A Virtual Simulation Platform for the Design, Testing, and Verification of Unmanned Aerial Vehicle Designs

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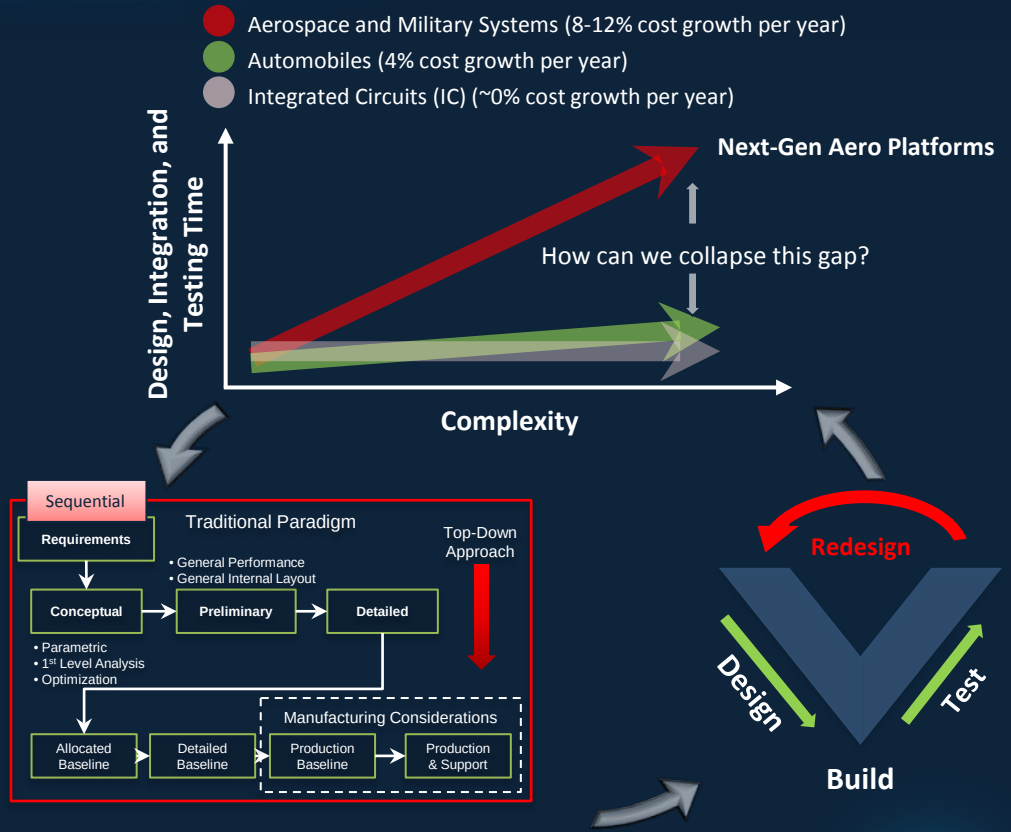
Atlanta, Georgia

Georgia Tech Aerospace Systems Design Laboratory

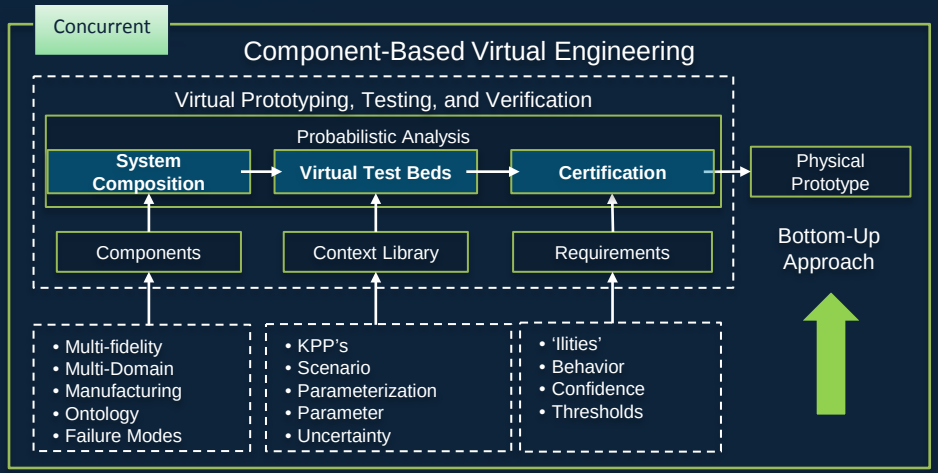
Virtual Prototyping: Experience and Motivation

