LAMINAR FLOW - THE CESSNA PERSPECTIVE

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ABSTRACT

A review of Natural Laminar Flow (NLF) and Laminar-Flow Control activities over the last twenty years at Cessna Aircraft Company is presented. Expected NLF benefits and remaining challenges are then described.

INTRODUCTION

The question might well be, "Why is Cessna involved in NLF Research and Development?" It's simply that we're convinced that there is a worthwhile prize in terms of speed increase, or engine size and fuel flow decrease. In other words, airplane efficiency <u>can</u> be improved and we want to apply the improvements to our products.

We are indebted to NASA for reviving the interest in this fundamental phenomenon and its control. Our involvement in the subject at Cessna goes back over twenty years - both in research and production application - so in a sense it's not new. But, the understanding and resulting benefits continue to increase and NASA's involvement is essential and applauded.

Work in NLF is like seeking a sunken treasure. After becoming convinced that it's worth going after, comes the realization that success will most likely come only by systematic and persistent pursuit of the goal. We believe that we remain on that course.

CESSNA BACKGROUND

The Cessna NLF experience goes back to the mid-1960's when Cessna and a number of other General Aviation manufacturers began using NASA 6-Series laminar flow airfoils.

Cessna 177 Cardinal	-	64 Series Airfoil
Cessna 210G Centurion	-	64 Series Airfoil
Piper Comanche	-	64 Series Airfoil
Piper Cherokee	-	65 Series Airfoil
Mooney Mark 20	-	63 and 64 Series Airfoils
Beech Musketeer	-	63 Series Airfoil
Bede BD-1*	-	63 Series Airfoil

(*later Grumman-American Yankee)

In addition to the two models shown and other production derivatives, Cessna built prototypes of two twin-engine models with 6-Series airfoils that did not go into production.

Our results with laminar flow airfoils in the 1960's and early 1970's was mixed. We know from more recent tests that some laminar flow was achieved but drag reduction based on gross performance measurements at the time was not overwhelming. At the time it was felt that conventional construction methods prevented achieving the laminar flow for which the airfoil sections were developed. Further, although the 210 was successful with the basic 6-Series airfoil, other applications required modification either to improve stall characteristics or in an attempt to improve performance.

RECENT WING NLF RESEARCH: RESULTS

In 1981 when Bruce Holmes of NASA initiated a review of NLF, Cessna cooperated with flight tests of transition point visualization (Fig. 1). These tests utilized a sublimating chemical and contributed to the realization that there was more NLF with real-world aircraft construction than had been earlier thought. As shown on the right of Figure 1, there is little difference in the extent of laminar flow between the inboard section, which was smoothed and painted, and the outboard section, which was only painted. We also all began to realize that more NLF than expected meant that airplane drag had been apportioned incorrectly. More importantly, it meant that NLF was worth pursuing, especially since Holmes' investigations showed that bugs and other irregularities were not as detrimental as expected.

