Hypersonic Project
Guidance Navigation & Controls

Associate Principal Investigator

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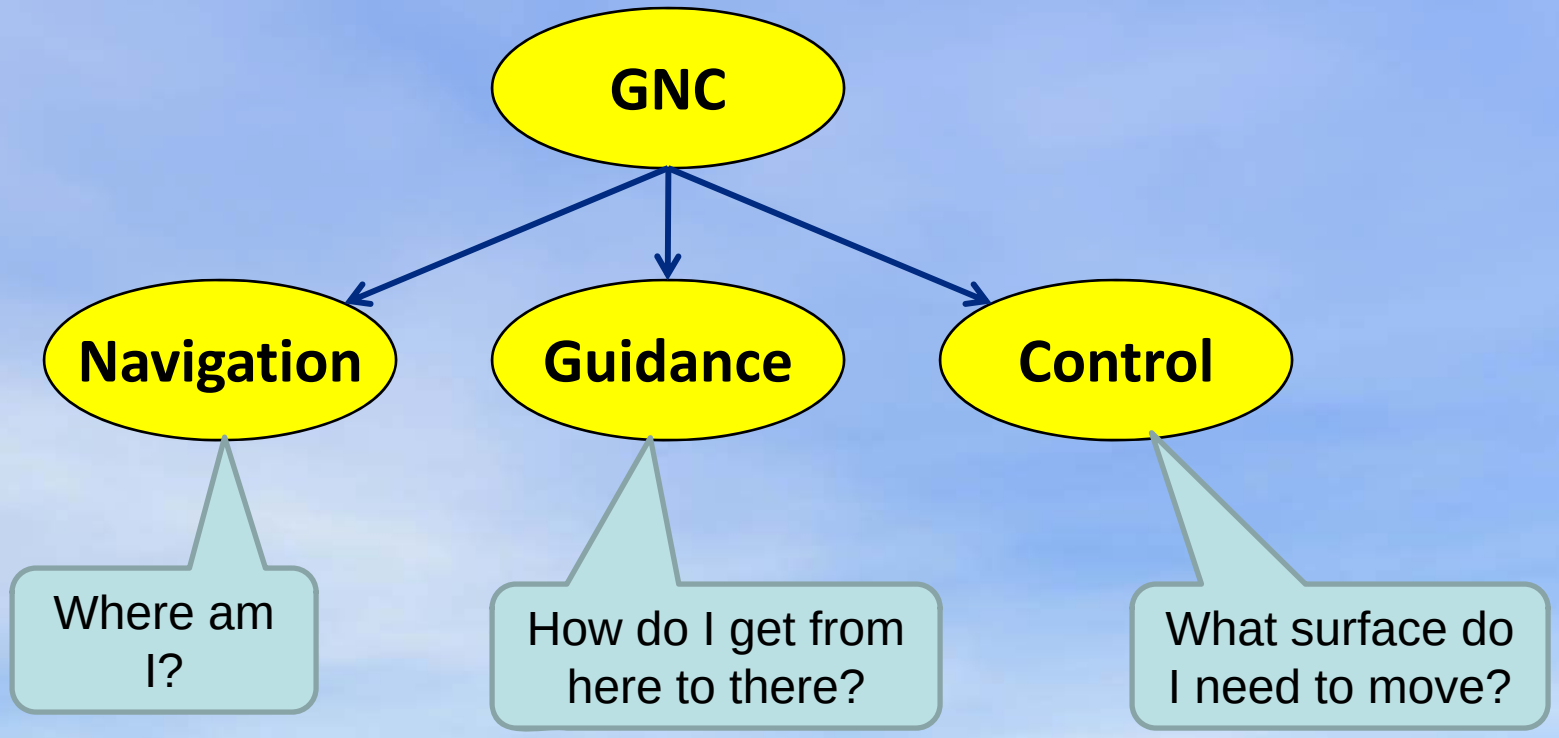
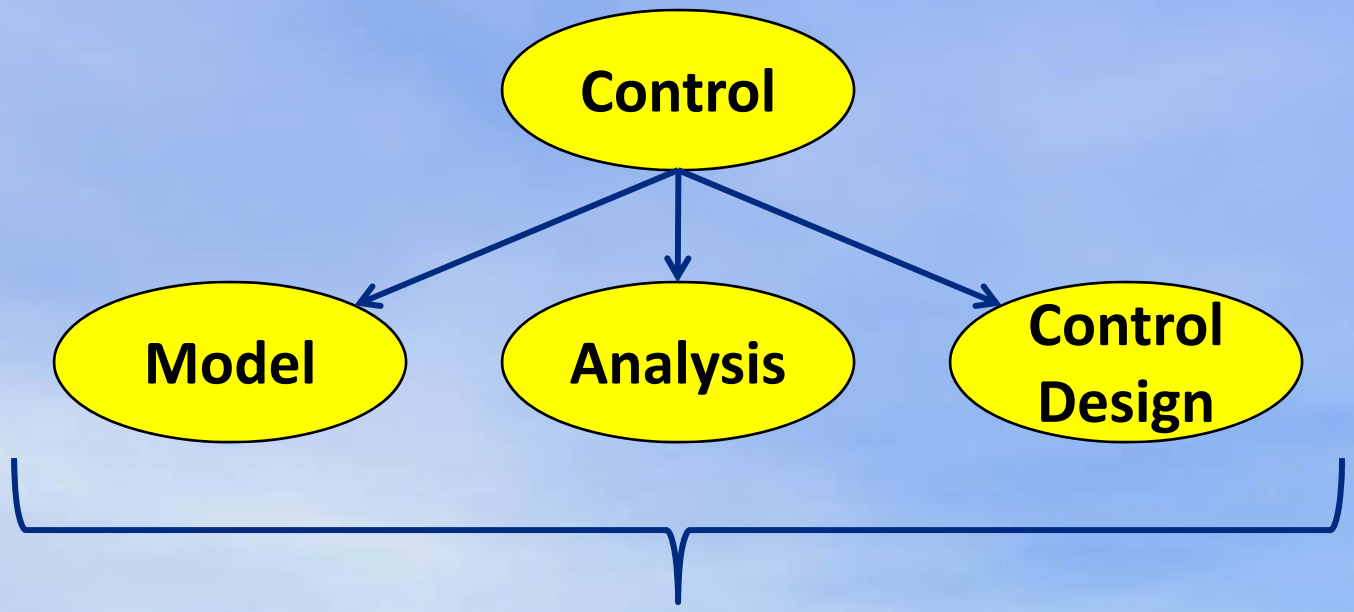
Guidance Navigation & Control