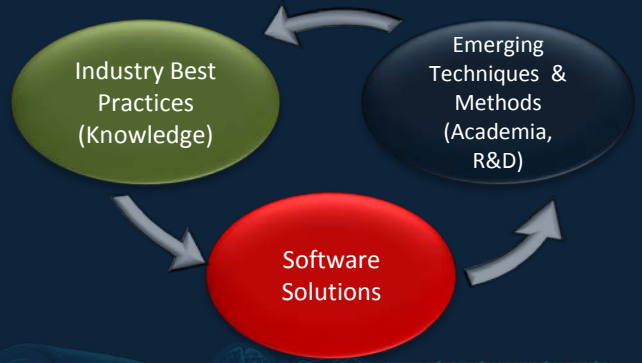
- Growth in systems complexity has increased risk and development time to unacceptable levels over the past 50 years
- Rapidly changing environments require systems to be designed with higher degrees of adaptability
- GT ASDL has developed a virtual prototyping framework supporting efficient design, manufacturing, product life-cycle analysis and verification of complex systems *before* physical prototyping
- Can we learn from other walks of life to help manage the ever-growing complexity that is inherent in next-generation systems?



Virtual Prototyping: New Paradigm

- The answer is yes…
  - Rethinking systems design by pulling “detailed” design aspects forward in design process
  - Leveraging latest systems engineering methodologies and computational capabilities
  - Focusing on virtual design and testing (limiting physical prototyping)
  - Enabling completely integrated design platforms and transparent requirements traceability





Systems Design Challenges

What is the underlying problem?

How is it done today?

Does the customer know what they want?

Customer Centric

What difference can we make if successful?

How will we know if we are successful?

What are our alternatives?

What are the critical functions?

How to we manage concept space?

Are we exploring all possible concepts?

Which concepts offer promising solutions?

Can we meet requirements?

What are the unknowns?

What tests are needed?

Have we captured enough information?

Is it worth building?

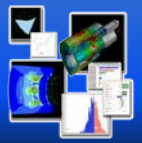
Understand

Define

Conceptualize

Prototype

Test & Certify



What are the requirements?

Do we understand the requirements?

Do we have the right resources?

How do we quantify success?

Does this require M&S?

Can I leverage existing models?

Do we have a verification plan?

Have we captured critical aspects?

How to we make the leap from conceptual to physical?

