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Key Activities

Manned vehicle programs:

- **Flight control upgrade programs:**
  - **CH-47**
  - **AH-64**
  - **UH-60 FBW**
  - **Sikorsky 53X**
- **UH-60 Slung-load flight testing and simulation**

UAV programs:

- **Precision Adaptive Landing Autonomous Control Experiment (PALACE) [full paper by Colin Theodore]**
- **Autonomous Rotorcraft Project (ARP)**
- **Obstacle field navigation**
- **Firescout -- simulation modeling**
- **OAV -- nonlinear dynamic inverse control and reconfiguration**

Flight Control Design Tools:

- **CIFER**
- **CONDUIT**
- **RIPTIDE**

CH-47F DAFCS Development Support

- **CH-47F modernization program**
  - CH-47 built by Boeing, first entered service 1962, upgrades will extend service beyond 2030
  - Engine, airframe, cockpit displays and flight control law upgrades

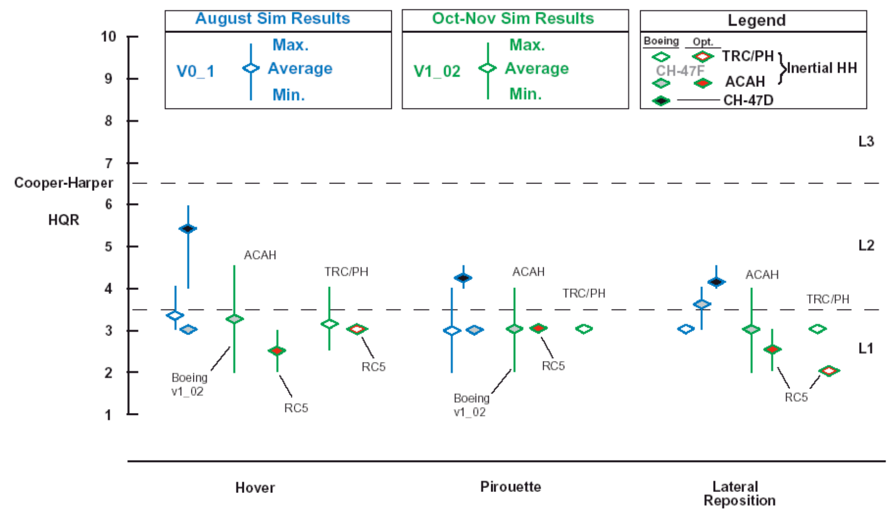
- **AFDD support – Digital Advanced Flight Control (DAFCS) evaluation/optimization**
  - VMS Piloted simulation study
  - Linear analysis/optimization of Attitude Command Attitude Hold (ACAH) and Translational Rate Command (TRC) configurations of DAFCS using CONDUIT®

CH-47F DAFCS Development Support

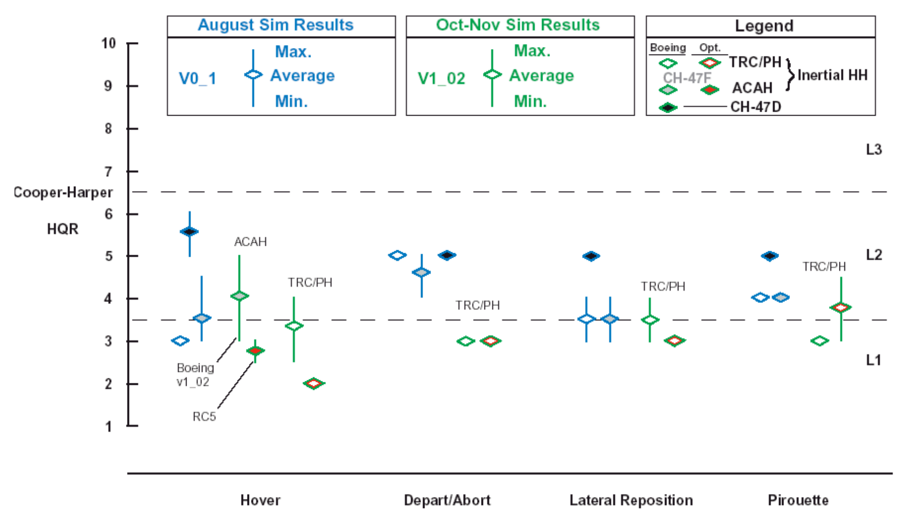
VMS Piloted simulation

- Conducted in two phases
  - Phase I – 2 wks August
  - Phase II – 4 wks Oct-Nov 2004
- Implementation/validation of Boeing non-linear math model in the VMS and applicable Rockwell Collins Common Avionics Architecture System (CAAS) displays
- 11 evaluation pilots
  - 7 Army experimental test pilots
  - 2 Army line pilots
  - 1 Boeing pilot
- Over 500 formal evaluations in day and simulated night (DVE)
- The Phase II DAFCS drop was level 1 for all low-speed and hover tasks in simulated day.

