 2.28

Gallons of Fuel

Flight Hours

Utilization

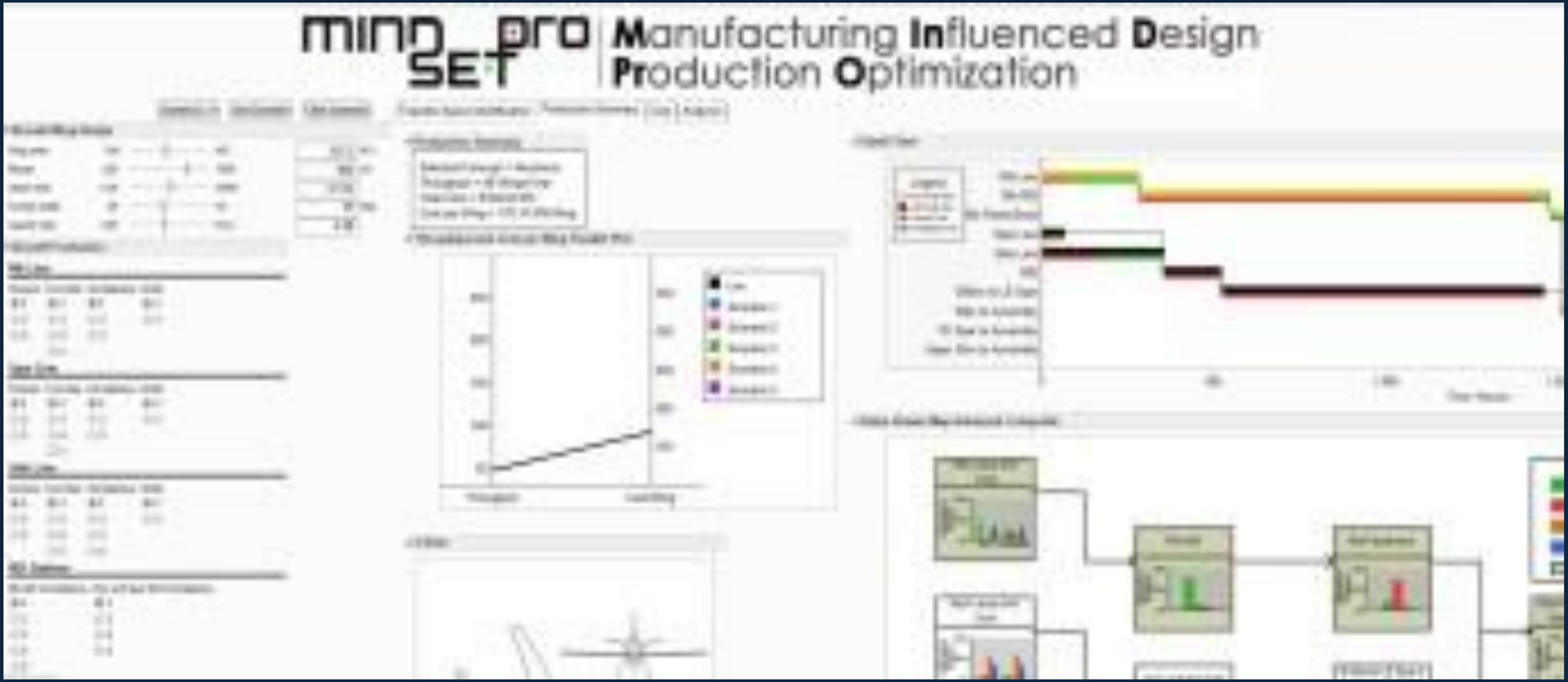
Bubble Plot

Bubble Plot of Lat by Lon Sized by Cargo Across Time Stamp ID Object Name

Time Stamp
Speed
Circle Size
Step | Prev | Go | Stop

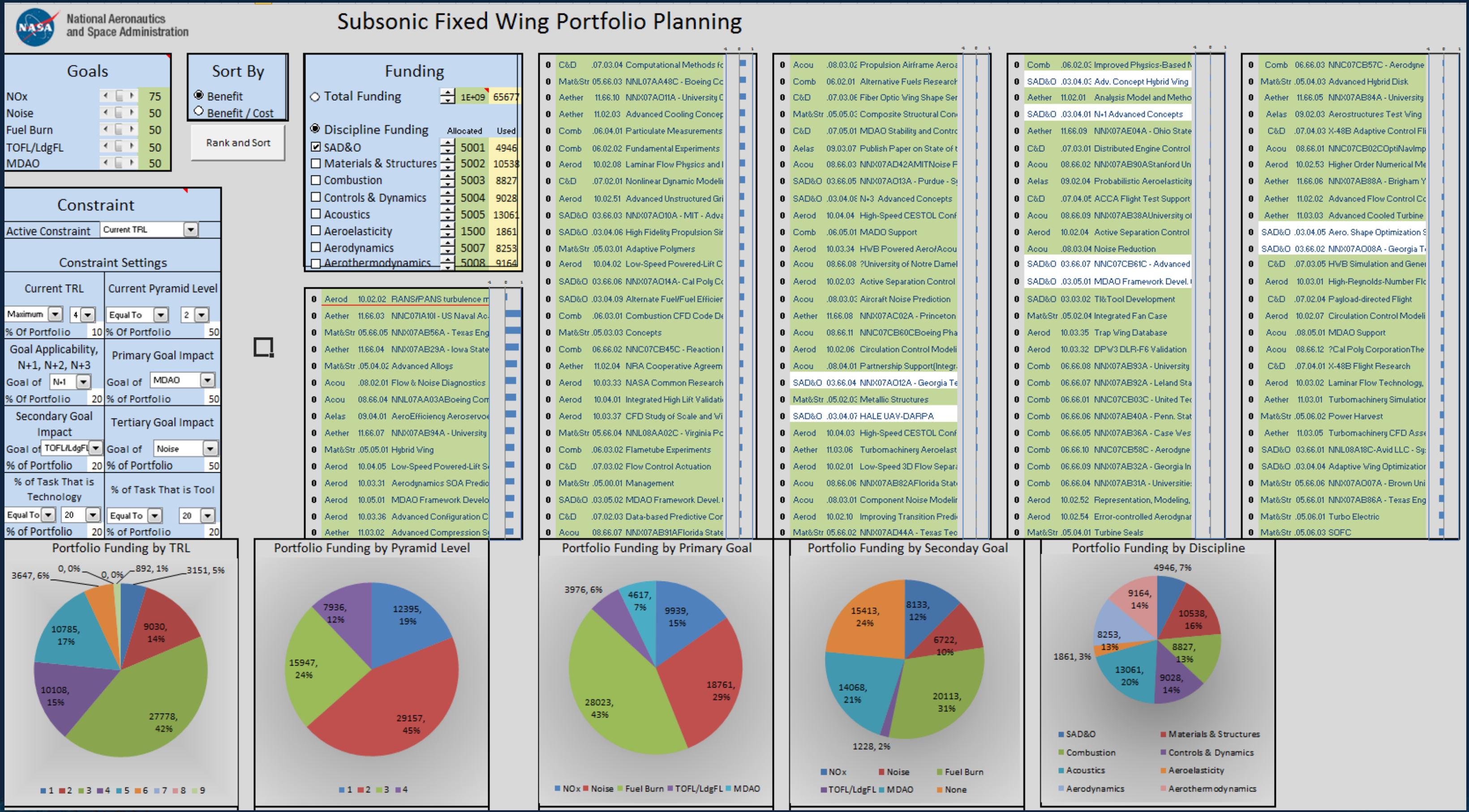
Production Planning & Scheduling

MINDPro



Portfolio Management

SFW Portfolio Calculator



National Aeronautics and Space Administration

Subsonic Fixed Wing Portfolio Planning

Goals

NOx	75
Noise	50
Fuel Burn	50
TOFL/LdgFL	50
MDAO	50

Sort By

● Benefit
○ Benefit / Cost

Rank and Sort

Funding

○ Total Funding 1E+09 65677

● Discipline Funding

	Allocated	Used
☑ SAD&O	5001	4946
☐ Materials & Structures	5002	10538
☐ Combustion	5003	8827
☐ Controls & Dynamics	5004	9028
☐ Acoustics	5005	13061
☐ Aeroelasticity	1500	1861
☐ Aerodynamics	5007	8253
☐ Aerothermodynamics	5008	9164

Constraint

Active Constraint: Current TRL

Constraint Settings

Current TRL	Current Pyramid Level
Maximum 4	Equal To 2
% Of Portfolio 10	% Of Portfolio 50
Goal Applicability, N+1, N+2, N+3	Primary Goal Impact
Goal of N+1	Goal of MDAO
% Of Portfolio 20	% of Portfolio 50
Secondary Goal Impact	Tertiary Goal Impact
Goal of TOFL/LdgFL	Goal of Noise
% of Portfolio 20	% of Portfolio 50
% of Task That is Technology	% of Task That is Tool
Equal To 20	Equal To 20
% of Portfolio 20	% of Portfolio 20

0	Aerod	10.02.02	RANS/PANS turbulence m
0	Aether	11.66.03	NNC07IA10I - US Naval Ac
0	Mat&Str	05.66.05	NNX07AB56A - Texas Eng
0	Aether	11.66.04	NNX07AB29A - Iowa State
0	Mat&Str	.05.04.02	Advanced Alloys
0	Acou	.08.02.01	Flow & Noise Diagnostics
0	Acou	08.66.04	NNL07AA03ABoeing Com
0	Aelas	09.04.01	AeroEfficiency Aeroservoe
0	Aether	11.66.07	NNX07AB94A - University
0	Mat&Str	.05.05.01	Hybrid Wing
0	Aerod	10.04.05	Low-Speed Powered-Lift S
0	Aerod	10.03.31	Aerodynamics SOA Predic
0	Aerod	10.05.01	MDAO Framework Develo
0	Aerod	10.03.36	Advanced Configuration C
0	Aether	11.03.02	Advanced Compression S

0	C&D	.07.03.04	Computational Methods fo
0	Mat&Str	05.66.03	NNL07AA48C - Boeing Co
0	Aether	11.66.10	NNX07AO11A - University C
0	Aether	11.02.03	Advanced Cooling Concep
0	Comb	.06.04.01	Particulate Measurements
0	Comb	06.02.02	Fundamental Experiments
0	Aerod	10.02.08	Laminar Flow Physics and I
0	C&D	.07.02.01	Nonlinear Dynamic Modeli
0	Aerod	10.02.51	Advanced Unstructured Gri
0	SAD&O	03.66.03	NNX07AO10A - MIT - Adva
0	SAD&O	.03.04.06	High Fidelity Propulsion Sir
0	Mat&Str	.05.03.01	Adaptive Polymers
0	Aerod	10.04.02	Low-Speed Powered-Lift C
0	SAD&O	03.66.06	NNX07AO14A- Cal Poly Co
0	SAD&O	.03.04.09	Alternate Fuel/Fuel Efficier
0	Comb	.06.03.01	Combustion CFD Code De
0	Mat&Str	.05.03.03	Concepts
0	Comb	06.66.02	NNC07CB45C - Reaction I
0	Aether	11.02.04	NRA Cooperative Agreem
0	Aerod	10.03.33	NASA Common Research
0	Aerod	10.04.01	Integrated High Lift Validati
0	Aerod	10.03.37	CFD Study of Scale and Wi
0	Mat&Str	05.66.04	NNL08AA02C - Virginia Po
0	Comb	.06.03.02	Flametube Experiments
0	C&D	.07.03.02	Flow Control Actuation
0	Mat&Str	.05.00.01	Management
0	SAD&O	.03.05.02	MDAO Framework Devel. (
0	C&D	.07.02.03	Data-based Predictive Cor
0	Acou	08.66.07	NNX07AB91AFlorida State

0	Acou	.08.03.02	Propulsion Airframe Aeroa
0	Comb	06.02.01	Alternative Fuels Research
0	C&D	.07.03.06	Fiber Optic Wing Shape Ser
0	Mat&Str	.05.05.03	Composite Structural Con
0	C&D	.07.05.01	MDAO Stability and Contro
0	Aelas	09.03.07	Publish Paper on State of t
0	Acou	08.66.03	NNX07AD42AMITNoise F
0	SAD&O	03.66.05	NNX07AO13A - Purdue - Sy
0	SAD&O	.03.04.08	N+3 Advanced Concepts
0	Aerod	10.04.04	High-Speed CESTOL Conf
0	Comb	.06.05.01	MADO Support
0	Aerod	10.03.34	HWB Powered Aero/Acou
0	Acou	08.66.08	?University of Notre Dame(
0	Aerod	10.02.03	Active Separation Control
0	Acou	.08.03.03	Aircraft Noise Prediction
0	Aether	11.66.08	NNX07AC02A - Princeton
0	Acou	08.66.11	NNC07CB60CBoeing Pha
0	Aerod	10.02.06	Circulation Control Modeli
0	Acou	.08.04.01	Partnership Support(Integr.
0	SAD&O	03.66.04	NNX07AO12A - Georgia Te
0	Mat&Str	.05.02.03	Metallic Structures
0	SAD&O	.03.04.07	HALE UAV-DARPA
0	Aerod	10.04.03	High-Speed CESTOL Conf
0	Aether	11.03.06	Turbomachinery Aeroelast
0	Aerod	10.02.01	Low-Speed 3D Flow Separa
0	Acou	08.66.06	NNX07AB82AFlorida State
0	Acou	.08.03.01	Component Noise Modelir
0	Aerod	10.02.10	Improving Transition Predi
0	Mat&Str	05.66.02	NNX07AD44A - Texas Tec