Market Research

Workshops

Surveys

QFD

Requirements Traceability

IRMA

Enabling Techniques & Methodologies

Bringing knowledge & detailed design aspects forward

Power Plant
Land Vehicle
Aircraft
V.Env
Aero
Structures
Controls
Dig. Mfg.
HX

Multi-aspect, Multi-fidelity model library

Parametric Modeling

Surrogate Modeling

Uncertainty Propagation

Model

Reliability-Based Design

Needs

Opportunity

Understand

Define

Conceptualize

Prototype

Test & Certify

Enabling Software Solutions

Collaborative Innovation

System Engineering/ Behavior Modeling

Capture Design Knowledge
Enable high-value design work

Integrated, Collaborative Virtual Modeling and Prototyping Environment

Integrated Simulation & Optimization Environment

3D CAD Modeling

3D Virtual Environments

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Market Research

Workshops

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Requirements Traceability

IRMA

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Enabling Software Solutions

Collaborative Innovation

CATIA DBM

- Capture Design Knowledge
- Enable high-value design work

WINNING PROGRAM

Integrated Simulation & Optimization Environment

3D CAD

3D Virtual Environments

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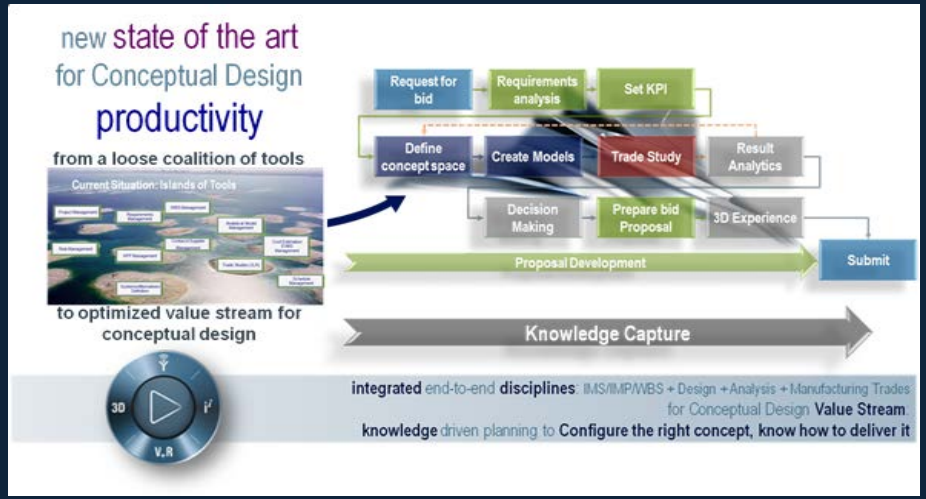
Enabling Completely Integrated Design Platforms and Transparent Requirements Traceability

Platform requirements:

- **Model Based Enterprise foundation** to **capture descriptive & computational models** across program lifecycle
- Ensure that the data is available in the **right place**, at the **right time**, and in the **right format**
- **Summarize, index, store and retrieve** previous exploration **information systematizing process & product data for reuse**
- **Manage and visualize the virtual validation & verification workflow** to
  - Capture fully models, scenarios & results
  - Understand the steps that led to a decision
  - **Provide full traceability and impact analysis** to analyze and understand impacts of decisions and potentials for improvement

DASSAULT SYSTEMES *The Winning Program*



Test Case – Army Research Lab MASR Program

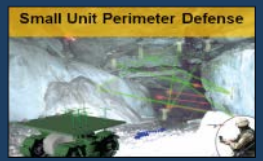
ARL

www.arl.army.mil
www.mast-cta.org

Micro-Autonomous Systems Research (MASR)

Initiative: Develop autonomous, multifunctional, collaborative ensembles of agile, mobile microsystems to enhance tactical situational awareness in urban and complex terrain for small unit operations.

Missions



Integrated Design Environment (vision)

Reason to Believe

Requirements

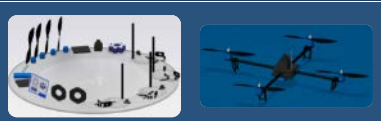
Testing

Concept Selection

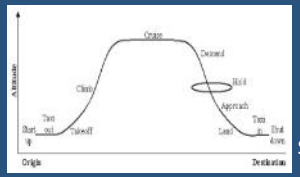
Prototyping

Concept Sizing

3D Design



Configuration Definition



System Trade Studies

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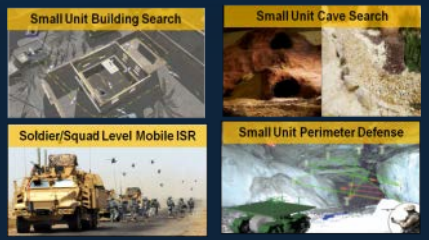
Requirements
Testing
Concept Selection
Prototyping
Concept Sizing

Translating Requirements: Operational Functions, Test Missions, and Measures of Effectiveness

GT ASDL Atrium

Program Planning & Control



1.1 Deploy & Startup → 1.2 Sense → 1.3 Create/Update Geom. Rep. → 1.4 Transfer Geom. Data
1.3 → 1.5 Navigate to next point → 1.6 Move to next point → 1.7 Evaluate for stopping point → 1.2 Sense
1.7 → 1.8 Shutdown

