Handling Qualities Optimization for Rotorcraft Conceptual Design

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NASA Revolutionary Vertical Lift Technology Project (RVLT)

Develop and Validate Tools, Technologies and Concepts to Overcome Key Barriers for Vertical Lift Vehicles

Vision

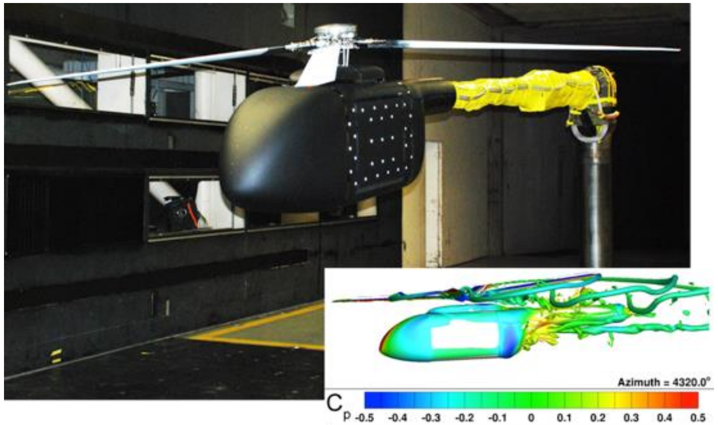
- Enable next generation of vehicles to expand capabilities and develop commercial markets with technologies for noise, speed, safety, mobility, payload, efficiency, environment

Scope

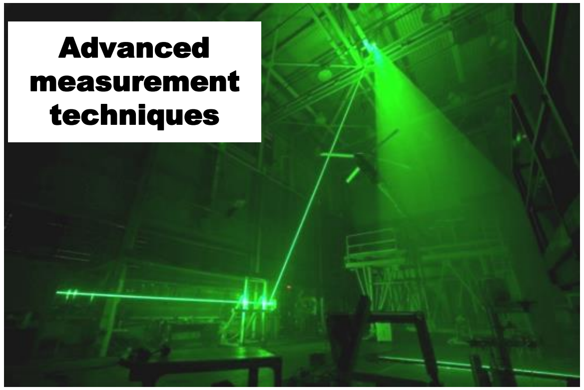
- Spectrum of configurations from very light (UAS) to ultra-heavy (transport size)

Conceptual Design Tool Development

- Developing an OpenMDAO framework to integrate discipline analyses: Sizing, propulsion, acoustics, structural loads and **handling qualities**



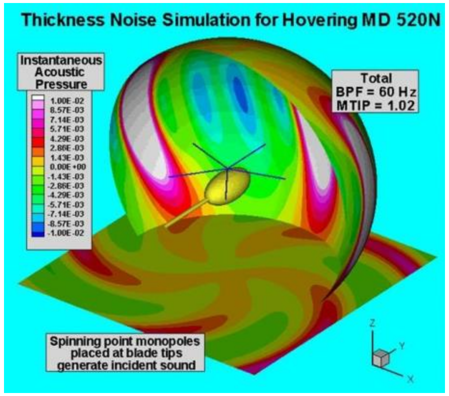
High-fidelity, validated CFD



Advanced measurement techniques

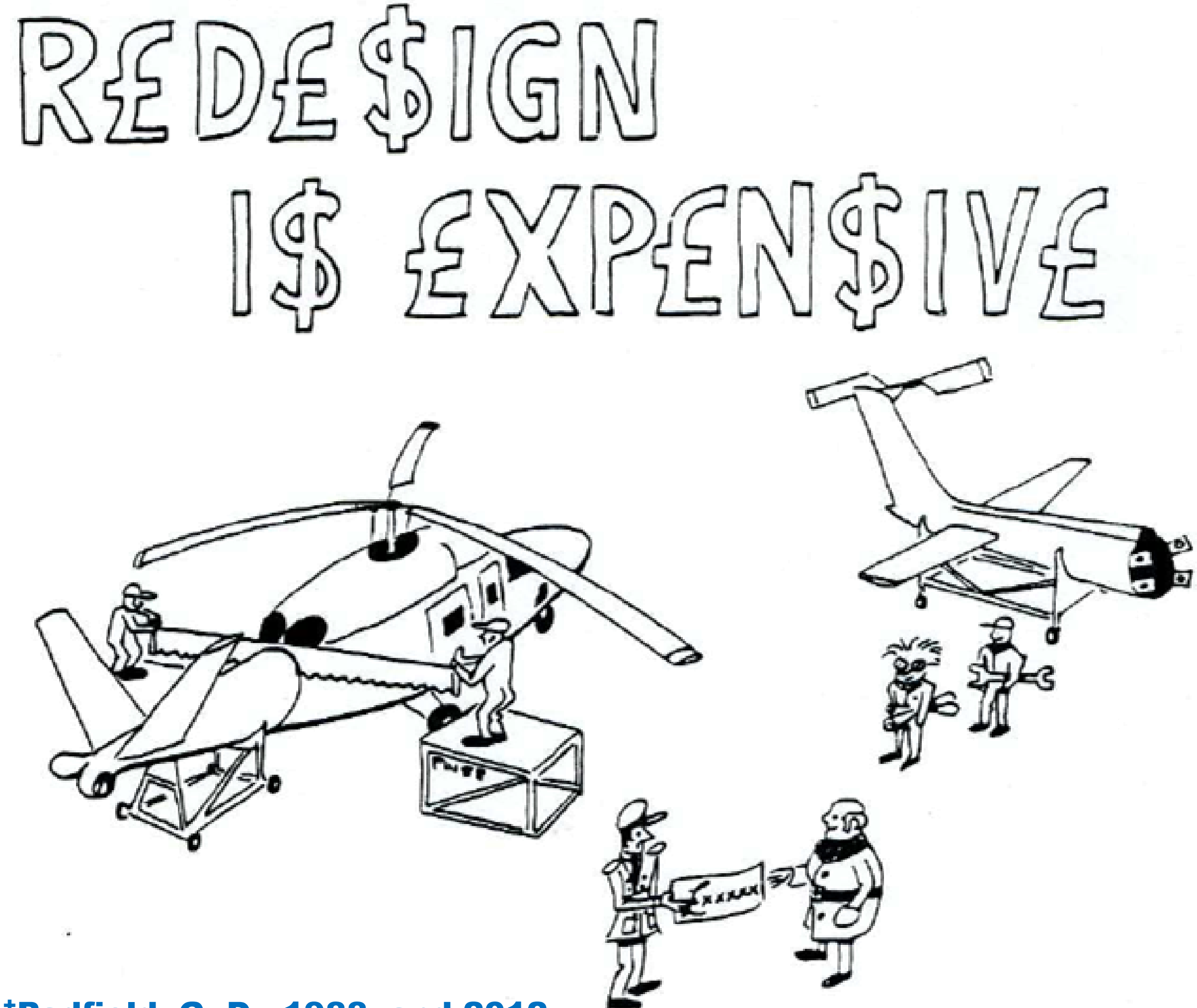
Conceptual Design Tool Development

Advanced propulsion and drive systems



Noise Modeling

Handling Qualities in Conceptual Design



†Padfield, G. D., 1988. and 2012

Stability, control and handling qualities (HQ) historically given little attention in conceptual design

- "not given their proper place in the early design trade-space, and often left until flight test to discover and 'put right'"†
- Weight savings by addressing over-design

Development of toolset: "SIMPLI-FLYD"

