Rotorcraft Flight Dynamics and Control Research

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Flight Control Technology Highlights

- **Cargo rotorcraft handling-qualities and control**
- **Flight control system design optimization tools**
- **Innovative flight control concepts**
- **Autonomous Control**

• What is the big picture vision/plan in each area?
• What are our key technical accomplishments in past year?
• Where are we headed/ remaining technical challenges?

CH-53G ADS-33 Handling Qualities Assessment

Objectives

- **Assess ADS-33 with medium-lift single main rotor helicopter to corroborate findings from CH-47D flight test.**
- **Identify fundamental differences or tandem rotor biases to ADS-33 medium lift helicopter requirements.**

Approach

- **Conduct CH-53G flight test at the German Armed Forces Test Center (WTD-61) in collaboration with DLR, AFDD, and NASA (US-German MOU on helicopter aeromechanics)**
- **Assessment performed in three phases (Jul 2004 – Aug 2005):**
  - **ADS-33 task selection, course set-up, initial eval.**
  - **Quantitative data collection (steps, pulses, sweeps)**
  - **Formal task eval. with 5 test pilots**

Initial Results

- **Many recommendations on ADS-33 task set-up, e.g., Slalom course is too small for CH-53-sized A/C.**
- **CH-53G mainly Level 2**
- **Initial results to be presented at AHS forum, May 2006**

Future Plans

- **DLR engineer 4-month visit to AFDD to analyze/correlate data to CH-47D results – propose ADS-33 revisions.**

Slope Landing task (9 deg slope)

Slalom task

Landing task

Flight Data for External Load Simulation Development

Objective

- Develop / validate realistic simulation for airworthiness certification of helicopter- slung load configurations, using FLIGHTLAB®.

Motivation

- Certifications require lengthy flight test evaluation
- Some classes of loads are not certified or unknown flight behavior (netted loads, helicopter retrievals).
- AED project, AFDD provided flight test data.
- Development based on AFDD UH60 slung load flight data base.
- Validation based on flight data for new configurations not previously flown.
- Instrumented loads (EGI/GPS) - cargo container and engine canister loads.

Archived configuration
- 6x6x8ft CONEX container
- 15ft sling, 4K lbs

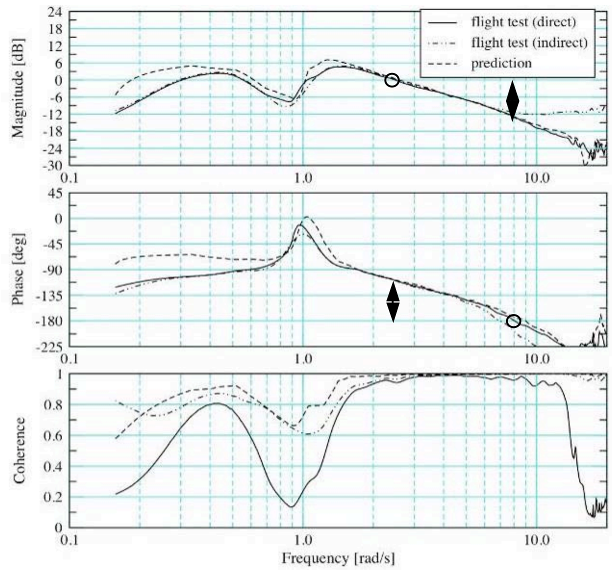
CONEX configuration
- 65ft pendant sling
- heavy load (6Klbs)

Engine can configuration
- 5 x 9ft cylinder
- 65 ft pendant sling

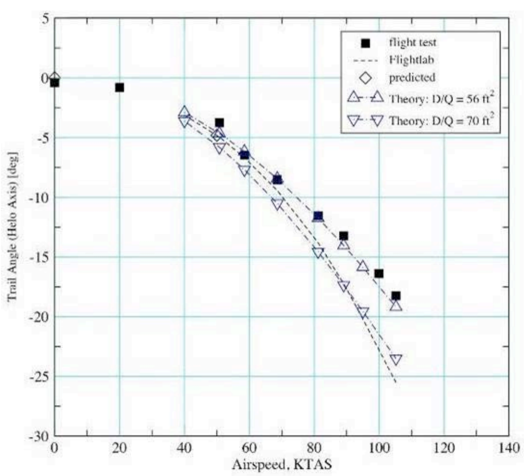
Slung Load Simulation Development

- **Good prediction of**
  - Frequency responses
  - Stability margins
  - Trail angle
- **HQ prediction**
  - ADS33 bandwidth and phase delay not applicable
  - Alternative HQ criteria for slung-load is needed.
- **Prediction of load stability speed envelopes.**
  - Requires unsteady aerodynamics for bluff body loads.
  - No theoretical models.