Top-Level Goals
Mission Types
Test Mission
Operational Functions
Requirements
Mission MoEs

MAST Measures of Effectiveness	Interior Building Reconnaissance
Entry Points Identified	> 80%
Routes through Building	> 1
Enemies Identified	> 95%
Enemies Analyzed	> 25%
Interior Coverage	> 90%
Weapons Identified	> 80%
Hazards Identified	> 80%
Counter-Surveillance Identified	> 50%
Data Transmitted to Soldier	> 95%
Data Transmitted to Base	> 70%
False Negatives	< 10%
False Positives	< 10%
Total Area Coverage	> 90%

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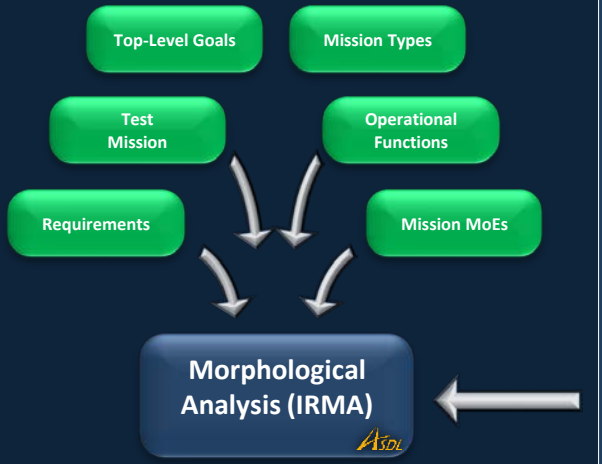
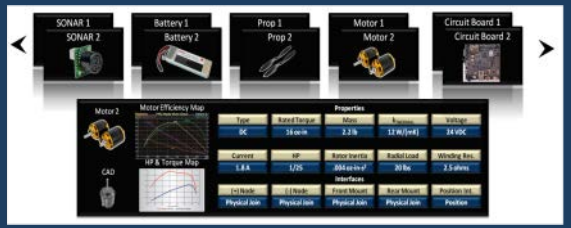
Define Concept Space

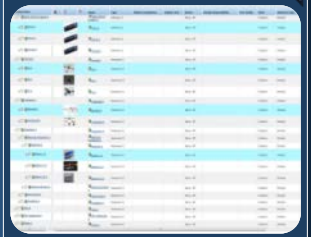
Given a set of requirements and potential technologies, which concepts can be explored?



Component Library



- Library consists of multi-fidelity, multi-domain, cyber-physical models
- Extensible & reusable – allows organizations to leverage internal knowledge



Candidate Technologies/Concepts

Challenge: Revolutionary Technologies and Massive Concept Space

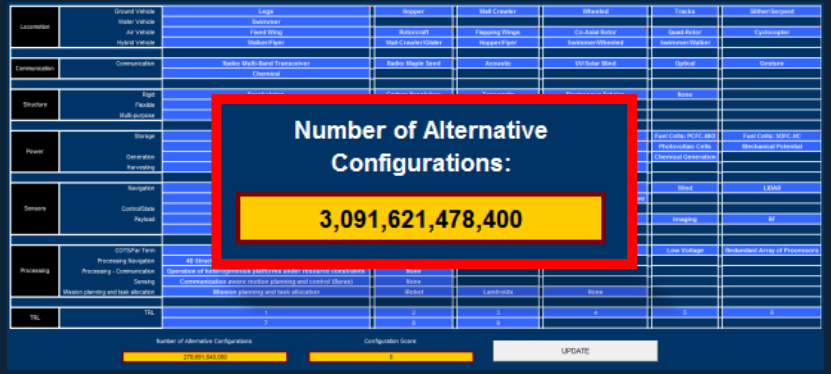
Interactive Reconfigurable Matrix of Alternatives (IRMA)