Control Design Process (Simplified)



Can vehicle be stabilized?
Is there sufficient control authority/bandwidth to meet mission requirements?
Is there sufficient control authority to mitigate disturbances and uncertainties?
What is minimum tolerable frequency for first structural mode?
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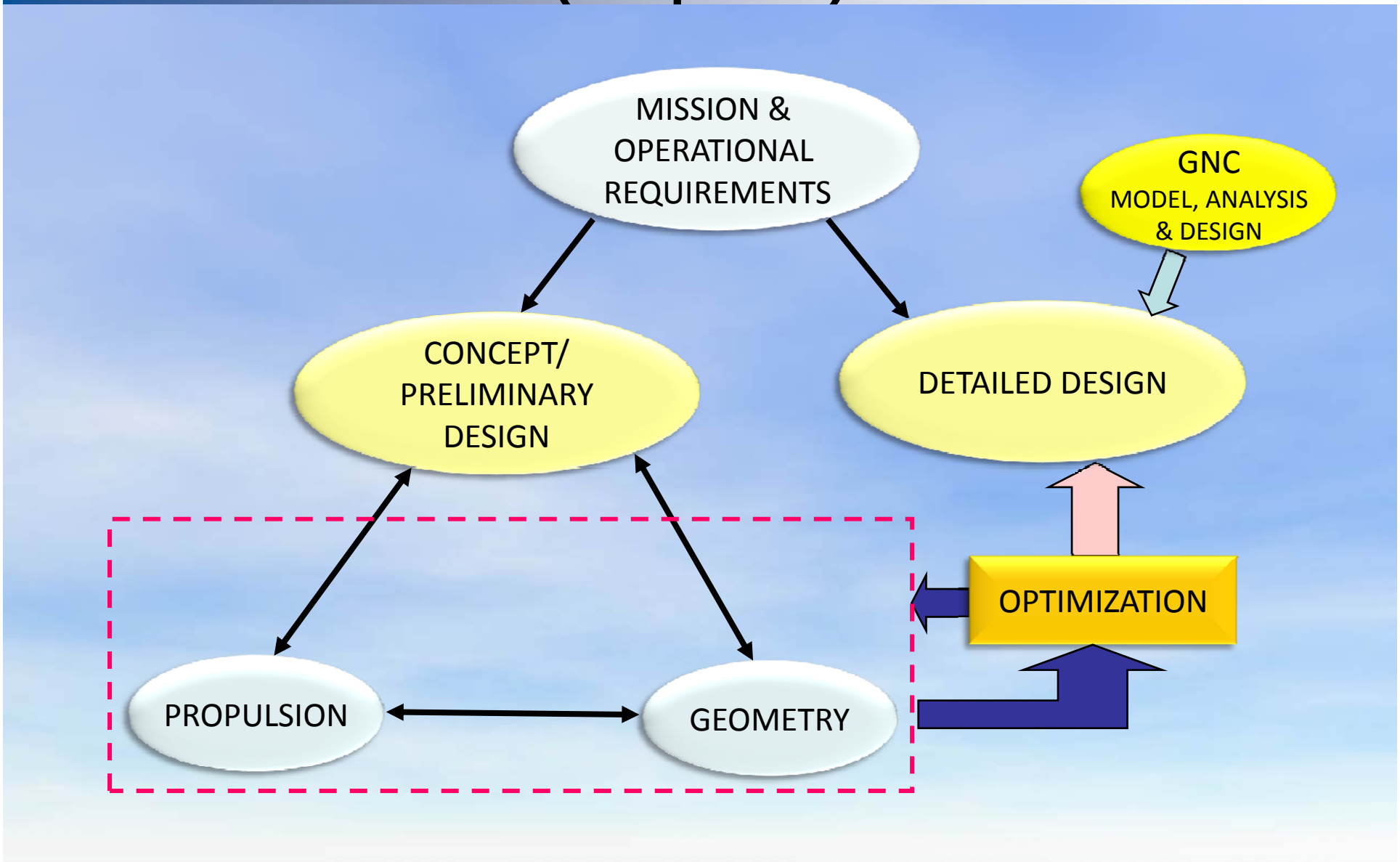
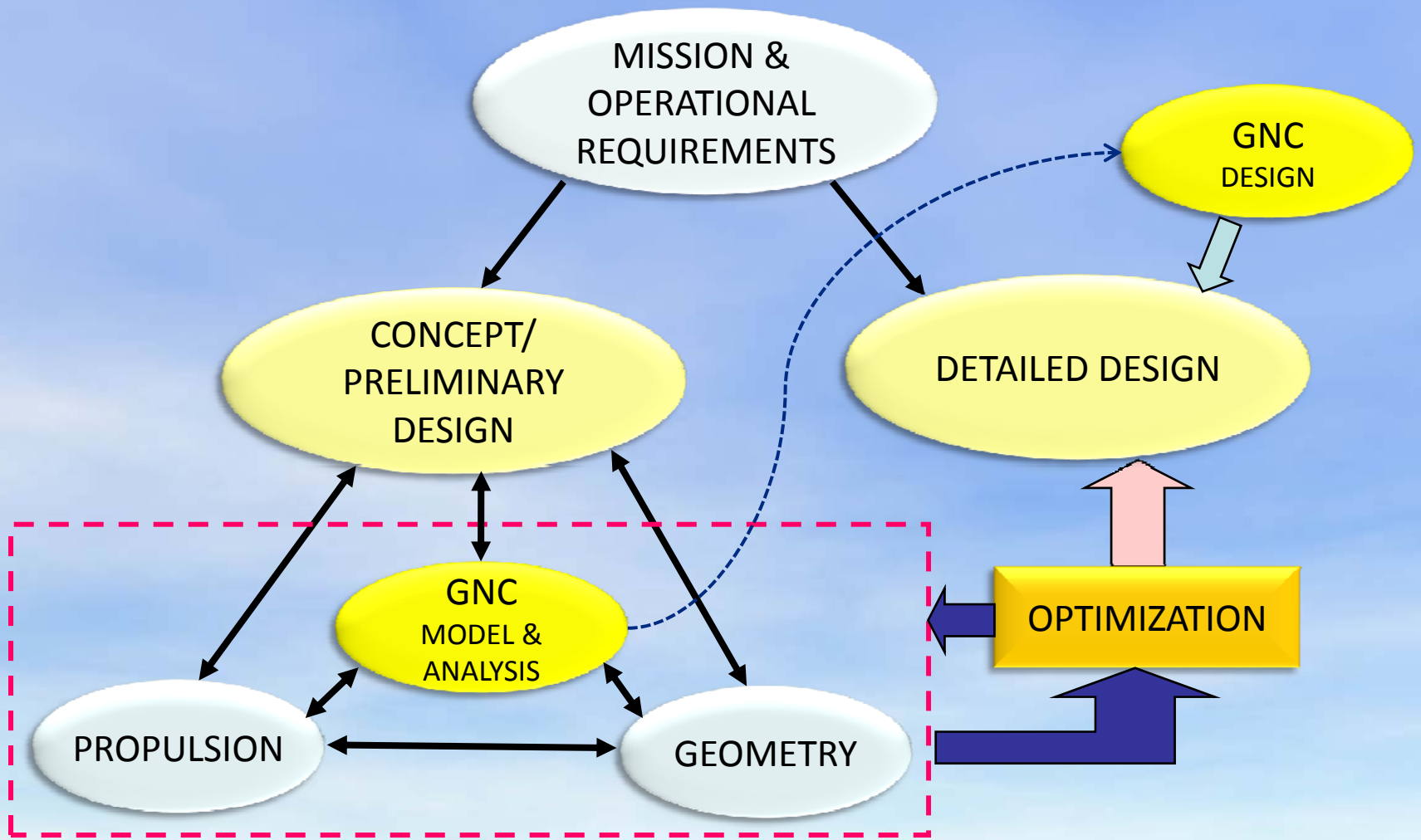
GNC in a Typical Vehicle Design Process (Simplified)