Exploring HQ in conceptual design

- integrate in a MDAO framework

Contents

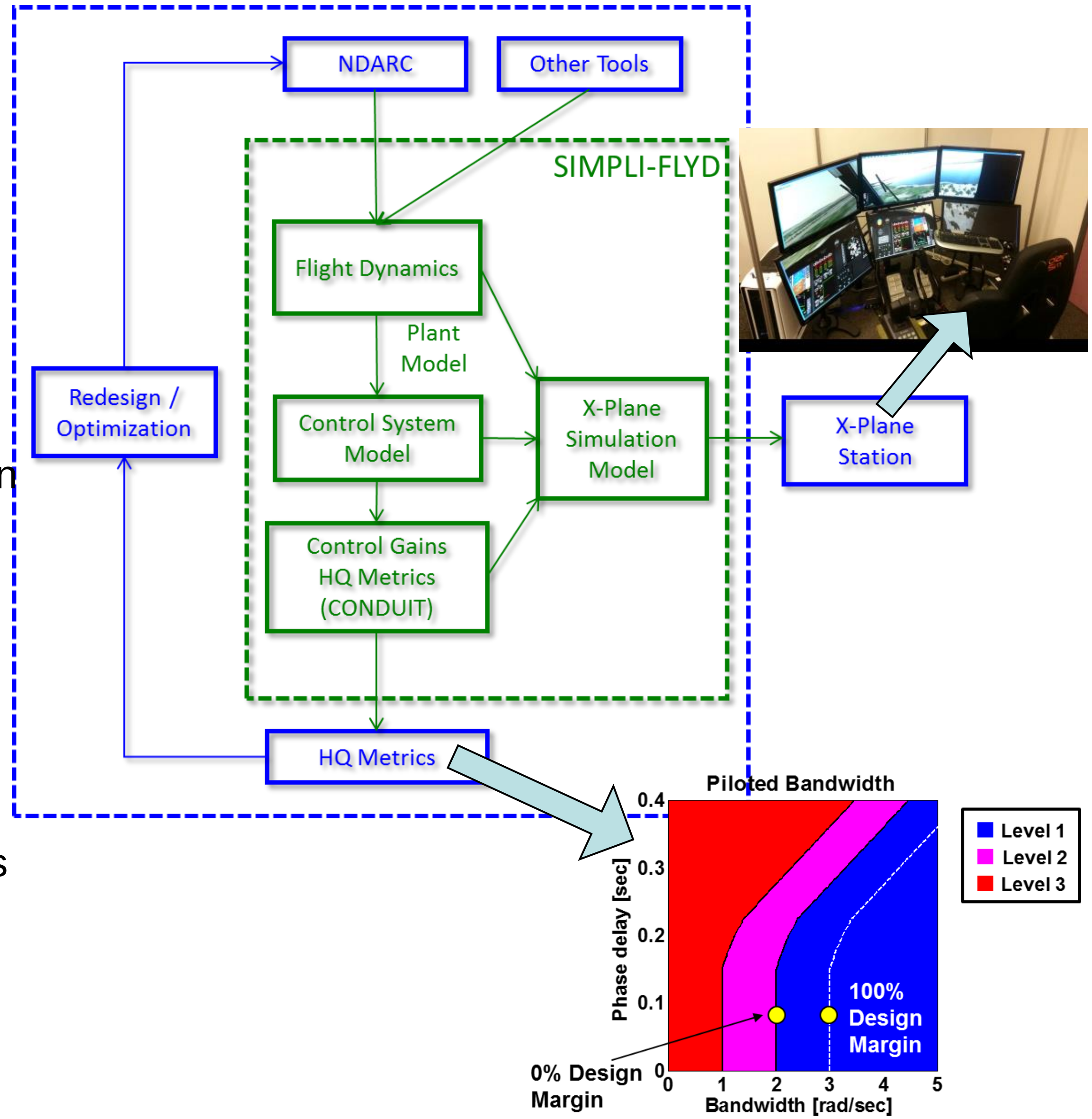
- SIMPLI-FLYD
  - CONDUIT optimization and HQ design margins
- NDARC/SIMPLI-FLYD coupling
- Results
  - Tiltrotor
  - Helicopter
- Lessons learned
- Future developments

SIMPLI-FLYD

- “SIMPLIfied FLight dYnamics for conceptual Design”
  - NASA/U.S. Army collaboration
  - NDARC: NASA Design and Analysis of RotorCraft

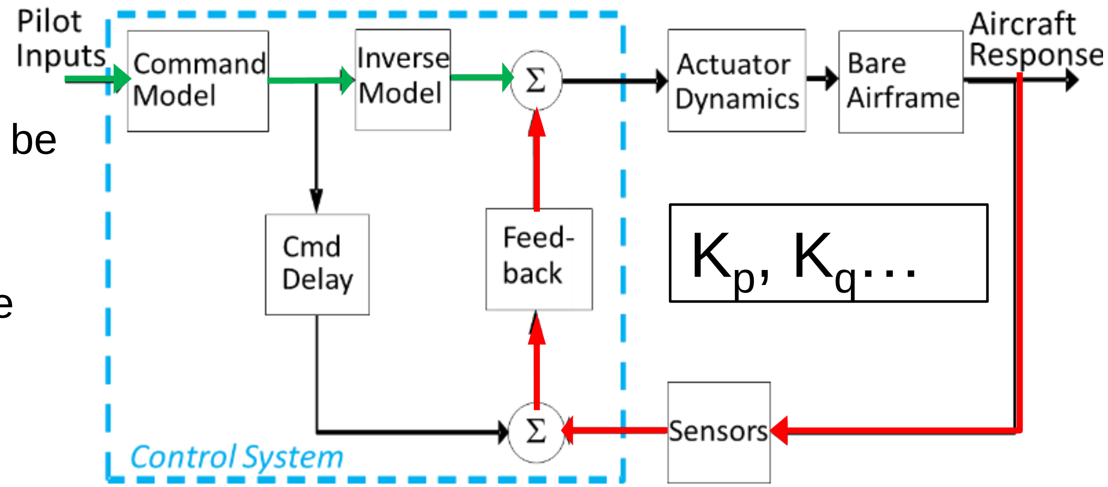
Automated process that:

- Calculates linear flight dynamics models
- Integrates control system optimization for roll, pitch, vertical and yaw response axes
- Calculates stability and control parameters for handling qualities metrics
- Generates a real-time flight dynamics and control model for piloted simulation in X-Plane



Control System Model

- Full-authority fly-by-wire
- Model-following architecture
  - Generic architecture that can be applied to multiple vehicle configurations
  - Feedback to stabilize, provide gust rejection
  - Feed-forward for piloted response, command shaping
- Appropriate piloted response types chosen automatically based on flight regime
- Control system gains need to be optimized



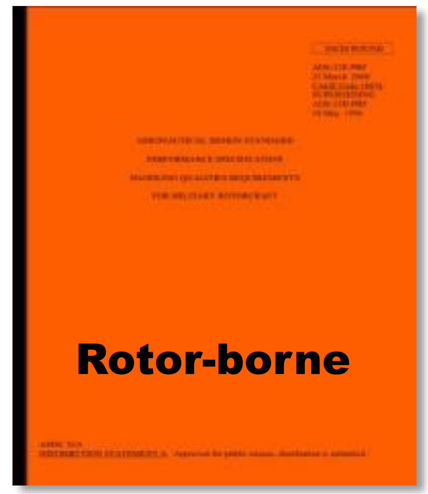
	Rotor-Borne		Wing-Borne
	Hover	Forward-Flight	Forward-Flight
Roll	RCAH	RCAH	RCAH
Pitch	RCAH	RCAH	Angle-of-Attack-Command
Yaw	RCDH	Sideslip-Command	Sideslip-Command
Thrust	RCHH	Open-loop	Open-loop

RCAH = Rate-Command/Attitude-Hold
RCDH = Rate-Command/Direction-Hold
RCHH = Rate-Command/Height-Hold

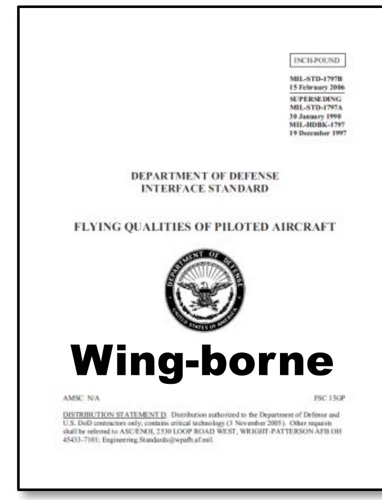
Control System Optimization - CONDUIT

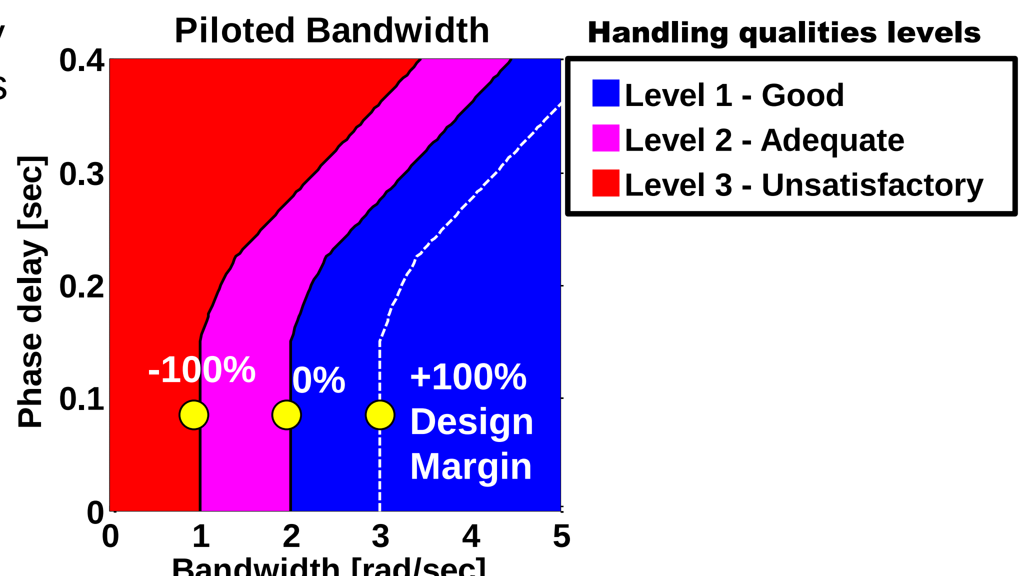
- Control Designer's Unified Interface (CONDUIT®)
  - Optimizes control system parameters to meet handling qualities specifications
- Automatic selection of different specification sets from ADS-33E and MIL-STD-1797B criteria for control optimization
  - 17 to 23 specs per axis
- Design margin
  - % over-/under-design based on ability of aircraft to meet metrics in each axis
    - 0% Just meets Level 1
    - -100% on Level 2/3 boundary
- Most limiting specification determines design margin for each axis
  - 2 per axis

