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 ($=4.5 \times 10^6$ kg) in emitted carbon dioxide, and $10^5$ lb ($=4.5 \times 10^4$ 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-
and evaluation of operational effectiveness. The flight tests will provide insight into such phenomena as effects of multipath propagation on GPS measurements and data communications and the dynamics of (including interactions between) vortices that cannot be adequately identified through simulation or ground test.

During the first phase of the program, two F/A-18 airplanes were outfitted with identical GPS receivers and an air-to-air telemetry system as a data link between the airplanes. In addition, the trailing airplane was equipped with an airborne research test system (ARTS) and a research flight-control computer. The ARTS hosted a precise autopilot control system, which received GPS and inertial measurement data from the leading airplane and computed stick commands to place the trailing airplane at the desired relative position. The research flight-control computer received and used the stick commands from the ARTS while engaged, but reverted to the production F-18 flight control system for the remainder of the mission. An interactive display was installed in the back seat of the airplane to enable the flight crew to control the flight experiment. Lateral and vertical position errors were displayed to the pilot by use of instrument-landing-system needles.

The results of this phase will be applicable to commercial and military cargo and passenger transport aircraft, unpiloted aircraft, increasing the ranges of aircraft in general, aerial refueling and resupply, and formation flying of satellites.

The AFF project is developing the first system for highly accurate in-flight relative positioning of two aircraft to incorporate differential-carrier-phase Global Positioning System (GPS) and inertial measurement information with an extended Kalman filter in a moving-base-station scenario. This system is expected to yield relative-position measurements accurate to within 0.5 ft (0.15 m). Flight tests will enable evaluation of control-system approaches and performance, validation of mathematical models for predicting vortex effects, quantification of reductions of drag, and evaluation of operational effectiveness. The flight tests will provide insight into such phenomena as effects of multipath propagation on GPS measurements and data communications and the dynamics of (including interactions between) vortices that cannot be adequately identified through simulation or ground test.

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