Simulated DAY ~ Cooper-Harper Handling Quality Ratings (HQRs)



Simulated DVE ~ Cooper-Harper Handling Quality Ratings (HQRs)



CH-47F DAFCS Development Support

- Evaluate and optimize Boeing supplied DAFCS control law design against design standards (ADS-33,MIL-F-9490)
- Linear analysis and control law optimization using CONDUIT® and Boeing supplied linear bare airframe model (M-97)
- More than 100 pages of VISVEC control law diagrams converted to SIMULINK, including multiple version conversions/updates (0.01 to 1.02)
- Verified against VMS non-linear implementation
- Analyzed all four axes: Pitch, Roll, Yaw, Collective

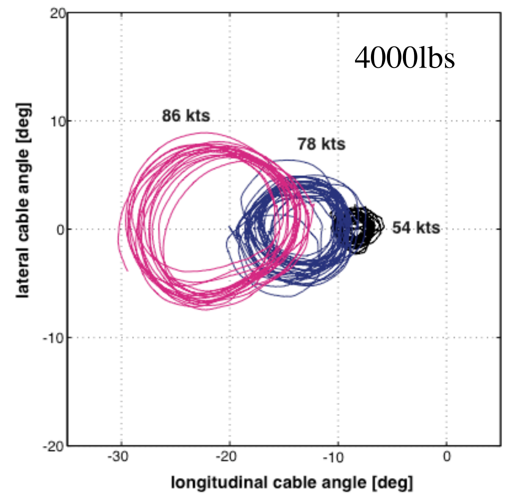
- Results
  - Pilots consistently identified and preferred the CONDUIT® optimized configurations
  - For the ADS-33 Depart/Abort maneuver, both the ACAH and TRC optimized configurations showed reductions in longitudinal SAS actuator saturation times
    - TRC
      - 61% reduction in pitch Integrated Lower Control Actuator (ILCA)
      - 56% reduction in the Differential Air Speed Hold (DASH) actuator
    - ACAH
      - 68% reduction in pitch Integrated Lower Control Actuator (ILCA)
      - 100% reduction in the Differential Air Speed Hold (DASH) actuator

Slung load aerodynamics from flight data

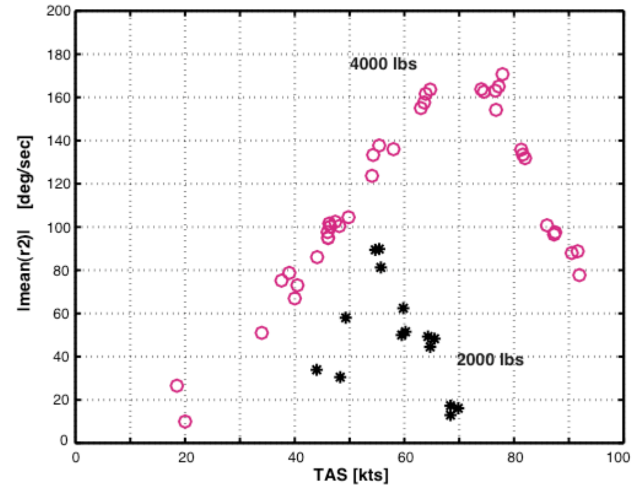
Test configuration

- HC instrumentation … INU, etc.
- Load acceler's, rates, attitude
- Bluff body load, unsteady aero
- Results used to validate simulation model and CFD
- Results limited to body axes X,Y forces and yaw moment
- Next: improved instrumentation to get all aero components.