0	Comb	.06.02.03	Improved Physics-Based M
0	SAD&O	.03.04.03	Adv. Concept Hybrid Wing
0	Aether	11.02.01	Analysis Model and Metho
0	SAD&O	.03.04.01	N+1 Advanced Concepts
0	Aether	11.66.09	NNX07AE04A - Ohio State
0	C&D	.07.03.01	Distributed Engine Control
0	Acou	08.66.02	NNX07AB90AStanford Un
0	Aelas	09.02.04	Probabilistic Aeroelasticity
0	C&D	.07.04.05	ACCA Flight Test Support
0	Acou	08.66.09	NNX07AB38AUniversity of
0	Aerod	10.02.04	Active Separation Control
0	Acou	.08.03.04	Noise Reduction
0	SAD&O	03.66.07	NNC07CB61C - Advanced
0	SAD&O	.03.05.01	MDAO Framework Devel. (
0	SAD&O	03.03.02	TI&Tool Development
0	Mat&Str	.05.02.04	Integrated Fan Case
0	Aerod	10.03.35	Trap Wing Database
0	Aerod	10.03.32	DPW3 DLR-F6 Validation
0	Comb	06.66.08	NNX07AB93A - University
0	Comb	06.66.07	NNX07AB92A - Leland Sta
0	Comb	06.66.01	NNC07CB03C - United Tec
0	Comb	06.66.06	NNX07AB40A - Penn. Stat
0	Comb	06.66.05	NNX07AB36A - Case Wes
0	Comb	06.66.10	NNC07CB58C - Aerodyne
0	Comb	06.66.09	NNX07AB32A - Georgia In
0	Comb	06.66.04	NNX07AB31A - Universitie:
0	Aerod	10.02.52	Representation, Modeling,
0	Aerod	10.02.54	Error-controlled Aerodynar
0	Mat&Str	.05.04.01	Turbine Seals

0	Comb	06.66.03	NNC07CB57C - Aerodyne
0	Mat&Str	.05.04.03	Advanced Hybrid Disk
0	Aether	11.66.05	NNX07AB84A - University
0	Aelas	09.02.03	Aerostructures Test Wing
0	C&D	.07.04.03	X-48B Adaptive Control Fli
0	Acou	08.66.01	NNC07CB02COptiNavImp
0	Aerod	10.02.53	Higher Order Numerical Me
0	Aether	11.66.06	NNX07AB88A - Brigham Y
0	Aether	11.02.02	Advanced Flow Control Co
0	Aether	11.03.03	Advanced Cooled Turbine
0	SAD&O	.03.04.05	Aero. Shape Optimization S
0	SAD&O	03.66.02	NNX07AO08A - Georgia Te
0	C&D	.07.03.05	HWB Simulation and Gener
0	Aerod	10.03.01	High-Reynolds-Number Flo
0	C&D	.07.02.04	Payload-directed Flight
0	Aerod	10.02.07	Circulation Control Modeli
0	Acou	.08.05.01	MDAO Support
0	Acou	08.66.12	?Cal Poly CorporationThe
0	C&D	.07.04.01	X-48B Flight Research
0	Aerod	10.03.02	Laminar Flow Technology,
0	Aether	11.03.01	Turbomachinery Simulation
0	Mat&Str	.05.06.02	Power Harvest
0	Aether	11.03.05	Turbomachinery CFD Asse
0	SAD&O	03.66.01	NNL08A18C-Avid LLC - Sy
0	SAD&O	.03.04.04	Adaptive Wing Optimization
0	Mat&Str	05.66.06	NNX07AO07A - Brown Uni
0	Mat&Str	05.66.01	NNX07AB86A - Texas Eng
0	Mat&Str	.05.06.01	Turbo Electric
0	Mat&Str	.05.06.03	SOFC

Portfolio Funding by TRL

Portfolio Funding by Pyramid Level

Portfolio Funding by Primary Goal

Portfolio Funding by Seconday Goal

Portfolio Funding by Discipline

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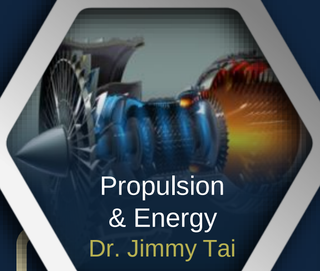

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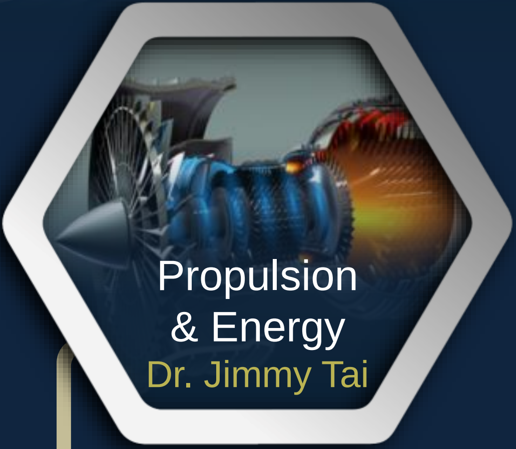
Georgia Tech | Aerospace Systems Design Laboratory

Propulsion & Energy Division



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(TBD)

Rocket Based Propulsion
(Stephen Edwards)

Cultivate the next generation of propulsion engineers through an internationally recognized, multidisciplinary educational program

and

Advance the state of the art in propulsion, power, and energy system design through innovative modeling and simulation methods

Advanced Propulsion Systems Modeling Capability

Cycle Refinements and Advancements

The state of the art cycle design using ***NPSS*** *for*

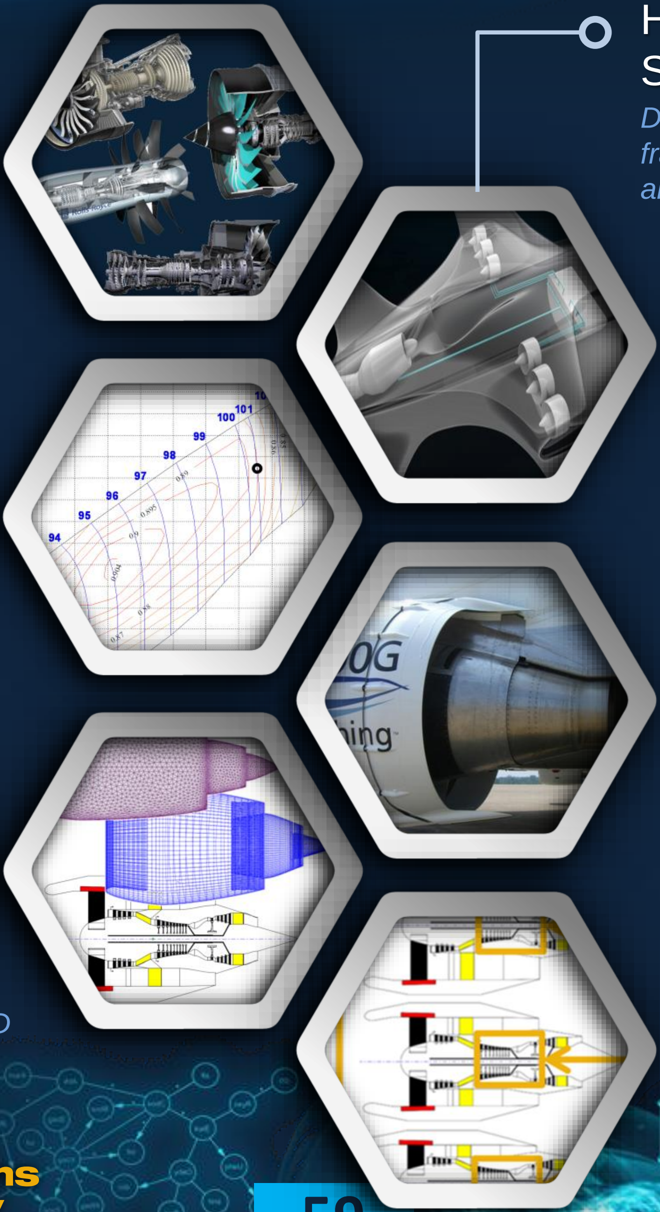
- *Advance Direct Drive High Bypass Turbofan (GEnx Class)*
- *Ultra High Bypass Turbofan with Variable Pitch Fan*
- *Open Rotor*
- *Geared Turbofan*

Parametric Component Map Generation

To develop a mean-line model of the multistage axial compression process to generate maps

Engine Flowpath Visualization

*2D Conceptual Design Codes (****NPSS****/WATE++) ➔*
Vehicle Sketch Pad ➔
Higher Order Surface Mesh for 3D CFD

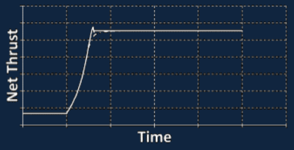


Hybrid Electric Propulsion System Modeling

Develop a suite of elements using ***NPSS*** *framework to support modeling hybrid electric architectures*

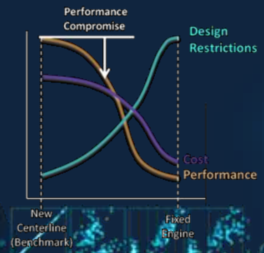
Technology Assessments Requiring Transient Engine Models Coupled with Controls

Beyond the common practice of steady-state technology assessments



Common Core Design for Multiple Applications

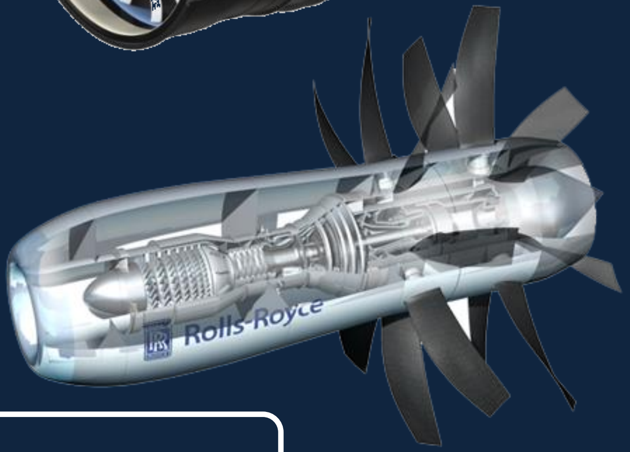
- *Market projection*
- *Robust common core design*
- *Multi-criteria decision making*



Cycle Refinements and Advancements

Advance Direct Drive High Bypass Turbofan (GEnx Class)

Ultra High Bypass Turbofan with Variable Pitch Fan



Open Rotor

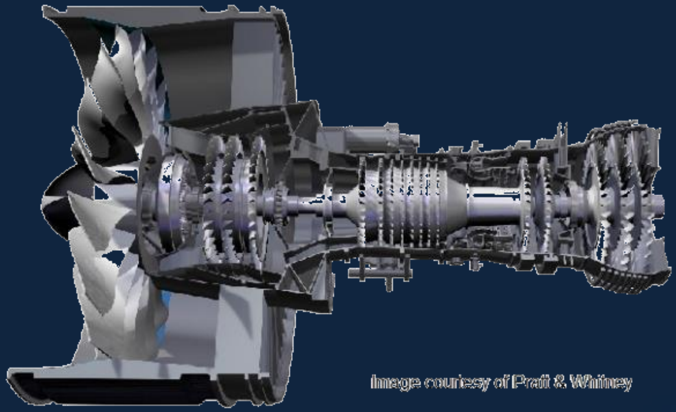


Image courtesy of Pratt & Whitney

Geared Fan Turbofan

What Sets Us Apart from Others In Cycle Design …

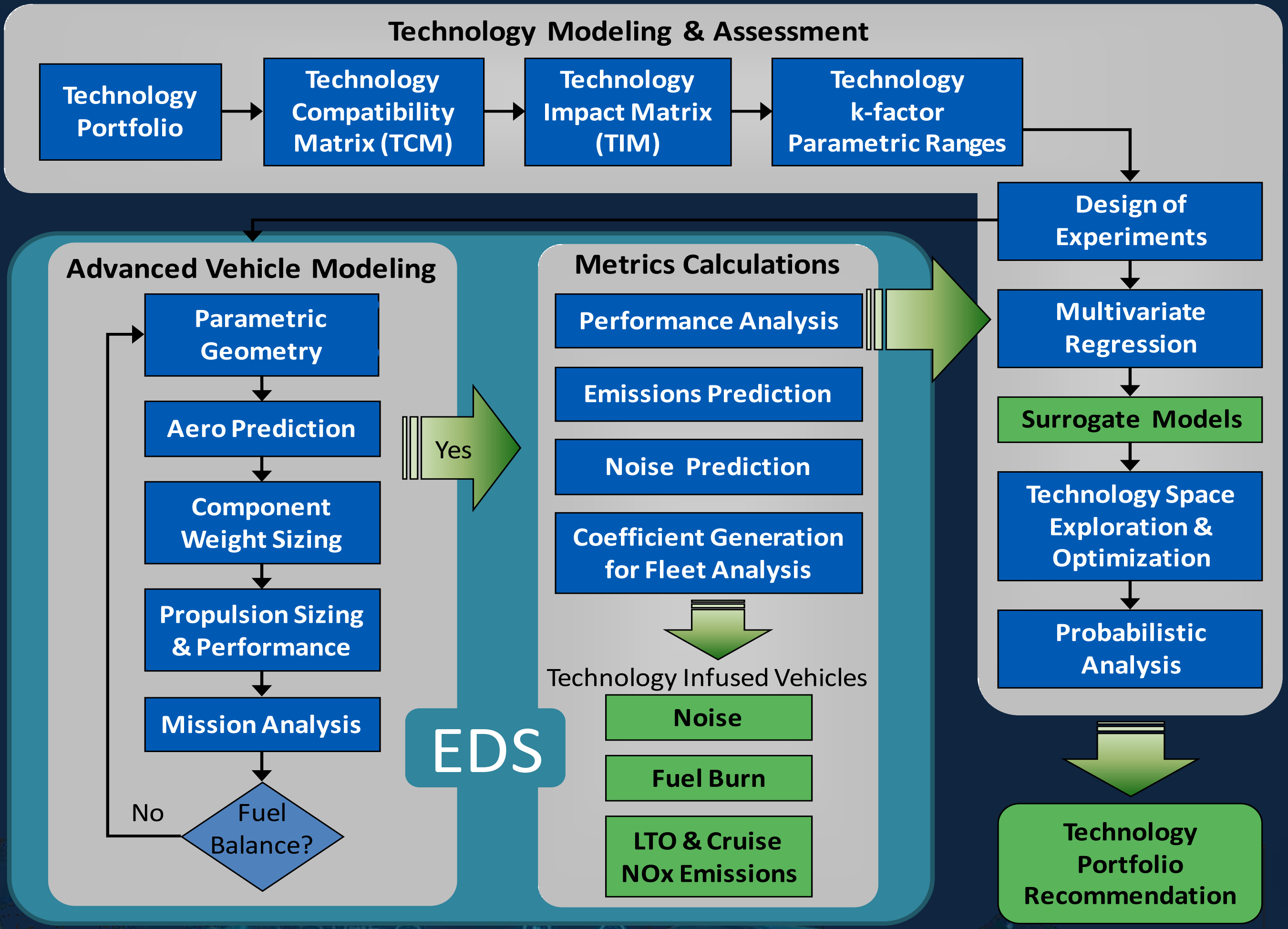
- Simultaneous Multi-Design Point Cycle Set-Up
- Cycle Selection Done with Aeromechanical and Aircraft Requirements in the Loop
- Proper Power Management
- In-line Parametric Component Map Generation
- Component Effects Empirically Captured (i.e. Reynold’s Effect, Size Effect, etc.)
- Use Industry Standard Tool (NPSS)
- Knowledgeable People!

