National Aeronautics and Space Administration

Multi-Vehicle Cooperative Control Research
at the NASA Armstrong Flight Research Center
2000 - 2014

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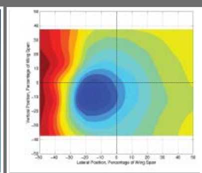
Autonomous Formation Flight / Automated Cooperative Trajectories

NASA / Boeing / UCLA

(2000)

Autonomous Station Keeping

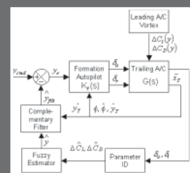
(2001)



Vortex Mapping Experiment

NASA

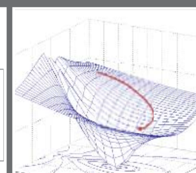
(2003)



Vortex-Based Navigation

NASA / UCLA

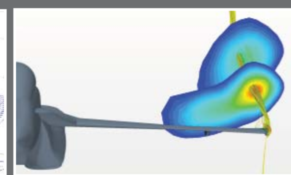
(2007-2011)



Peak-Seeking Optimization

NASA

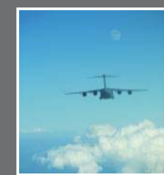
(2011-2012)



Optimized Lift Distribution

NASA / USAF / Boeing

(2010)



CAPFIRE

NASA

(2012-Present)

Automated Cooperative Trajectories

F/A-18 Autonomous Formation Flight (AFF)

- Autonomous Station Keeping
  - INS/GPS relative navigation using experimental data link
  - Measured 4 ft. relative position error with common satellite sets
  - Formation autopilot (no inner-loop changes) tracking error < 2ft.
- Vortex Mapping Experiment
  - Pilot-flown using cockpit relative navigation cues
  - Measured wake-induced forces and moments at 2-6 wing spans of nose-to-tail separation
  - Drag reductions of more than 20% were measured at some points
  - Demonstrated a 14% fuel savings over a 1.5 hour cruise mission

Formation Flight Paper Studies

- Vortex-Induced Navigation Experiment (VINE)
  - Investigation of formation flight without inter-ship communication
  - Fuzzy estimator of wake location based on measured disturbances
- Peak-Seeking Relative Position Optimization
  - Real-time estimates of gradient and curvature of fuel savings vs. position
- Peak-Seeking Optimization of Spanwise Lift Distribution
  - Real-time optimization of the roll trim solution using wing effectors
  - Predicted an additional 2% drag savings during formation flight

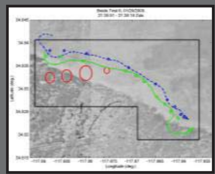
Extended Formations / Cooperative Trajectories

- Cargo Aircraft Precision Formations for Increased Range and Efficiency (CAPFIRE)
  - Demonstration of extended (>0.5 nm) formation drag reduction w/ C-17
  - Measured 9% fuel savings
- Automated Cooperative Trajectories
  - COTS data link (ADS-B) coupled with commercial avionics (ILS autopilot)
  - Real-time estimation of wake location and vortex circulation
  - Robust automated wake avoidance
  - Automated join-up and self-separation
  - Targeted for flights on the NASA G-III SCRAT aircraft in 2015-2016

Multi-Vehicle Cooperative Control

NASA

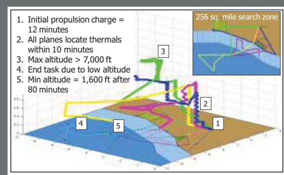
(2004-2005)



Networked UAV Teams

NASA

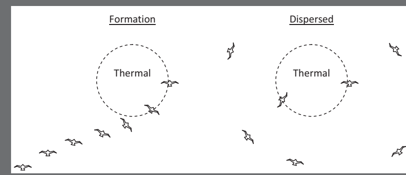
(2005)



UAV Flocking for Energy Efficiency

NASA / Cal. State Fresno

(2008)



Cooperative Autonomous Thermal Soaring

NASA / DARPA / Sierra Nevada

(2005-2007)

Automated Aerial Refueling Demonstration

NASA / DARPA / Northrup Grumman

(2011-2012)

KQ-X

Cooperative Control of Small UAVs

- Networked UAV Teams
  - Demonstrated the use of small UAV swarms to find, track and suppress forest fires
  - Bird Android (BOID) algorithms for cooperative behavior, dynamic cooperative mission re-planning and 4D relative navigation
- UAV Flocking for Energy Efficiency
  - Simulation study of small UAV swarms for Coastal Patrol missions (oil platform/pipeline monitoring, wildfire detection, earth science and marine wildlife monitoring)
  - Dynamic cooperative mission planning included formation drag reduction and thermal soaring for extended mission duration
  - Studied formation drag reduction for unpowered (glider) applications
- Cooperative Autonomous Thermal Soaring
  - BOID-like encoding of migratory hawk cooperative soaring behaviors
  - Self-separation for improved random thermal encounter, thermal congregation, and cooperative climb-rate feedback for enhanced thermal centering

Autonomous Aerial Refueling

- Automated Aerial Refueling Demonstration (AARD)
  - Characterization and modeling of hose-and-drogue dynamics
  - Integrated GPS-INS and video tracking for relative navigation
  - First ever autonomous probe-and-drogue aerial refueling operation
  - Successful repeated autonomous drogue captures
- KQ-X
  - Planned high-altitude, automated aerial refueling between two Global Hawk UAVs
  - First ever HALE close, precision formation flight
  - Lead receiver aircraft demonstrated successful hose-drogue extension
  - The aircraft flew as close as 30 ft.

NASA