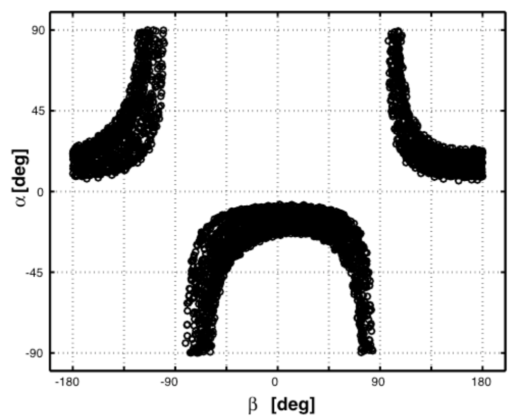
Cable angles limit cycle



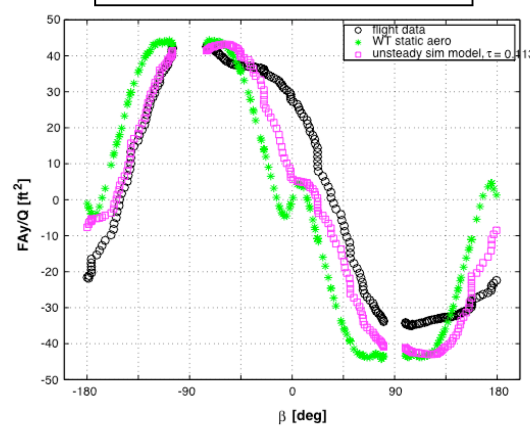
Steady state spin rate



Aerodynamic angles

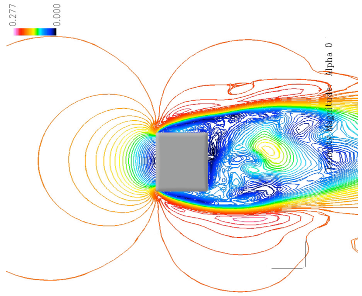


Aerodynamic y-force

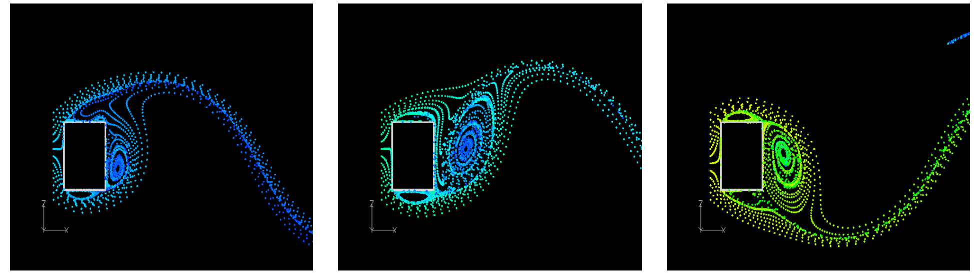


Unsteady Aerodynamic model for Cargo Containers and Bluff Bodies

Bluff Body Aerodynamics:
- unsteady flow
- periodic vortex shedding
- massive wake
- no theory



Periodic vortex shedding

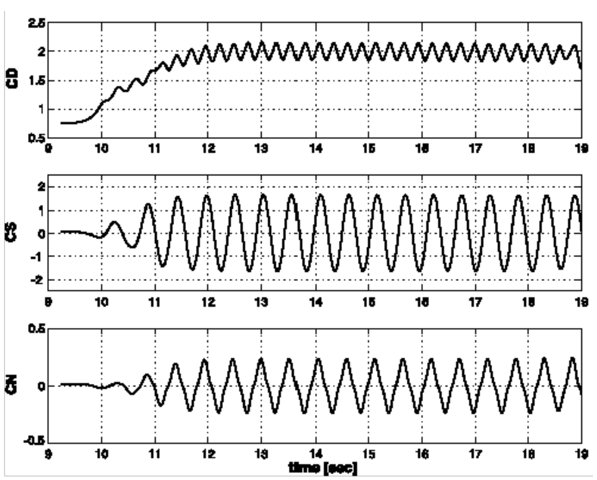


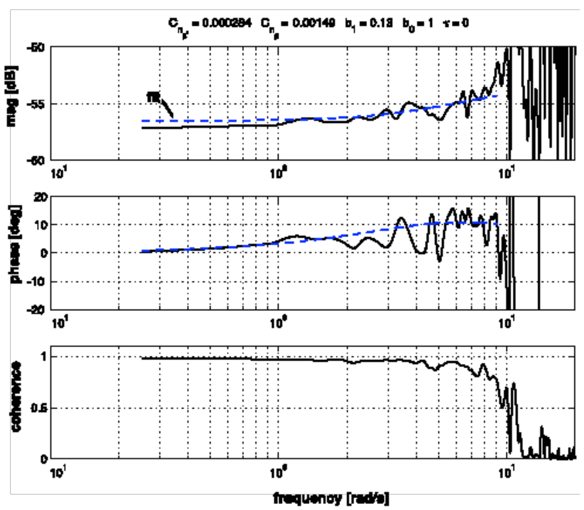
Approach:
- Treat aerodynamics as dynamic system
- frequency sweep forced oscillation (CFD)
- frequency domain fit to frequency response
- Results so far based on 2D CFD
- Next: 3D CFD computations in progress

Results from 2D CFD:
1st order system (delayed static aerodynamics)

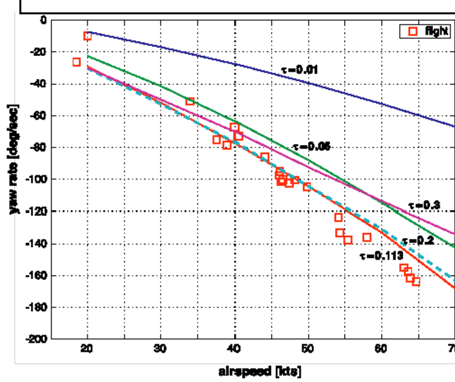
$$CN = CN_{static} \frac{1}{\tau s + 1}$$

$$\tau \overset{o}{CN} + CN = CN_{static}(\alpha(t), \beta(t))$$





Steady state yaw rate - comparison w flight



Slung load work: next 6 months

- Flight tests with enhanced load instrumentation. Add load cells to measure cable force vector. This allows computation of all aerodynamic components.

- Flight tests with cylindrical load. Provide flight data for validation of simulation being developed for simulation-based certification of helicopter-slung load configurations at AED.

- CFD 3D unsteady flow computations of spinning CONEX and forced oscillations of CONEX. Validation against flight and model analysis.