Technology Assessment for NASA ERA

- Work in support the Environmentally Responsible Aviation (ERA) project goal
  - "… to advance vehicle concepts and technologies that can *simultaneously* reduce fuel burn, noise, and emissions."
- Use system-level analysis with the "appropriate" level of fidelity to quantify feasibility, benefits and degradations, and associated risk.
- Provide NASA not only with system level assessments results but also a structured process for modeling and assessing concepts and technologies for ERA
- Key deliverable are:
  - Rapid assessment environment for NASA to make informed decisions
  - All vehicle and technology models including expanded unconventional configurations
  - Technology report

Technology Assessment for NASA ERA

- Technology and Vehicle Assessment Process



Technology Modeling & Assessment

Technology Portfolio → Technology Compatibility Matrix (TCM) → Technology Impact Matrix (TIM) → Technology k-factor Parametric Ranges

Advanced Vehicle Modeling

Parametric Geometry → Aero Prediction → Component Weight Sizing → Propulsion Sizing & Performance → Mission Analysis → Fuel Balance?

No → Parametric Geometry

Yes → Metrics Calculations

Metrics Calculations

Performance Analysis

Emissions Prediction

Noise Prediction

Coefficient Generation for Fleet Analysis

Technology Infused Vehicles

Noise

Fuel Burn

LTO & Cruise NOx Emissions

EDS

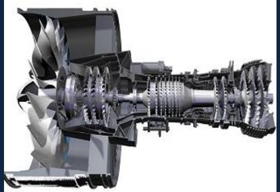
Design of Experiments → Multivariate Regression → Surrogate Models → Technology Space Exploration & Optimization → Probabilistic Analysis

Technology Portfolio Recommendation

Georgia Tech Aerospace Systems Design Laboratory

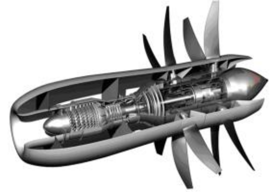
Technology Assessment for NASA ERA

Engines Modeled for ERA



Geared Fan

Advanced Direct Drive Turbofan



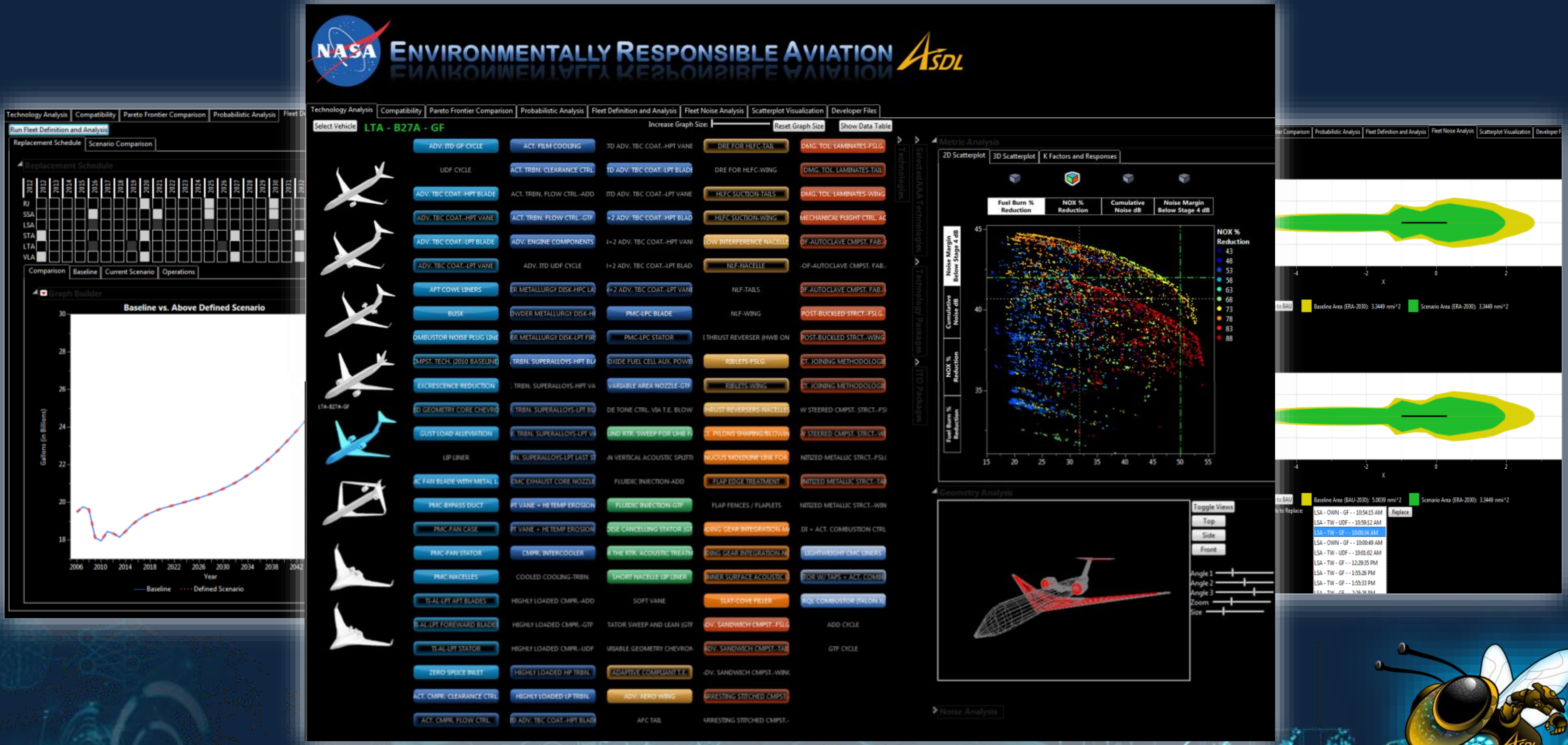
Open Rotor

Vehicles Modeled for ERA

Georgia Tech Aerospace Systems Design Laboratory

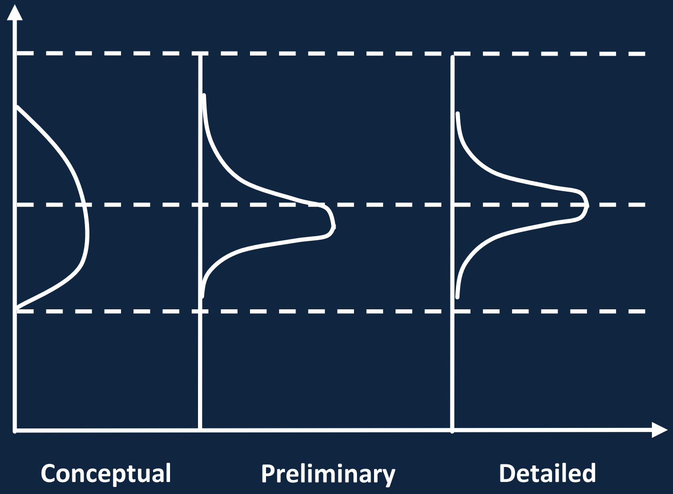
NASA ERA JMP Dashboard

- Enables efficient exploration of vast environmental design space concurrently considering aircraft configuration, new technologies, and fleet composition



Uncertainty Quantification and Propagation

- Uncertainty is inherent in engineering, design and problem solving
  - Design is a time variant process
  - Substantial uncertainty exists about future states
  - Decisions must be made now
- Project decisions carry consequence
  - No action: There are consequences
  - Some action: The consequences may be altered
    - What actions are available?
    - What are the consequences?
    - What is the best decision in light of the consequence?



Smart Energy Campus Initiative

- Goal: a virtual M&S testbed for future campus energy technologies that
  - Use existing meter data & expertise of GT Facilities
  - Address GT Administration energy goals & planning needs
  - Facilitate "what if?" gaming, scenario evaluation, & trade studies

Development Phases:

Observe Data & Trends

Model & Analyze

Design & Optimize

Multi-Scale, Integrated Modeling & Simulation (M&S)

Distribution Networks:
Electricity, Steam, Cooling

Buildings

Tech Impact

Occupant Influence

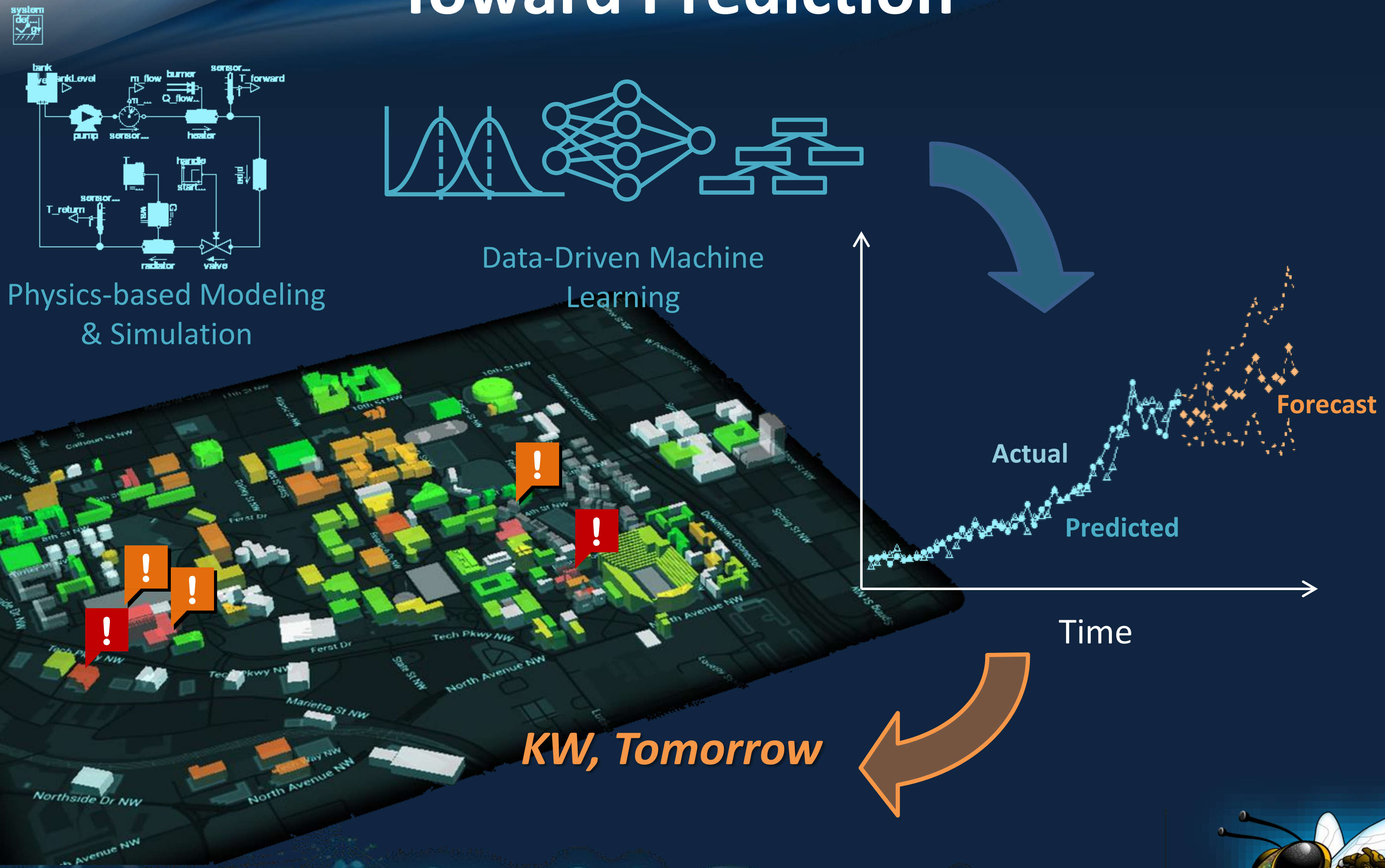
Desired capabilities:
- Situational Awareness
- Analytics & Prediction
- Living Experiments
- Prototyping of Smart Control paradigms

Real Time Situation Awareness

- GT INSIGHT for real time, campus energy flow monitoring

[2098.51] 133 Tenth Street Chiller Plant
[1217.27] 167 Molecular Science & Engineering Buil
[1204.38] 147 Ford Motor Company Environmental
[1118.43] 160 Campus Recreation Center (CRC)
[1059.87] 026 Holland Building (Whistle)
[1031.58] 181 Marcus Nanotechnology Building
[803.60] 146 Petit Biotechnology Building
[788.86] 129 Institute of Paper Science and Technol
[787.59] 086 Bunger-Henry Building
[674.13] 126 Callaway Manufacturing Research Cer
[670.43] 095 Pettit Building (Microelectronics Resea
[621.95] 051F Rich Chiller Plant
[610.32] 017 Bobby Dodd Stadium
[571.14] 790 Centenial Research Building
[535.69] 172 College of Management
[531.99] 051D Rich Computer Center
[439.58] 144 Love Manufacturing Building (MRDC II
[421.95] 165 Whitaker Building
[421.85] 153 Klaus Advanced Computing Building
[407.73] 073 Alexander Memorial Coliseum and Ann
[399.39] 085 Van Leer Building (Electrical and Comp
[396.96] 100 Crosland Tower (Library)
[396.81] 103 Boggs Building
[393.09] 050 College of Computing
[357.97] 138 Printing and Copying Services (811 Ma
[337.07] 099 Baker Building (GTRI)
[318.79] 166 Clough Undergraduate Learning Comm
[312.90] 047 Wardlaw Center
[302.34] 170 Global Learning and Conference Cente
[286.95] 081 Howey Physics Building
[280.18] 065 Sixth Street Apartments
[248.82] 180 Family Housing (Tenth & Home)
[245.23] 033 O'Keefe - Main Building / Language Ins
[238.41] 052 Graduate Living Center