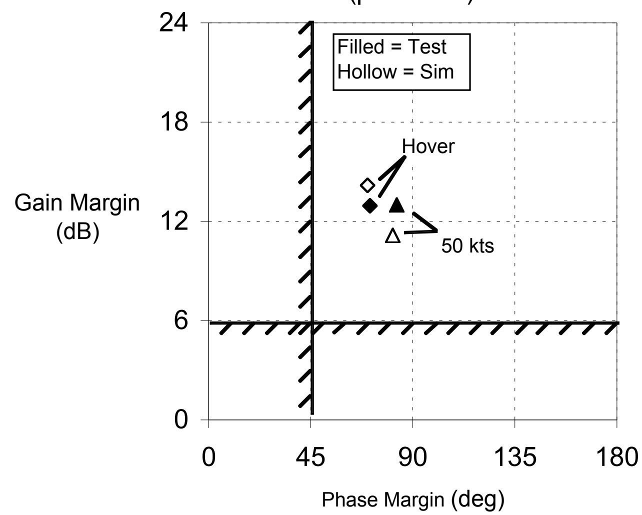
Broken Loop Response to Small Inputs
(6K CONEX, pitch axis, hover)



Load trail angle prediction
(6K CONEX)



Aircraft stability margin prediction
(pitch axis)

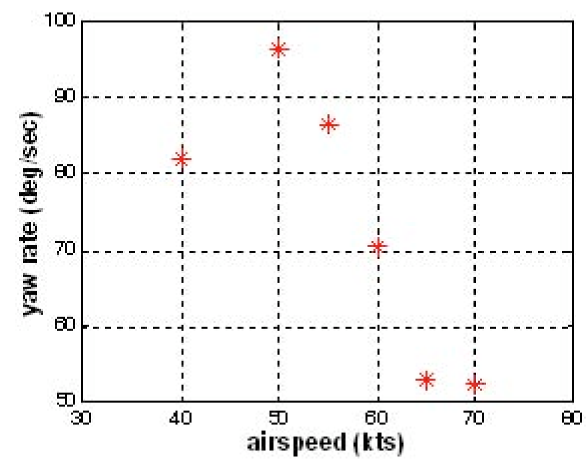


Stabilization Flight Tests

MAFAT

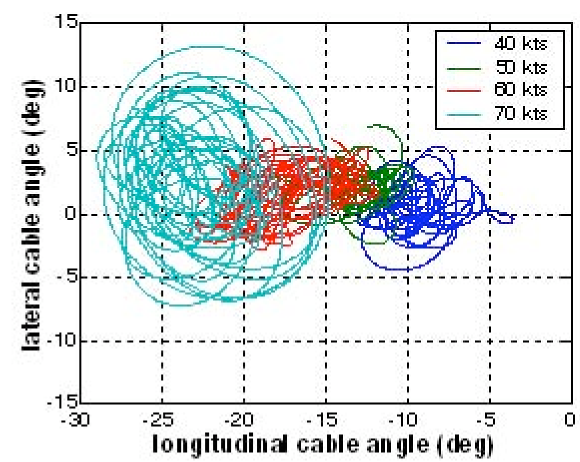
Objective

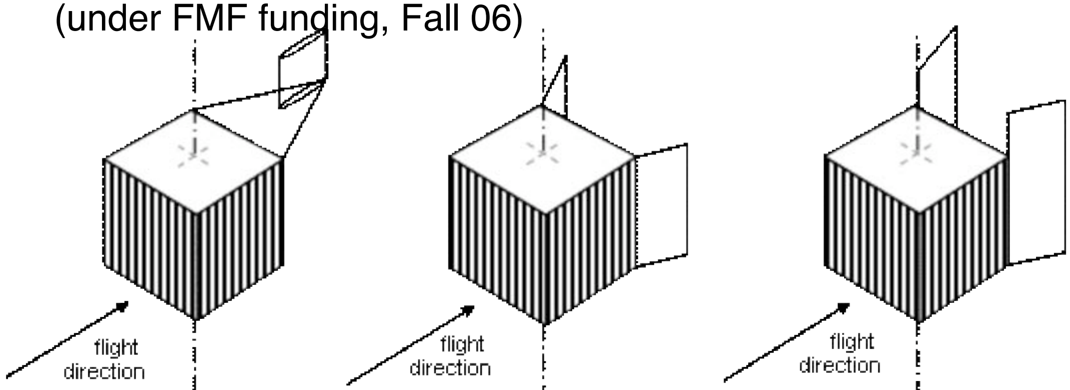
- Demonstrate benefits of passive stabilization of two external loads through:
  - Improvements in stability by damping coupled yaw-pendulum motion
  - Reduction in load drag by maintaining minimum drag orientation
  - Increase in load speed envelope compared to unstabilized configurations



