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New Technology's Challenge to Fuel/Cost Spiral
Whitcomb winglet undergoes tests on a scale model of a USAF/Boeing KC-135 jet tanker in the 8-ft. transonic tunnel at NASA-Langley. Pickup rake is cantilevered in free stream behind the winglet. Tests have shown that lift/drag ratio was improved 8% through reduction in induced drag, which translates as a reduced fuel consumption of 9%. One explanation of the winglet effect is that it creates several smaller trailing vortices that are weaker in total strength than a single wingtip vortex. Another theory is that the forward component of the side-force generated by the airfoil-shaped winglets exceeds their profile drag, yielding a net forward thrust component. Close-up of winglet shows the upper and lower sections inclined outward about 17° to the plane of the wing. Lower section is smaller to permit ground clearance. Pressure pick-up trees are buried in the winglet and wingtip. NASA-Langley estimates that the winglets are four times as efficient for the same weight and wing root bending moment in reducing induced drag as by increasing the aspect ratio of the wing by lengthening the span, and would alleviate airport gate parking problems created by longer spans.

**Langley Presses Fuel Efficiency Programs**

By Warren C. Wetmore

Hampton, Va.—National Aeronautics and Space Administration’s Langley Research Center is mounting a multipronged attack on the problems associated with fuel conservation in commercial transport aircraft, but also is maintaining a modest effort aimed at improving the speed performance of such aircraft.

“We think the fuel efficiency of aircraft can be increased almost without limit over present aircraft,” A. L. Nagel, chief of Aeronautical Systems Div., said. “But we don’t want to lose sight of improving performance, including supersonic aircraft. Even though they are less fuel-efficient, we may still want them.”

The quest for reduced fuel consumption is changing the fundamental design philosophy for aircraft. “We used to optimize aircraft in minimizing their gross weight.” Nagel said. This tended to give the best overall cost of acquisition and operation. “A fuel-optimum aircraft would be somewhat heavier, due to improved aerodynamics, for a given technology,” he said.

In addition to aerodynamics, Langley’s aircraft energy efficiency program includes:

- Composite materials and structures.
- Laminar flow control, which is separated from other aerodynamics work.
- Active controls.
- Unconventional aircraft configurations.

Much of the work in aerodynamics as applied to reducing fuel consumption was developed in the Transonic Aerodynamics Branch, Subsonic-Transonic Aerodynamics Div. in the East Area of Langley, under the leadership of Dr. Richard T. Whitcomb. This includes the first and second generation of supercritical airfoils and vortex diffusers, or Whitcomb winglets, designed to be fitted to the wingtips of aircraft.

“Just as sure as the sun rises, the next new commercial transport aircraft will have winglets.” Whitcomb told AVIATION WEEK & SPACE TECHNOLOGY, “but we may not be able to convince airlines to retrofit the winglets to existing aircraft. The whole subject of flying them is up in the air. We feel if the airlines are going to use them, they would want to see them demonstrated in flight.”

NASA and the Air Force are embarked on a joint program studying the retrofitting of winglets to Boeing KC-135 jet tankers and to Lockheed C-141 transports (AW&ST Nov. 3, p. 11), which may lead to flying the winglets, if funding can be found either from NASA or the Air Force. USAF has awarded study contracts to Lockheed and Boeing, which additionally will determine the effect of the winglets on flutter and static structural strength.

NASA has been running the units in its transonic wind tunnel on half-models of the KC-135 and obtaining an 8% improvement in lift/drag (L/D) ratio, which translates into an estimated 9% reduction in fuel consumption. Whitcomb
said. This would apply more in a newly

designed aircraft due to the cascade effect

on reduced structural weight, lighter en-
gines and lower on-board fuel require-
mets for the same range.

Commercial transports now in exist-
ence would not benefit to the same de-
gree as an entirely new design. Whitcomb

nevertheless believes that an average fuel

saving of 7% would result from retro-
fitting the winglets.

"By next year, U.S. airlines will be

spending $3 billion on fuel," he said. "The

saving would be $200 million with a

7% improvement in fuel economy. Our

guess is that the winglets would pay for

themselves in a year."