Toward Prediction



Physics-based Modeling & Simulation

Data-Driven Machine Learning

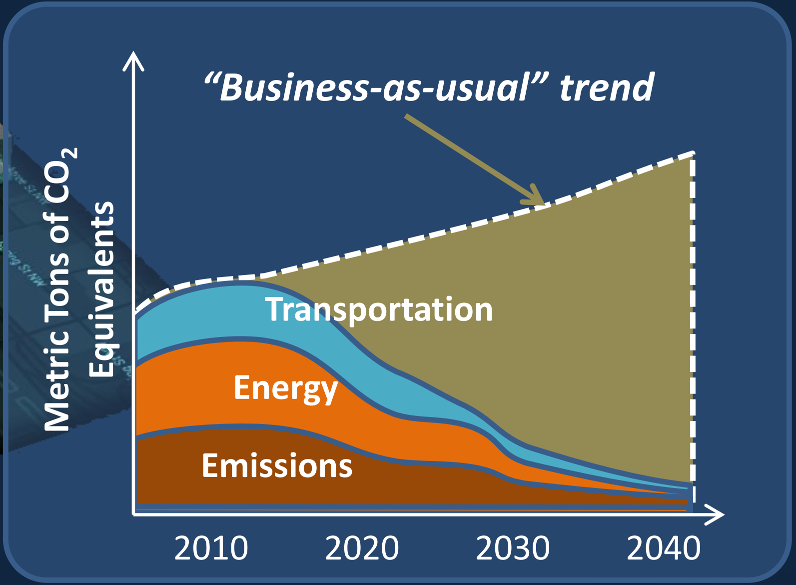
KW, Tomorrow

Toward Carbon-Neutral Campus

Building Efficiency Projection

2015 2025

Carbon Neutrality Projection



Georgia Tech | Aerospace Systems Design Laboratory

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Defense & Space Division

Mission Statement:

"To educate future industry and government leaders of the defense and space community while improving the acquisition and operation of defense and space systems through the use of innovative methods and techniques"

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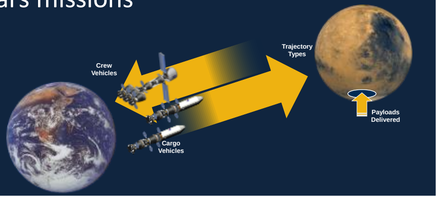
D&S Division: Space Research Overview

Systems Analysis of Advanced Concepts for NASA's Space Launch System

Sponsor: NASA Marshall Space Flight Center

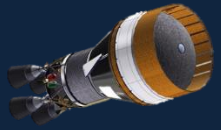
- Objective 1: To enable and support a broad design space exploration for advanced upper stages and boosters for SLS development and evolution for Earth-to-Orbit architectures
- Objective 2: To perform a broad analysis of alternatives and develop a portfolio of recommended system architectures and technologies for manned Mars missions



SLS Manufacturing Influenced Design (MInD)

Sponsor: NASA Marshall Space Flight Center

- Objective: Develop a methodology to *quantitatively* incorporate *advanced materials* and new *manufacturing processes* into the conceptual design of launch vehicles
  - Advanced materials usage invalidates the weight-based regressions used traditionally for conceptual design
  - Manufacturing processes are one of the main cost drivers for advanced materials
  - Therefore, a non-weight based approach that captures structural, manufacturing and production planning considerations earlier in the design process is needed

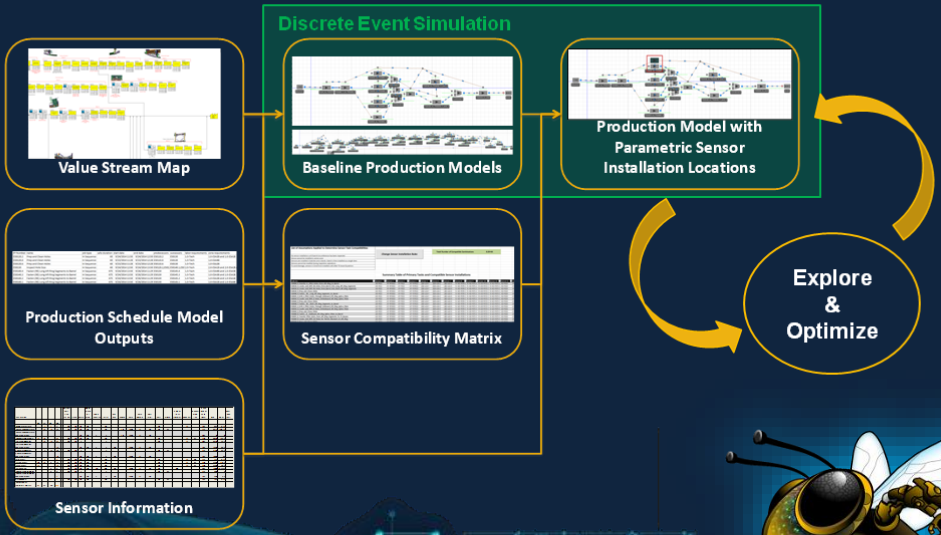


Exploration Upper Stage (EUS) used as proof of concept study to demonstrate developed methodology

SLS Core Stage Production & Integration Study

Sponsor: Boeing Research & Technology

- The Space Launch System (SLS) has over 1,000 sensors required to be integrated on the core stage of the vehicle at the Michoud Assembly Facility
- Objective: Develop an approach to identify integration sequences that minimize the schedule risk and cost impacts of incorporating sensor installations into the production flow
- Types of analyses/trade studies
  - Determine total installation time required
  - Allow sensors to be installed in series or parallel
  - Track man hours by personnel responsibilities (installation, inspection, etc.)
  - Trade man hours vs. flow time to completion

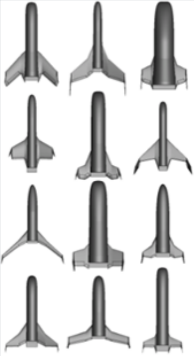


D&S Division: Space Research Overview

Aeromechanic and Vehicle Configuration Risk Reduction for RBS

Characterized the design space for reusable booster systems:

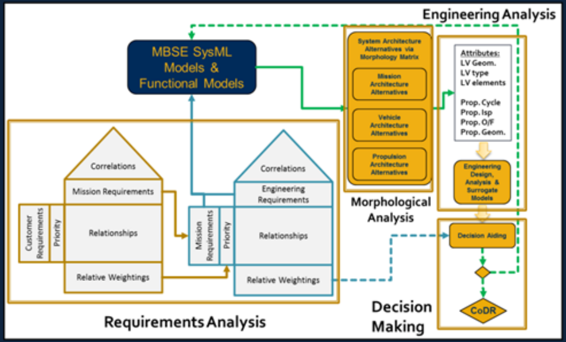
- Created an integrated, parametric geometry and packaging environment
- Analyzed performance and trim limitations of a reusable first stage
- Identified feasible, trimmable design space



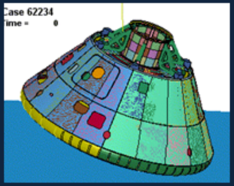
SAMBE

Systems Architecting for Model-Based Engineering

Characterize various mission concepts, vehicle designs, propulsion technologies, and future scenarios for space system architectures

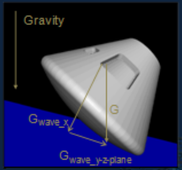


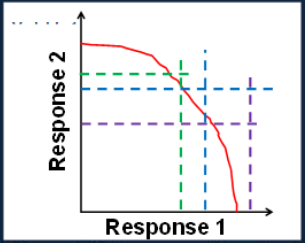
Utilizing Response Surface Methods in Support of Launch Vehicles and Orion Loads Analysis Efforts



Loads Analysis using LS-Dyna:
~76 hr / case

Developed and applied methodology for performing probabilistic analysis of Orion structural response to water landings





Model-Based Systems Engineering End-to-End Modeling Environment

Jupiter-Europa "Buzzer" (JEB): sanitized version of Europa Clipper

- Integrating SysML single-source-of-truth as backbone to mission simulator and decision-support tool
- Developing in open-source environments established by JPL

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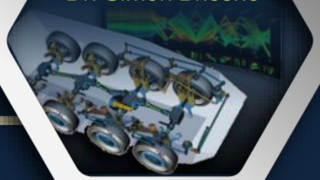

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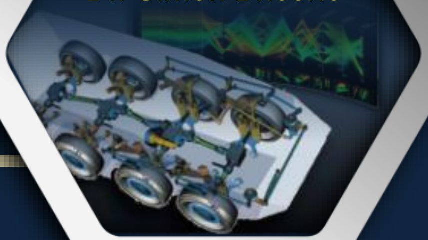

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Support the design *of* ***innovative and revolutionary concepts*** by developing **state-of-the-art methods and techniques**

Increase in complexity

Subsystem integration

Increasing use of unconventional materials

Introduction of new manufacturing processes

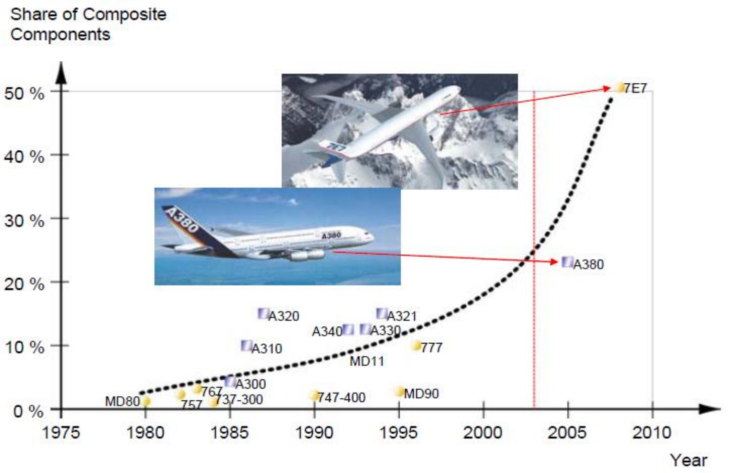
Curse of dimensionality

....

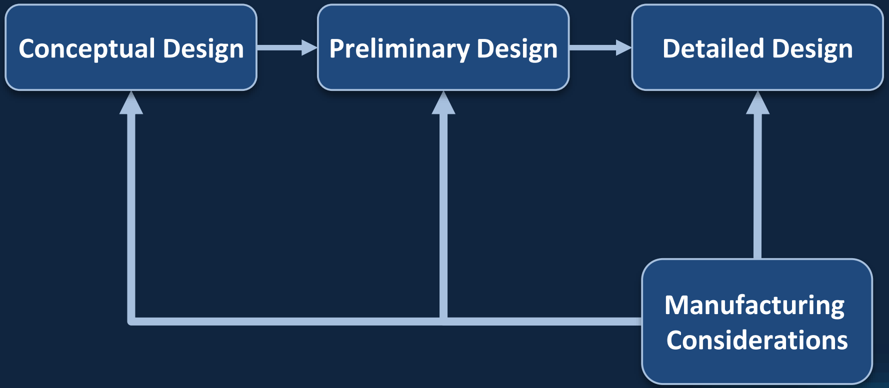
Manufacturing Influenced Design

The shift from aluminum alloys to composites, while resulting in important weight reductions, brings a new set of issues and challenges to aircraft manufacturers

- The increase in advanced materials usage **invalidates the traditional empty-weight regressions used for conventional aluminum designs**
- Manufacturing processes are one of the **main cost drivers for advanced materials**
- Therefore a non-weight based approach that brings **structural, manufacturing and production planning considerations earlier in the design process is needed**



Source: EADS Deutschland, Corporate Research Centre



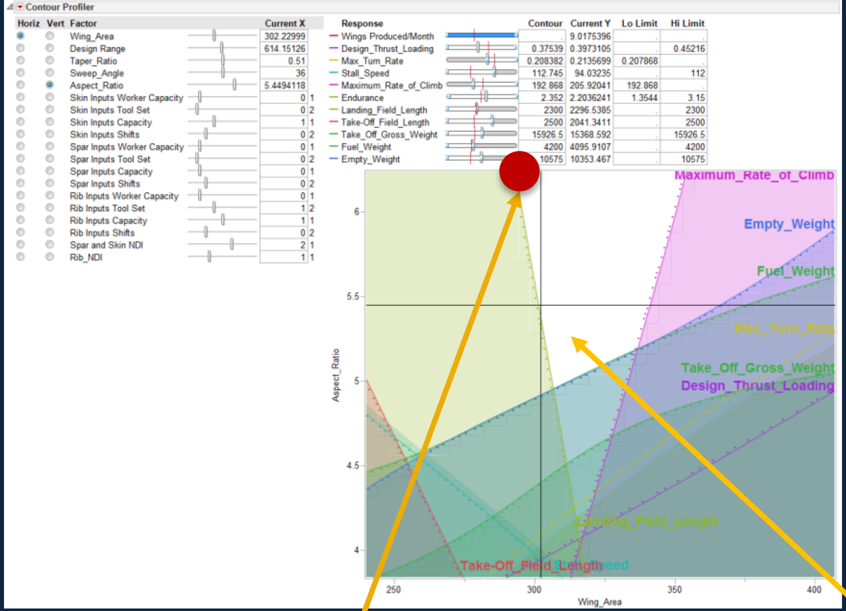
Conceptual Design → **Preliminary Design** → **Detailed Design**