ADS-33E



MIL-STD-1797B





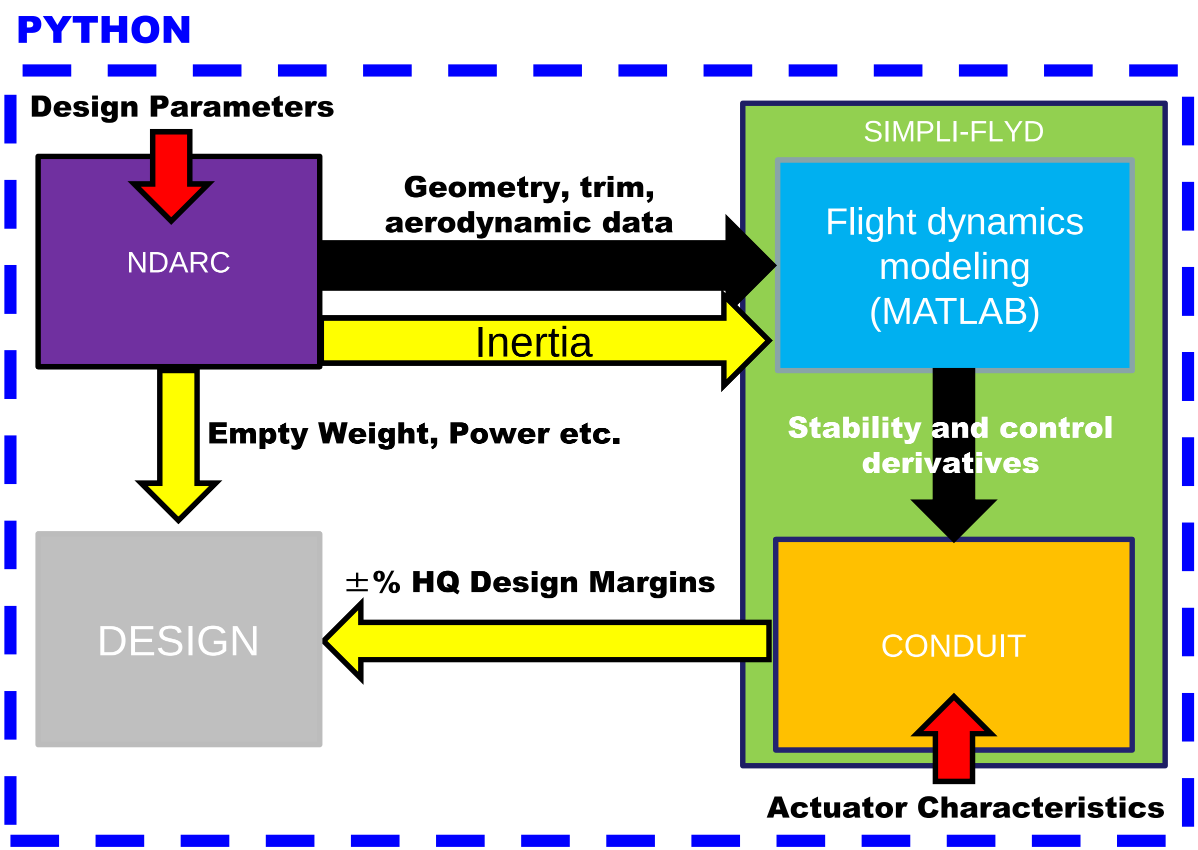
Objectives and example cases

- Evaluate NDARC/SIMPLI-FLYD coupled analysis to explore handling qualities in conceptual design

- Example aircraft/HQ scenarios chosen:
  - NDARC models with typical missions for sizing task
  - Varied a mix of design and actuator parameters

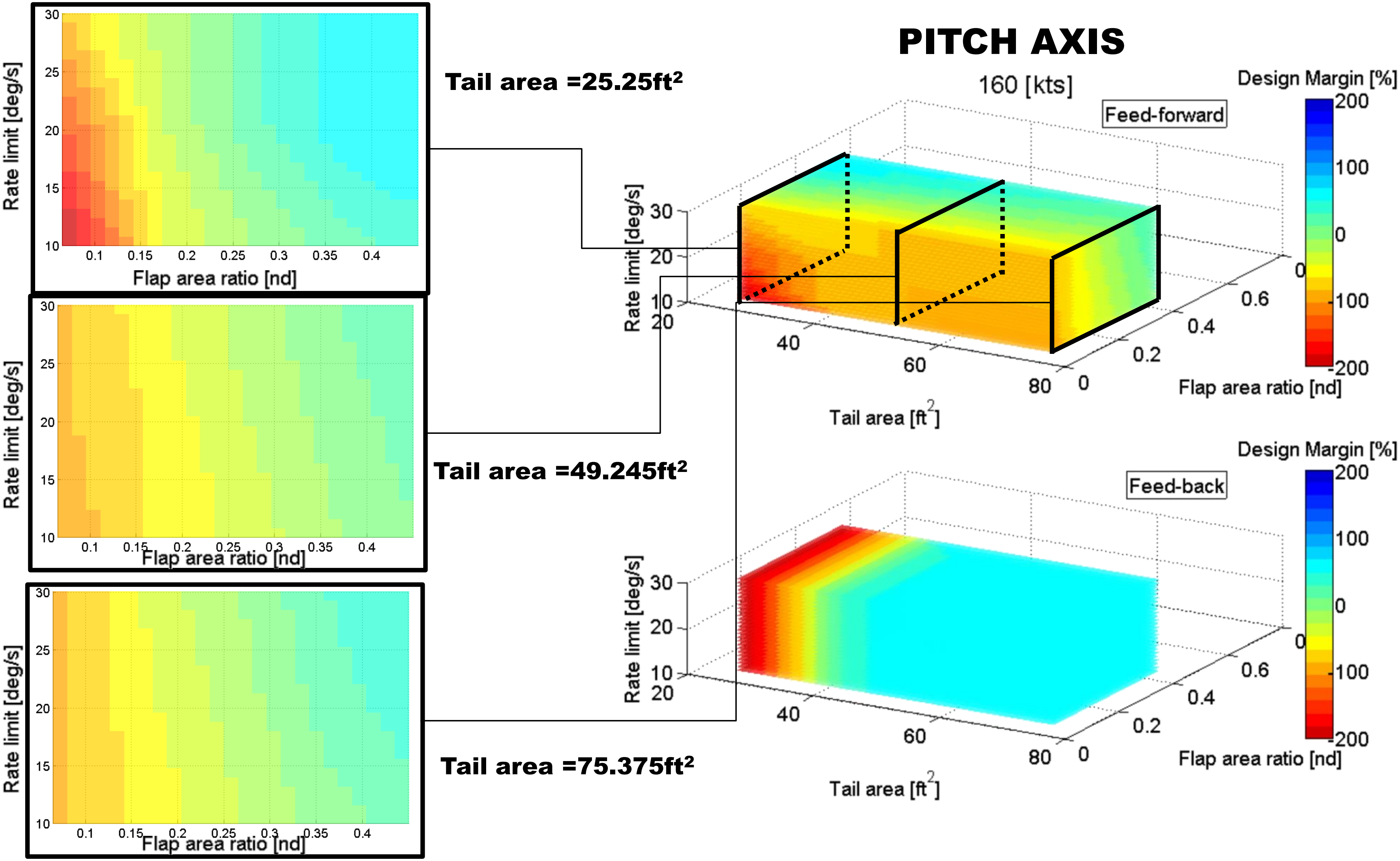
- Tiltrotor pitch axis
  - Forward flight only
  - Varied horizontal tail size, location, flap area ratio, actuator rate limit
- Single Main Rotor (SMR) helicopter yaw axis
  - Hover & forward flight
  - Varied tail rotor size, location, collective actuator bandwidth and rate limit