Winglets reduce induced drag through-
out the entire operating regime of an air-
craft, Whitcomb said, and the percentage

reduction at high lift coefficients is the

same as at low. At high lift, the induced
drag is much higher, so its reduction is

much greater. This can give a higher rate

of climb—thus ameliorating problems

with noise on the ground—or, alternati-
vely, can be used to get more payload

off the ground.

One of the ways of increasing the ef-
iciency of an aircraft is to increase the as-
pact ratio of its wing. This leads to greater

wingspans and their attendant problems

with maneuvering and parking on the

ground. "We can't go to an aspect ratio of

12, which would give the best L/D," he

said.

The airframe industry has been consid-
ering folding wingtips such as Navy car-
rier aircraft have used for over 30 years.

Whitcomb believes he has a more elegant

solution.

"Why not use big, fixed winglets?" he

said. "Essentially, this would be like turn-
ning up the wingtips to get a higher aspect
ratio effect. Winglets are four times as

efficient in reducing drag as wingtip ex-
tensions, for the same weight and wing-

root bending moments. A longer-span

wing creates the need for a stronger wing-

root structure to compensate for the

higher moments.

Such winglets would have about twice

-the area as winglets designed for retrofit
to existing aircraft, and would have a

height 40% greater. The optimum semi-

span aspect ratio is about 2.5. This would

enable keeping the aspect ratio to 10 and

the span within manageable limits.

"We have not yet optimized a design

constrained in span, assuming it to be de-
sign from the start to include winglets,"

Whitcomb said. "We'll be getting into

this with wind tunnel testing."

The wing probably would be designed

with a taper ratio of 0.4-0.5, compared

with the current figure of about 0.3, in or-

der to give a wider tip chord to mount the

larger winglet.

A new avenue in drag-reduction lies in

an element that has had a passive struc-
tural function in the past—engine pylons.

"If you design the engine pylons right,
you can get lower induced drag by 3-4%,"

Whitcomb said. These pylons would be

configured as lifting airfoils. "They are

not as efficient [as winglets] because they

are farther inboard, but they're still

worthwhile." In certain twin-engine in-
stallations, the pylons could be relocated

farther outboard.

On the Lockheed C-5A transport, air-
foil pylons could reduce induced drag by

about 5%, he said.

Whitcomb's branch also is in the pro-
cess of designing a family of second-gen-
eration supercritical airfoils, which will

have the designation SC-2. "Earlier this

year," he said, "we got a tremendous out-

cry from industry because we didn't have

a family." These airfoils exhibit a flat

drag plot before the elbow at the drag-

rise Mach number, rather than a slight in-
clination upward as in the earlier airfoils,

but at a small sacrifice, of the order of

0.01 Mach, in the point at which the drag

rise occurs.

Airfoils in the family range in thickness

ratio from 18% to 14%—for transports—
down to 3%, which would be useful for a

high-speed supercritical propeller and

of Hamilton Standard Div. of United Tech-

nologies. Lift coefficients range from 0.4
to 1.0.

Design criteria of the airfoils are still

security-classified. Whitcomb and his

group now have a new theory to refine

airfoil shape. An analytical method was
developed under NASA grant by David

Korn, Antony Jameson, Frances Bauer

and Paul Garabedian in what Whitcomb
calls "probably the best applied mathe-

matics group in the country" at New

York University.

"Predictive ability is quite close to

wind-tunnel results," he said. "We now

feel safe using it as a design tool. It can
be used for detail design—it tells you what would happen if you changed the airfoil a little here, a little there.” The analytical tool is available as a computer program.

NASA's very large aircraft systems technology (VLAST) program will employ supercritical aerodynamics, in order to gain thick, efficient wings with good drag characteristics. The program has a number of technology goals to be accomplished by 1980:

- **Investigate and develop** large transport concepts having substantial improvements in payload efficiency and economy in design, construction and operation.

- **Develop an evaluation base** that covers total system performance—technology impact, economics, operation and market requirements.

- **Identify and conduct** research in the areas of propulsion-lift, thick airfoil development, configuration studies, air-cushion landing systems, active controls, and composite structures.