Approach

- Passive load stabilization wind tunnel study (Technion)
- Detailed stabilizer design (Technion)
- Fabricate passive stabilizer for CONEX container, flight test evaluation of stabilized CONEX (under FMF funding, Fall 06)





Vertical fin Doors High doors

Rotorcraft In-Flight Simulator

Research Applications

Flight Control & Displays
- Full authority Fail-Safe
- Programmable Displays
- Programmable Inceptors
- Desktop-to-Flight rapid-prototyping environment of Matlab/Simulink/CONDUIT

Autonomous/Remote Control Development Platform
- Precision Navigation
- Imaging sensor mounts
- telemetry uplink/downlink
- Safety Pilot monitored

IVHM Technology
- Extensive FCS Health monitoring
- Model-Based Diagnostics of Complex Subsystems

Features

Comprehensive Instrumentation
- Inertial and Air Data
- Precision DGPS
- Rotor State
- Load Measurement

Extensive Computing Capacity
- R3081 RISC 32bit
- 6 C30 DSPs
- 4 IBM PCs

Flexible Data Communication Architecture
- 1553B
- Ethernet
- RS 232, 422

Rotorcraft Aircrew Systems Concepts *Airborne Laboratory*

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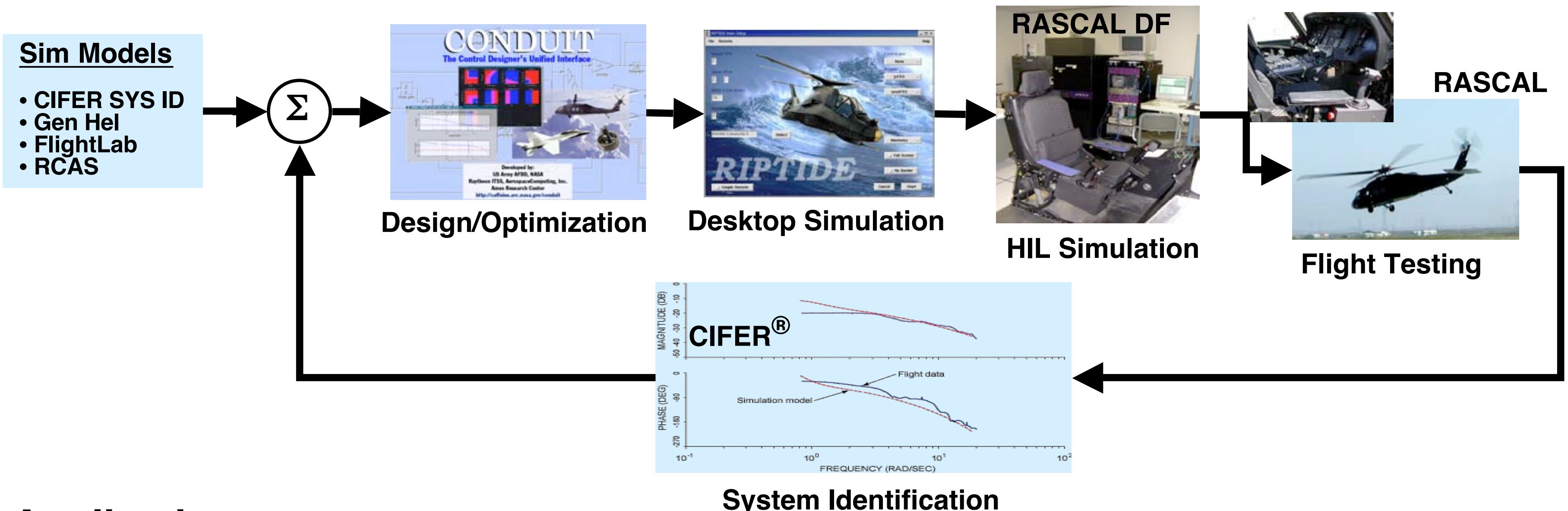
Rapid Desktop-to-Flight Development Pathway



Applications:

- Improved handling qualities of new and current aircraft
- UAV control laws with any level of autonomy or cooperation
- Advanced system control modes (INav&FC) and displays (HMDs)
- Hardware-in-the-loop (HIL) simulation and on-board-monitoring
- Basic launch platform for advanced concepts including advanced rotors

