The **F-15 ACTIVE Airplane** is a test bed for advanced flight-control systems.

The goals of the IFCS ACP are to (1) develop the concept of a flight-control system that uses neural-network technology to identify aircraft characteristics to provide optimal aircraft performance, (2) develop a self-training neural network to update estimates of aircraft properties in flight, and (3) demonstrate the aforementioned concepts on the F-15 ACTIVE airplane in flight. The activities of the initial IFCS ACP were divided into three Phases, each devoted to the attainment of a different objective. The objective of Phase I was to develop a pre-trained neural network to store and recall the wind-tunnel-based stability and control derivatives of the vehicle. The objective of Phase II was to develop a neural network that can learn how to adjust the stability and control derivatives to account for failures or modeling deficiencies. The objective of Phase III was to develop a flight control system that uses the neural network outputs as a basis for controlling the aircraft. The flight test of the IFCS was performed in stages. In the first stage, the Phase I version of the pre-trained neural network was flown in a passive mode. The neural network software was running using flight data inputs with the outputs provided to instrumentation only. The IFCS was not used to control the airplane. In another stage of the flight test, the Phase I pre-trained neural network was integrated into a Phase III version of the flight control system. The Phase I pre-trained neural network provided real-time stability and control derivatives to a Phase III controller that was based on a stochastic optimal feedforward and feedback technique (SOFFT). This combined Phase I/III system was operated together with the research flight-control system (RFCS) of the F-15 ACTIVE during the flight test. The RFCS enables the pilot to switch quickly from the experimental-research flight mode back to the safe conventional mode.

These initial IFCS ACP flight tests were completed in April 1999. The Phase I/III flight test milestone was to demonstrate, across a range of subsonic and supersonic flight conditions, that the pre-trained neural network could be used to supply real-time aerodynamic stability and control derivatives to the closed-loop optimal SOFFT flight controller. Additional objectives attained in the flight test included (1) flight qualification of a neural-network-based control system; (2) the use of a combined neural-network/closed-loop optimal flight-control system to obtain level-one handling qualities; and (3) demonstration, through variation of control gains, that different handling qualities can be achieved by setting new target parameters. In addition, data for the Phase-II (on-line-learning) neural network were collected, during the use of stacked-frequency-sweep excitation, for post-flight analysis. Initial analysis of these data showed the potential for future flight tests that will incorporate the real-time identification and on-line learning aspects of the IFCS.

The majority of the design for this work was performed by Ron Davidson of Boeing Phantom Works and John T. Bosworth, Steven R. Jacobson, and Michael P. Thomson of **Dryden Flight Research Center**, *and Charles C. Jorgensen of Ames Research Center. For further information, contact the Dryden Commercial Technology Office at (661) 276-3689.*
DRC-01-35

Slat Heater Boxes for Thermal Vacuum Testing

These devices are superior to infrared lamps for controlling sink temperatures.

Lyndon B. Johnson Space Center, Houston, Texas

Slat heater boxes have been invented for controlling the sink temperatures of objects under test in a thermal vacuum chamber, the walls of which are cooled to the temperature of liquid nitrogen. A slat heater box (see Figure 1) includes a framework of struts that support electrically heated slats that are coated with a high-emissivity optically gray paint. The slats can be grouped together into heater zones for the purpose of maintaining an even temperature within each side.

The sink temperature of an object under test is defined as the steady-state temperature of the object in the vacuum/radiative environment during the absence of any internal heat source or sink. The slat heater box makes it possible to closely control the radiation environment to obtain a desired sink temperature.

The slat heater box is placed inside the cold thermal vacuum chamber, and the object under test is placed inside (but not in contact with) the slat heater box. The slat heaters occupy about a third of the field of view from any point on the surface of the object under test, the remainder of the field of view being occupied by the cold chamber wall. Thus, the radiation environment is established by the combined effects

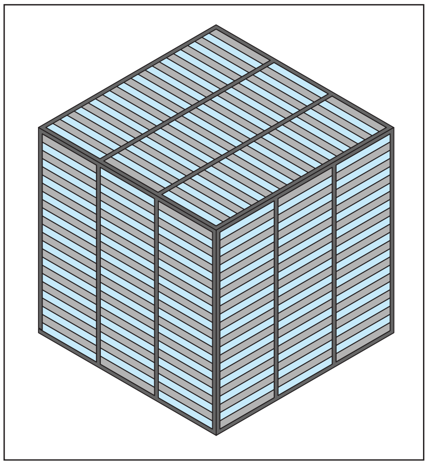

Figure 1. A **Slat Heater Box** surrounds an object under test and is heated to a controlled temperature.