- **Purpose**
  - A structured methodology to integrate objective and implicit information into the concept selection process
- **Objectives**
  - Functional Decomposition
  - Allows exploration and traceable reduction of the design space from an astronomical number of combinations to a manageable set
- **Characteristics**
  - Bottom-up approach
  - Flexible, reconfigurable, and collaborative
  - Multi-level mappings
  - Mission scenario evaluation to score and rank alternatives
  - Compatibility relations
  - Calculation of number of alternatives
  - Multi-Attribute Decision Making
  - Metadata Filters

Locomotion	Ground Vehicle	None	*Legs*	Hopper	Crawling Robot	Wall Crawler		
	Water Vehicle	*None*	Reaction	Swimmer				
	Air Vehicle	*None*	Fixed Wing	Micro Quadrotor	Rotorcraft	Ornithopter	Cycloidal Rotor	
Communication	Signal Transfer	Wifi	*Bluetooth*	Optical	Wired	Acoustic		
Power	Storage	*Capacitor*	Primary Batteries	Li-Po	Fuel Cells	Thrust Vectoring		
Structure	Rigid	Exoskeleton	*Carbon Frame/Spar*	Carbon Nanotubes				
	Flexible	*None*	Flex Joints					
Processing	Navigation	PandaBoard	PIC	*Custom Board*	Offboard PC			
Sensor	Mapping	Microphone	LIDAR	Chemical Sensor	SONAR	*RADAR*	Stereo Video	
	Location	GPS	Gyros	Magnet-ometer	*IMU*			

Filtered IRMA for Concept Sizing

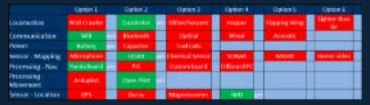
- A set of filters applied to the MASR IRMA provides a starting point for concept sizing and virtual prototyping
- TRL of 9 (mature technologies)
- Must be composed of components off-the-shelf (COTS)



Apply filters

	Option 1		Option 2		Option 3		Option 4		Option 5		Option 6
Locomotion	Wall Crawler		Quadrotor	yes	Slither/Serpent		Hopper		Flapping Wing		Lighter than Air
Communication	Wifi	yes	Bluetooth		Optical		Wired		Acoustic		
Power	Battery	yes	Capacitor		Fuel Cells						
Sensor - Mapping	Microphone		LIDAR	yes	Chemical Sensor		SONAR		RADAR		Stereo video
Processing - Nav.	Panda Board	yes	PIC		Custom board		Offboard PC				
Processing - Movement	Ardupilot		Open Pilot	yes							
Sensor - Location	GPS		Gyros		Magnetometer		IMU	yes			

IRMA Concept Selection



Tech 1 Crawler, Quadrotor, Ornithopter…

Tech 2 Capacitor, Li-Po, Fuel Cells…

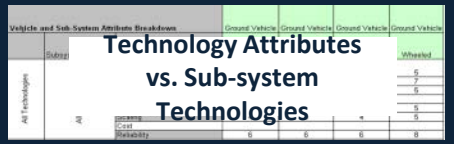
Tech 3 Microphone, LIDAR, SONAR…

Tech n

Technology Attributes

Mass, power required, processing, memory, scaling, cost…
Maneuverability, endurance/range, speed…
Noise, stability, safety, terrain index…
Strength, deformability, morphability, self-healing…
Energy density, specific mass…

Subject-matter Expert Inputs



X

W_{OF}	Operational Functions
2	Perform system warmup
8	Deploy/Startup
9	Sense
8	Receive/Retrieve
5	Create/Update Geo. Data
6	Navigate
7	Generate planned path