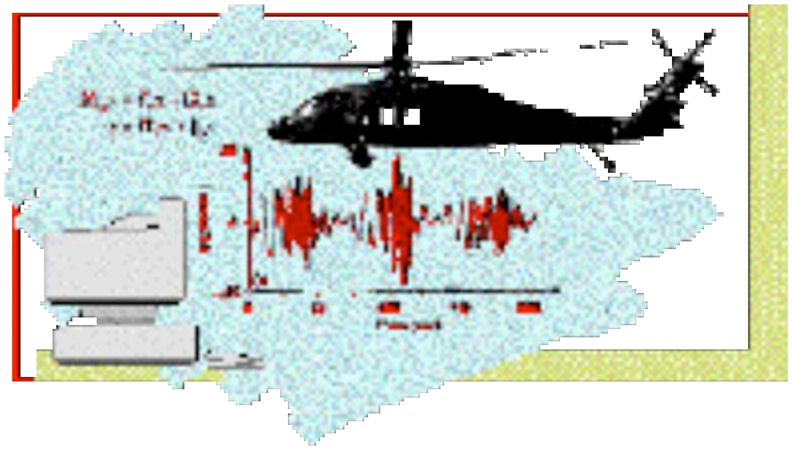
=> Successfully applied to CH-47F DAFCS, AH-64D MCLAWS, CH-53X, Fire Scout, improving accuracy and speed of design

CIFER®

Comprehensive Identification from FrEquency Responses

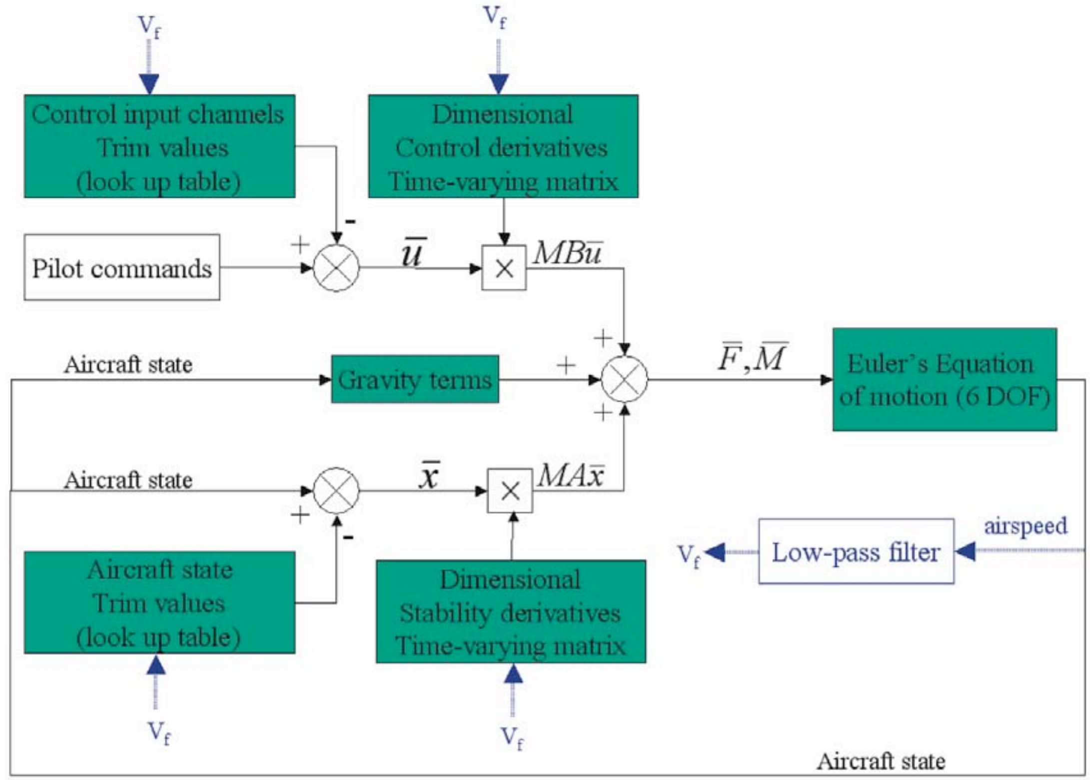
Key features of the CIFER® approach are:

- **Integrated databasing and screen-driven commands**
- **Unique ID and analysis algorithms highly-exercised on many flight projects (r/c and fixed-wing)**
- **MIMO frequency-response solution**
- **Highly-flexible and interactive definition of ID model structures.**
- **Very reliable, systematic, and integrated model structure procedure**
- **Integrated model verification in the time-domain**



Full Flight Envelope Simulation from Identified Models (B206)

Block Diagram for Full Envelope Simulation Model from ID Results (IAI Bell 206)