Manufacturing Considerations

Manufacturing Influenced Design

- Bringing Manufacturing/Production Constraints in the Early Design Phases

With performance constraints only

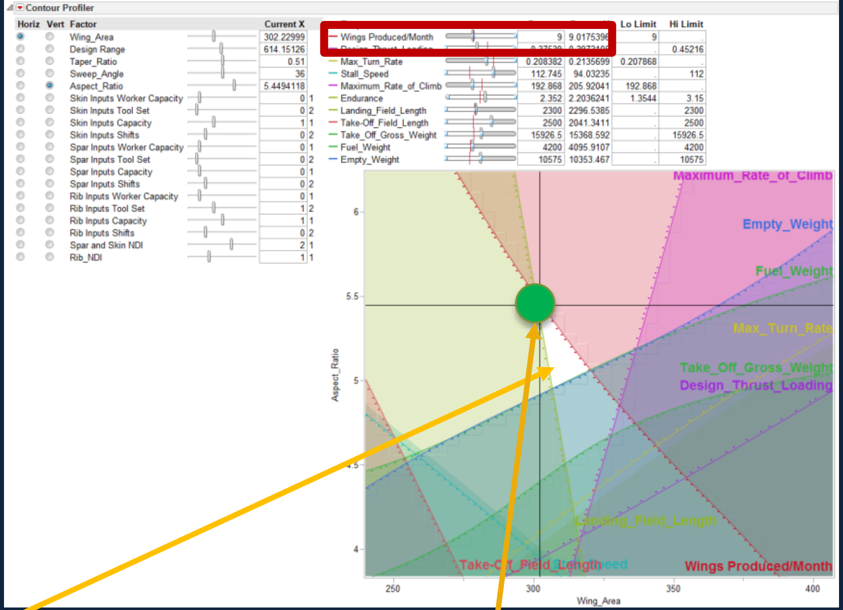


Contour Profiler

Horiz	Vert	Factor	Current X	
●	○	Wing_Area	302.22999	
○	○	Design Range	614.15126	
○	○	Taper_Ratio	0.51	
○	○	Sweep_Angle	36	
○	●	Aspect_Ratio	5.4494118	
○	○	Skin Inputs Worker Capacity	0	1
○	○	Skin Inputs Tool Set	0	2
○	○	Skin Inputs Capacity	1	1
○	○	Skin Inputs Shifts	0	2
○	○	Spar Inputs Worker Capacity	0	1
○	○	Spar Inputs Tool Set	0	2
○	○	Spar Inputs Capacity	0	1
○	○	Spar Inputs Shifts	0	2
○	○	Rib Inputs Worker Capacity	0	1
○	○	Rib Inputs Tool Set	1	2
○	○	Rib Inputs Capacity	1	1
○	○	Rib Inputs Shifts	0	2
○	○	Spar and Skin NDI	2	1
○	○	Rib_NDI	1	1

Response	Contour	Current Y	Lo Limit	Hi Limit
Wings Produced/Month	.	9.0175396	.	.
Design_Thrust_Loading	0.37539	0.3973105	.	0.45216
Max_Turn_Rate	0.208382	0.2135699	0.207868	.
Stall_Speed	112.745	94.03235	.	112
Maximum_Rate_of_Climb	192.868	205.92041	192.868	.
Endurance	2.352	2.2036241	1.3544	3.15
Landing_Field_Length	2300	2296.5385	.	2300
Take-Off_Field_Length	2500	2041.3411	.	2500
Take_Off_Gross_Weight	15926.5	15368.592	.	15926.5
Fuel_Weight	4200	4095.9107	.	4200
Empty_Weight	10575	10353.467	.	10575

After adding a throughput constraint



Contour Profiler

Horiz	Vert	Factor	Current X	
●	○	Wing_Area	302.22999	
○	○	Design Range	614.15126	
○	○	Taper_Ratio	0.51	
○	○	Sweep_Angle	36	
○	●	Aspect_Ratio	5.4494118	
○	○	Skin Inputs Worker Capacity	0	1
○	○	Skin Inputs Tool Set	0	2
○	○	Skin Inputs Capacity	1	1
○	○	Skin Inputs Shifts	0	2
○	○	Spar Inputs Worker Capacity	0	1
○	○	Spar Inputs Tool Set	0	2
○	○	Spar Inputs Capacity	0	1
○	○	Spar Inputs Shifts	0	2
○	○	Rib Inputs Worker Capacity	0	1
○	○	Rib Inputs Tool Set	1	2
○	○	Rib Inputs Capacity	1	1
○	○	Rib Inputs Shifts	0	2
○	○	Spar and Skin NDI	2	1
○	○	Rib_NDI	1	1

			Lo Limit	Hi Limit
Wings Produced/Month	9	9.0175396	9	.
Design_Thrust_Loading	0.37539	0.3973105	.	0.45216
Max_Turn_Rate	0.208382	0.2135699	0.207868	.
Stall_Speed	112.745	94.03235	.	112
Maximum_Rate_of_Climb	192.868	205.92041	192.868	.
Endurance	2.352	2.2036241	1.3544	3.15
Landing_Field_Length	2300	2296.5385	.	2300
Take-Off_Field_Length	2500	2041.3411	.	2500
Take_Off_Gross_Weight	15926.5	15368.592	.	15926.5
Fuel_Weight	4200	4095.9107	.	4200
Empty_Weight	10575	10353.467	.	10575

Design point based on **performance constraints only**

Feasible space

Design point based on both **performance and throughput constraints**

Production Areas of Interest

Manufacturing Tooling Decision Making

Structures Analysis

Maintenance and Operations

Manufacturing Variability

Capacity Planning

Demand Variability

Supply Chain Design

Aggregate Planning

Production Optimization

Lean Production

Robust Factory Design

Resource Allocation

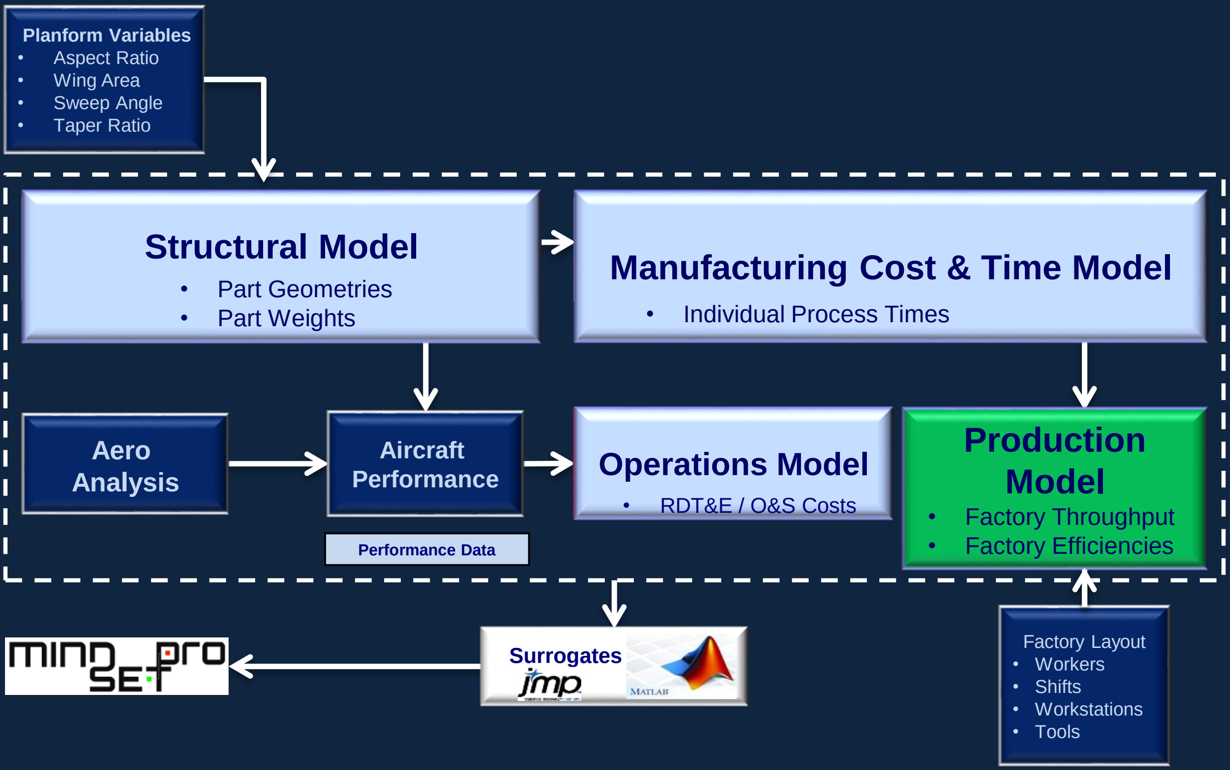
The MInD Framework

SEER for Manufacturing [5]

- SEER-MFG is a cooperative effort between government and industry to reduce acquisition cost of aero-composite structure under the Composite Affordability Initiative (CAI)
  - Commercially available tool
  - Wide breadth and depth of manufacturing data
  - Product and process based high fidelity modeling

Simio [6]

- Simio (Simulation Modeling framework based on Intelligent Objects) is an object oriented modeling software that allows for process and event orientation modeling that provides:
  - Process improvements using Lean Manufacturing
  - Production planning/scheduling
  - Best layout for production facility with respect to service, cost and quality



Planform Variables
- Aspect Ratio
- Wing Area
- Sweep Angle
- Taper Ratio

Structural Model
- Part Geometries
- Part Weights

Manufacturing Cost & Time Model
- Individual Process Times

Aero Analysis

Aircraft Performance

Performance Data

Operations Model
- RDT&E / O&S Costs

Production Model
- Factory Throughput
- Factory Efficiencies

Factory Layout
- Workers
- Shifts
- Workstations
- Tools

Surrogates

Rotorcraft Research Capabilities

Georgia Tech Rotorcraft Center of Excellence

- Providing long term research and education at respected U.S. academic institutions for the advancement and sustainment of rotary wing aircraft technologies since 1982
- Currently Vertical Lift Research Centers of Excellence (VLRCOE)
- A partnership between the nation’s leading Schools of Aerospace Engineering
- Over 80 Ph D. degree recipients

Rotorcraft Analysis Capabilities

Applicable Concepts

Helicopters & Variations


Conventional


Tandem


Coaxial


Compound


Autogyro

Innovative Designs


Tiltrotor


ABC

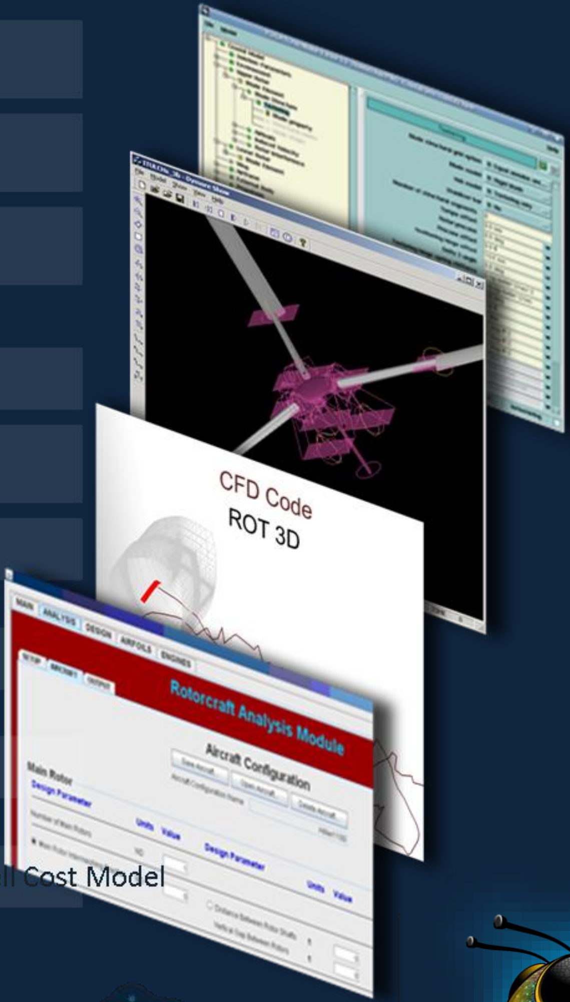

CRW


Tilt-nacelle


SRC

Rotorcraft Analysis Tools

Sizing **Performance**	NDARC (NASA Design and Analysis of Rotorcraft) GTPDP (Georgia Tech Preliminary Design and Performance program) CIRADS (Concept Independent Rotorcraft Analysis and Design Software)
Aerodynamics **Rotor Dynamics** **Flight Dynamics** **S&C**	Overflow, GT-HYBRID RCAS, Flightlab (Rotorcraft Comprehensive Analysis System) DYMORE
Noise	WOPWOP
Propulsion	NPSS
Others	GTPROP, CHECSS, GTAUSP, RDFD, ROSPER, Bell Cost Model



Heliplane Program

- DARPA heliplane program to develop a modified A700 with tip-jet rotor system
  - VTOL capability
  - High Speed Flight
- Georgia Tech heavily involved during Phases 1 & 1B.
- Partnered with:
  - Groen Brothers Aviation
  - Williams International
  - Adam Aircraft

GBA

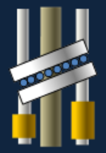
Adam Aircraft

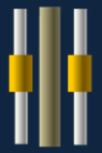
Williams International

- Georgia Tech Contributions
  - Mission Analysis
  - Aeromechanic Analysis
  - CFD Analysis
  - Tip-jet Design / Analysis
  - Rotor Stability Analysis
  - 2G Maneuver Simulation

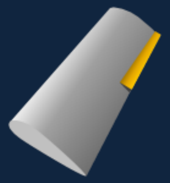
Quantitative Active Rotor Technology Analysis

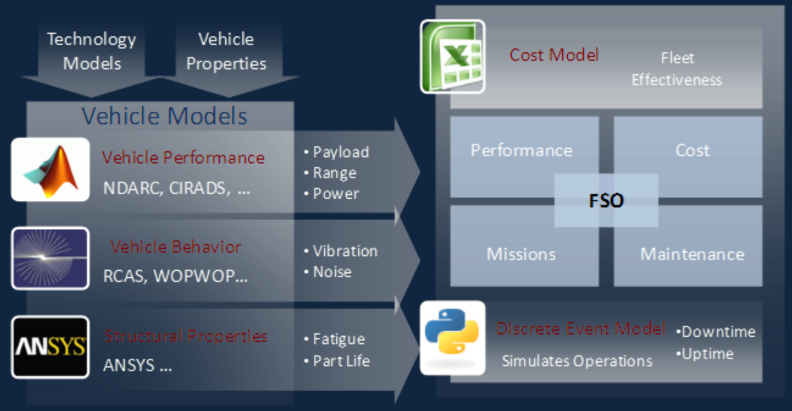
Active Rotor Technologies (ARTs)


Active Swashplate


Active Pitch Links


Active Camber/Twist


Active Trailing Edge Flaps/Tabs


Technology Models

Vehicle Properties

Vehicle Models

Vehicle Performance

NDARC, CIRADS, ...