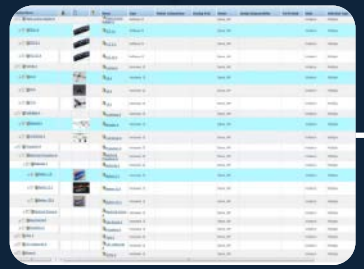
Generate score for each technology

Evaluate All Possible Alternatives

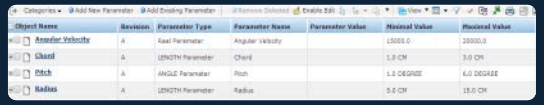
Ranked List of Concepts

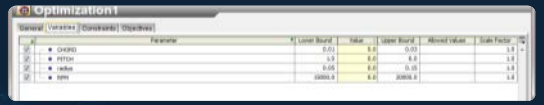
Concept Sizing

Component Identification

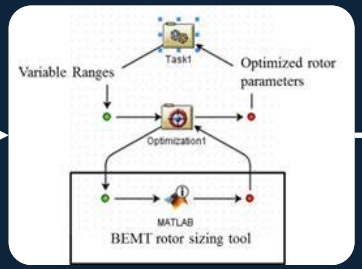


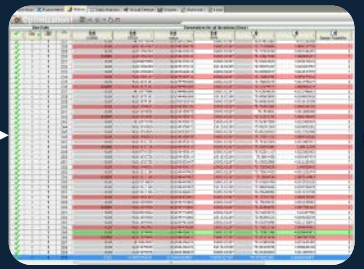
Parameter Identification

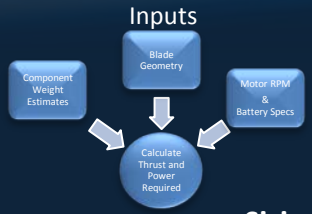


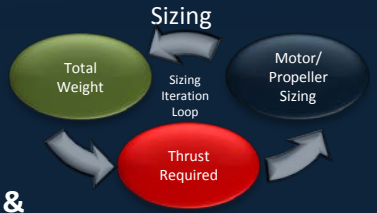


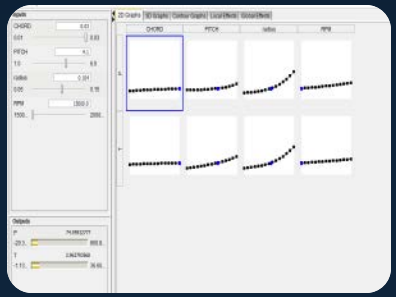
Sizing & Optimization



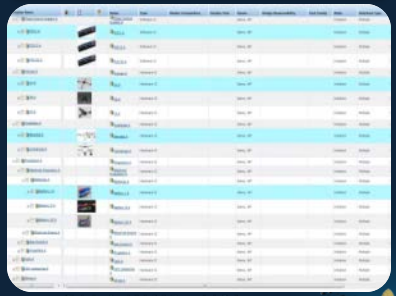








Parameter	Optimal
Chord	0.03 m
Pitch	4.1 degree
Angular velocity	15,000 RPM
Thrust	4.1 N
Power required	75 W
Radius	0.104 m



- Concept optimized to meet requirements/constraints
  - Ability to sustain flight at 50% throttle
  - Doorway entry width constraint
  - Off-the-shelf components
  - Etc.

System Prototyping

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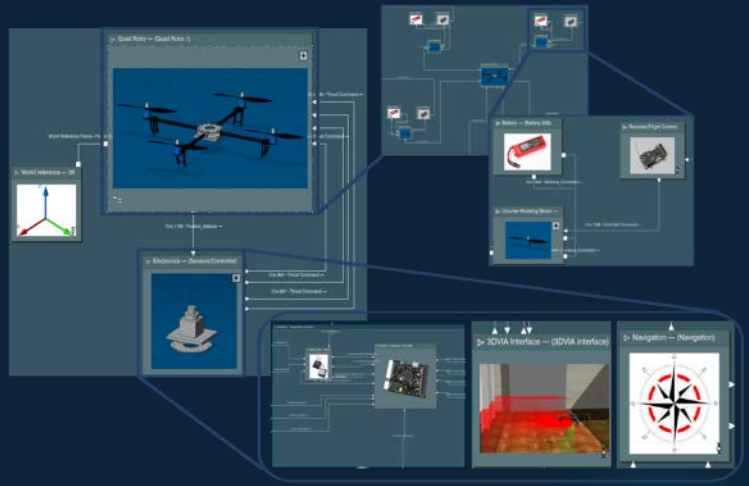
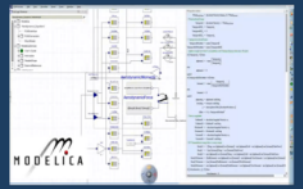
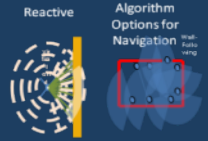


Behavior Models. CAD. Etc.