ARP RMAX Linear Model Identification

Research Goals

- **Identify ARP RMAX hover- and forward-flight linear models from flight-test data using the frequency-domain system identification method.**

ARP RMAX Linear Model

- **Flight-identified linear model**

$$\dot{x} = [A]\,x + [B]\,u$$
$$y = [C]\,x + [D]\,u$$

- **State vector**

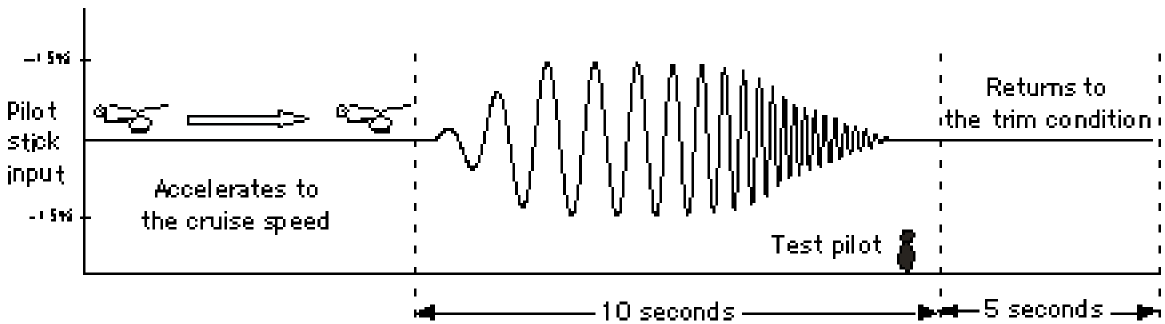
$$x = \begin{bmatrix} u & v & w & p & q & r & \phi & \theta & \psi & \beta_{1c} & \beta_{1s} & \kappa_{1c} & \kappa_{1s} & r_{fb} \end{bmatrix}$$

- **Input vector (Transmitter stick commands)**

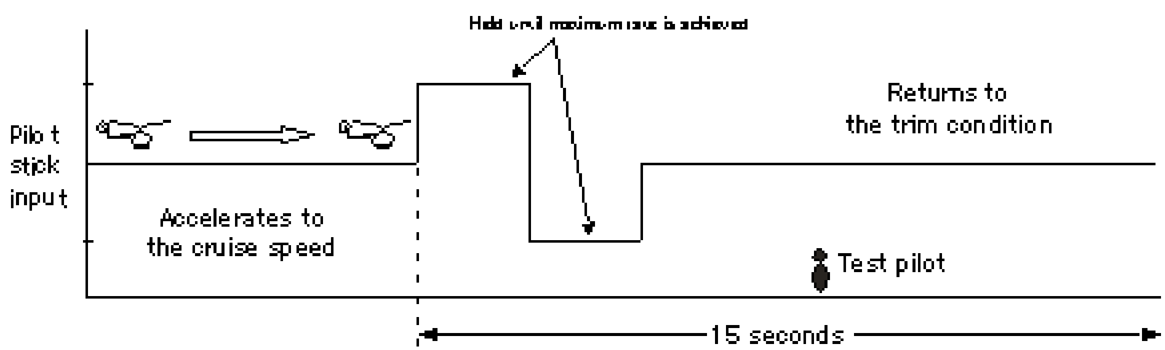
$$u = \begin{bmatrix} \delta_{lat} & \delta_{lon} & \delta_{col} & \delta_{ped} \end{bmatrix}$$

Prescribed Flight Test Maneuvers

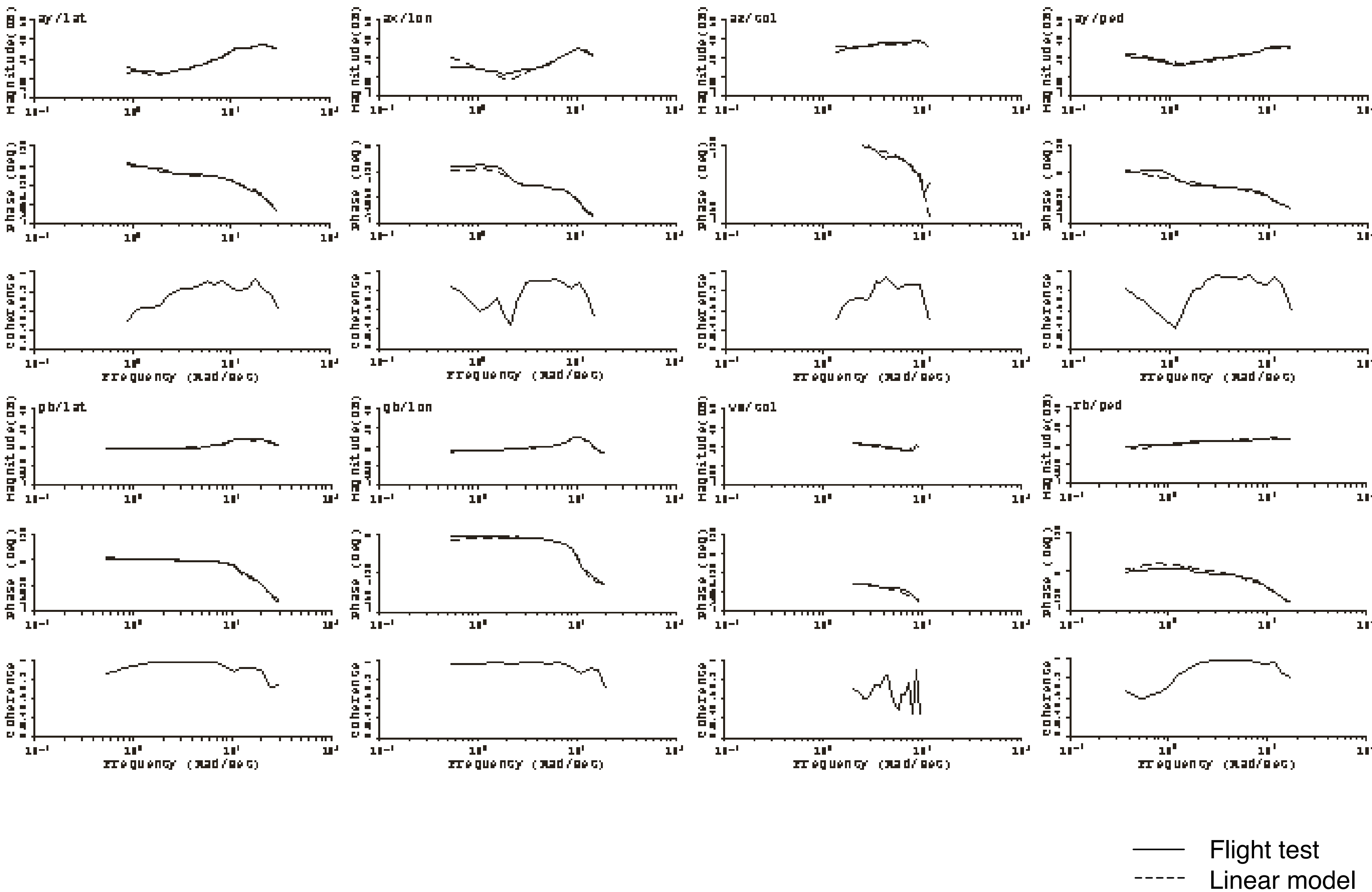
- **Frequency sweep maneuver**
  - **Input frequency: 0.05~2 Hz**
  - **Captures vehicle dynamics**