Role of GNC in Vehicle Design Process



Benefits

- Controllability of vehicle determined during conceptual design phase. This will ensure that the mission requirements are met.
- Reduce design cycle time
- Reduce control design time
  - The models and analysis will significantly aid control designers in design of the control system

GNC Discipline Overview

- Top Three Challenges
  - Modeling that captures relevant phenomena, such as:
    - High temperature effects
    - Aero-Propulsion dynamics/coupling
    - Aero-thermo-elasticity
  - Determine fundamental vehicle limitations to develop realistic control system specifications
  - Robust dynamic performance in the presence of significant uncertainty

- GNC Discipline Objective:
  - Develop models, analysis tools and design methodologies that permit the design of reliable hypersonic airbreathing vehicles
    - which offer robust dynamic performance in the presence of significant parametric and dynamic uncertainty
    - by exploiting real-time measurements and
    - developed control algorithms to coordinate available control actuators.

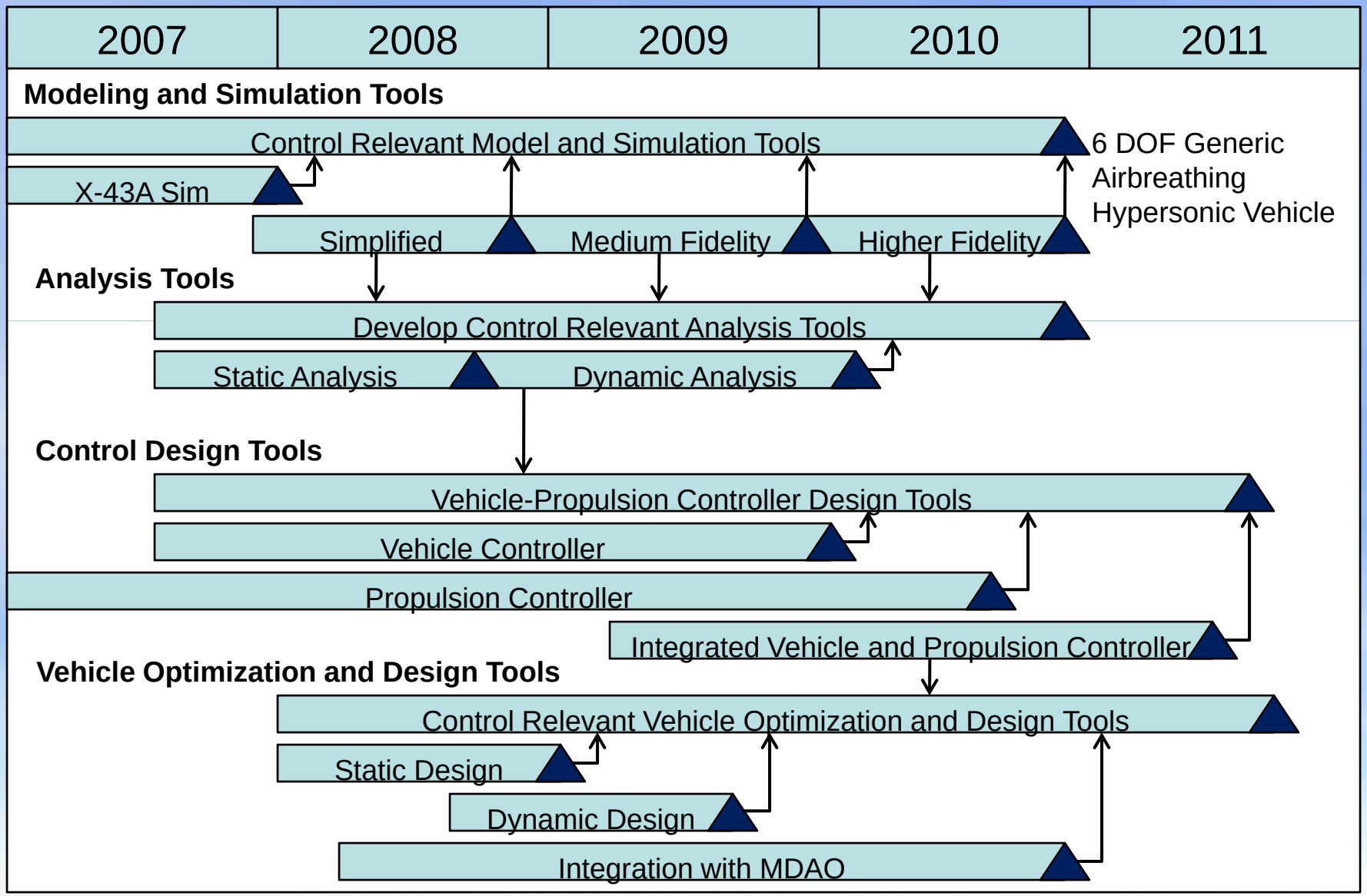
Hypersonic GNC Focus

- **Development of tools and methodologies to facilitate**
  - **Modeling**
    - development of suitable control-relevant models* with uncertainty bounds (Control Design and Control Evaluation models)
  - **Analysis**
    - assessment of fundamental performance limitations during system conceptualization, mission requirement development, vehicle design and control system design
  - **Control design**
    - development of robust control system design methodologies
    - management of system-level and component-level uncertainty
    - design and control of combined-cycle engine technologies