Full Envelope Simulation Model from ID Results
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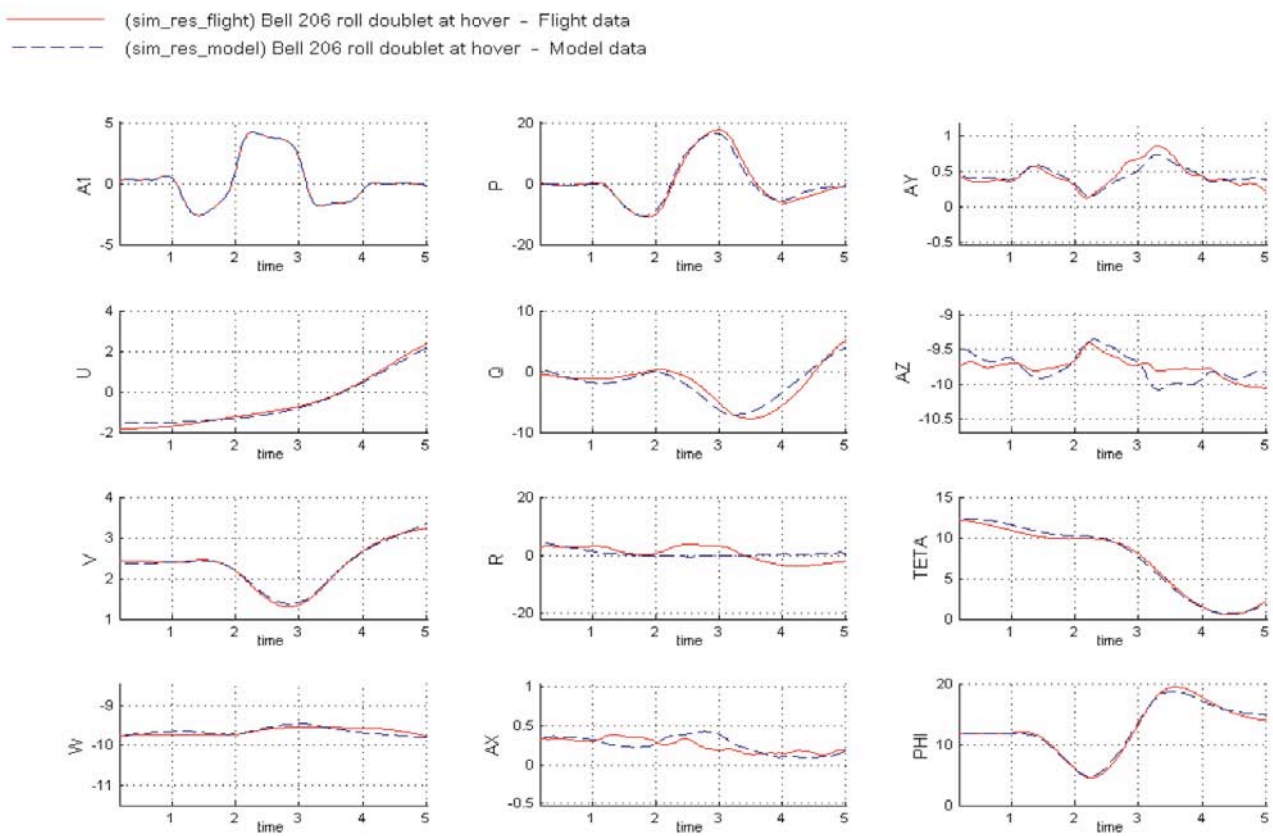


• Efficient and very accurate approach to developing piloted/engineering sim

Fire Scout System Identification

- **New 4-bladed configuration (RQ-8B)**
- **System ID at hover using CIFER®**
- **Identification of differences between three / four bladed configurations**
- **States:**

$$x = \begin{bmatrix} u & v & w & p & q & r & \phi & \theta & \Omega_R & \Omega & \dot{\Omega} & \eta_T \end{bmatrix}^T$$