- Payload
- Range
- Power

Vehicle Behavior

RCAS, WOPWOP...

- Vibration
- Noise

Structural Properties

ANSYS ...

- Fatigue
- Part Life

Cost Model

Fleet Effectiveness

Performance

Cost

FSO

Missions

Maintenance

Discrete Event Model

Simulates Operations

- Downtime
- Uptime

- Provide Greater than 1/rev control
- ARTs have a large potential
  - Reduce: vibration, noise, etc.
- How do they buy their way into a fleet?
  - By benefiting Full Spectrum Operations
- Full Spectrum Operations (FSO)
  - Involves life cycle costs, performance, etc.
  - Maintenance, mission impact
- Use QTA to decide which ARTs are the most promising
  - IRMA and SP2 to manage data and make decisions
  - Experts, Modeling and Simulation create data

JMR Capability Assessment & Tradeoff Environment

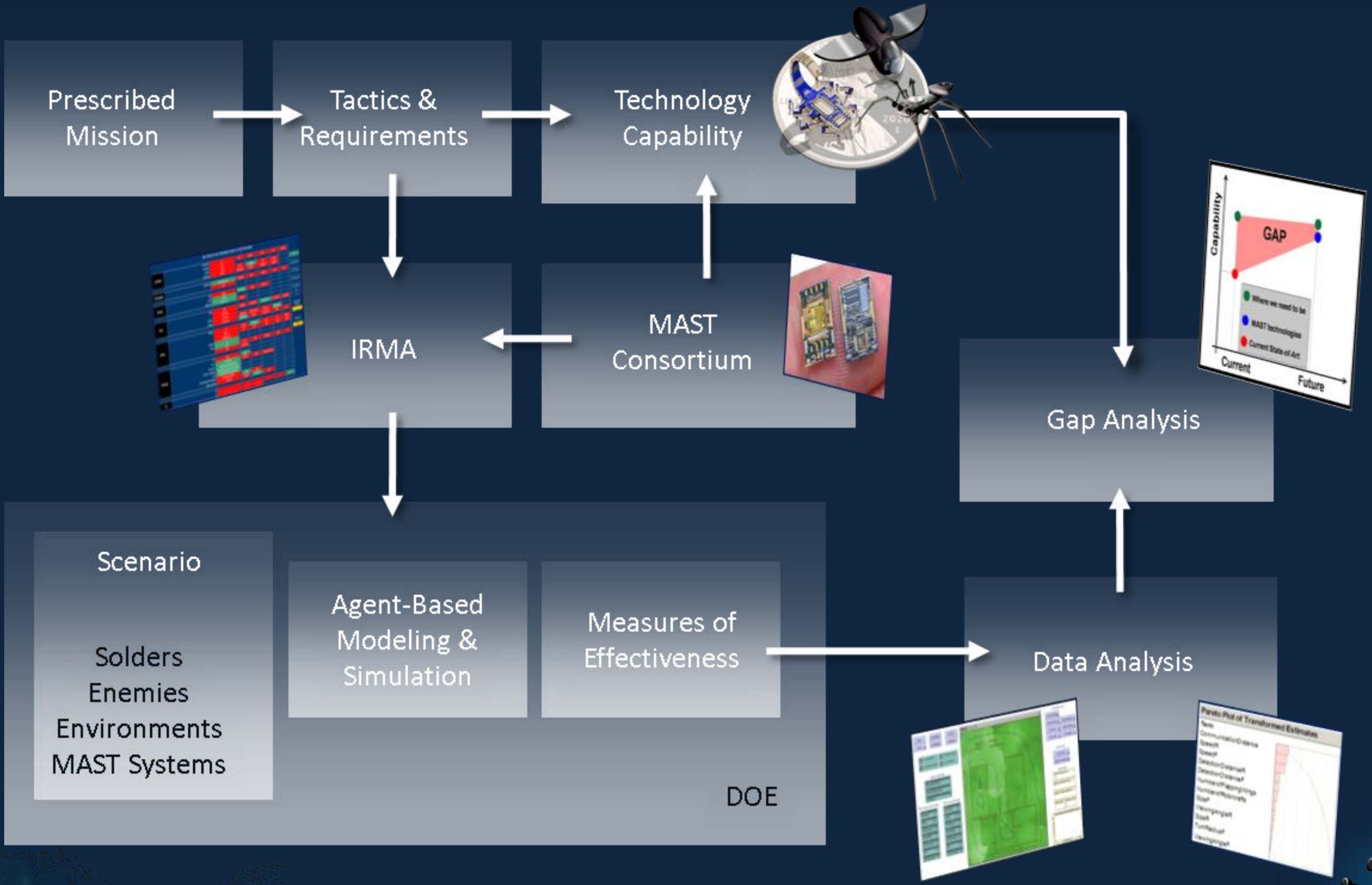
Sizing Dashboard

- Unified Tradeoff Environment
  - Interactive correlated response of flight conditions/mission parameters/design parameters/technology factors
  - Sizing results comparison to the baseline numbers
  - Technology impact analysis using the preset technology tab
  - Design feasibility investigation
- Visual Analytics
  - Visualization of vehicle configuration and mission profile
  - Easy manipulation of inputs and outputs
  - Instance response with pre-generated RSE based calculation

Off-Design Dashboard

- Off-design mission fallout
- Payload/Range evaluation
- Point performance condition sweeps

Micro Autonomous Systems and Technology (MAST)



Prescribed Mission

Tactics & Requirements

Technology Capability

IRMA

MAST Consortium

Gap Analysis

Scenario

Solders
Enemies
Environments
MAST Systems

Agent-Based Modeling & Simulation

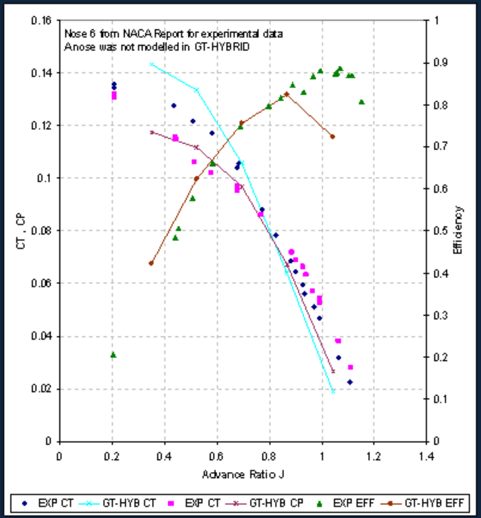
Measures of Effectiveness

DOE

Data Analysis

Propeller Analysis and Design

10 ft Propeller Validation

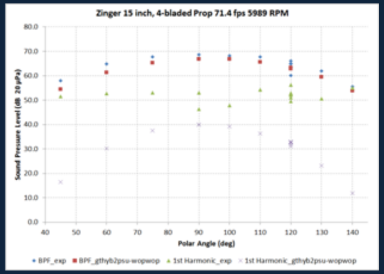


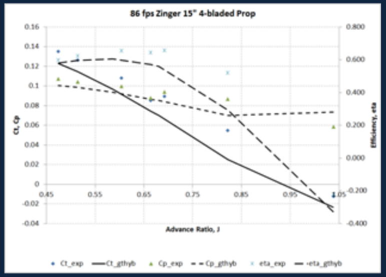
A capability has been developed to perform first principles, physics-based analysis of propellers in forward flight.

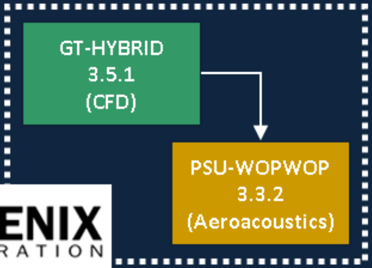
The analysis utilizes a hybrid methodology developed for rotors, with Navier-Stokes solver for a near field analysis coupled with a helical vortex model of the wake.

With automation provided by the design framework ModelCenter® and a cluster of computers, hundreds of designs can be analyzed.

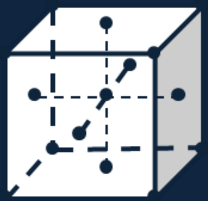
Model Propeller Validation



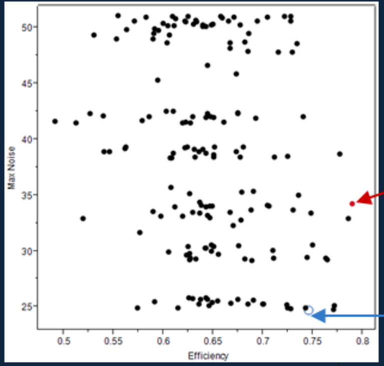




Automation using ModelCenter®
By Phoenix Integration
www.phoenix-int.com



Design Of Experiments
(DOE)



design for maximum efficiency

design for minimum noise

Unmanned Air Systems Design

Vehicle Concepts

Unmanned Air Systems Design

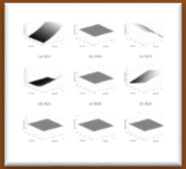
Integration of UAS into the national airspace

Representative focus areas of this research domain include:

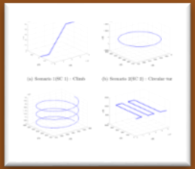
- *UAS mission **performance and flight capabilities***
- *UAS **interactions with other airspace actors***
- *Benchmarking of UAS NAS integration efforts*
- ***Effect of critical functions** (e.g. communication, surveillance) on UAS interactions with the NAS*
- ***Integration of functions and systems critical for UAS operations**, such as sensors and GNC for sense and avoid*
- *The **characterization of emergent UAS-NAS behavior** quantified through meaningful tradeoffs, interactions, and sensitivities*
- *Requirements definition and performance assessment*
- ***Safety analyses and quantification** at the vehicle level and total airspace level of safety*
- *The development of enabling analytical methods and modeling & simulation capabilities*

Current Research Efforts:

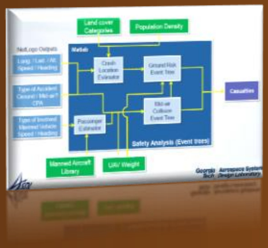
Gain-scheduling method using surrogate models for **UAS controller design and simulation**



Gain surrogate matrix

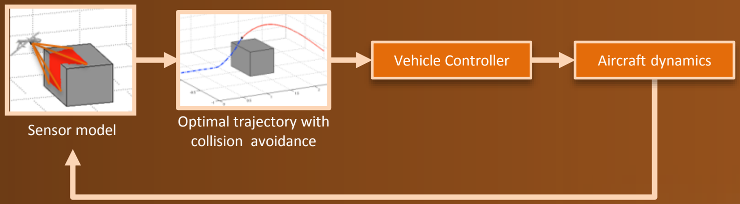


Maneuvers evaluation



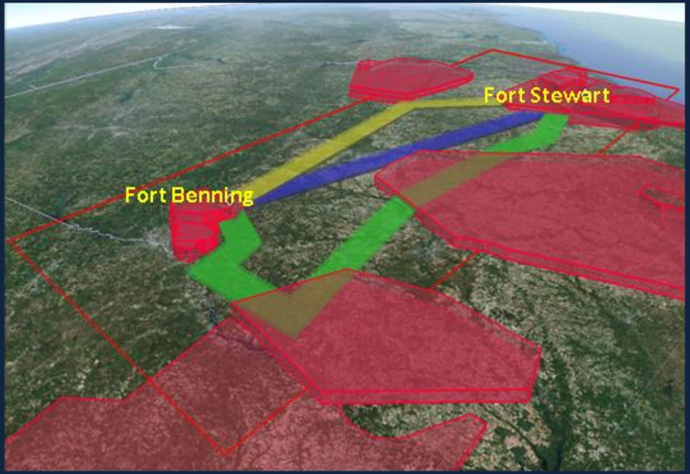
UAS Simulation for **Airspace Integration Analysis**

Evaluation Framework for Unmanned Aircraft Systems Integration in the National Airspace System



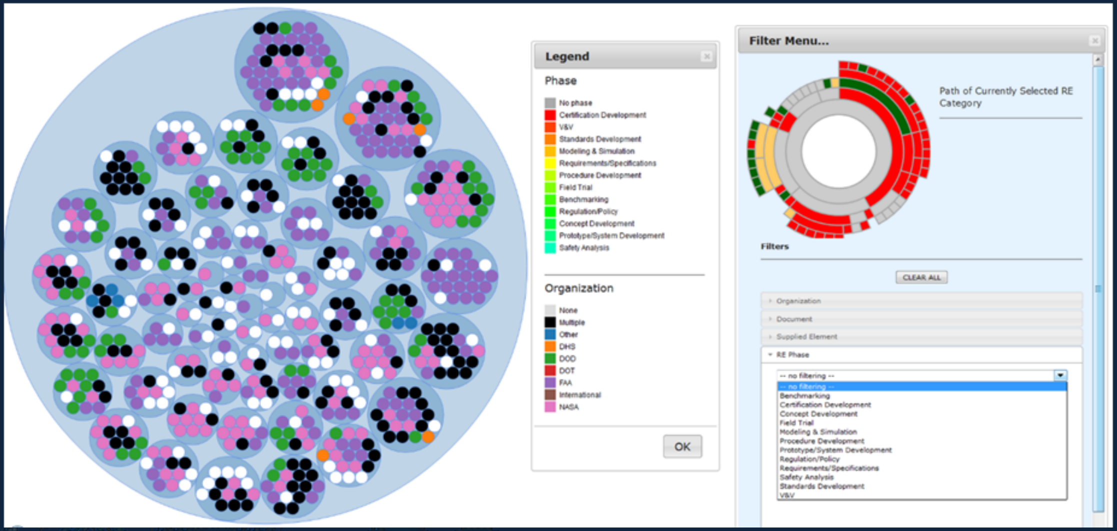
Unmanned Aircraft Systems Integration into the National Airspace System Research efforts and experience