Motors, Batteries, etc.

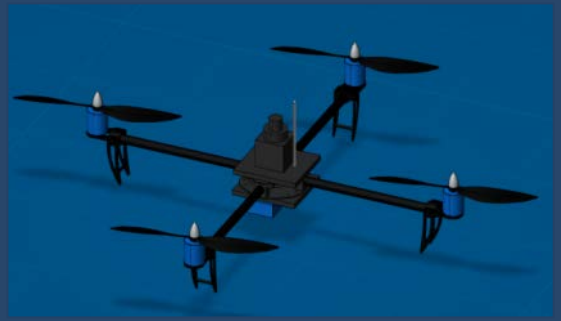


Navigation



Implement Sensors Logic

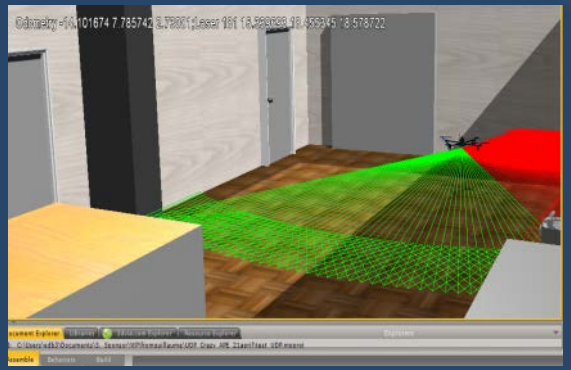
Mission Simulation



- Multi-domain physical modeling (Modelica)
- Sends distance and position data to Simultaneous Localization and Mapping (SLAM) software

New positions and behaviors sent by FMI

SONAR and LIDAR data returned by FMI

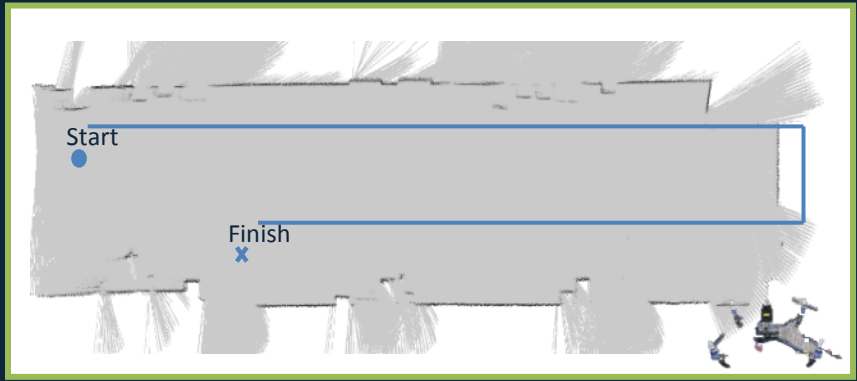


- Update positions and behaviors
- Detect obstacles and evaluate distance
- Return sensor information

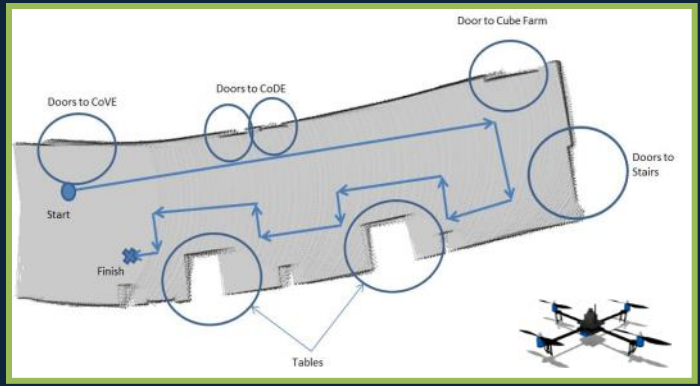
Simulation Results

Test Mission:
Weber 2nd Floor Atrium, ASDL

Physical Experiment



Virtual Experiment



Measures of Effectiveness

Coverage Area	Full coverage
Coverage Time	4-5min
Obstacles Identified	Objects = 5
Entrance Points Identified	5

