Autonomous Formation Flight

A primary goal is to reduce fuel consumption during cruise by 10 percent.

Dryden Flight Research Center, Edwards, California

NASA's Strategic Plan for the Aerospace Technology Enterprise includes ambitious objectives focused on affordable air travel, reduced emissions, and expanded aviation-system capacity. NASA Dryden Flight Research Center, in cooperation with NASA Ames Research Center, the Boeing Company, and the University of California, Los Angeles, has embarked on an autonomous-formation-flight project that promises to make significant strides towards these goals.

For millions of years, birds have taken advantage of the aerodynamic benefit of flying in formation. The traditional “V” formation flown by many species of birds (including gulls, pelicans, and geese) enables each of the trailing birds to fly in the upwash flow field that exists just outboard of the bird immediately ahead in the formation. The result for each trailing bird is a decrease in induced drag and thus a reduction in the energy needed to maintain a given speed. Hence, for migratory birds, formation flight extends the range of the system of birds over the range of birds flying solo. The Autonomous Formation Flight (AFF) Project is seeking to extend this symbiotic relationship to aircraft (see Figure 1).

Predicted benefits of AFF as applied to commercial transport airplanes for typical transcontinental routes include annual per-trailing-airplane reductions of $0.5 \times 10^6$ (year 2000 average prices) in the cost of fuel, $10^7$ lb ($\approx 4.5 \times 10^6$ kg) in emitted carbon dioxide, and $10^5$ lb ($\approx 4.5 \times 10^4$ kg) in emitted nitrous oxide. In addition, improvements in cooperative guidance and control could one day enable air-traffic-control systems to manage formations of aircraft as though they were single aircraft, thereby increasing overall throughput.

AFF was competitively selected in May 2000 by the Revolutionary Concepts in Aeronautics (RevCon) project, funded under Dryden Flight Research Centers’s R&T Base Program. RevCon was designed to accelerate, through flight research, the dissemination of new aircraft and system concepts.

The primary goal of the AFF project is to demonstrate a sustained 10-percent reduction in the consumption of fuel by a trailing airplane during cruise. The project intends to advance the concept of autonomous-formation-flight drag reduction from the experimental proof-of-concept stage to a prototype demonstration within three years. The prototype demonstration will be accomplished by use of two highly instrumented NASA F/A-18 aircraft equipped with the necessary research systems.

The AFF project will involve three phases, with flight tests beginning in the first quarter of fiscal year 2001 and completion by the end of fiscal year 2003. The first phase, which has taken place, was devoted to the demonstra-
Expansible ice-prevention and cleanliness-preservation (EIP-CP) chambers have been proposed to prevent the accumulation of ice or airborne particles on quick-disconnect (QD) fittings, or on ducts or tubes that contain cryogenic fluids. In the original application for which the EIP-CP chambers were conceived, there is a requirement to be able to disconnect and reconnect the QD fittings in rapid succession. If ice were to form on the fittings by condensation and freezing of airborne water vapor on the cold fitting surfaces, the ice could interfere with proper mating of the fittings, making it necessary to wait an unacceptably long time for the ice to thaw before attempting reconnection. By keeping water vapor away from the cold fitting surfaces, the EIP-CP chambers would prevent accumulation of ice, preserving the ability to reconnect as soon as required.

Basically, the role of an EIP-CP chamber would be to serve as an enclosure for a flow of dry nitrogen gas that would keep ambient air away from QD cryogenic fittings. An EIP-CP chamber would be an inflatable device made of a fabric-like material. The chamber would be attached to an umbilical plate holding a cryogenic QD fitting. The chamber would include inner and outer subchambers that would be inflated with gaseous nitrogen through separate supply tubes. The outer subchamber would resemble a small tire tube. The inner chamber would be perforated on its innermost circle to allow nitrogen to flow onto and around the QD surfaces. When deflated, the EIP-CP would be about 1 in. (=2.5 cm) thick.

When not in use, the EIP-CP would be kept deflated, flat against the umbilical plate. Before disconnecting the QD fitting, the two subchambers of the EIP-CP would be pressurized with nitrogen. As disconnection proceeded, the pressurized outer tube would expand to follow the moving umbilical plate of the mating fitting, up to a maximum axial thickness (corresponding to a tire width) of about 6 in. (=15 cm). The subchambers would be shaped so that once maximum expansion was reached and the chamber could no longer seal against the receding umbilical plate of the mating fitting, the opening on the exposed end of the chamber would narrow to a small hole. The purge flow of nitrogen would prevent accumulation of ice or airborne particles.

Expandable Purge Chambers Would Protect Cryogenic Fittings
Flowing dry nitrogen would prevent accumulation of ice or airborne particles.

John F. Kennedy Space Center, Florida

A standard test block of six maneuvers was repeated for each of four different autopilot gain sets. These maneuvers included five-minute steady-state tracking tests and 30 ft (=9 m) commanded step inputs in each axis. The dynamic response of the system was observed in maneuvers in which the leading airplane performed heading sweeps of a few degrees and altitude sweeps of several hundred feet (=100 m).

A total of 167 test points was reached in 11 research flights. The experiment met all project objectives. The formation autopilot maintained relative position to within 2 ft (0.61 m) [see Figure 2] for all four gain sets during straight and level flight with turbulence levels ranging from nonexistent to light chop. An additional position error of up to 3 ft (0.91 m), due to GPS navigation errors, brought the total formation position error to less than 5 ft (1.52 m). Accurate, predictable tracking was observed during the step and dynamic maneuvers.

This work was done by Gerard S. Schkolnik and Brent Cobleigh of Dryden Flight Research Center. For more information on the AFF project contact Gerard S. Schkolnik, AFF Project Manager, gerard.schkolnik@dfrc.nasa.gov, (661) 276-3055 or Brent Cobleigh, AFF Chief Engineer, brent.cobleigh@dfrc.nasa.gov, (661) 276-2249. DRC-01-46