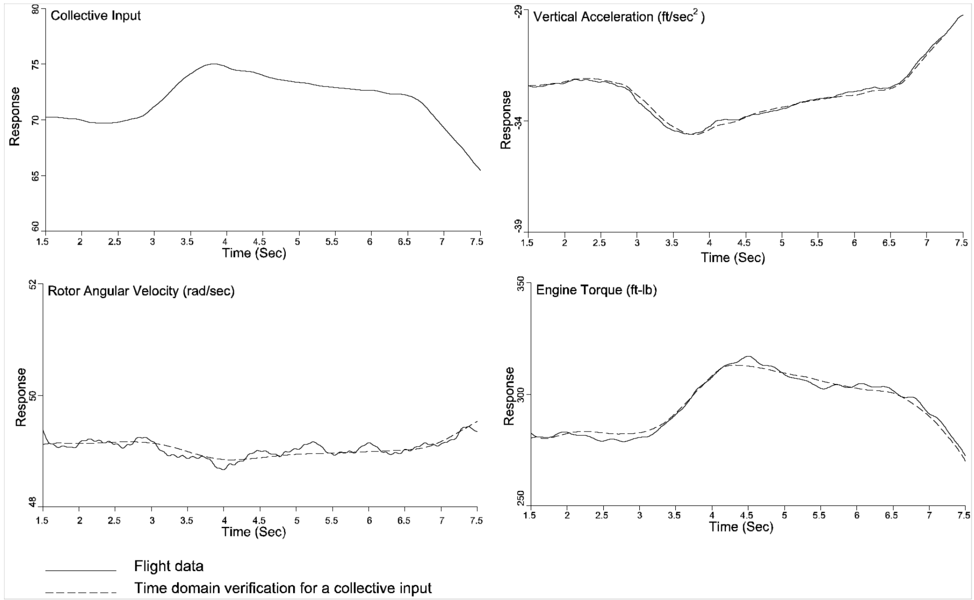
is rotor speed w.r.t. fuselage

Ω_R

$\Omega = \Omega_R - r$ (engine torque)

$\dot{\eta}_T = T$

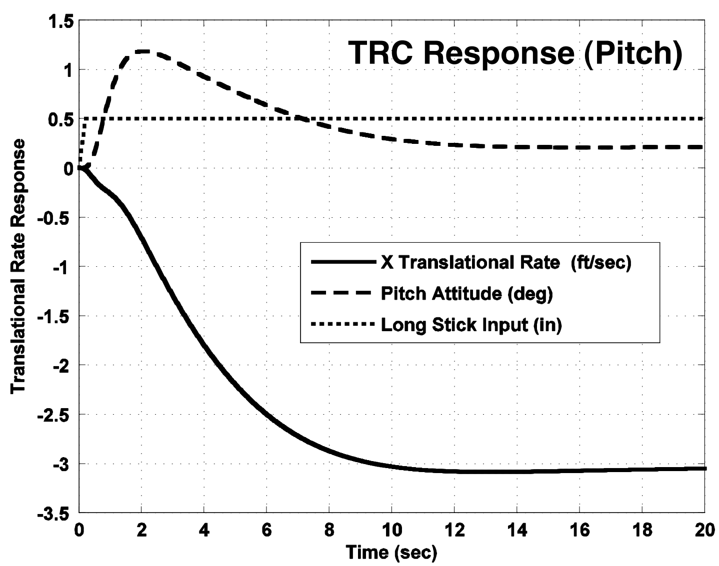
- **Accurate ID of torque and rotor speed**
- **Model matches flight data in time domain and frequency domain**
  - **Example of predictive accuracy for a collective input**

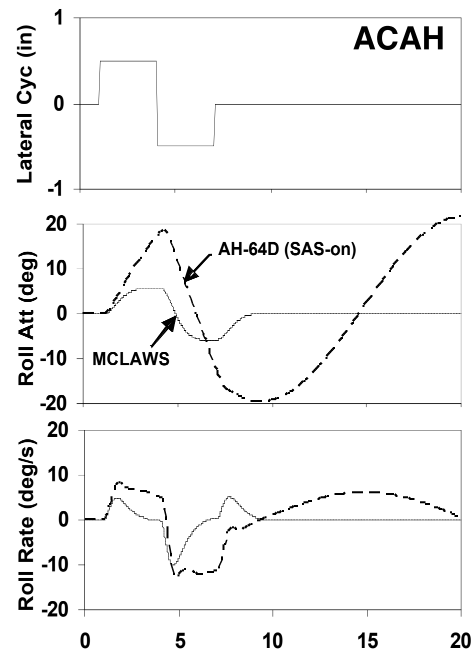


Design/Optimization

AH-64D Modernized Control Laws

- Improve AH-64D HQs at hover/low speed
- Provide ACAH response type with TRC, Heading Hold, and Position Hold as selectable modes
- Use existing partial authority system without excessive SAS saturation
- Employ advanced design tools to speed development
- Leverage work on UH-60L and CH-47F





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IBC Wind Tunnel Test Program

Objectives

- **Validate/calibrate IBC math model using wind tunnel data**
- **Verify AFCS/IBC interaction models and identification techniques prior to flight**
- **Demonstrate IBC has a minimal effect on handling-qualities**
  - Significantly reduce safety concerns and increase the likelihood of flight test approvals
- **Quantify the effect of maneuvers on vibration and noise response (with IBC on/off)**
- **Projected Wind Tunnel test date: Q1, 2007**

HeliPlane Program (DARPA)