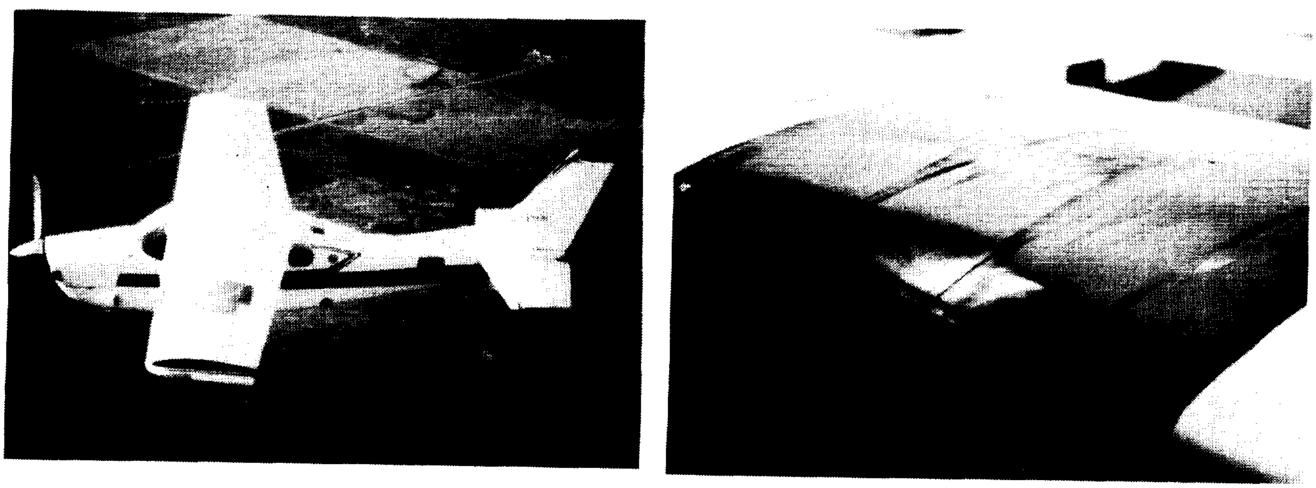

Figure 1

RECENT WING NLF RESEARCH: TECHNIQUES REFINED

This research led to Citation III transition measurements which introduced higher speeds and modest wing sweep. Hot film transition measurement techniques were refined during these tests. Figure 2 shows the test aircraft on the left and laminar flow results on the right. The lack of laminar flow behind the stall strip is in contrast to that which exists on the remainder of the test section. No significance should be attached to the speed brake position at the time the photo was taken.

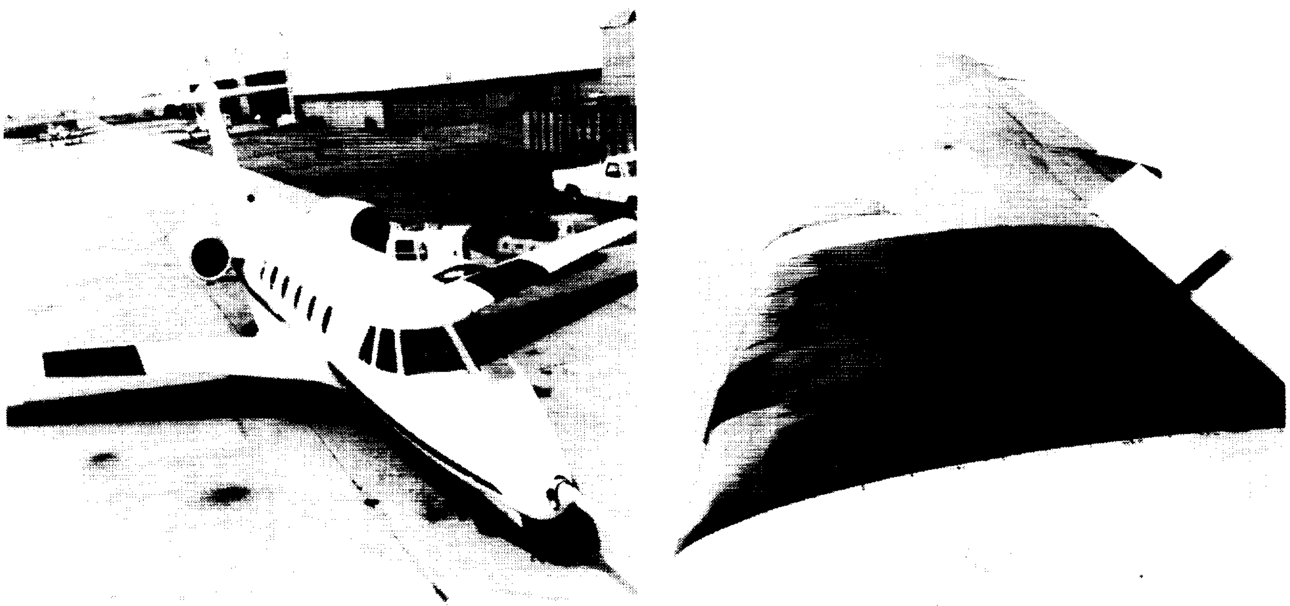

Figure 2

C-2

RECENT WING NLF RESEARCH: AIRFOIL IMPROVEMENTS

Additional tests on a Cessna 210 involved measurements above a 20,000 foot altitude on a modified airfoil designed by Gerry Gregorek at Ohio State. Good laminar runs were obtained on the lower surface as shown in Figure 3.