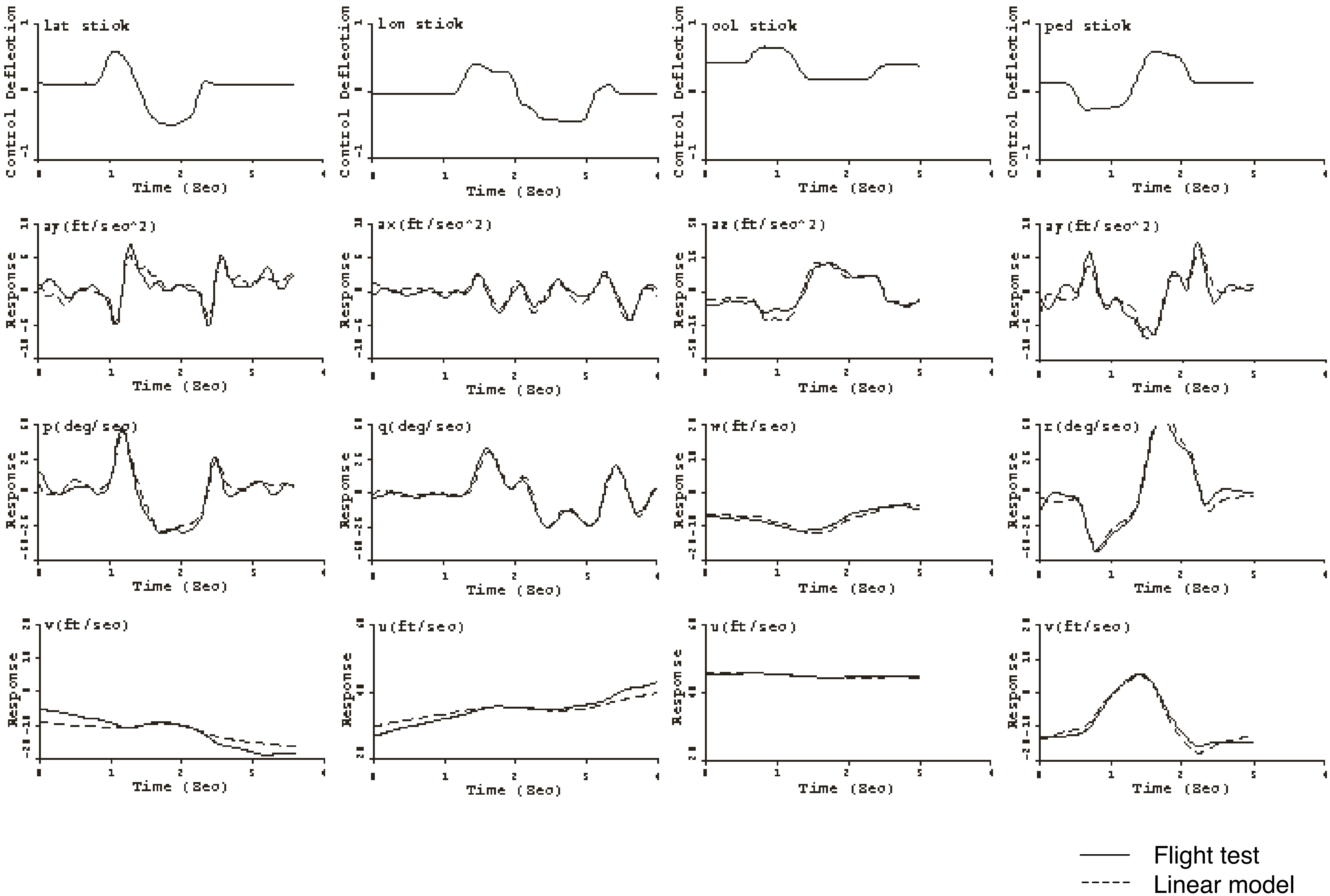
- **Doublet maneuver**
  - **Time-domain verification**