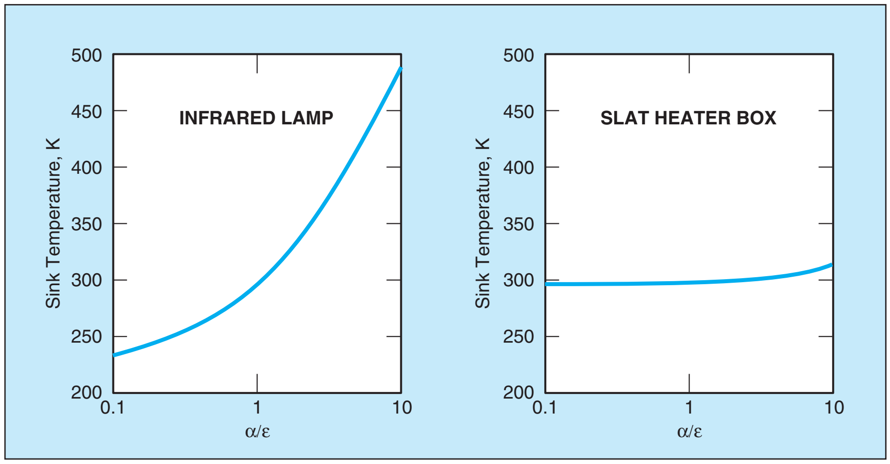

Figure 2. The **Sink Temperature** of a test object as a function of α/ε was calculated for a representative case of heating with a quartz infrared lamp at 10-percent power and a representative case of a slat heater box occupying a third of the field of view, with an emissivity of 0.865 and slat temperature of 410 K.

of the slat heater box and the cold chamber wall.

Given (1) the temperature of the chamber wall, (2) the fractions of the field of view occupied by the chamber wall and the slat heater box, and (3) the emissivities of the slats, chamber wall, and the surface of object under test, the slat temperature required to maintain a desired sink temperature can be calculated by solving the equations of gray-body radiation for the steady-state adiabatic case (equal absorption and emission by the object under test).

Slat heater boxes offer an important advantage over the infrared lamps that have been previously used to obtain desired sink temperatures: In comparison with an infrared lamp, a slat heater box provides a greater degree of sink temperature uniformity for a test-object surface that includes multiple areas with differing optical properties. This advantage can be seen by solving gray-body radiation equations for some representative cases of test objects for which the emissivity or absorptivity at wavelengths <4 µm (denoted α) differs from the emissivity or absorptivity at wavelengths >4 µm (denoted ε). [The term α is often denoted solar absorptivity because most of the power of solar radiation lies in the wavelength range below 4 µm, while the term ε is often denoted infrared or thermal emissivity because most of the power of room-temperature objects lies in the wavelength range >4 µm.] Figure 2 presents the results of one such calculation that illustrates the superiority of a slat heater box over an infrared lamp, in that the sink temperature is much less sensitive to α/ε in the case of the slat heater box.

This work was done by Eugene Ungar of **Johnson Space Center.** *Further information is contained in a TSP (see page 1).*
MSC-23023

System for Testing Thermal Insulation of Pipes

Thermal and flow conditions are carefully controlled to minimize errors.

John F. Kennedy Space Center, Florida

An apparatus and method have been developed for measuring the rates of leakage of heat into pipes carrying liquids, the purpose of the measurements being to quantify the thermal performance of the insulation system. The apparatus is designed primarily for testing pipes used to carry cryogenic liquids, but can also be used for measuring the thermal performance of other insulated pipes or piping systems.

The basic measurement principle is straightforward: The outer surface of the pipe insulation is maintained at a fixed warmer temperature. The interior of the pipe is maintained in a narrow fixed lower-temperature range by means of a regular liquid (e.g., water) that is pumped through the pipe at a known flow rate or a cryogenic liquid (e.g., nitrogen) that is saturated at atmospheric pressure and replenished until steady-state conditions are achieved.

In the case of water or another liquid pumped through, the inlet and outlet temperatures are measured and heat-leak power is calculated as the mass flow rate of the liquid multiplied by the specific heat of the liquid multiplied by the inlet-to-outlet temperature rise of the liquid. In the case of liquid nitrogen or another low-temperature boiling liquid, the heat-leak power is calculated as the rate of boil-off multiplied by the latent heat of vaporization of the liquid. Then the thermal-insulation performance of the pipe system can be calculated as a function of the measured heat-leak power, the inner and outer boundary temperatures, and the dimensions of the pipe.

The apparatus can test as many as three pipes simultaneously. The pipes can have inner diameters up to ≈15 cm and outer diameters up to ≈20 cm. The lengths of the pipes may vary; typical lengths are of the order of 18 m.

Two thermal guard boxes — one for each end of the pipe(s) under test — are used to make the inlet and outlet fluid connections to the pipe(s) (see figure). The connections include bellows that accommodate thermal expansion and contraction of the pipes. The guard boxes