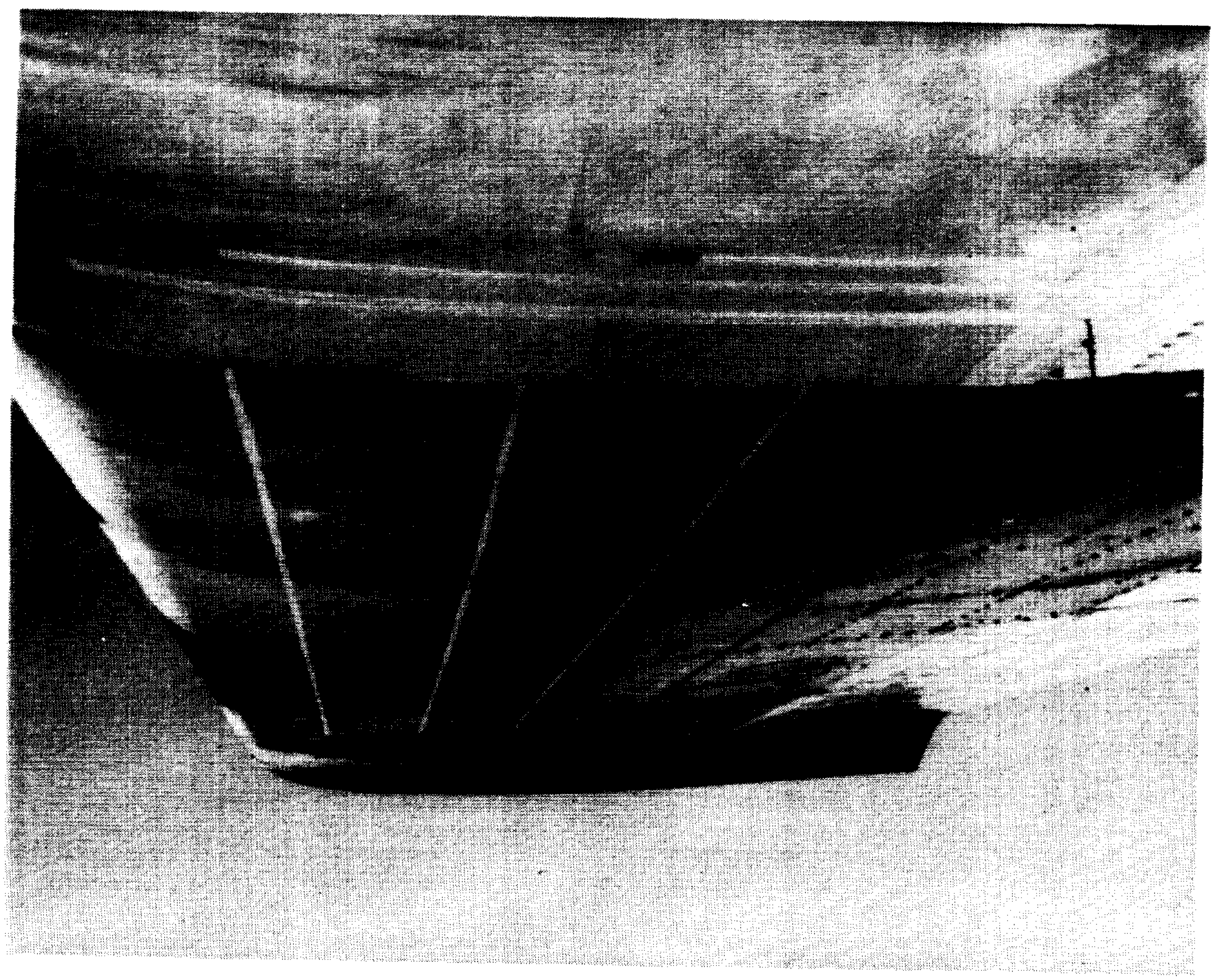

Figure 3

RECENT WING NLF RESEARCH: MAJOR NLF IMPROVEMENTS

As our interest in NLF continued to increase, the 210 prototype wing was modified as shown in Figure 4 with the NLF (1)-0414(F) airfoil designed by J. K. Viken of Complere, Inc. and W. Pfenninger of Analytical Services and Materials, Inc. The program involved construction and flight tests by Cessna and both full-scale and small-scale wind tunnel tests by NASA.

A mixture of polyester resin and glass microballoons was applied to the basic metal construction wing and contoured using sailplane profiling methods. Local waviness was less than 0.003 inch per 2 inches, with most of the forward 70% chord within 0.001 inch per 2 inches. With these tight tolerances, which were more rigorous than necessary, the results were spectacular! Also, since the wing had conventional flaps, ailerons, and spoilers, the need for other means of lift and roll control was avoided.

The wing worked as predicted with runs of laminar flow at cruise to approximately 70% chord; section drag (as measured with an integrating wake rake) matched values obtained in the wind tunnel. No unusual behavior occurred when transition was induced at the leading edge with a trip strip, and stall behavior was good. In other words, a very workable wing was obtained.