NDARC/SIMPLI-FLYD coupling



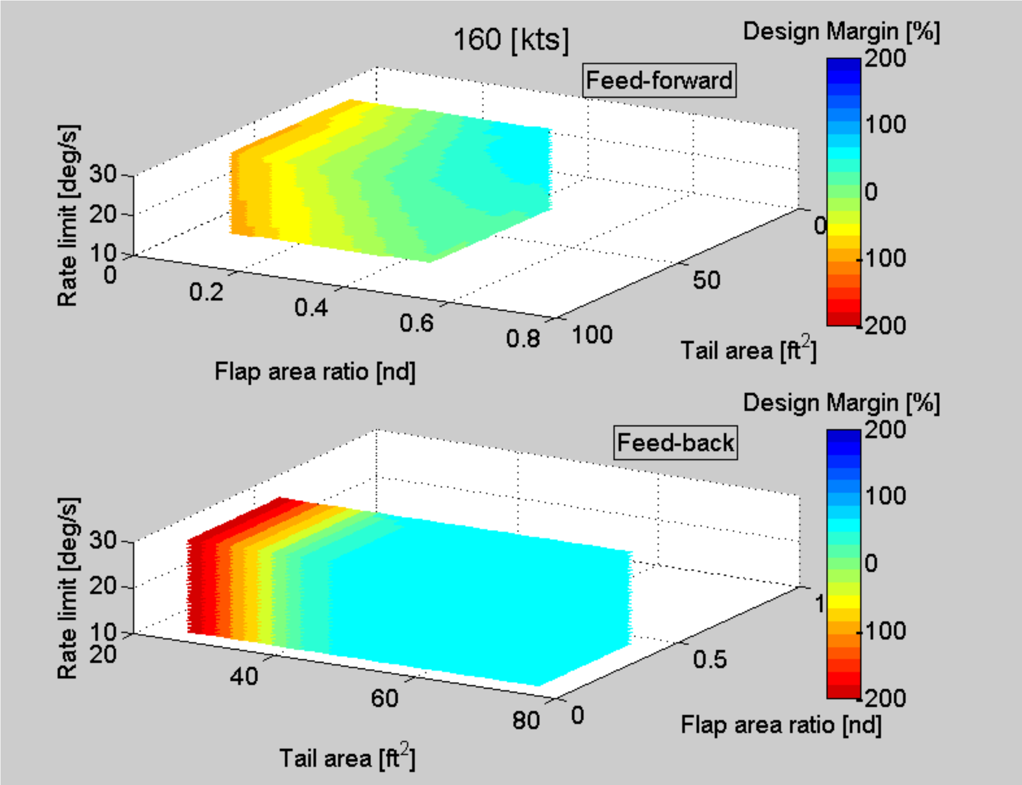
- NDARC sizes aircraft for design mission
- Python scripting used to integrate NDARC and SIMPLI-FLYD in single process
- Design parameter, actuator characteristic and flight condition sweeps
- Outputs:
  - CONDUIT computed HQ Design Margins
  - NDARC empty weight
- Moments of inertia derived from fixed radii of gyration and weight

Handling Qualities Design Margin Data



Handling Qualities Design Margin Data

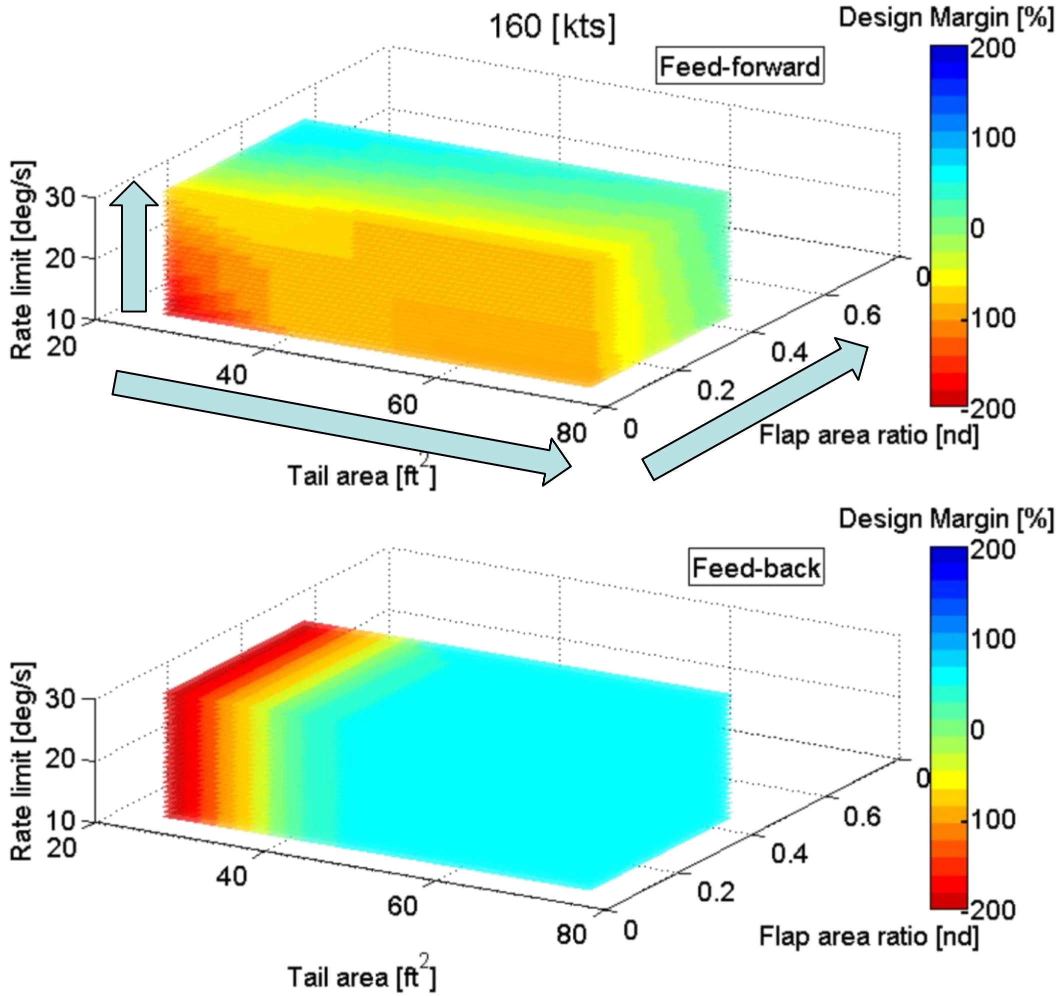
- Compact visualization of 3-D/4-D data
- Primary intent is to illustrate trends and sensitivities



Tiltrotor Pitch Axis HQ - Introduction

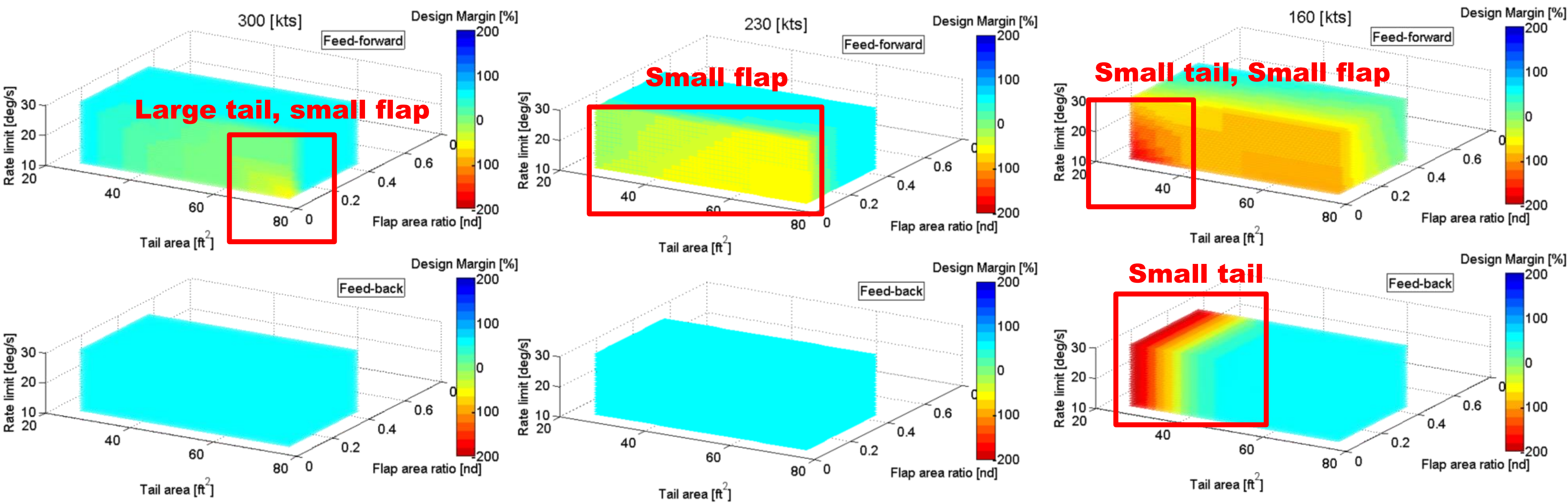
- Feed-forward:
  - Maneuver response
- Feedback:
  - Stabilization, disturbance rejection
- Tail size varied at constant Aspect Ratio
- Elevator flap area ratio:
  - 1.0 = all moving tail
  - 0.0 = no flap
- Elevator flap control actuator rate limit

