Physical Sciences

Role of Meteorology in Flights of a Solar-Powered Airplane

Meteorological support helped ensure safety and success of experimental high-altitude flights.

Dryden Flight Research Center, Edwards, California

In the summer of 2001, the Helios prototype solar-powered uninhabited aerial vehicle (UAV) [a lightweight, remotely piloted airplane] was deployed to the Pacific Missile Range Facility (PMRF), at Kauai, Hawaii, in an attempt to fly to altitudes above 100,000 ft (30.48 km). The goal of flying a UAV to such high altitudes has been designated a level-I milestone of the NASA Environmental Research Aircraft and Sensor Technology (ERAST) program. In support of this goal, meteorologists from NASA Dryden Flight Research Center were sent to PMRF, as part of the flight crew, to provide current and forecast weather information to the pilots, mission directors, and planners. Information of this kind is needed to optimize flight conditions for peak aircraft performance and to enable avoidance of weather conditions that could adversely affect safety.

In general, the primary weather data of concern for ground and flight operations are wind speeds (see Figure 1). Because of its long wing span [247 ft (≈75 m)] and low weight [1,500 to 1,600 lb (about 680 to 726 kg)], the Helios airplane is sensitive to wind speeds exceeding 7 kn (3.6 m/s) at the surface. Also, clouds are of concern because they can block sunlight needed to energize an array of solar photovoltaic cells that provide power to the airplane. Vertical wind shear is very closely monitored in order to prevent damage or loss of control due to turbulence.

Two flights were successfully completed during the deployment at PMRF (see Figure 2). The sequence of meteorological activities in support of each flight included the following:

- Daily forecasts of surface and upper-level meteorological conditions were issued, 48 hours before the planned flight day.
- Current and forecast weather conditions were described at briefings of the crew.
- A weather briefing was given in early morning on the planned flight day to help determine whether the airplane should be taken out of its hangar and prepared for flight.

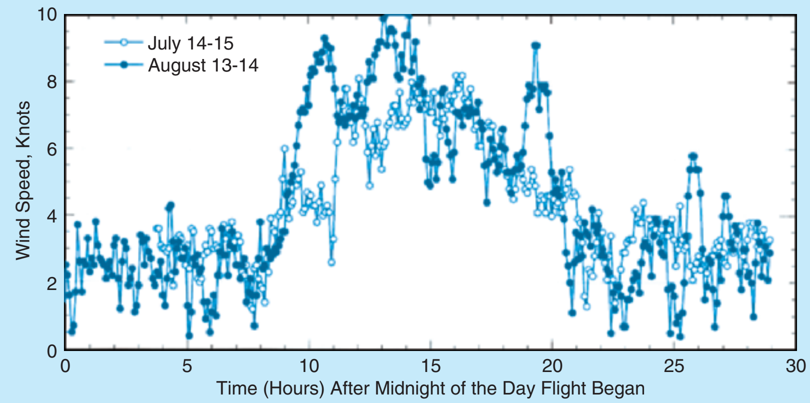
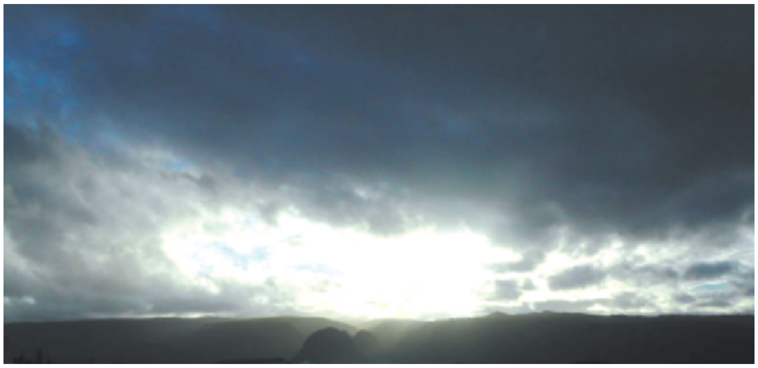


Figure 1. These **Surface-Wind Histories** were recorded at PMRF during intervals that included two flights. Data like these, plus other data, are needed to increase the likelihood of safe and successful flight.



Clouds as Seen From Runway After Sunrise

Helios Prototype Airplane at Takeoff on its Way to a Record Altitude on August 13, 2001

Figure 2. The **Takeoff of the Helios Prototype Solar-Powered UAV** was delayed because of clouds. The airplane then took off and flew to a record altitude.

- A final such "go/no-go" briefing was given 2 hours prior to scheduled takeoff.
- After takeoff, periodic updates based of weather-balloon and satellite data were provided to the pilot and mission planner.
- Approximately 2 hours before landing, a final weather forecast was issued to enable estimation of the earliest possible landing time and selection of a runway.
- After landing, surface conditions were monitored until the airplane was safely in the hangar.