The speed increment between having no laminar flow (transition at 5%c) and full laminar flow on the wing was 14 Kts or about 7%.

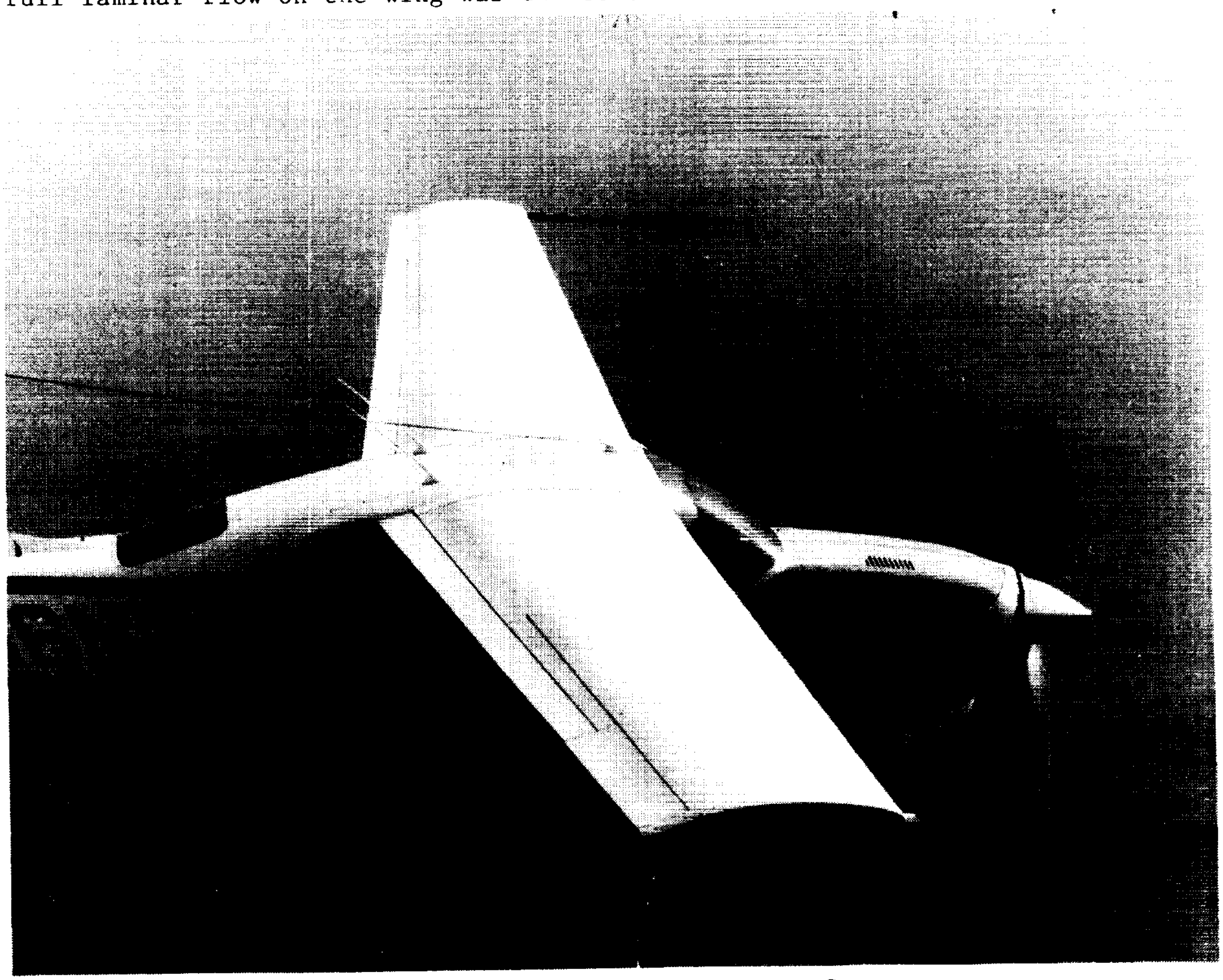

Figure 4

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THREE-DIMENSIONAL BODY NLF RESEARCH

NASA has been working the problem of NLF on 3-D bodies for several years. From lofts of the Cessna T303 fuselage nose provided to NASA by Cessna, computer models of the shape were developed and it was concluded that the nose shapes had good potential for laminar flow. Flight tests in conjunction with Kansas University and NASA are now in the final stage. Preliminary results are encouraging with laminar runs beyond the propeller plane. Figure 5 depicts the test aircraft and results of an initial flight.