PITCH AXIS



Tiltrotor Pitch Axis HQ – Effect of Speed

PITCH AXIS

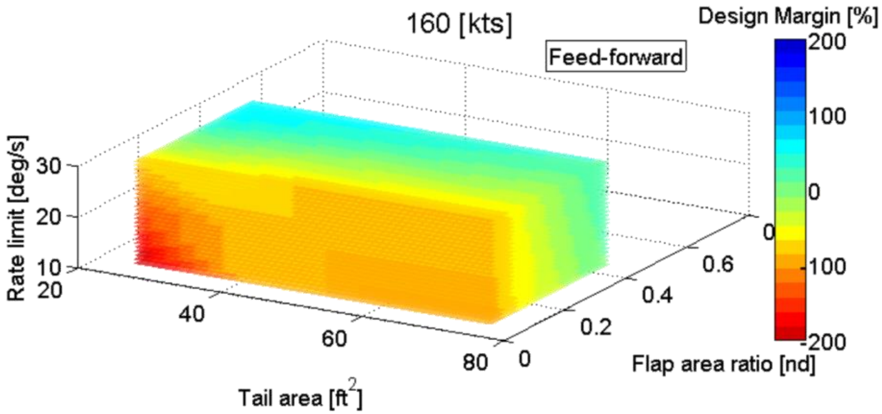


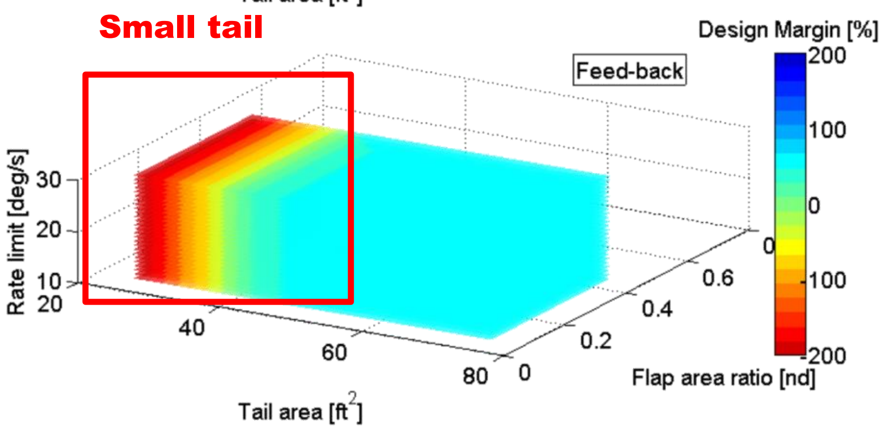
300 kts **230 kts** **160kts**

Reducing Speed

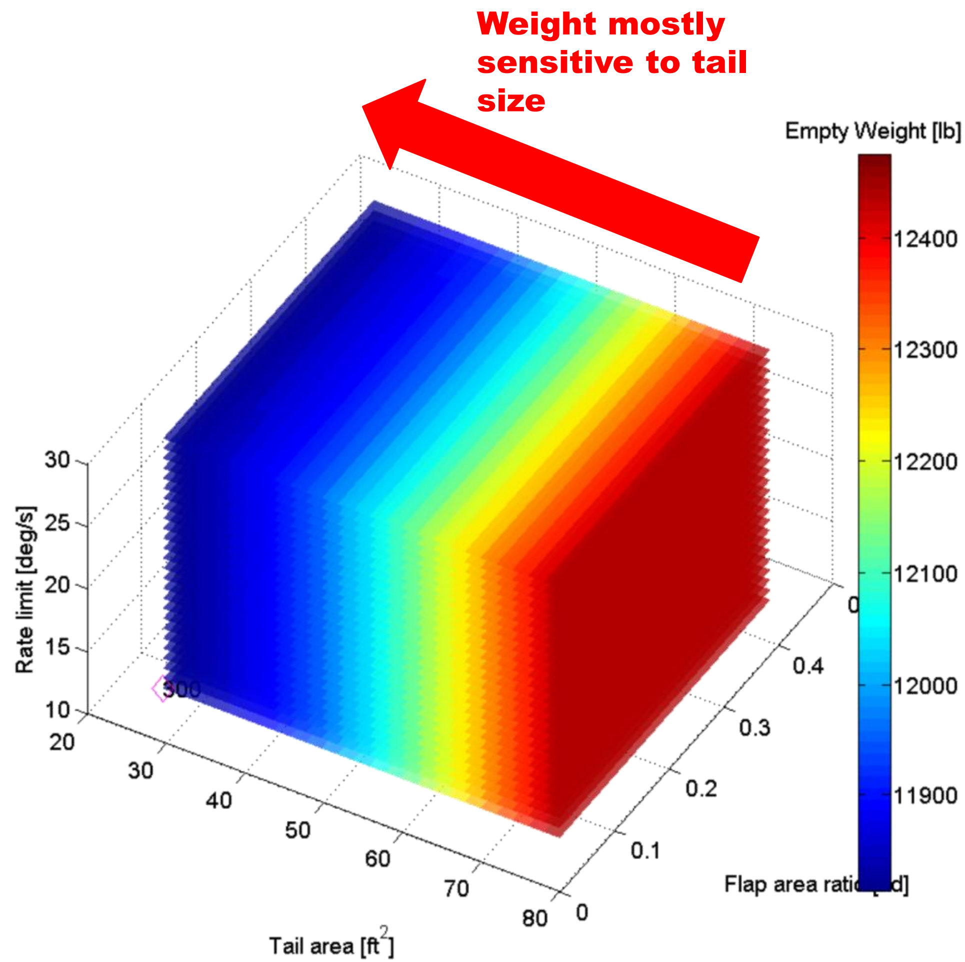
Low airspeed is critical for sizing tail but important to check whole envelope