Validation

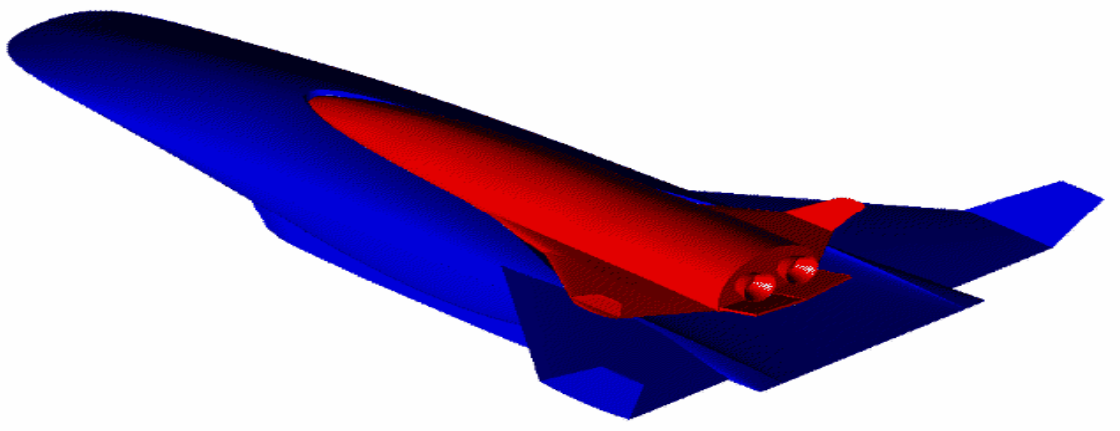
* Control-relevant models relate performance variables to inputs by capturing essential physical phenomena.

Road Map


2007
2008
2009
2010
2011
Modeling and Simulation Tools
Control Relevant Model and Simulation Tools
6 DOF Generic Airbreathing Hypersonic Vehicle
X-43A Sim
Simplified
Medium Fidelity
Higher Fidelity
Analysis Tools
Develop Control Relevant Analysis Tools
Static Analysis
Dynamic Analysis
Control Design Tools
Vehicle-Propulsion Controller Design Tools
Vehicle Controller
Propulsion Controller
Integrated Vehicle and Propulsion Controller
Vehicle Optimization and Design Tools
Control Relevant Vehicle Optimization and Design Tools
Static Design
Dynamic Design
Integration with MDAO

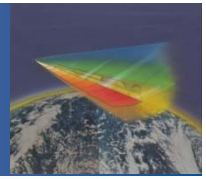
Control Relevant Models

- Generate tools to develop control relevant models with varying levels of complexity and fidelity
- Models will be used for:
  - control relevant vehicle design optimization
  - controller analysis and design
  - controller validation



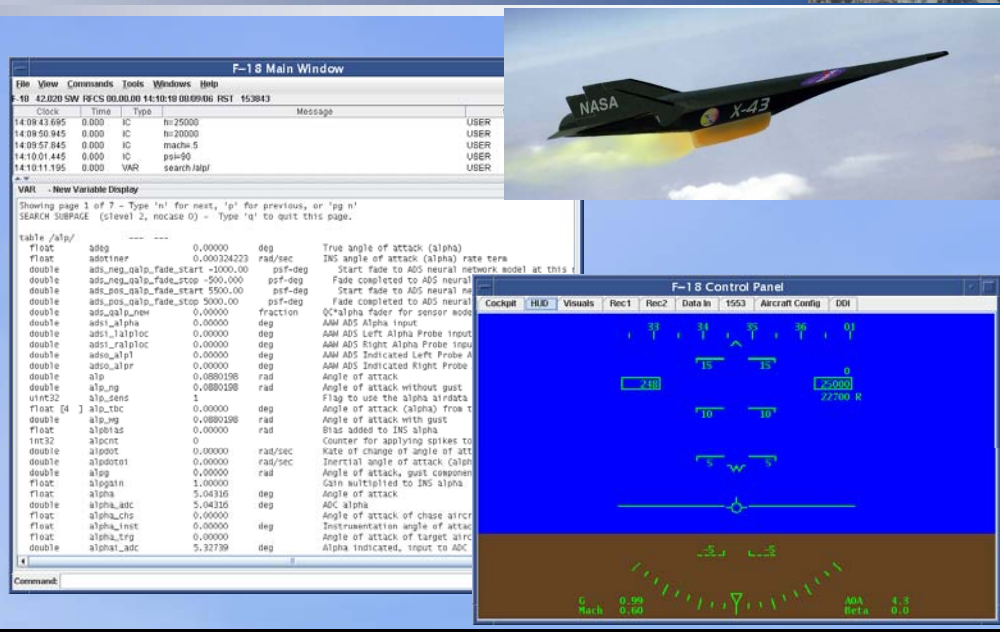
Two Stage to Orbit Concept
Reference Vehicle for technology evaluation