- UAS Integration into the NAS - Tradeoff Analysis for En Route Transit Operations
  - Research Focus: tactical separation as a subset of the UAS traffic separation assurance
  - Objective: to examine how tactical ATC separation may be realized for integrated UAS operations and to characterize it on the basis of logical/procedural separation rules
- Requirements Analysis of UAS for Emergency Response Operations
  - Objective: To conduct a articulate unmanned aircraft requirements for emergency response functions



Unmanned Aircraft Systems Integration into the National Airspace System Research efforts and experience

- Systems Gap Analysis for the Integration of UAS into the NAS
  - Objectives
    - Assess national needs, existing capabilities, research & development efforts, and resulting capability gaps
    - Develop a framework to create and structure needs vs. capabilities, discover gaps and relationships, communicate findings, and guide portfolio recommendations based on the prioritization of gaps



Advanced System Engineering Division

5 Divisions

28 Branches

40 Research Engineers

50 Undergrads

200 Master's & PhD Students

Academic Manager
Allison Hill

International Program Manager
Elena Garcia

Chief Engineer
Neil Weston
Senior Advisor
Robert Loewy

Director
Dimitri Mavris
Assoc. Director
Brian German

Front Office

- Communication & Program Initiation Manager: Kara Kelch
- Research Operations Program Manager: Marisol Vega-Holthaus
- Financial Manager: Glenn Campopiano
- Admin. Assistant: Loretta Carroll
- System Admin.: Diego Remolina

Civil Aviation Research
Dr. Michelle Kirby

- Environmental & Policy Programs *(TBD)*
- Air Transportation Syst. of Systems *(Holger Pfaender)*
- Air Transportation Economics *(Don Lim)*
- System Analysis *(TBD)*

Propulsion & Energy
Dr. Jimmy Tai

- P&E Chief Engineer *(Russell Denney)*
- Aerothermo-Mechanical Design *(Jeff Schutte)*
- Subsystem & Aero-Power *(Chris Perullo)*
- Power Generation *(Scott Duncan)*
- Controls & Operability *(TBD)*
- Rocket Based Propulsion *(Stephen Edwards)*

Advanced Concepts
Dr. Simon Briceno

- Rotary & Fixed Wing Systems *(Kyle Collins)*
- Manufacturing Systems & Process Design *(Olivia Pinon)*
- Cyber-Physical Systems *(Blaine Laughlin)*
- Unmanned Aircraft Systems Design *(Hernando Jimenez)*
- Aircraft Certification, Ops. & Safety *(Simon Briceno)*
- Design, Build, Fly Lab *(Carl Johnson)*
- Autonomy & Robotics *(Daniel Cooksey)*

Advanced System Engineering
Dr. Kelly Griendling

- Requirement & Uncertainty *(Brad Robertson)*
- Modeling & Simulation *(TBD)*
- Data Analysis, Decision Science & Optimization *(Matt Daskilewicz)*
- Model Based Systems Engineering *(Russell Peak)*
- Syst. of Systems Engineering *(Kelly Griendling)*
- Collaborative Engineering *(David Fullmer)*

Defense & Space
Dr. Charles Domercant

- Airborne Systems *(Blaine Laughlin)*
- Space Systems *(Stephen Edwards)*
- Naval Systems *(Charles Domercant)*
- Ground Systems *(Blaine Laughlin)*
- C4ISR *(Charles Domercant)*

Advanced System Engineering Division

Advanced System Engineering
Dr. Kelly Griendling

*To **educate** the next generation of aerospace systems engineers and to **research** methods and tools that **advance** the state-of-the-art in systems engineering and design from the technology level to the system of systems level*

- Requirement & Uncertainty *(Brad Robertson)*
- Modeling & Simulation *(TBD)*
- Data Analysis, Decision Science & Optimization *(Matt Daskilewicz)*
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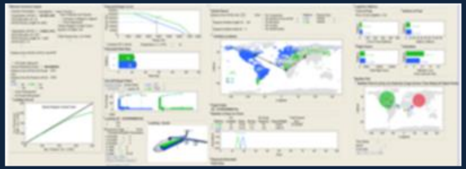
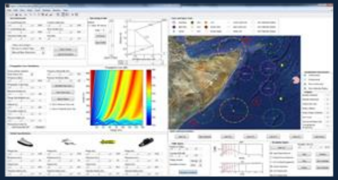


Lockheed Logistics

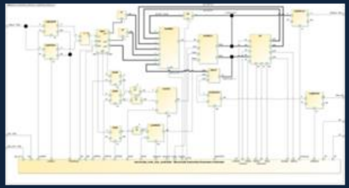


NEEC Maritime Communications

ONR ARCHITECT

FedEx Airline Schedule Optimization

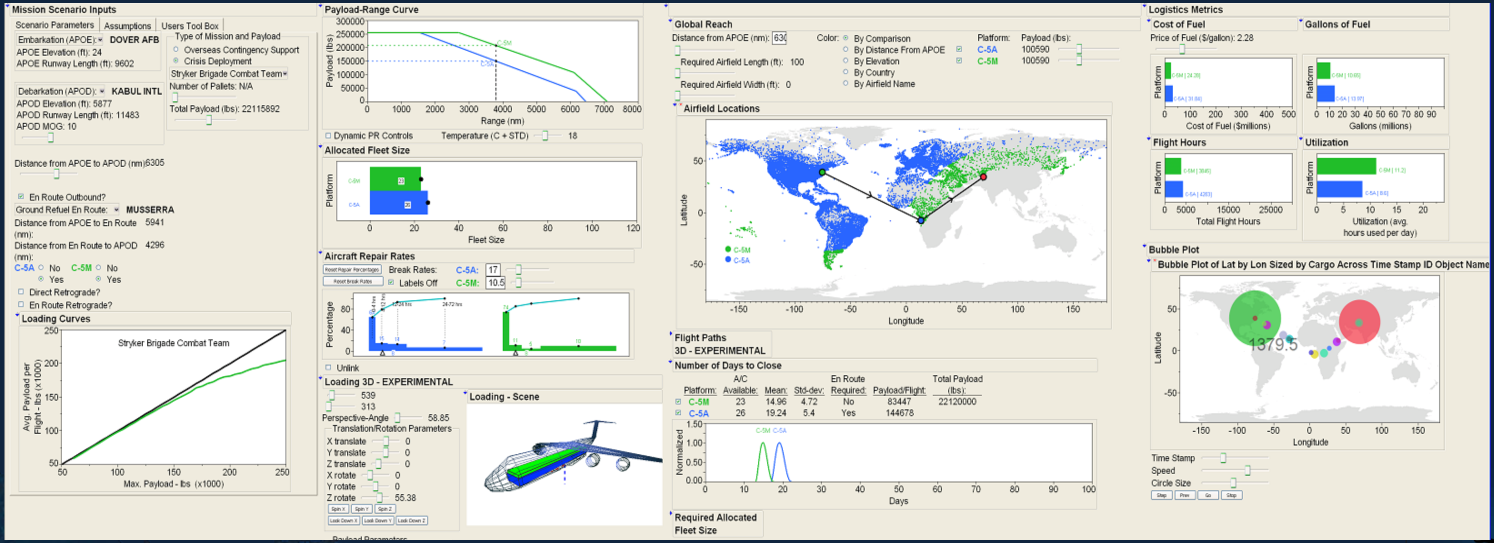
AFRL CX



Model-based Systems Engineering

Strategic Airlift Comparison Tool: A high-level modeling, simulation and analysis of logistics and operations

- Lockheed Martin has provided data and resources to ASDL to develop a prototype model and interface which allows real-time logistical and operational analyses of heavy-cargo transport military aircraft.
- Surrogate models are used to increase the computational speed and allow for system level trade-offs and decision making in real-time



Mission Scenario Inputs

Scenario Parameters | Assumptions | Users Tool Box

Embarkation (APOE): DOVER AFB
APOE Elevation (ft): 24
APOE Runway Length (ft): 9602

Debarkation (APOD): KABUL INTL
APOD Elevation (ft): 5877
APOD Runway Length (ft): 11483
APOD MOG: 10

Type of Mission and Payload
○ Overseas Contingency Support
● Crisis Deployment
Stryker Brigade Combat Team
Number of Pallets: N/A
Total Payload (lbs): 22115892

Distance from APOE to APOD (nm)6305

☑ En Route Outbound?
Ground Refuel En Route: MUSSERRA
Distance from APOE to En Route (nm): 5941
Distance from En Route to APOD (nm): 4296
C-5A ○ No ● Yes C-5M ○ No ● Yes
☐ Direct Retrograde?
☐ En Route Retrograde?

Global Reach

Distance from APOE (nm): 630
Required Airfield Length (ft): 100
Required Airfield Width (ft): 0
Color: ● By Comparison ○ By Distance From APOE ○ By Elevation ○ By Country ○ By Airfield Name
Platform: ☑ C-5A Payload (lbs): 100590
Platform: ☑ C-5M Payload (lbs): 100590

Aircraft Repair Rates
Break Rates: C-5A: 17 C-5M: 10.5
☑ Labels Off

Temperature (C + STD) 18

Loading 3D - EXPERIMENTAL
539
313
Perspective-Angle 58.85
Translation/Rotation Parameters
X translate 0
Y translate 0
Z translate 0
X rotate 0
Y rotate 0
Z rotate 55.38

Price of Fuel ($/gallon): 2.28

Number of Days to Close

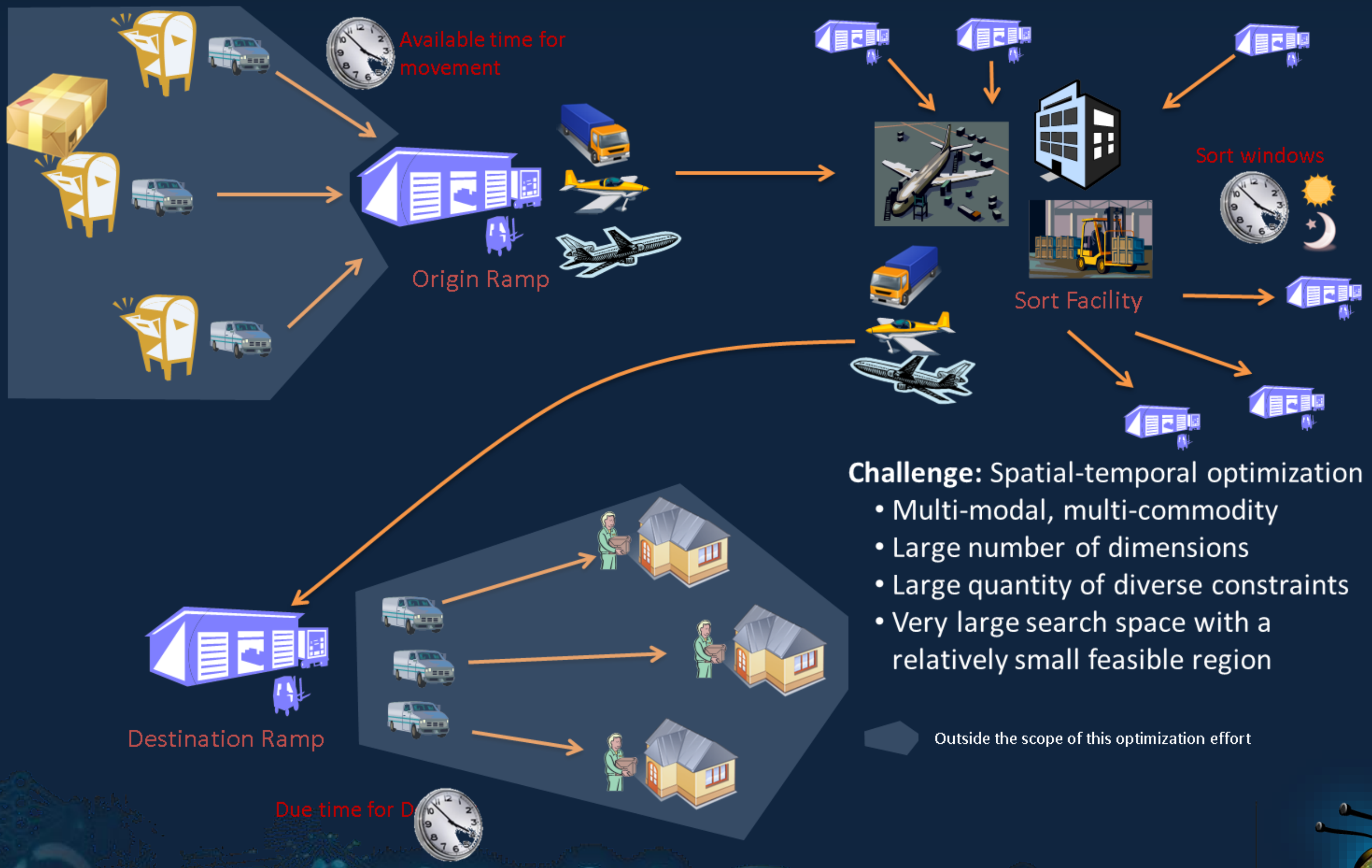
	Platform:	A/C Available:	Mean:	Std-dev:	En Route Required:	Payload/Flight:	Total Payload (lbs):
☑	C-5M	23	14.96	4.72	No	83447	22120000
☑	C-5A	26	19.24	5.4	Yes	144678	

Airline Schedule Optimization

Goals:

- Develop an overall approach for airline schedule optimization which is:
  - Thorough: Includes all key considerations identified by FedEx as priorities
  - Flexible: Able to be adapted easily to include future considerations
  - Portable: Able to be transferred to FedEx to work within current FedEx practices
  - Modular: Include technically sound building blocks which can be used as a baseline for future improvements
- Demonstrate feasibility of the methodology and the value of such an approach to FedEx