Frequency-Domain Comparison (V=25 kts)

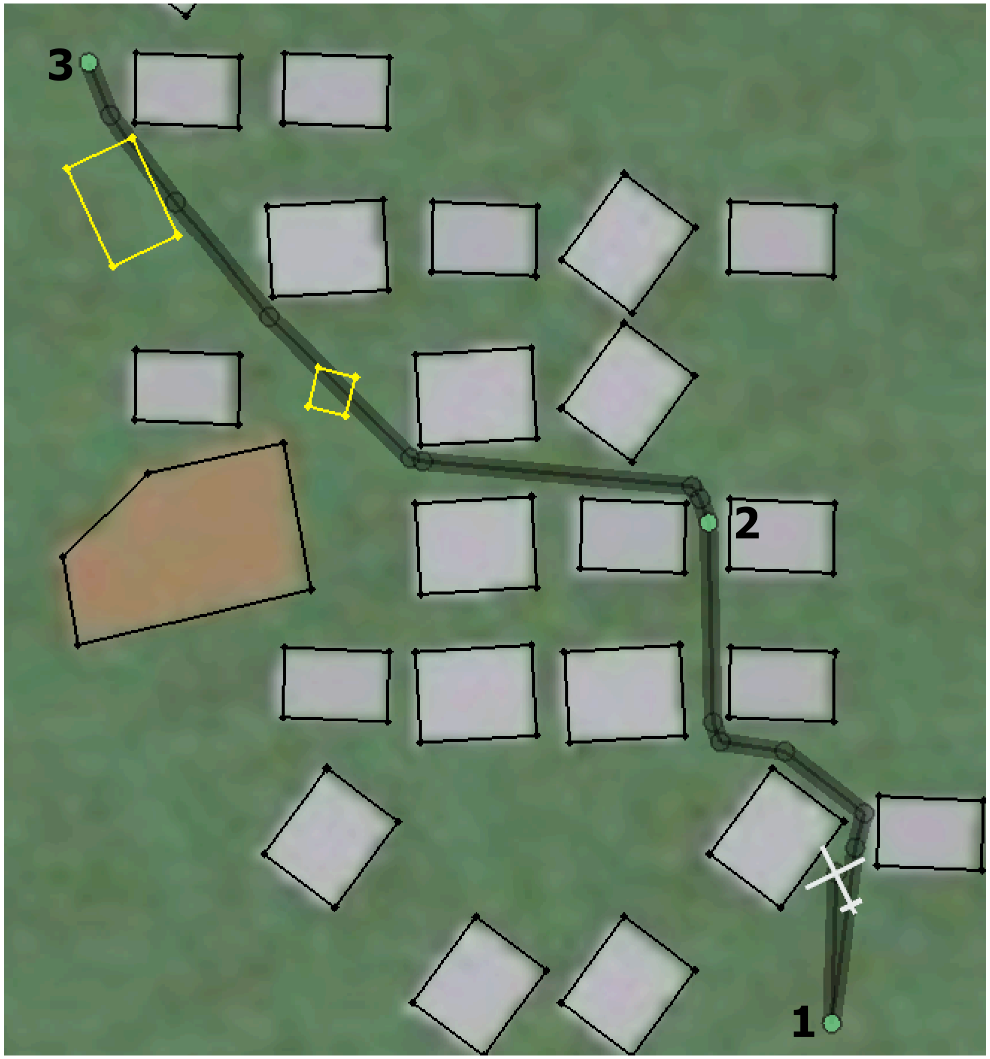


Time-Domain Comparison (V=25 kts)