Modeling and Simulation



Objectives

- Provide vehicle simulations for support of advanced control methods design, analysis, and test for hypersonics research
- Build the simulation framework such that models can be incorporated in a modular and common fashion to allow for quick turnaround time for optimal usage of the simulation



Status

- The simulation script for running the Mach 10 flight trajectory executed the X-43A RV simulation from separation to splashdown.
- Established relationships and received public domain hypersonic vehicle models from
  - Cal. State – Los Angeles
  - Air Force Research Lab (Wright-Patterson)
- Plan and executing the incorporation of aforementioned models into Dryden simulation
- Delivery to NASA ARC and to NRA PI at ASU

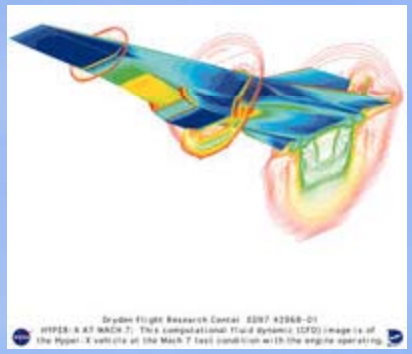
FY 2007/08 Key Deliverables and Milestones

- FY07Q2: Provide an up-to-date, flight-validated X-43A RV simulation to the NASA ARMD Hypersonic GNC team. **COMPLETE**
- FY07Q4: Provide a generic, 6-DOF, high-fidelity, real-time, hypersonic vehicle simulation as a tool for GNC research and technology testing to the ARMD Hypersonic GNC team.

Modeling and Simulation

Status and Progress

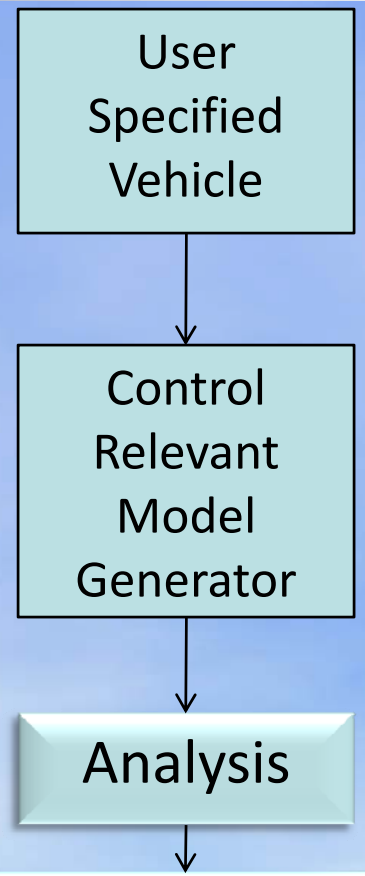
- TASK COMPLETED X-43A core sim:
  - Updated simulation incorporates new sim capabilities and supportability and matches previous sim dynamics
  - The simulation script for running the Mach 10 flight trajectory executed the X-43A RV simulation from separation to splashdown.
  - This sim is considered “State of Art” in hypersonic simulations



- Generic sim:
  - Established relationships and received public domain hypersonic vehicle models from
    - Cal. State – Los Angeles
    - Air Force Research Lab (Wright-Patterson)
  - Next Step: Plan and executing the incorporation of aforementioned models into Dryden simulation

Analysis Tools

- Static:
  - Trimming
  - Performance Measures
    - L/D, Range, Drag
- Dynamic
  - Linearization
    - State Space/Transfer Function
  - Modal Analysis (poles/zeros)
  - Frequency Response
  - Time Domain (simulation)