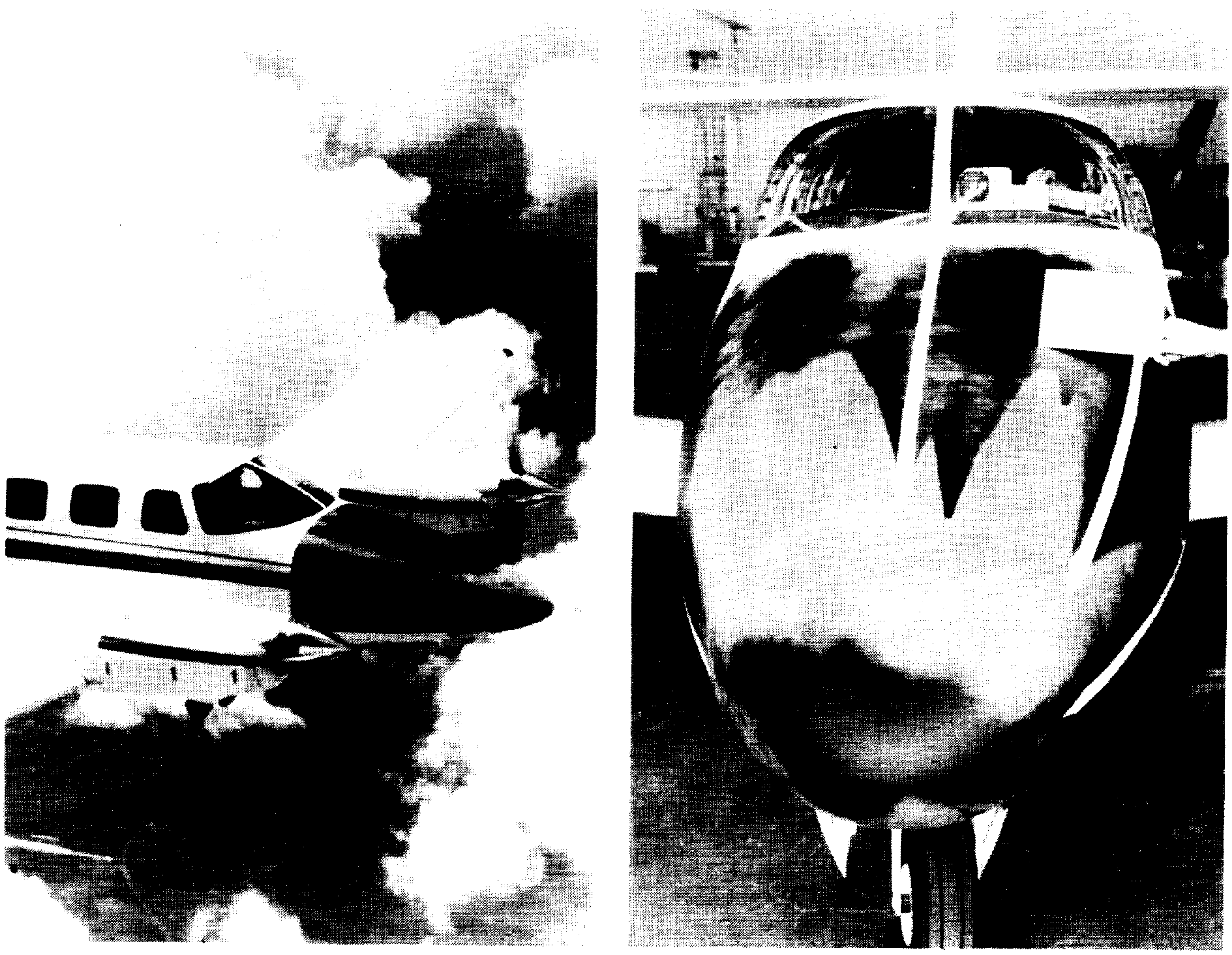

Figure 5

LAMINAR-FLOW CONTROL RESEARCH

The companion to natural laminar flow is laminar-flow control. While the mechanical simplicity of achieving laminar flow by careful tailoring of pressure distribution through contour design is desirable, this may not always be possible. In that case, laminar-flow control through boundary-layer suction may be appropriate.

Cessna's experience with laminar-flow control consists of experiments on the Citation III nacelle under contract to Rohr Industries (Fig. 6).