Tiltrotor Pitch Axis HQ vs. Empty Weight





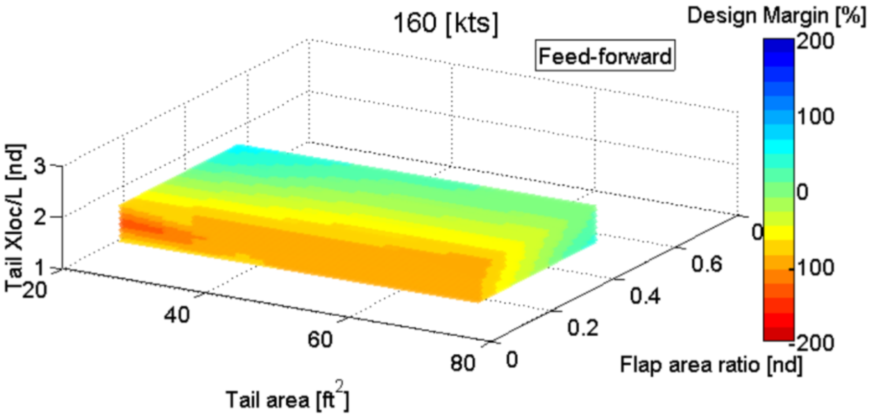
160kts

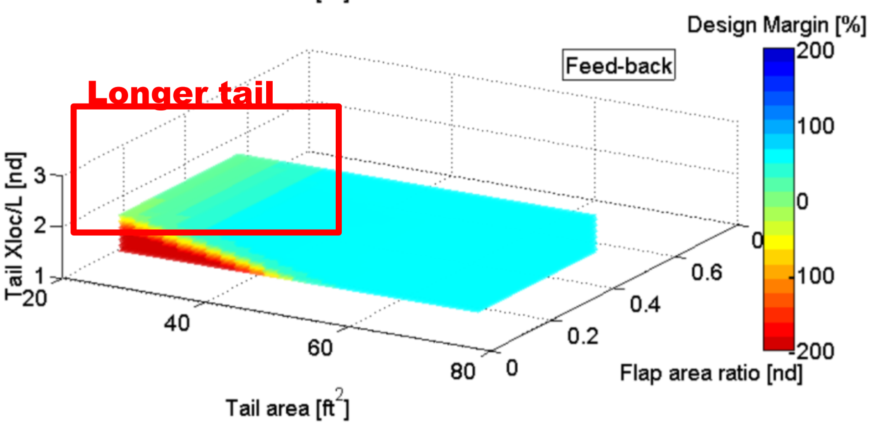


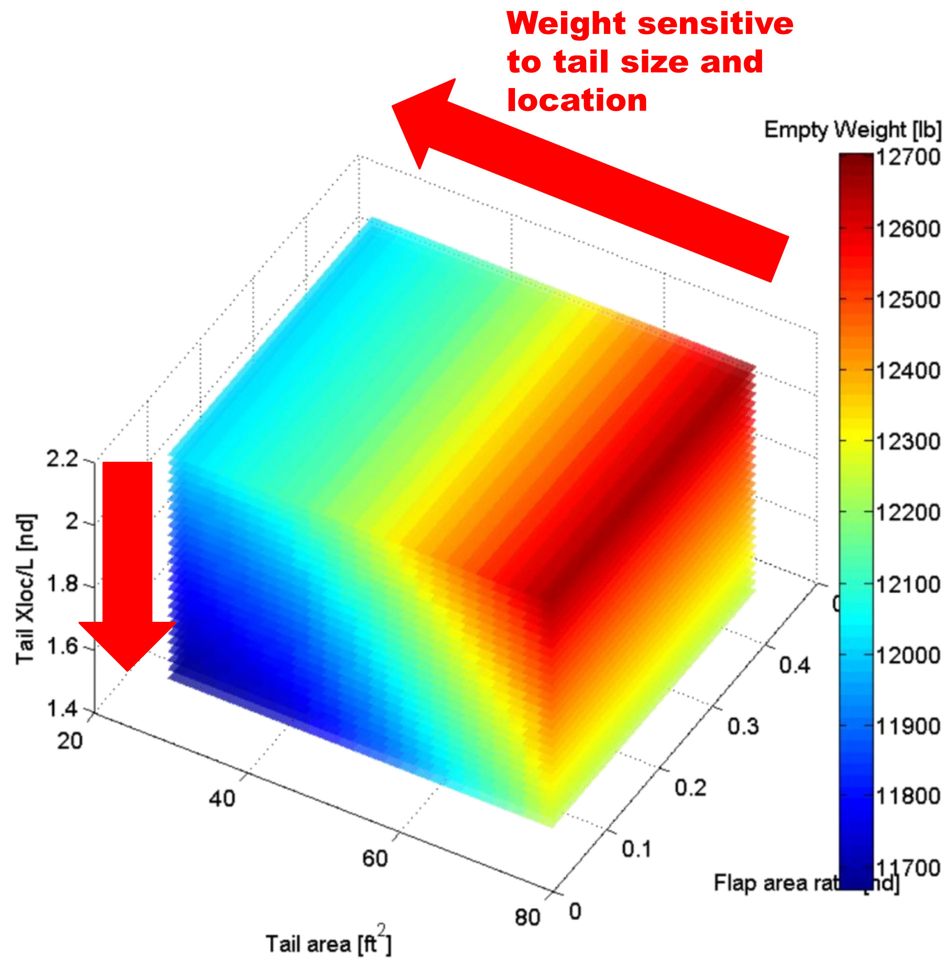
Tradeoff between minimum weight and handling qualities constraints

Tiltrotor Pitch Axis HQ – Tail length Variation

Rate limit = 20 deg/s, Tail length varied





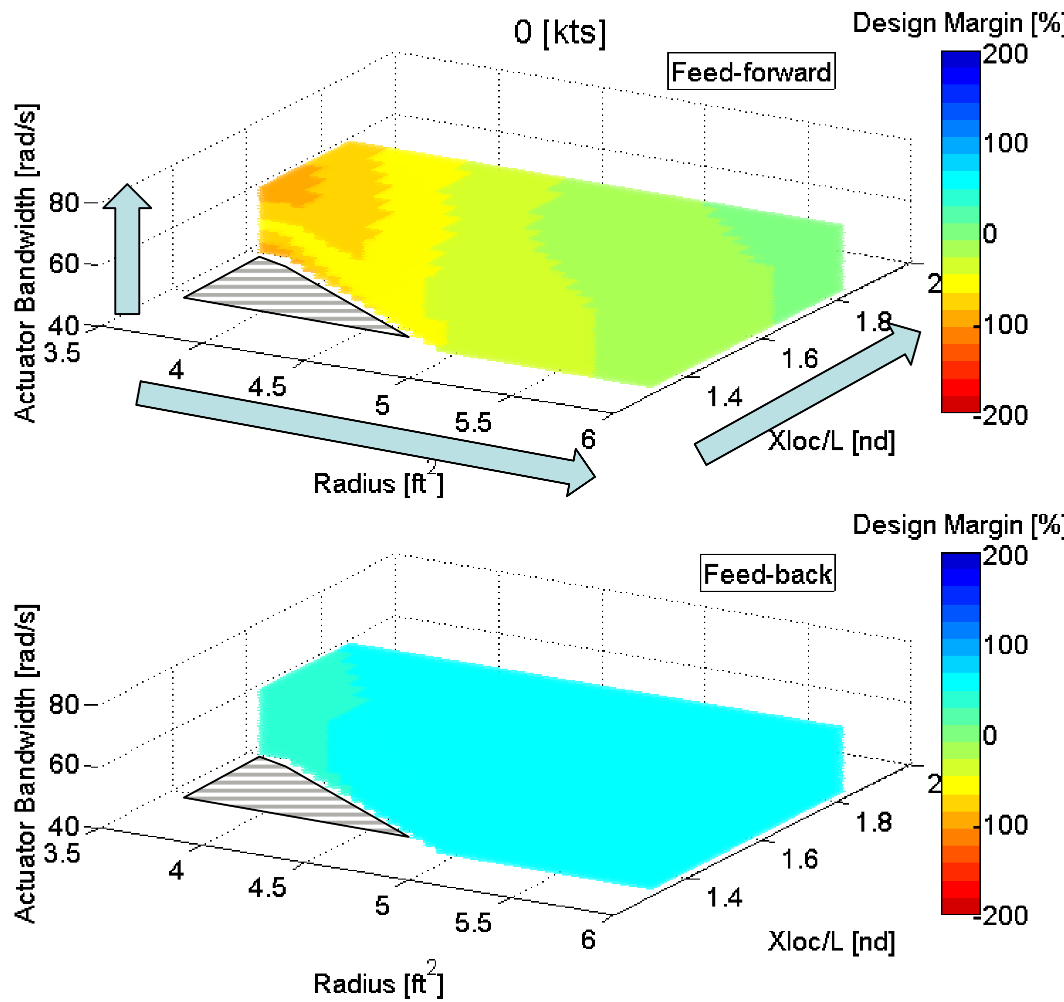


160kts

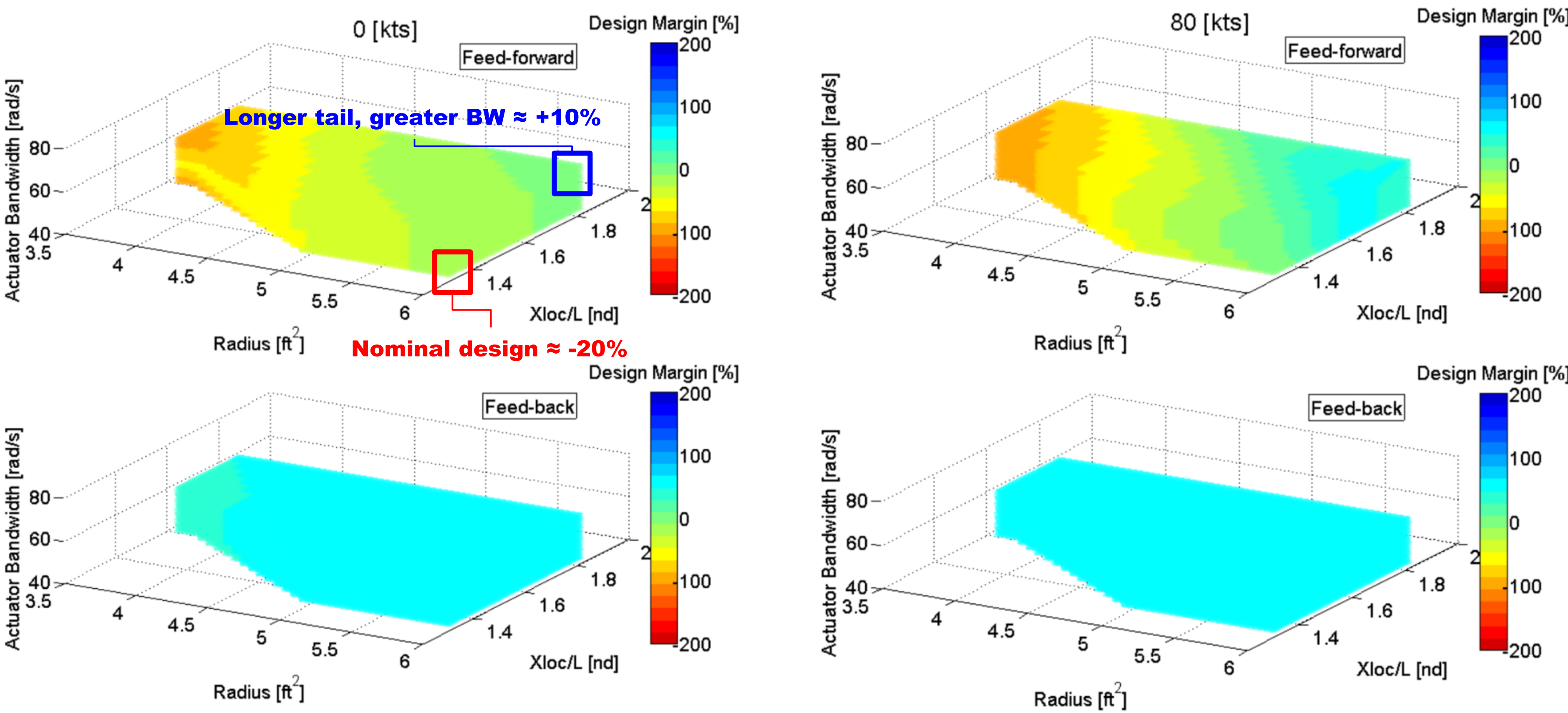
Tradeoff between minimum weight and handling qualities constraints