Airline Schedule Optimization



Challenge: Spatial-temporal optimization

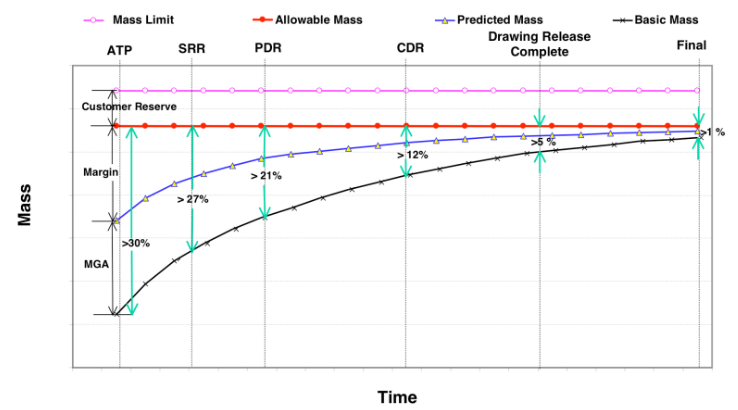
- Multi-modal, multi-commodity
- Large number of dimensions
- Large quantity of diverse constraints
- Very large search space with a relatively small feasible region

⬟ Outside the scope of this optimization effort

Uncertainty Propagation Research

Programmatic Uncertainty

- A fundamental challenge in the development of a system is uncertainty
  - This uncertainty manifests itself when estimating cost, schedule, and performance
- Primarily handled at a program level by assigning a margin (or contingency, management reserve, etc.) to critical items
  - The estimate of this margin value has a first-order impact on project success
    - Can mean the difference between going over-cost and schedule
    - Performance margins will size vehicles
- Margin is assigned early on in the program lifecycle and is consumed throughout the development process



- Deciding on the amount of margin is a critical design decision
  - Too much margin can lead to an oversized vehicle or sticker shock
  - Too little margin can lead to the inability to meet performance, cost, and schedule goals

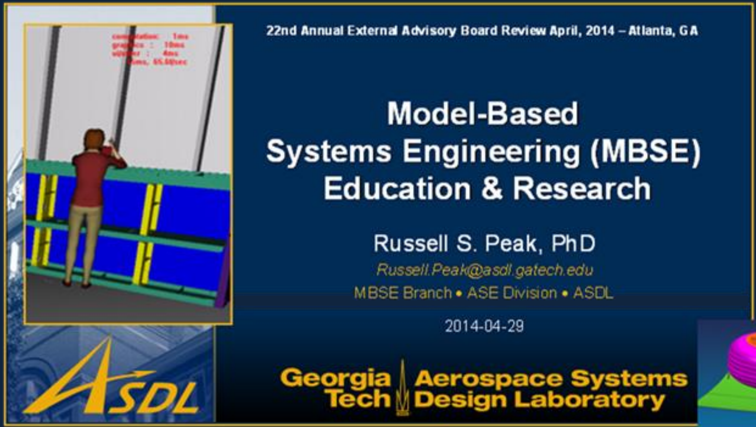
Large Scale Mixed Integer Programming

- We are researching the use commercial MILP solvers to solve large-scale optimization problems related to real-world airline network design
- Recent advances in MILP software and continuing improvements in computer hardware are enabling larger, more realistic network design problems to be optimized.
- These improvements are allowing us to consider more realistic problems than those described in previous literature, which are typically limited to “one complicating factor” per study.
- We are also investigating heuristic optimization techniques for discrete/combinatorial problems to:
  - Replace MILP solvers for intractably large problems
  - Make supplemental decisions in a feedback loop with a MILP solver

Integrating Optimization in Surrogate-Enabled Decision-Making Processes

- The most common barrier to using numerical optimization is the run time required for high or medium fidelity design analyses.
- When design analyses are replaced with fast surrogate models, this barrier is removed
- We are seeking to develop rigorous methodologies for using fast optimization in a surrogate-enabled design process, to improve on current *ad hoc* uses of optimization.
  - What fundamentally new ways of exploring a design space can be enabled by access to fast optimization studies?
- Fast optimization enables experiments on:
  - Changing the objective function, e.g. when an unequivocal objective function does not exist
  - Changing the problem parameterization: ranges of independent variables; adding/removing constraints
  - The choice of optimization algorithm
- How can optimization interact with other decision-support techniques? (Visualization, sampling, surrogate modeling, MADM, etc...)

Model Based Systems Engineering



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Model-Based Systems Engineering (MBSE) Education & Research

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MBSE Branch • ASE Division • ASDL

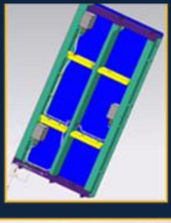
2014-04-29

Georgia Tech | Aerospace Systems Design Laboratory

MBSE/SysML Education & Research

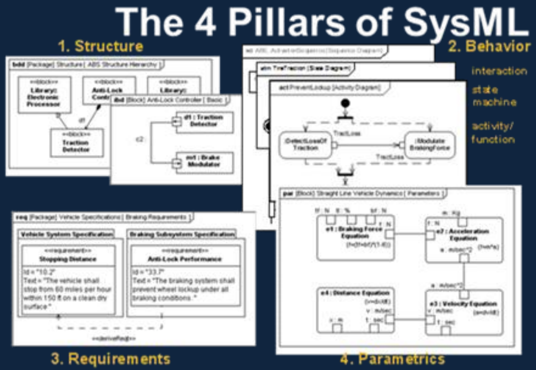
EAB 2014 Presentation Contents

- Introduction & current practice of MBSE & SysML
- Academic & professional education
- Recent & current research
- Conclusion



MBSE Branch Team

- *Branch Chief:*
  - Russell Peak, PhD
- *Research Engineers:*
  - Selcuk Cimtalay, PhD
  - Miyako Wilson
- *Undergraduate Students:*
  - Ryan Andersen, Rohan Deshmukh, Ivan Gomes, Stephanie Macleod



The 4 Pillars of SysML

MBSE/SysML Research

Selected Recent Projects

See Supplemental Material on CD (under ASE Division / MBSE Branch)

- MBSE for Advanced Manufacturing (MBSEAM)
  - *Sponsor: Boeing*
- Systems Engineering Research Center (SERC)
  - *Sponsor: DoD - www.sercuarc.org*
  - RT21: Verification, Validation & Accreditation (VV&A) for Modeling & Simulation – An MBSE/SysML-based Approach
  - RT24: Integration of M&S and DoDAF for Software/IT Systems
  - RT46 ITAP: SysML Building Blocks for Cost Modeling
- SysML-based Execution and Operation of Physical Systems
  - *Sponsor: Internal R&D and Undergrad Research*

System of Systems Research

Handling Stochastic Modeling

- Stochastic modeling is becoming common practice in operational assessments and capability-based design
- However, applications of these models are ad hoc, and there is little rigor behind the applications of these models
- Furthermore, high performance computing has really changed the game in terms of model performance and design space exploration using these models
  - Computational limits are not as restrictive as they were previously, allowing for increased exploration of sensitivity to stochastic effects
- Key topics of research interest include:
  - When is/isn’t stochastic modeling appropriate?
  - How to develop meaningful stochastic models?
  - Design of Experiments for stochastic models?
  - How to create surrogates for stochastic models?

System of Systems Research

Multi-Agent Systems

- As communications and autonomy technologies continue to surge, multi-agent systems are becoming of increasing interest
- However, these types of systems present increasing complexity in their design and life cycle management
- Key research areas include:
  - Design of constituent systems in a multi-agent system
  - Impact of interoperability on system performance
  - Operational performance modeling and predictions for multi-agent systems
  - Heterogeneous multi-agent systems

System of Systems Research

Other Active SoS Research Areas

- Multi-stakeholder decision support
  - Creating decision support environments which demonstrate impact on other stakeholders and suggest compromise solutions
  - Geared toward collaborative SoS
- Impact of integration
  - Cost estimation for integration
  - Estimating performance boost/degradation due to integration effects
- Verification and Validation of SoS Models
  - Non-traditional techniques for V&V to mitigate validation challenges associated with large SoS models
- Consideration of “soft” factors in SoS analysis
  - Human behavior
  - Policy

Resilience Engineering

Motivation

"Uncertain futures and threats outpace our ability to create & field affordable, effective systems"[1]

- Need for agile and flexible Systems and SoS
    - Under presence of great uncertainty and volatility
    - Must remain cost effective and affordable
    - Must quickly respond to mission needs in a rapidly changing and dynamic threat environment
- Challenges:
    - Uncertain operational futures and resultant mission volatility → Rapidly changing user needs
    - Adapting to dynamic disturbances
        - Constraints and vulnerabilities of global supply chain
        - Rapid changes in operating environment itself
        - Enemies & adversaries co-evolve
    - Uncertainties compound with long and growing planning horizons
- Goal is affordable, effective, and adaptable systems development:
    - System effectiveness maintained in a wide range of situations
    - Readily adaptable to others through reconfiguration or replacement
    - Graceful and detectable degradation of function

Current Approaches

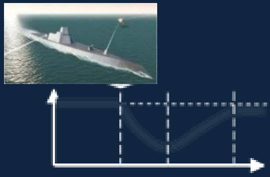
- Historical Approach[1]
    - Over-design
    - Resist disruptions (Traditional Systems Engineering)
    - Classical Reliability Methods such as redundancy and preventative maintenance (Survivability-based Design)
- Difficulties in applying historical methods to a joint, capability-based SoS acquisition environment
    - Increased component system heterogeneity, geographical distribution, and interdependencies
    - Heavy emphasis on backup systems may be costly and impractical
    - Additional complexities from overlapping functionality, acquisition cycles, and organizational/stakeholder constraints
    - Must be able to quickly adapt and integrate new technologies such as autonomy and cyber-physical systems, newly emerging manufacturing methods, etc.

Research Objectives

Develop a metrics-based analysis & evaluation framework for use during the conceptual design phase that allows:

Modeling of environment/adversary and possible 'directions' from which threats/disturbances can arise

Understanding the impact of disruption/disturbances on system dynamics



Understanding tradeoffs between avoidance and/or recovery from disturbances (adapt vs. absorb vs. restore)

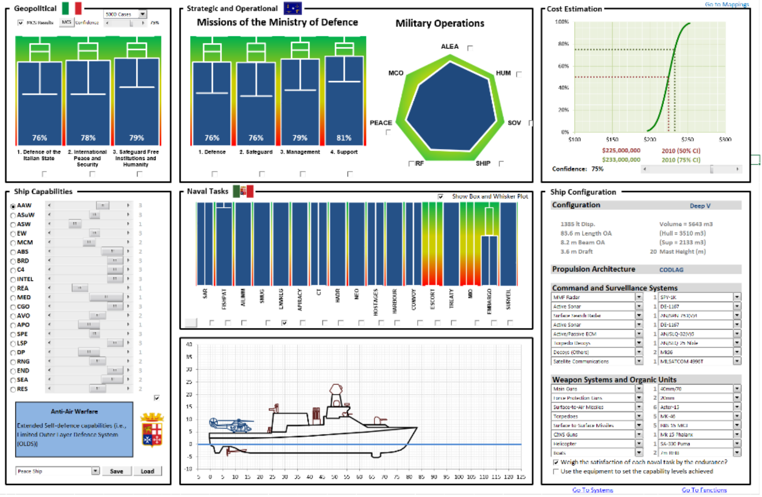
Cost/benefit analysis of mitigation tactics

The end result will be the development of cost effective, flexible, and agile systems that can respond to evolving threats and mission needs

Huddle:
SME Mathematical Requirement Model

- Developing New Mathematical Models for Subject Matter Expert (SME) Requirements Models
  - Capture and use SME variability analytically in order to show complete transparency into multi-level complex problems with minimal computational overhead
- Developing New Visualization Techniques for SME Data and SME based Tools
  - Visualize SME Model results in terms of SME variances and confidence
- Developing Methods to Integrate Organizations and Resources as Service Orientated Architectures
  - Account for both the technical and the social aspects in an effort to build an integrated digital community and ecosystem
- Issues with Current Models
  - Rely on composite indexes based on averages
  - The averages loose some of the information from the experts
  - The indexes do not reflect what is being gained or lost
  - It is expensive to analyze both top-down and bottom-up

- Goals
  - Fully represent the experts in each point of a requirements hierarchy or network
  - Develop efficient algorithms for analyzing the prorogating effects of changes (in terms of either requirements or proposed solutions)



Anti-Air Warfare

Extended Self-defence capabilities (i.e., Limited Outer Layer Defence System (OLDS))

Configuration Deep V

1385 lt Disp.
83.6 m Length OA
8.2 m Beam OA
3.6 m Draft
Volume = 5643 m3
(Hull = 3510 m3)
(Sup = 2133 m3)
20 Mast Height (m)

Propulsion Architecture CODLAG

Command and Surveillance Systems

MMF Radar 1 SPY-1K
Active Sonar 1 DE-1167
Surface Search Radar 1 AN/SPN 753(V)4
Active Sonar 1 DE-1167
Active/Passive ECM 1 AN/SLQ-32(V)3
Torpedo Decoys 1 AN/SLQ-25 Nixie
Decoys (Others) 2 Mk36
Satellite Communications 1 MILSATCOM 4990T

Weapon Systems and Organic Units

Main Guns 1 40mm/70
Force Protection Guns 2 20mm
Surface-to-Air Missiles 6 Aster-15
Torpedoes 5 MK-46
Surface to Surface Missiles 5 NBS 15 MK3
CIWS Guns 1 Mk 15 Phalanx
Helicopter 1 SA-330 Puma
Boats 2 7m RHIB

☑ Weigh the satisfaction of each naval task by the endurance?
☐ Use the equipment to set the capability levels achieved

Final Thought: The Latest ASDL Initiative

After 25 years of continuous support and collaboration between NASA LaRC and ASDL, an opportunity presents itself to establish :

The ASDL@NIA

… an entity to be defined cooperatively to suit the future research needs of NASA LaRC