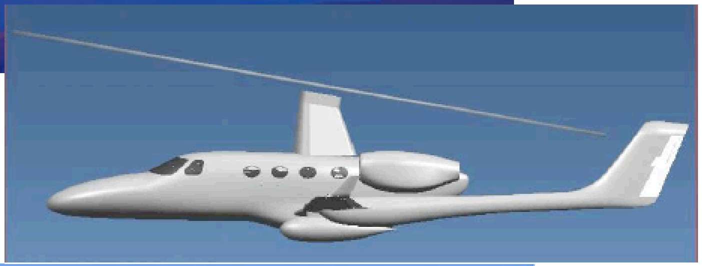
- Prime contractor Groen Brothers with help from Georgia Tech, etc.
- 15 month first-phase under way ending in 2nd QTR FY 2007

Goals

- –High speed flight (350 kts)
- –Hover and low speed operation using tip jets
- –1000 lb payload
- –1000 nm unrefueled range

Our Involvement

- –Validate Flightlab model of existing autogyro against published identification results
- –Implement HQ specs for autogyros
- –Develop interface between Flightlab and CONDUIT®/RIPTIDE



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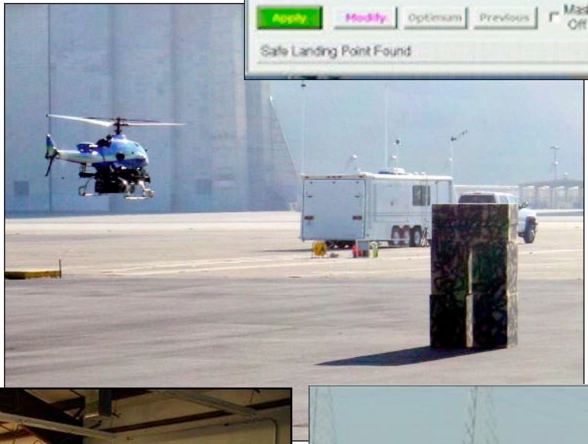
Flight Validation and Performance Evaluation

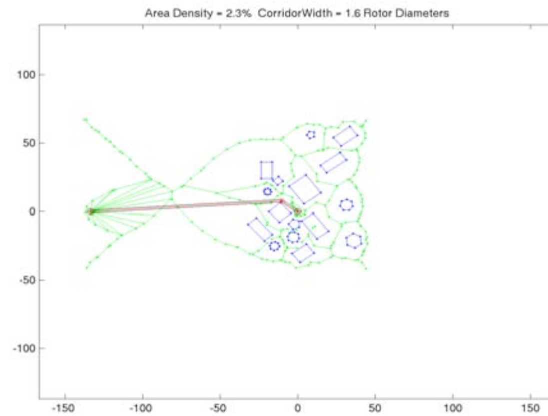
PALACE flight trials:

- **Hardware-in-the-loop simulation prior to each flight**
- **Component flight testing to validate performance of machine vision algorithms and coupling to control laws:**
  - **MPE performance for hover, descent and landing**
  - **Stereo ranging performance for different surfaces**
  - **SLAD performance with different obstacle fields**
- **Integrated landing system flight trials to verify PALACE system functionality, transitions and mode switching**
- **On-board data recording for post-flight validation and regression testing of system components**
- **Approx 30 flights for PALACE development, validation, evaluation test points**
- **Preliminary flight test report**
  - **December 2005**
- **Public flight demonstration**
  - **January 31, 2006**



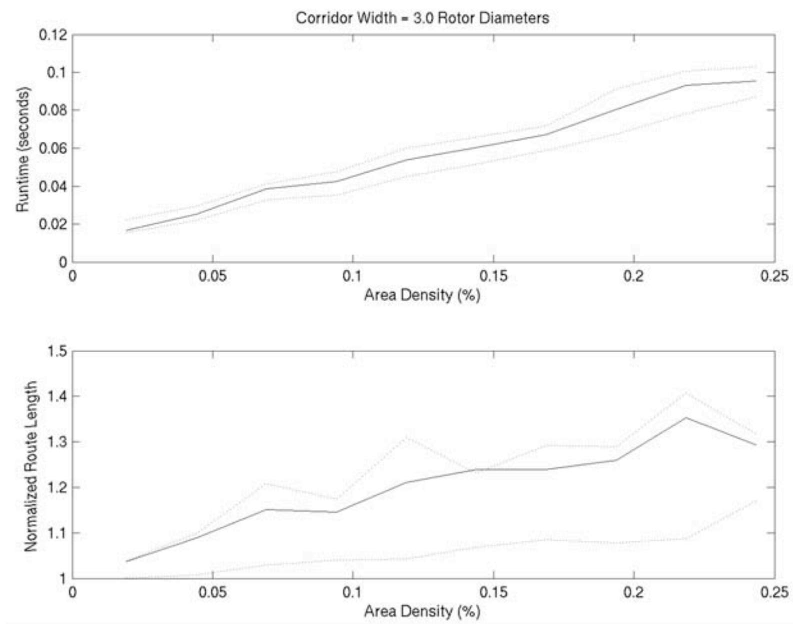
2D Obstacle Field Route Planner Evaluation