Single Main Rotor Yaw Axis HQ - Introduction

- Tail rotor size varied at constant solidity and tip speed
- Tail rotor longitudinal location
- Actuator bandwidth limit for tail rotor collective
- Region of no data for non-converged NDARC cases



Single Main Rotor Yaw Axis HQ – Effect of Speed



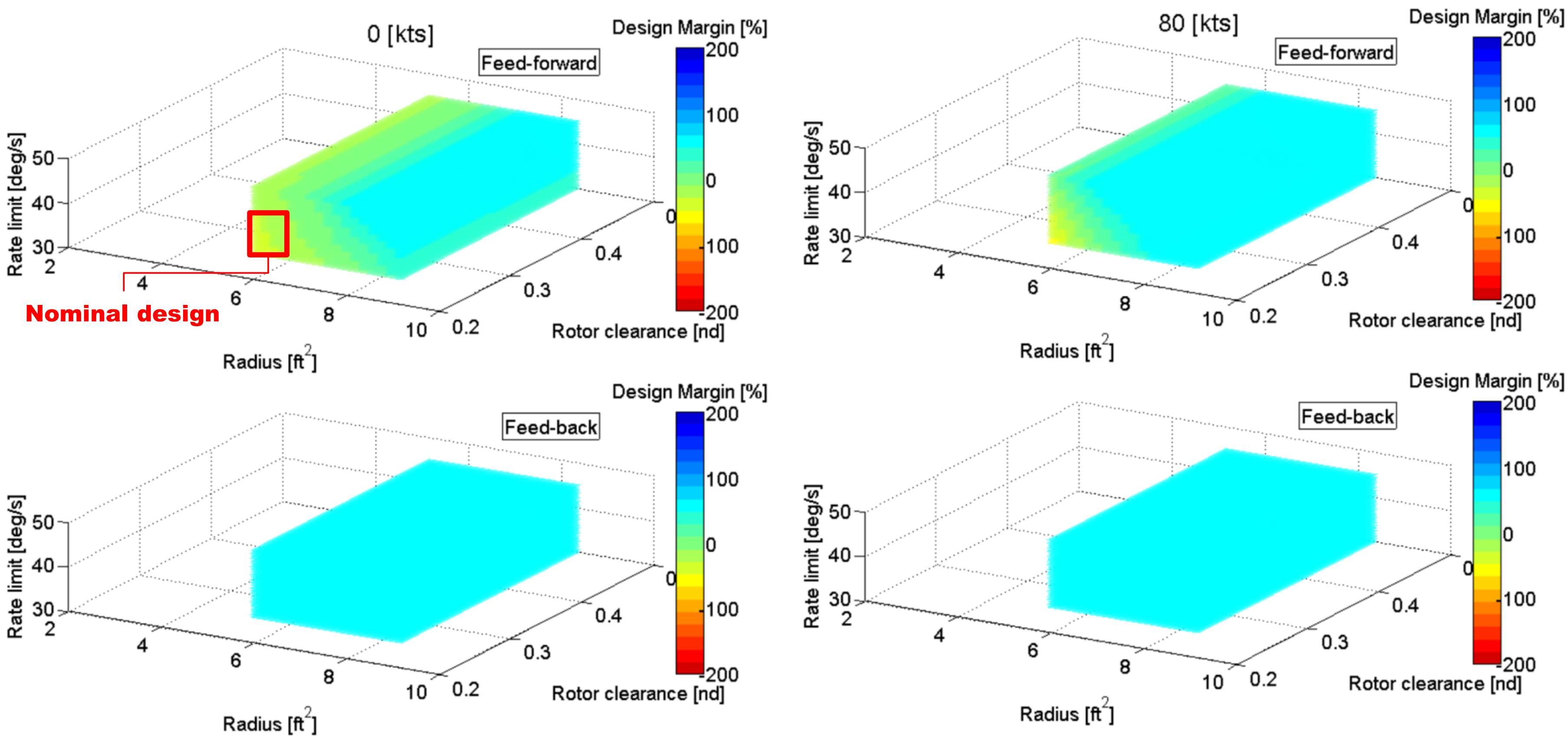
0 kts (hover)

80 kts

Increasing Speed

Speed change includes change of control mode and HQ spec requirements

Single Main Rotor Yaw Axis HQ – Larger Tail Rotors

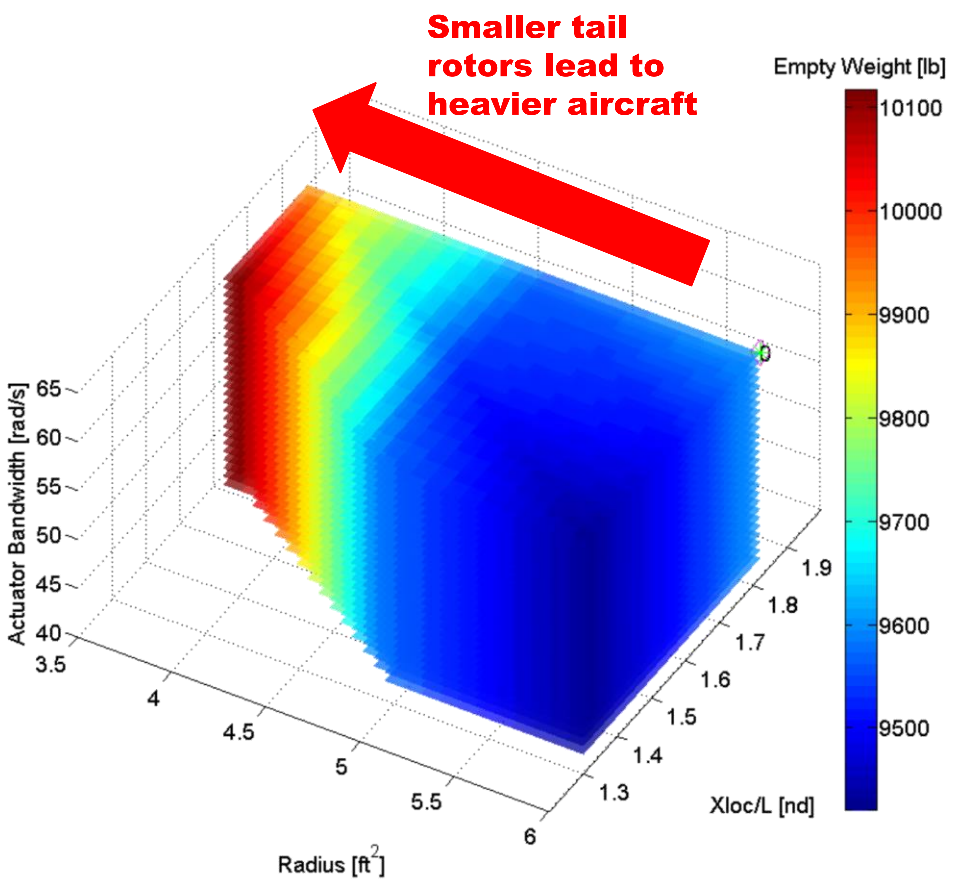


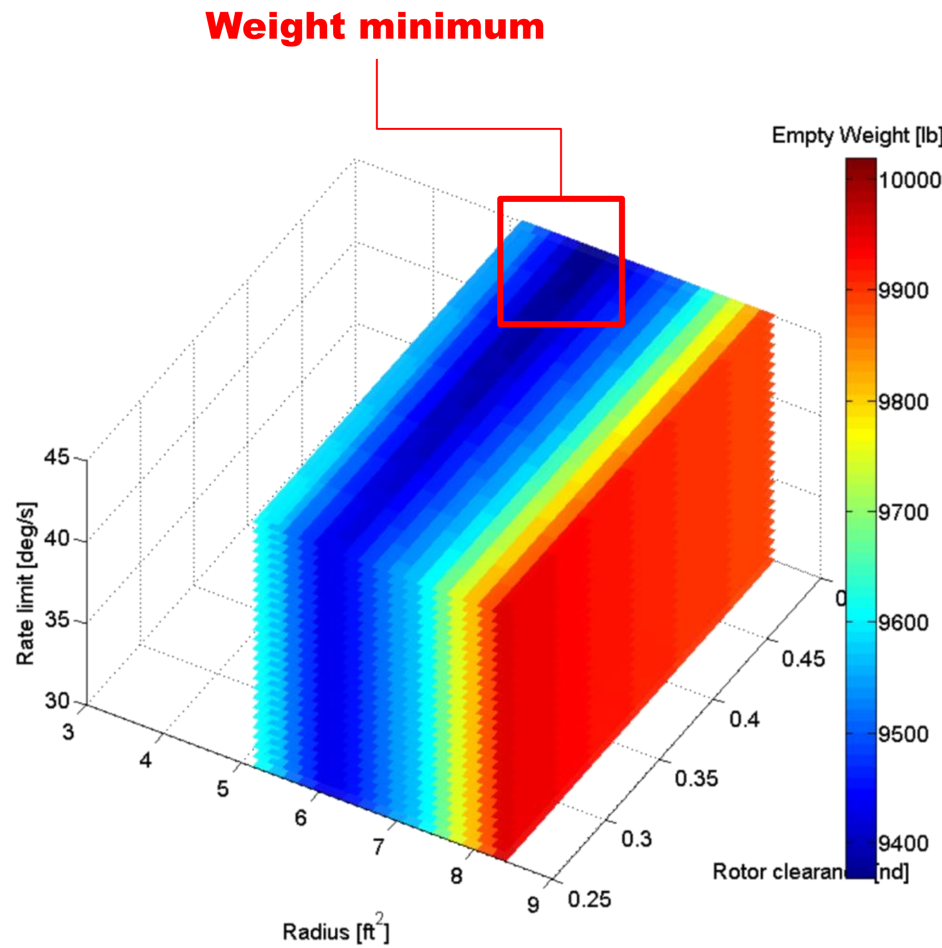
0 kts (hover)

