Surfing Aircraft Vortices for Energy (SAVE) DARPA/AFRL Formation Flight for Efficiency Program
What are we trying to do?

- Demonstrate 10% trailing aircraft fuel burn reduction using enhanced C-17 autopilot guidance WITHOUT adversely effecting the airframe, engines, or aircrew.
- Obtain data to mitigate remaining concerns associated with airframe, engines, and workload.
- Understand system level opportunities and effects on transportation networks: military and commercial.
What has been done before?

- Benefits of formation flight are known and confirmed by numerous analytical and experimental studies
- Only Hummel had success automating, all other efforts piloted
- Efforts have focused on benefits not the costs
- NASA/USAF effort in 2010 provided key data for program

Hummel, 1996 (Do-28/Do-228)  
Wagner et. al, 2002 (T-38)  
NASA Formation Flight Program, 2002 (F-18)  
NASA/USAF, 2010 (C-17)
What are we doing differently?

Large transport class aircraft

Extended formations
3000-8000 ft (20-50 spans)

Fully autonomous

Comprehensive look at range of challenges
How is it done today?

**Military Transports**

- C-17 has the capability to fly formation missions for airdrop using the C-17 Formation Flight System.
- Other aircraft, such as C-130, have some capability via Station Keeping Equipment.
- Military routinely plans and executes complex tanker missions involving large formations.
- Military makes use of Military Assumes Responsibility for Separation Assurance (MARSA) to plan and execute formation missions.

**Commercial**

- Formation missions not flown.
What are the SAVE opportunities?

- Total USAF fuel use in 2010 was 2.5 billion gallons
- C-17 fuel use was approx. $2 billion
- Just 1% reduction is $20 million a year
- Possibly double with inclusion of other large transports.

Breakdown of USAF Aviation Fuel Usage by Aircraft Type, Fiscal Year 2010
What are the challenges? Five “showstoppers.”

We* will not be interested in Formation Flying for Aerodynamic Benefit if:

• It is unsafe
• It beats up the aircrew
• It beats up the aircraft
• It makes no business sense
• It makes no operational sense

*Perspective provided by Air Mobility Command Chief Scientist, Dr. Don Erbschloe.
What are the program focus areas?

Engineering, Operations & Technology

**Flight test planning**

**Data analysis**

**Sensing and control**

**Propulsion**

**Structures**

**Systems**

**Aerodynamic analyses**

**Simulation**

**Operational analysis**
What were some of the tests conducted?

Demonstration and data gathering flight test included wide range of test points to meet the program success criteria.

Wake Confirmation Tests

Vertical Wake Passes

Wake Crossings

Dwells in Proximity to the Wake
**Program Addressed Safety Challenges**

- Demonstrated robust tracking of lead wake at separations of 4000-8000 ft.

*View from cockpit, 5000 ft spacing. Indicated cross-track visible.*

- Airframe safety and engine operability from 40+ wake crossings reveal no concerns.

*Normalized peak responses over wake crossings.*
Program Addressed Aircrew Challenges

- Enhanced Mission Computer enables fully automated and robust flight in close proximity to the wake.

- Workload and ride quality assessed during flight test.

- Minor ride quality degradation for locations close to wake.

- Ride quality observations strongly affected by turbulence.

Automated station-keeping performance from Sep. 2012

![Diagram showing relative lateral and vertical spacing with color-coding for discomfort level change from lead to trail.]

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Program Addressed Aircraft Challenges

- Flight test, consisting of wake crossings and dwells, has substantially increased the aerodynamic, structural, and engine response database.

  Trajectories during 20 inadvertent wake crossings

  Database after 2012 Flight Tests

- No increase expected in engine wear due to SAVE.
- No significant increase in airframe wear due to SAVE.
Program Confirmed Fuel Burn Savings

- Subset of stable locations flown for extended duration (30 min each).
- Flight test analysis indicates 5-10% fuel flow reduction.
- Benefits consistent with predictions.

Tares taken out of wake

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Surfing Aircraft Vortices for Energy (SAVE)  
Hickam to Travis Mission Demonstration: 07/11/2013

Substantial fuel burn savings observed, exceeding 10% over 90 min segment and totaling >4000lbs for the mission.

Multiple human factors ratings taken on workload, ride quality, and fatigue – all satisfactory.
Program Addressing Operational Concerns

Statistics over random sample of days

Assuming C-17 flights remain in the same 24 hour window as historically flown, millions of gallons saved per year possible.
Estimated Yearly Fuel Savings
C-17 NORTHCOM Route Network
12 hours schedule flexibility, 1000 NMi radius, standard reserves

Cross-track position [ft]

Projected fuel savings [Million gallons / year]
Two aircraft results:
- Projected fuel savings: 1.9 to 2.6
- Percent fleet wide savings: 1.7 to 2.3%

Three aircraft results:
- Projected fuel savings: 2.8 to 3.9
- Percent fleet wide savings: 2.5 to 3.5%

Over the expected cross-track range, fleet fuel consumption benefits from 60+% of all C-17 flights joining a formation.
Summary

- Surfing Aircraft Vortices for Energy has demonstrated >10% fuel burn savings without adversely effecting the airframe, engines, or aircrew.

- Technology has potential for substantial fleet wide savings and can be obtained with a software change and operational flexibility.
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