The nacelle was lengthened approximately 10 inches and the exterior surface of the forward 40% was re-skinned with DYNAROHR™, which has a woven wire exterior surface with honeycomb backup. Suction was applied through the honeycomb. By adjusting the honeycomb size and interior suction, surface suction was controlled as desired.

During the tests, piping connected the surface pressure system to a low pressure tank in the fuselage. Surface pressures were measured and an array of hot film gages were used to determine boundary-layer transition from laminar to turbulent flow. The tests occurred in August and September of 1986 and all data were forwarded to Rohr.

Figure 6

EXPECTED NLF BENEFITS

A comparative study has been made, based on a conventional six-place, single engine aircraft weighing approximately 4700 lb. In one case, flow on the wing and tail was assumed turbulent and in the other, laminar. The NLF speed advantage is 12.5%, and specific range is over 11% better. If the laminar flow of current aircraft is considered, the benefits may be slightly less but still well worth the effort.

NLF CHALLENGES

A. Practical Construction

The new NLF wing has yet to be made on a production airplane. The Cessna 210 test wing is an aerodynamic proof-of-concept article. While it has conventional flaps, ailerons, spoilers and some access panels, it has not been fitted with landing lights, radar pods, pitot tubes, fuel or deicing. However, it is believed that these can be accommodated by paying attention to design details and carefully checking the results. No doubt some unsuspected opportunities will be found as the wing is developed further.

The question of metal versus composites remains, and either is probably acceptable. Therefore, cost and weight will determine which is better for the marketplace. In either approach, the wing surface will have to be built in a female mold for contour control, especially at rib locations. However, this has already been done with both metal and composites, so cost control is the only challenge.

B. Ice Protection

It is generally accepted that conventional deice boots will not be acceptable. The newer versions that have been or are being developed to minimize discontinuities may find acceptance. It is too early to say. Careful tests must be conducted.

TKS, glycol exuding systems are a definite possibility for NLF wings and tail surfaces. This system is used on the latest Citation SII business jet. Although B. J. Holmes' work (ref. 1) has shown that bugs aren't as significant a problem as first suspected, the TKS system has a bug clearing advantage. However, the cost may be prohibitive for small aircraft.

The newest possibility for NLF wing deicing is electro-impulse, which allows a smooth exterior surface. Cessna is quite familiar with this approach since icing flight tests were conducted on a Cessna Model 206 with the system applied to both the wing and tail leading edges and to the wing struts. Some of the testing was done in conjunction with Wichita State University working under NASA and State of Kansas sponsorship; the remainder has been done with in-house funding. As the system is being developed and structural fatigue considerations are being resolved, Cessna is grappling with making leading edges removable with joints that NLF will tolerate.

Thus, deicing is felt to be a solvable problem but it remains to be accomplished in the NLF environment.

C. Transonic NLF

As mentioned earlier, limited experiments have been conducted on the Citation III. NASA is working the transonic NLF problem with some promising results. While compressibility is beneficial, wing sweep is detrimental. It appears that by careful airfoil design and the use of a minimum sweep to prevent drag rise, useful runs of laminar flow may be achieved up to Mach 0.8. It is worth pursuing but will take extensive wind tunnel and flight testing.

D. Certification Rules

Cessna's main concern about this challenge is that it not become disproportionate. Aircraft with varying amounts of NLF have been produced for over twenty years. Although there is a drag change when NLF is lost, acceptable flight characteristics must be maintained; results to date indicate no compromise in safety. Each new certification should not become a research project. In determination to inform the pilot of the effects of losing laminar flow, straight-forward checks and a reasonable amount of testing must be provided. Further, practical data need to be presented, both for certification and in pilot manuals. These items become a real challenge in today's environment - but it may help to remember that NLF isn't new to production aircraft. It would also be beneficial to have test results with a modern NLF wing in the areas of certification concerns before new rule making is started.

SUMMARY

Cessna's perspective is based on over twenty years involvement in laminar flow work, for both research and application to production aircraft. Natural laminar flow is attainable and the more learned, the greater the potential gain. Manufacturing and deicing challenges will be overcome; methods are currently available but achieving solutions with acceptable production costs remains a goal. Nonetheless, aircraft with significant NLF will prevail. Efforts to keep certification reasonable must continue.

The basic thrust at Cessna is to attain greater and greater amounts of natural laminar flow. It provides the design simplicity and greatly aids in achieving significant improvements in aircraft performance.

REFERENCE

1. B. J. Holmes, C. J. Obara, and Long P. Yip: Natural Laminar-Flow Experiments on a Modern Airplane Surface, NASA TP-2256, June 1984.