The first successful flight took place on July 14, 2001. The takeoff was delayed for 20 minutes because of clouds. Convection over the runway generated moderate turbulence during takeoff. The airplane climbed to a maximum altitude of 76,500 ft (≈23.3 km). The airplane landed in stable conditions after more than 15 hours of flight.

The second successful flight took place on August 13, 2001. This time, the takeoff was delayed 45 minutes because of clouds. Strong wind shear due to strong trade winds and island wake was observed at an altitude of 2,000 ft (≈600 m). The airplane then climbed until it reached a world-record altitude for a non-rocket-powered aircraft — 96,863 ft (29,524 m). This altitude is more than 11,000 ft (≈3.35 km) higher than the record set in a flight of the SR-71 airplane. The airplane landed safely after a last-minute change in runway because of winds.

This work was done by Casey Donohue of AS&M, Inc., for **Dryden Flight Research Center**. *For further information, contact the Dryden Commercial Technology Office at (661) 276-3689.*

DRC-02-25

Model of Mixing Layer With Multicomponent Evaporating Drops

Effects of multiple chemical components are represented with computational efficiency.

NASA's Jet Propulsion Laboratory, Pasadena, California

A mathematical model of a three-dimensional mixing layer laden with evaporating fuel drops composed of many chemical species has been derived. The study is motivated by the fact that typical real petroleum fuels contain hundreds of chemical species. Previously, for the sake of computational efficiency, spray studies were performed using either models based on a single representative species or models based on surrogate fuels of at most 15 species. The present multicomponent model makes it possible to perform more realistic simulations by accounting for hundreds of chemical species in a computationally efficient manner.

The model is used to perform Direct Numerical Simulations in continuing studies directed toward understanding the behavior of liquid petroleum fuel sprays. The model includes governing equations formulated in an Eulerian and a Lagrangian reference frame for the gas and the drops, respectively. This representation is consistent with the expected volumetrically small loading of the drops in gas (of the order of 10^{-3}), although the mass loading can be substantial because of the high ratio (of the order of 10^3) between the densities of liquid and gas. The drops are treated as point sources of mass, momentum, and energy; this representation is consistent with the drop size being smaller than the Kolmogorov scale. Unsteady drag, added-mass effects, Basset history forces, and collisions between the drops are neglected, and the gas is assumed calorically perfect.

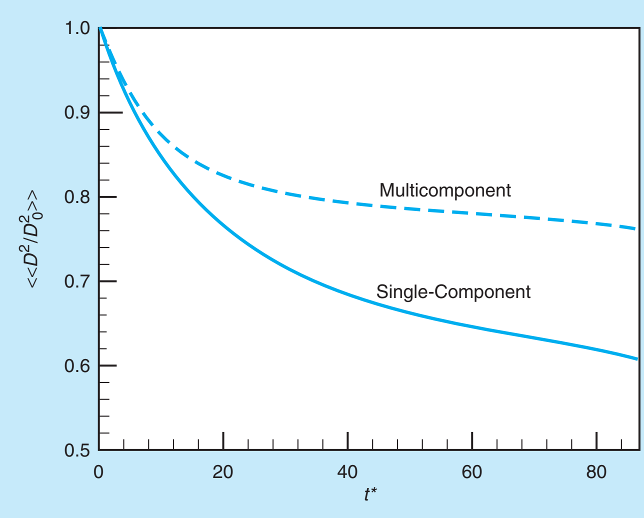


Figure 1. The **Evolution of Residual Droplet Areas** was computed for the single-component and multicomponent cases. Here t* is time in units of a characteristic time calculated from initial parameters of the mixing layer, D_o is the initial drop diameter, D is the drop diameter as a function of time, and << >> denotes an ensemble average.

The model incorporates the concept of continuous thermodynamics, according to which the chemical composition of a fuel is described probabilistically, by use of a distribution function. Distribution functions generally depend on many parameters. However, for mixtures of homologous species, the distribution can be approximated with acceptable accuracy as a sole function of the molecular weight. The mixing layer is initially laden with drops in its lower stream, and the drops are colder than the gas. Drop evaporation leads to a change in the gas-phase composition, which, like the composition of the drops, is described in a probabilistic manner.

The advantage of the probabilistic description is that while a wide range of individual species can be accommodated in the mixture, the number of governing equations is increased minimally over that necessary for a single species because the composition is represented only by the parameter(s) necessary to construct the distribution function. Here the distribution function is entirely defined by the mean and variance. For this choice of distribution function, the model accounts for evaporation-induced changes in the composition of fuel drops and the surrounding gas, yet involves only two more conservation equations (one for the mean and one for the