Noise level measurement

Location	Peak(dB)	Peak(dB)
Noise at furthest point	73.9	71.9
Noise near vehicle	93.0	91.4

Maximum noise level is encountered at Take-Off

Mission Requirements Review

	Attribute	R	Target Value	Unit
R1	Surface of floor explored	>	90	%
R2	Discover obstacles	---	---	---
R3	Mission time	<	10	min
R4	Reserve time	=	2	min
R5	Noise at furthest point in room	<	50	dB
R6	Noise around vehicle	<	70	dB
R7	Number of operators	=	2	---
R8	Deployment time	<	5	min
C1	Size of the vehicle	<	doorway	ft

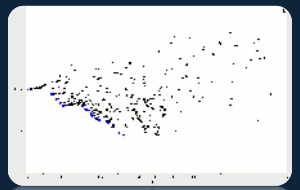
- Goal was to provide a comparable mapping result with physical experiments
- Captured most of the requirements
- Noise was not tested in virtual environment
- Test-bench improvements:
  - Navigation effectiveness
  - Mapping effectiveness

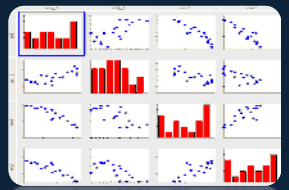
Results and Decision Support

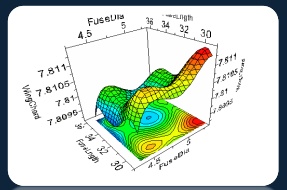
Advances in numerical simulation techniques and computational methods have allowed for **significant amounts of data to be generated, collected, and analyzed**

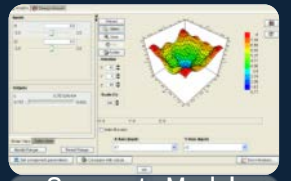
Runtime Gateway (Isight Decision Support Tool)

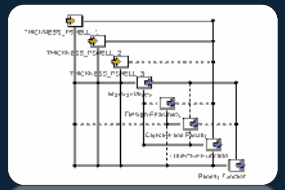
- Directly integrated in V6 platform for analyzing data to support decision-making
- Supports intelligent exploration of data and promotes innovation through discovery of new design possibilities and early design trade-offs

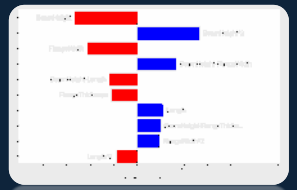

Real-time plots

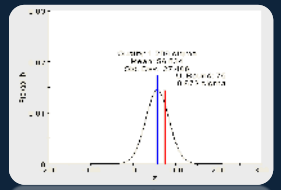

Data Mining

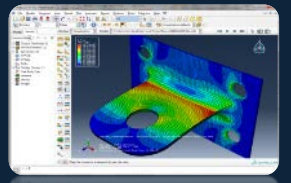

Design Space Visualization


Surrogate Model Visualization


Design parameter correlation


Statistical processing


Robustness / Reliability


Integrated Analysis Framework

Summary

- Rethinking systems design by pulling “detailed” design aspects forward in design process
- Leveraging latest systems engineering methodologies and computational capabilities
- Focusing on virtual design and testing (limiting physical prototyping)
- Enabling completely integrated design platforms and transparent requirements traceability
- 2015 team focus on design cycle time reduction
- Provide mission-based rapid prototyping of vehicles for immediate on-field deployment
- Launched a new 2014-2015 grand challenge on Certification-Influenced Design – Leveraging *Licensed to Fly* Experience – introducing certification constraints and validation methods in conceptual design

Thank you

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