- **175,000 Monte-Carlo test cases**
- **Randomly-generated obstacle fields**
- **Parameters**
  - **Obstacle field density (1% - 26%)**
  - **Average passage width (8.7 Dia. – 14.2 Dia.)**
  - **Safe corridor width (1.3 Dia. - 13.3 Dia.)**
  - **Do route optimization (yes/no)**
- **Measures**
  - **Normalized route length**
  - **Algorithm running time**
  - **Probability of successfully finding a solution**
  - **Cumulative heading change**



Low area density example

High area density example

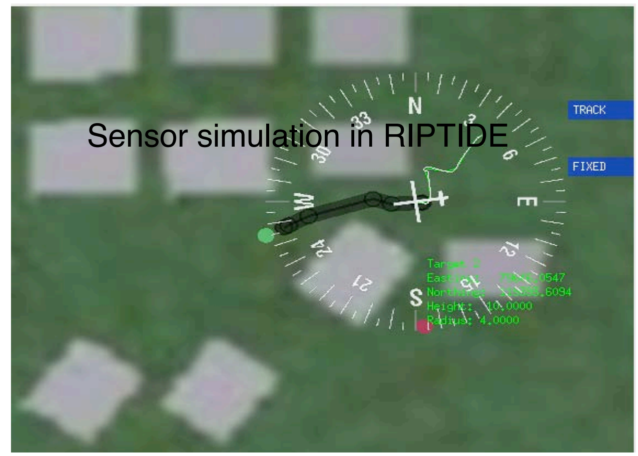


Algorithm runtime and resultant route length increase with area density

3D Reactive Planning

- **Key requirements**
  - **Adjust plans efficiently as new data is collected**
  - **Satisfy various mission-level and nav. constraints**
    - **Exposure to threats**
    - **Vehicle dynamic capabilities**
    - **Proximity to obstacles along with winds**
    - **Fuel cost and time to destination**

- **Possible approaches**
  - **Extended optimization-based methods**
    - **Don't scale well to more complex problems**
  - **Extended heuristic-based methods**
    - **Easier to extend , still suffer the "curse of dimensionality"**



Sensor simulation in RIPTIDE

Map view showing obstacle edges and planned navigation corridor

- **Our approach**
  - **Quasi-3D path using 2D planner in multiple planes**
  - **Scheduled periodic and reactive replanning**
    - **Replan after each sensor scan if possible**
    - **Limited by sensor range/scan-rate, time to calc new path**
  - **Cost function combines metrics via Fuzzy Logic**
  - **Simulation integrates all OFN technologies**

* Work done in conjunction with US/Israel MOA

Autonomous Rotorcraft Project Status

Accomplishments:

- **Mission-level autonomy flight demonstrated**
- **Integrated laser and stereo vision sensing**
- **Obstacle sensing and 2D route planning**
- **ID of hover and forward flight dynamics (JAHS article)**

Flight Demonstrations:

- **Fully autonomous surveillance mission**
  - Mission-level reactive planner - Apex
  - Web-based AJAX planning interface
  - Autonomous takeoff and landing
  - Route planning for optimum target coverage
  - Autonomous sensor selection
  - Complex maneuvering for optimum sensor vantage point
  - Multiple simultaneous users
  - Scalable autonomy - operator override
  - Contingency behavior for loss of RF
- **Vision-based GPS-denied autonomous landing**
  - Autonomous landing site selection using stereo vision
  - Monocular vision self-localization
- **2D route planning in real obstacle field (Ft Hunter Liggett)**

ARP Web-Based Mission Planning Interface

ARP RMAX preparing to land amidst obstacles

Widespread Applications of Flight Control Technologies


Solar Pathfinder


Large modern transports


TU-144LL (HSCT)


S92


F14D - Block Upgrade


SH-2G


RASCAL, P^3I


Honeywell OAV


AAI Shadow


Marine BURRO Demo


FireScout


CH47


ARH


AH-64D


H-53E/X


S-76C

Summary

- **Flight Control Research Program**
  - 20 member group: strong mix of civil servants, academia, contractors
  - Approx. $2M S&T budget for FY06/07
  - Matching level of S&T and external (contract) funding
- **Balance of manned and unmanned research programs in a focused, interdisciplinary team**
  - Cargo Rotorcraft Handling-Qualities and Control
  - Flight Control Design Optimization Tools
  - Innovative Control Concepts
  - Autonomous Control
- **Widespread use of flight control design tools**
- **Opportunities**
  - Participate in research programs
  - Employment opportunities via UC Santa Cruz
  - Access to state-of-art tools
    - » Student version of CIFER (with book)
    - » Demo licences
    - » Academic licenses (10% of full cost)