80 kts

Increasing Speed

Single Main Rotor – Empty Weight





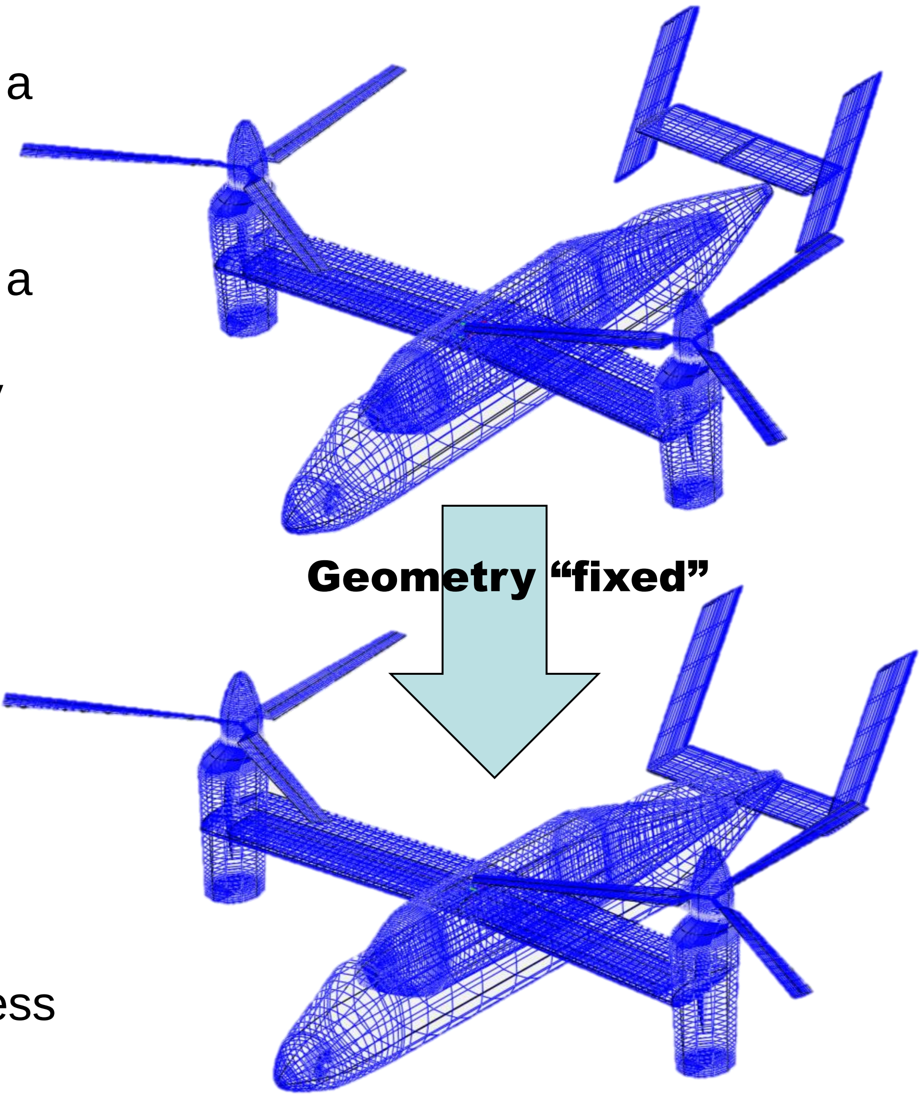
Trading weight via trim/performance aspects

Lessons Learned From Application Of The Tools

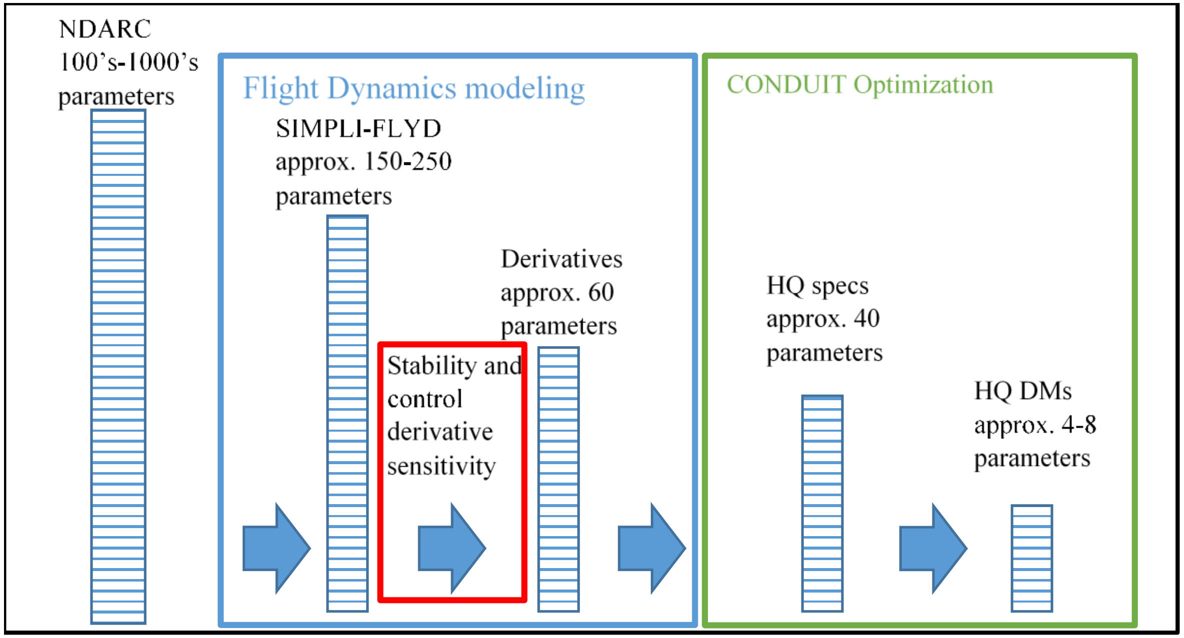
- Handling qualities vary with flight condition:
  - Due to different characteristics and different HQ requirements
  - CONDUIT Design Margin helps to provide a consistent metric
- Actuator characteristics important factor
  - “Cost” (weight) needs to be accounted for in design
- Inertia modeling probably not sensitive enough to design changes relevant to HQs
- Ensuring geometry “consistency” also important
- Current SIMPLI-FLYD process approx. 15-20 min per flight condition

OpenVSP and ALPINE

- OpenVSP is a 3D geometry tool with a focus on conceptual design
- ALPINE tool (Automated Layout with a Python Integrated NDARC Environment) developed by US Army ADD to generate OpenVSP models from NDARC output
- OpenVSP sub functions:
  - mass properties tool offers a higher resolution prediction of moments of inertia
  - Integration plans underway
- OpenVSP offers possibilities to address geometry management



SIMPLI-FLYD in Conceptual Design Process



- Current SIMPLI-FLYD process approx. 15-20 min per flight condition
- CONDUIT optimization main computational cost
- NDARC/SIMPLI-FLYD process is sequence of parameter reductions
- Many sub-stage parameter sets faster to compute
- Stability and control derivative sensitivity study example (in paper)

Summary

- Coupled NDARC/SIMPLI-FLYD analysis to examine:
  - Different vehicle types
  - Mix of design parameters and flight conditions
  - Different handling qualities problems

- Future Developments:
  - OpenMDAO integration – tradeoffs with other disciplines
  - Inertia modeling – ALPINE integration
  - Actuator modeling – weight/cost, greater fidelity
  - Other configurations – e.g. rotor interference
  - Computational requirements – SIMPLI-FLYD role in conceptual design

Questions?