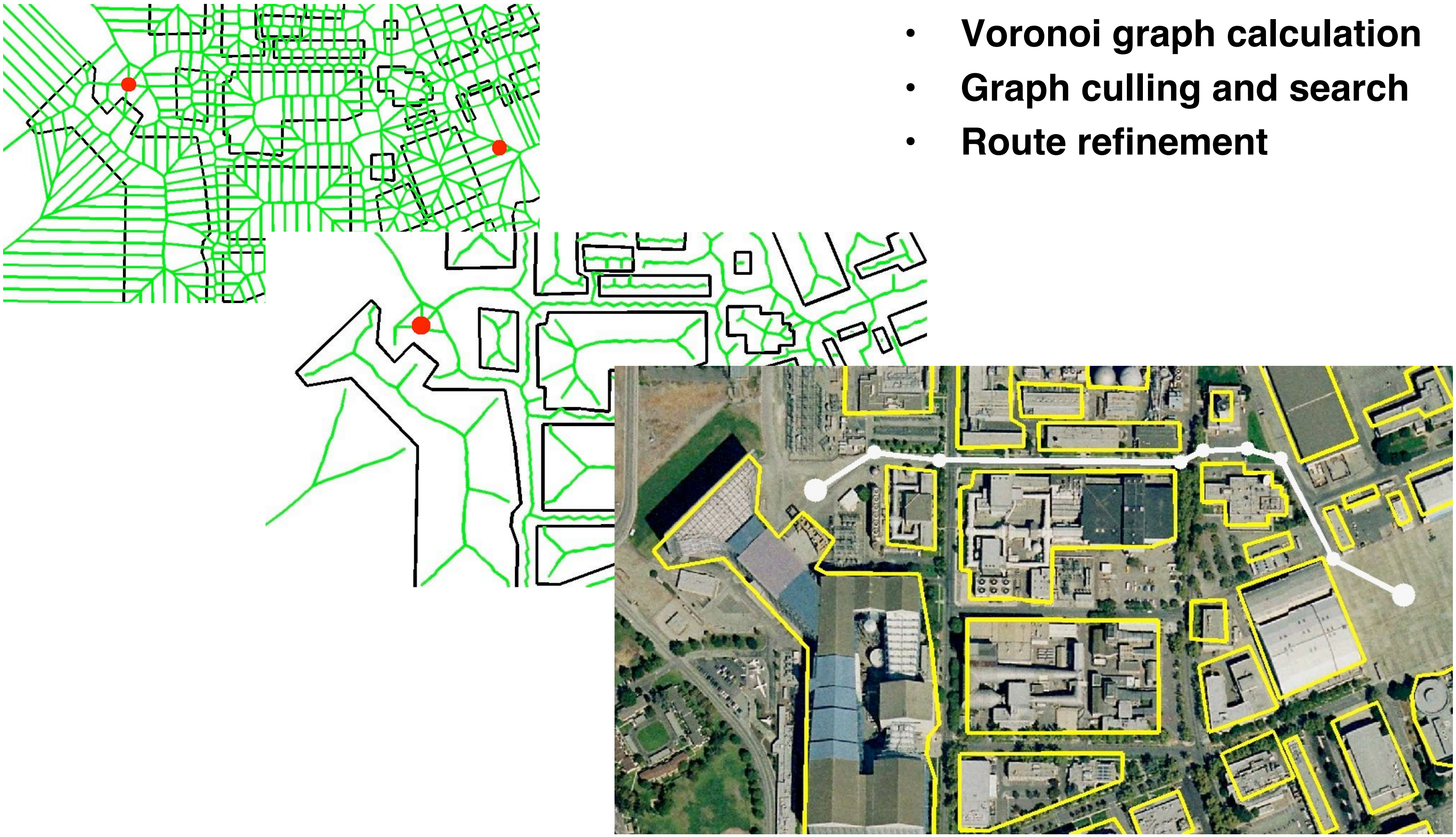
Obstacle Field Navigation Problem Description

- Navigate thorough the obstacle field at high speed and at constant AGL altitude
- Visit each of the target points
- Black obstacles are know a priori
- Yellow obstacles are detected while in route
  - React to and avoid the new obstacles
- The route should
  - Maintain a safe distance from the obstacles
  - Be as direct as possible



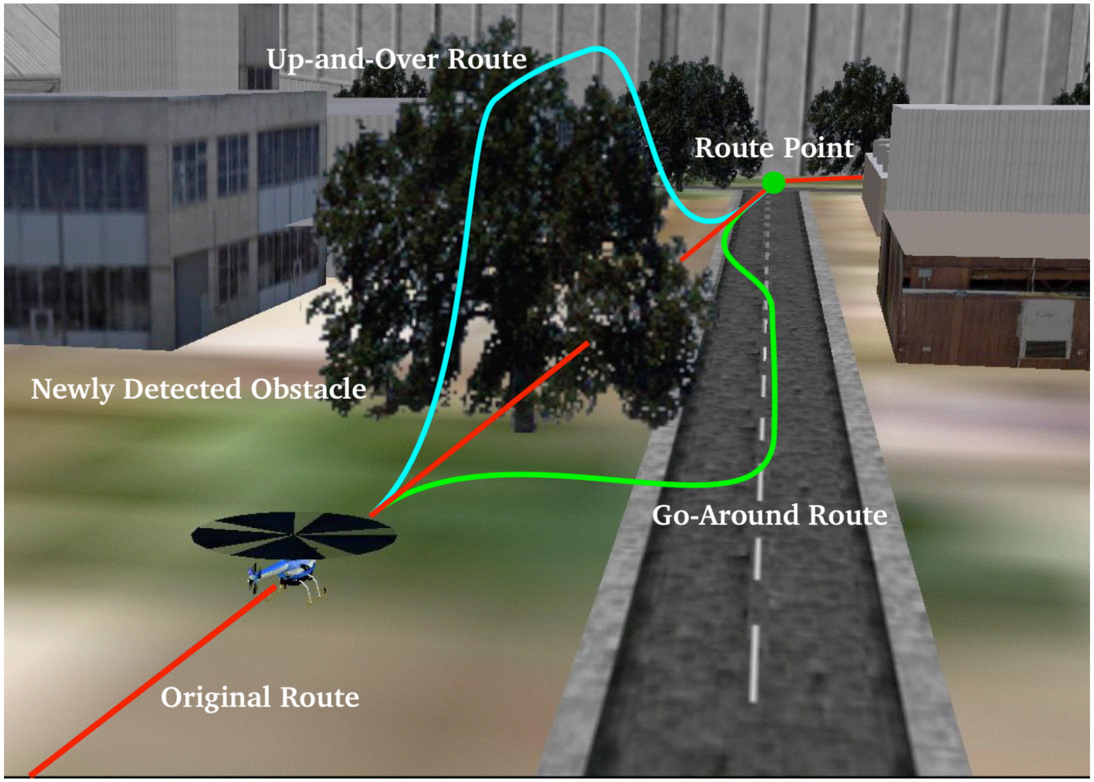
Voronoi-Based Obstacle-Field Route Planner

