Laminar flow, propfans, and marginal stability are cultivating an array of new instruments and techniques

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Flight testing keeps pace

Laminar flow over advanced airframes, the noise and vibration of propfan engines, and marginal stability for agile control are pushing advancement of flight testing methods faster than any driver of that technology since the early '70s. That was when digital technology multiplied the number of measurements possible in flight by a factor of 100.

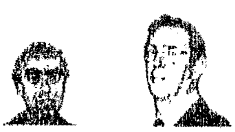
Design and fabrication of a natural laminar flow (NLF) wing for the Cessna 210 in 1986 accelerated incorporation of laminar flow into production aircraft and development of flight test methods to match. Werner Pfenninger, senior research scientist at Analytical Services and Materials (AS&M), Hampton, VA, and Jeff K. Viken, a graduate student at George Washington Univ., completed the seminal design at NASA's Langley Research Center. After full scale wind tunnel testing at the center, Cessna flight tested the aircraft and found laminar flow up to 70% chord. The result was a total aircraft drag reduction of 20%. An approach to mass production of this aircraft with NLF is expected within two years.

Viken, now working for Cirrus Design, Baraboo, WI, since designed the kit-built VK30, a four-place, composite aircraft with an NLF wing and tail, and a cruise flap for a design cruise speed of 250 mph. The aircraft is currently undergoing flight tests.

Both qualitative and quantitative measurements are needed to test laminar flow in flight. Bruce Holmes, chief of the flight applications branch at the center, and his associates in the branch have developed a qualitative tool consisting of liquid crystal coatings (LCC). This is expected to replace conventional sublimating chemicals used for testing the 210's wing. Such chemicals can only display one flow condition during a flight because the visual pattern once formed cannot change. But LCCs—mixtures of various phenoyl benzoates—can respond continuously and thus show the location of the boundary layer transition point as it moves during a test.

LCCs are sensitive to surface shear and respond to the higher stresses in turbulent flow by changing color. The temperature sensitivity of the liquid crystals is minimized by varying the LCC mixture, which in turn varies the color play bandwidth so it responds only to surface shear stress. This technique for visualizing flow transition in flight is nonintrusive, reusable, robust, and easy to handle. It will be used on the branch's unique flight research F-106 that employs a vortex flap to trap the leading-edge vortex. The flap improved the aircraft's lift to drag ratio.

Quantitative pressure and velocity measurements must be nonintrusive to avoid disturbing the flow. Multielement flow sensors are one way to determine the separation point and the extent of the separation bubble on laminar flow wings. NASA-Langley's fluid dynamics branch and AS&M developed a particularly ingenious technique using a multielement hot film anemometer made by depositing nickel, via electron beam evaporation, onto a substrate. The sensor is about 1 micron thick while the leads, also made by



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Turbulent flow shows up as green and laminar flow as blue when NASA Ames/Dryden Flight Research Facility uses an F-14 wing glove with liquid crystal coatings to test laminar flow performance.

deposition, are about 5 microns thick. The sensor's 25-micron-thick Kapton substrate can be eliminated and the sensor deposited directly on the wing to be tested.

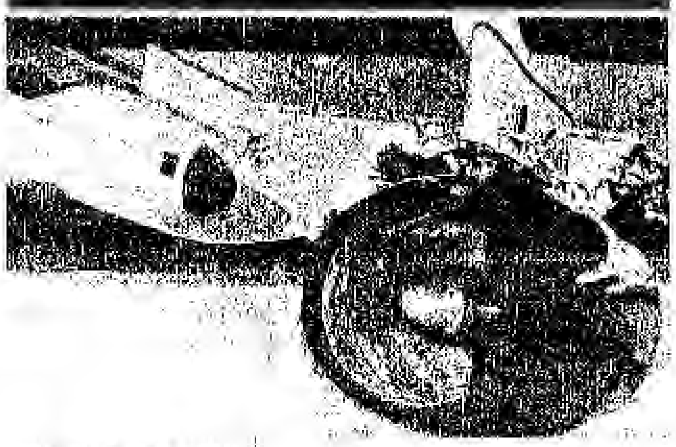
Wind tunnel tests performed so far used a Kapton gloved sensor wrapped around laminar flow test wings. The data analysis technique associated with the sensor simultaneously detected the laminar separation point, the transition of laminar to turbulent flow, and the point where flow reattachment occurred. For the transonic flows, the sensor has detected shock locations as well as the shock-induced separation point.

The technique's developers, J. Peter Stack, aerospace engineer in the center's fluid dynamics branch, and Siva M. Mangalam, senior scientist at AS&M, observed a phase reversal in the shear stress fluctuations that occur around a separation point. This is what allows the sensor to locate a separation point. When the electrical output signals from two films are simultaneously passed through a spectrum analyzer, the cross correlation shows a clear 180° phase reversal when the two films straddle a separation or reattachment point. This phenomenon was observed over a frequency range of 0-500 Hz for subsonic and transonic flows. Furthermore, measurement of the most amplified laminar flow instability waves, called the Tollmien-Schlichting waves, were made up to 10 kHz.