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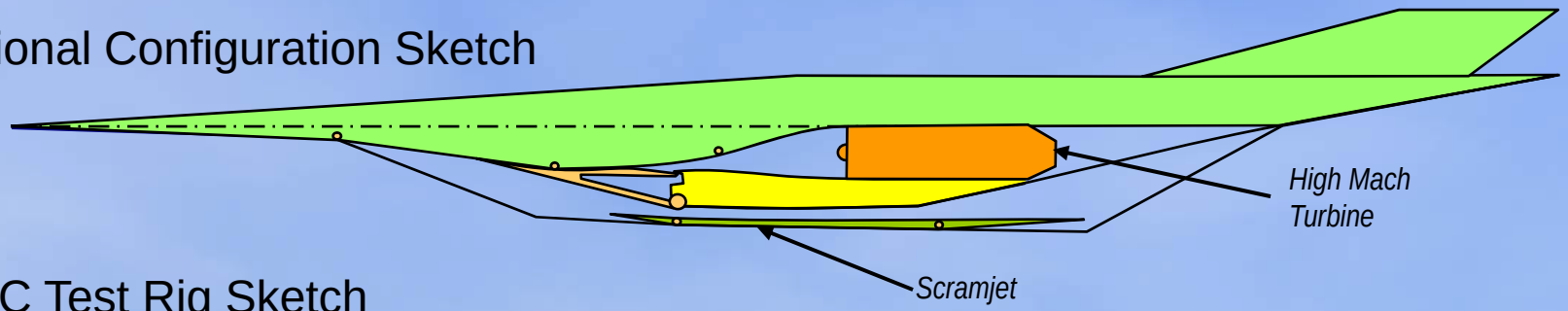
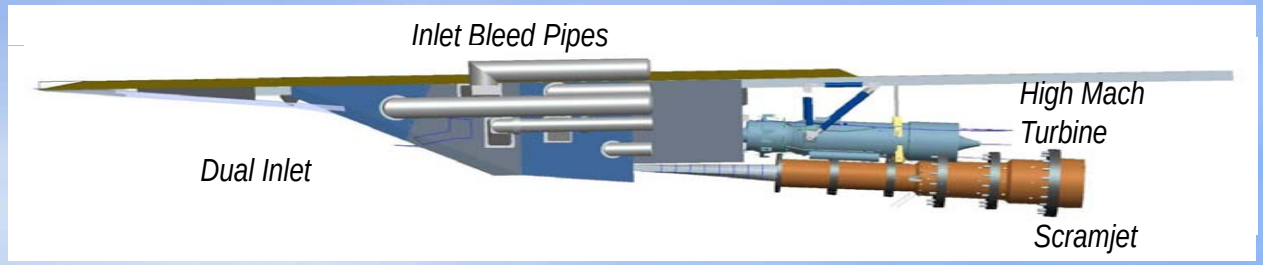
Turbine Based Combined Cycle (TBCC)Engine

Notional Configuration Sketch



TBCC Test Rig Sketch



OBJECTIVES

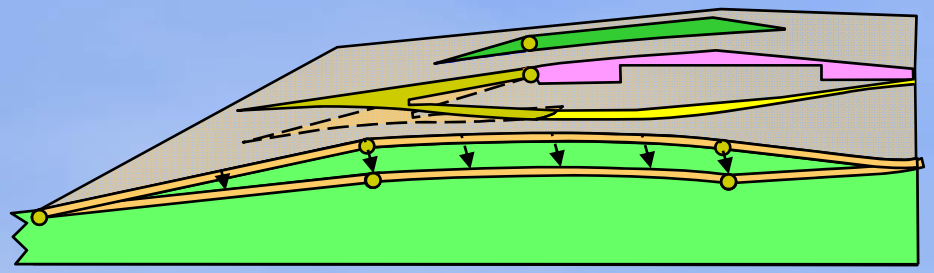
Proof of concept of over/under split flow inlet for TBCC.
- Demonstrate mode transition at large-scale.
- Validate CFD predictions
- Develop realistic inlet distortion characteristics

Testbed for integrated inlet/engine propulsion system tests
Testbed for inlet/engine/controls research

Hypersonic Propulsion System Control Development

Objectives:

- Model and control hypersonic propulsion system components:
  - Fore body compression surface,
  - Inlet,
  - Isolator,
  - Combustor, and
  - Nozzle.
- Support L-IMX inlet testing in GRC 10x10



L-IMX (Large-Scale Inlet Mode Transition) Model

Status

- Incorporated simple ramjet model into AFRL hypersonic vehicle model.
- Simulink turbine engine model running
  - Need to extend to higher Mach operation (afterburner schedule/control)
- MATLAB code capable of graphical representation of the inlet shock structure.
- Control hardware has been delivered

FY 2008/09 Key Deliverables and Milestones:

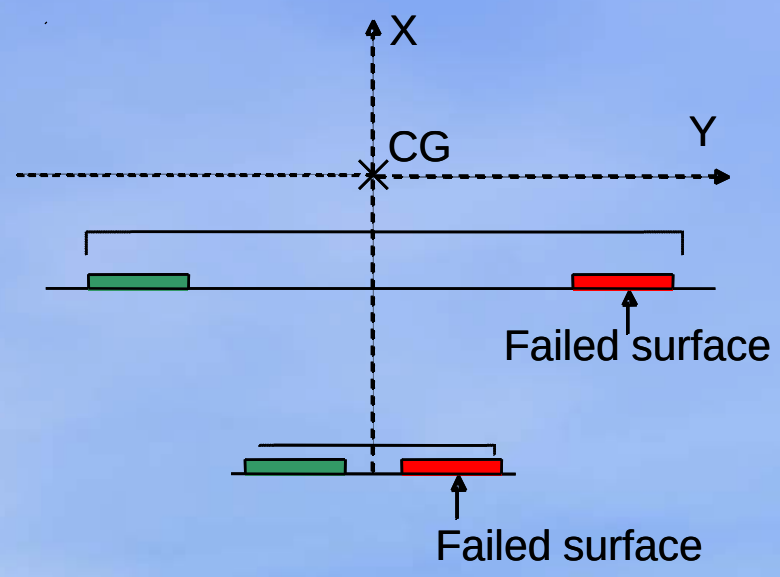
Support GRC 10x10 wind tunnel test of a SOA L-IMX model:

- Develop a hypersonic dynamic propulsion system and mode transition model.
- Mode transition control design criteria (1Q08), [15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, May 2008]
- FY09Q4 – Low fidelity model verification.

Adaptive Management of Subsystem Interactions

Objectives

- Hypersonic vehicles comprise multiple subsystems that do not model each other.
  - need to manage subsystem interactions.
- Management itself done adaptively, under model uncertainty, plant failures and adaptive subsystems



Status

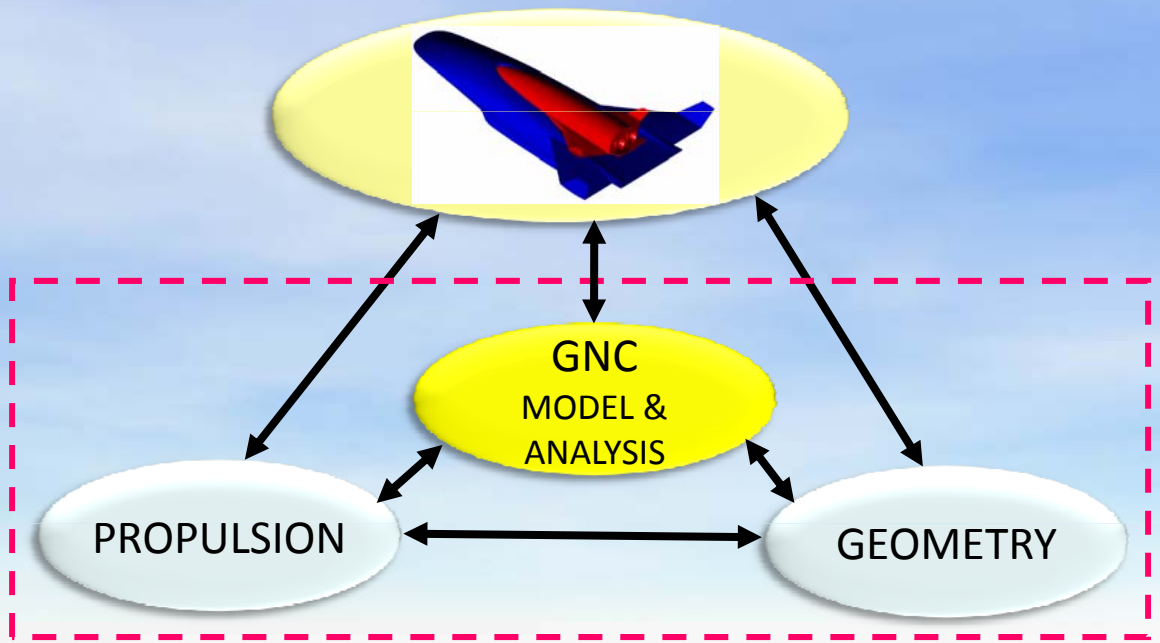
- Built coupled longitudinal / lateral / inlet-exhaust / MHD 6 DOF model based on Doman and Sachs models
- Begun to design a simulation of the non-cooperative game underlying a simple scenario involving multiple uncoordinated controllers

FY 2008/09 Key Deliverables and Milestones

- 2Q/08: Assess performance on the model produced in 2007 of a baseline system
- 1Q/09: Explicitly work through the game theory mathematics for adaptive management of subsystems in a dynamic environment.
- 4Q/08: Construct game-theory-based techniques for management of subsystem interactions. Compare to the baseline system across multiple operating regimes

Control Relevant Vehicle Optimization and Design Tools

- Use vision vehicle as benchmark
- Use tools and work with sub-disciplines to develop:
  - methodology for assessing worst case uncertainty/scenarios
  - integrated multi-disciplinary performance measures
  - specific benchmark test scenarios



Presentations

- GNC Overview
  - Donald Soloway, NASA Ames Research Center
- Modeling and Control Challenges for Air-Breathing Hypersonic Vehicles
  - Armando A. Rodriguez, Arizona State University
- Air Breathing Hypersonic Vehicle Propulsion System Control Model Development
  - Thomas J. Stueber, NASA Glenn Research Center
- Game theory for adaptive management of subsystem interactions
  - David Wolpert, NASA Ames Research Center