- Voronoi graph calculation
- Graph culling and search
- Route refinement

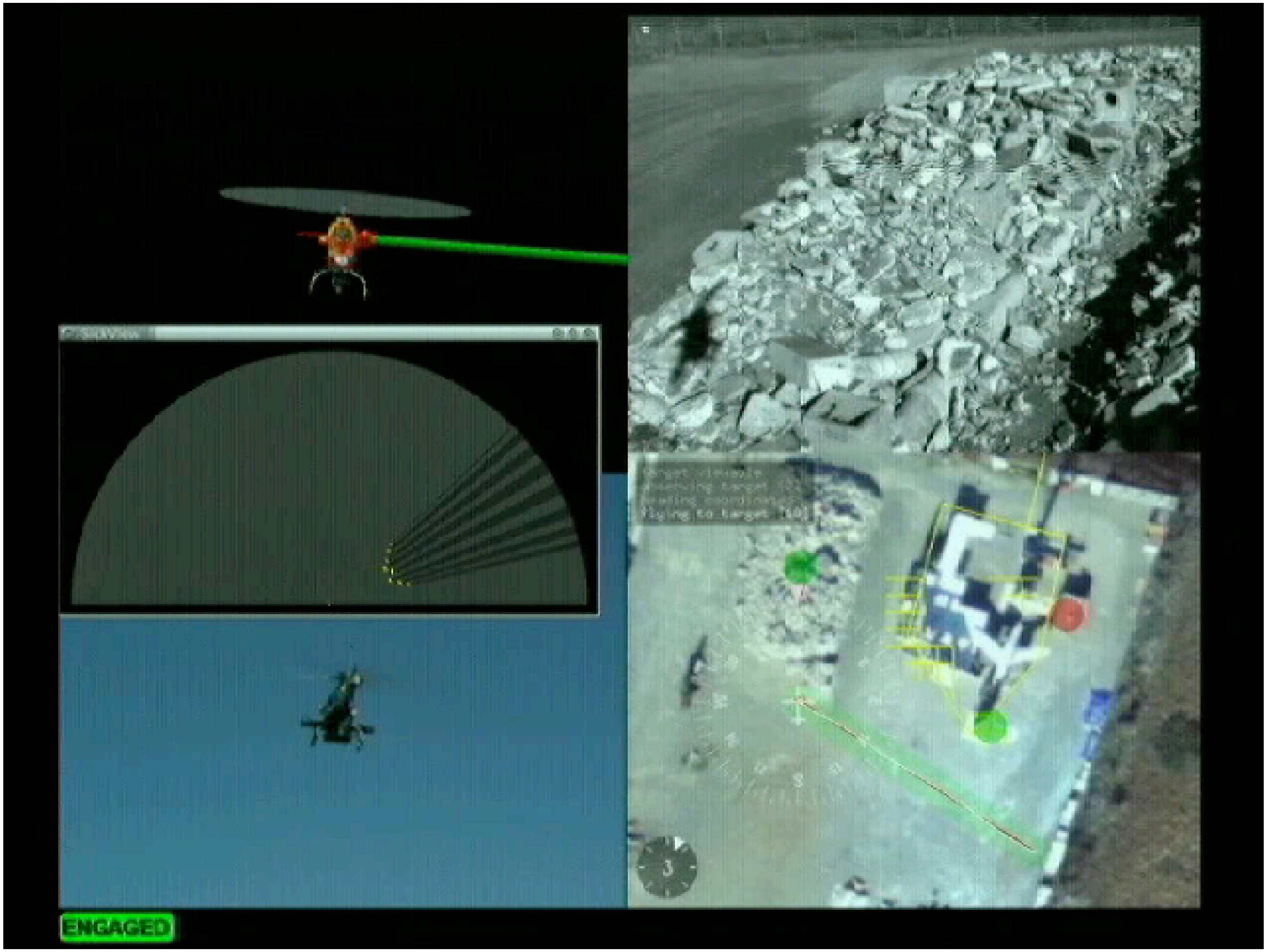


Reactive Obstacle Avoidance

- React to and avoid new obstacles as they are detected
- Select the best option from a library of possible behaviors
  - Survivability
  - Execution time
  - Level of aggressiveness
- Simple rule-based selection of the appropriate choice



Flight Demonstration



Flight Control Design Tools

- **CIFER® -- System Identification**
  - Significant improvements in algorithms over past 2 years
  - MATLAB library of core functions to allow scripting
  - AIAA Textbook on System Identification / student version of software

- **CONDUIT® -- Control System Analysis and Optimization**
  - Improvements to sensitivity tools
  - Development of gust response specifications for helicopters
  - 22 active users sites

- **RIPTIDE -- Desktop simulation**
  - Implement Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) protocol interfaces for connectivity to other simulation assets
  - Simulate advanced obstacle avoidance strategies and sensors including use of machine vision for navigation and obstacle detection