This month, flight tests using this sensor to locate the laminar separation point as well as the stall-induced separation point on a wing will begin. This opens the possibility of using the sensor for stall buffet warning.

Other airframe locations where laminar flow can cut drag are engine nacelles and the forward fuselage. Nacelle design must account for the effect of acoustic disturbances—propulsion and airframe noise—on the stability of the laminar boundary layer. Because experimental data on these effects are limited and prediction methods need experimental validation, Langley and General Electric collaborated on obtaining data in flight. The center's flight applications branch used a NASA OV-1 aircraft to conduct the tests at flight Reynolds numbers of about 1.8×10^6/ft.

A 7-ft-long flow-through NLF nacelle was mounted on a stores pylon under the OV-1's right wing. Loudspeakers serving as an external noise source and a video camera were mounted in a streamlined pod outboard of the nacelle. Another loudspeaker was inside the nacelle, and the starboard propeller was feathered to eliminate propeller induced disturbances. Hot-film sensors measured the extent of laminar flow to observe noise effects on the laminar boundary layer. The hot films are conventional sensors that determine flow heat transfer rates by measuring fluctuations in the electrical voltage applied to the film. Researchers repeated the OV-1 procedure for a matrix of acoustic levels and frequencies. Finally, the extent of laminar flow was compared with what is observed without noise and with predicted values.



NASA-Langley uses the OV-1 aircraft with a laminar flow nacelle under the right wing to measure the effect of noise on nacelle flow. An acoustic source in the OV-1's outboard instrumentation pod (bottom) radiates noise onto the nacelle test surface. A camera behind the square window on the pod records the results.

Preliminary results show that adverse effects of acoustic disturbances on NLF are not as severe as predicted by using the modified X21 criteria of the '60s. Laminar flow covered 50% of the nacelle under most flight conditions. The modified X21 criteria derive from wind tunnel testing that predicted a forward movement of transition when the acoustic noise frequency matches that of the Tollmien-Schlichting waves. However, disturbances reflected by the walls in a wind tunnel test are absent in flight. This may explain why the transition-point location is largely unaffected by noise.

Flight testing of propfan and ultra high bypass (UHB) engines has pressed into service improved airborne data acquisition and processing systems for noise and vibration. McDonnell Douglas has used a high speed data acquisition system to gather noise and vibration data during UHB testing on its MD-80 test aircraft. Features include 256 channels, 1.6 million samples/sec, 0.1% accuracy, dynamic range of more than 80 dB, 2 and 10 kHz data bandwidths, 80 dB/octave roll-off, four 64-channel 14-bit analog/digital converters, 16-channel monitoring digital/analog converters for calibrations, a liquid crystal display terminal, and 256 antialiasing filters, which use a processing algorithm to smooth out steps in the data to more closely approximate reality.

Combined with advanced data processing on the ground, the system reduced the time for dynamic data reduction to two days from six to eight weeks for analog recording and processing techniques. The ground processing system has a DEC LSI-11/73 controller with an RSX-11M+ operating system. Signal processing is handled by a CSPI MM-211 array processor. A Versatec V80 and a 6,250-bit/in. tape drive are the primary output devices, but the system also has a DEC PDP-11/44 minicomputer, a 1,600-bit/in. tape drive, and BGL LZR 2600 laser printer/plotter for graphics output.

Combining hot film sensors and acoustic microphones has recently proven to be valuable in another flight experiment. The laminar flow control project office at NASA-Langley retained Boeing under a contract to fit a 757 with an NLF wing glove to measure the effects of noise on a wing's laminar flow in flight. Throttling the engine between flight idle and maximum thrust varied the noise. Flush microphones measured the noise field impinging on the wing, and hot films detected the transition point. Frequencies of the engine fan noise reached 40 kHz, Mach numbers flown ranged from 0.6 to 0.82 at altitudes of 30,000-41,000 ft. Laminar flow on the wing upper surface was up to 30% chord and did not vary either with noise frequency or engine power. Engine noise caused transition to move forward 2% on the lower surface to 28% chord.

Another new flight-test visualization technique for laminar flow being developed is the use of an infrared camera to differentiate between laminar and turbulent flow. Langley's flight applications branch illuminates the wing with an infrared light source and uses the camera to pick up differences in surface temperature. At Mach numbers as low as 0.2 the difference due to surface shear stress variations in the boundary layer is about 0.1 F, while near Mach 1 it can increase to 20-30 F. This technique is nonintrusive and appears promising despite the expense.

A team headed by John Hicks and Neil Matheny, former and present chief engineers of the X29A project, respectively, are flight testing this forward-swept-wing technology demonstrator at NASA Ames/Dryden Flight Research Facility. The flight test aircraft is a joint project of the Defense Advanced Research Projects Agency, the Air Force,

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