- **Determine the need** for flight experiments and demonstration aircraft.

The large-aircraft program now covers several aircraft types:

- **Span-distributed load** aircraft, which have a thick wing in which the cargo is loaded and greatly increased structural efficiency. Wing-root structure does not have to take the full bending moments of a conventional, loaded fuselage. In this category are more or less conventional-appearing wing-and-fuselage aircraft and flying wings. The latter include designs by Lockheed and by NASA. NASA's cargo wing has a gross weight of 2.4 million lb., a payload of 1.2 million lb., a 20%-thick wing with a 30-deg. sweep, an aspect ratio of 7 and a span of 375 ft.—nearly twice that of the Boeing 747. At a speed of 430 kts., this aircraft could fly 6,500 naut. mi. at a fuel efficiency of 3.3 ton-naut-mi. per pound of fuel, as compared with about 1.5 for the Lockheed C-5A.

- **Externally braced wings.** This is a structurally more efficient way of supporting high-aspect-ratio wings, which are themselves aerodynamically very efficient, as compared with cantilever designs. The problem of drag on the struts would be alleviated largely by using thinner profiles in composite materials.

- **Surface-effect takeoff** and landing (SETOL) aircraft, possibly hydrogen-fueled, would have a partial boat hull and operate from water in and out of containership port facilities. Cargo would be stored in the wing, up to 1 million lb. for a 2.5-million-lb. gross weight. The design would use 10 or 12 engines of the size that power the Boeing 747, and its operable principal involves entraining deflected exhaust gases to form a surface-effect cushion under the large-chord wing, which would have an aspect ratio of 2-4.

- **Flying boats.** Germany's Dornier has proposed a multinational effort to build a large, modern flying boat grossing out at several million lb.

NASA's Allen Whitehead noted that the large aircraft program designs generally have a constant-chord wing to simplify construction and reduce the parts count by 50%.

NASA's efforts in active controls are aimed at producing fuel efficiency by reducing structural weight required for flutter suppression and maneuver- and gust-load alleviation and by allowing negative static stability, which means a smaller, lighter empennage.

Flutter suppression and load-alleviation would facilitate the development of a high-aspect-ratio wing without a severe weight penalty for strengthening the wing root to handle the bending moments. Essentially, the flight control surfaces would be actuated to shape the wing loading during flight through turbulence and during maneuvers.

There may be nothing in the federal air regulations prohibiting active controls, a NASA engineer said. “We just have to prove its safety.”

NASA's program in laminar flow control (LFC) is gathering a head of steam. Lockheed has done some preliminary configuration design under contract, and Boeing has built some examples of wing slot-and-duct designs with composite and
titanium skins. A slot arrangement was used on the USAF/Northrop X-21 lami-
nar flow research aircraft.

Perforated skin also can be used, and this and the slot are a good approxima-
tion to the ideal porous wing surface through which air would be sucked to
thin down the boundary layer and main-
tain laminar flow over the wing. The
porous surface—actually, a very dense fil-
ter of 1% porosity or less—possibly can be
made of a woven composite, such as
graphite epoxy.

"Here's where innovation comes in,"
said Albert L. Braslow, head of the Sys-
tems Technology Branch, who is in
charge of the laminar flow control effort
at Langley. "We must try to marry the
best characteristics of each type into a
practical design."

Possible Problem

One of the problems associated with
laminar flow control lies in maintenance,
in keeping obstructing debris out of the
system. "My feeling is that you would not
use laminar flow on takeoffs because of
the ingestion problem," Braslow said.

Lockheed designed two aircraft using
the most modern technology, one with
and one without laminar flow control,
with a 5,500-naut-mi. range design point
and capable of carrying about 200 pas-
sengers. Because of the range, both had
wingtip auxiliary fuel tanks, though this
would not be necessary in aircraft carry-
ing 400 passengers.

This design had small gas turbine en-
gines mounted in wing fairings to provide
15-20 lb./sec. of airflow through the su-
tection system. Such turbines could be
mounted in the fuselage in a larger air-
craft, which would also give an increase
in the amount of wing to which suction
can be applied.

The design aircraft also had laminar
flow control over only 75% of the wing
chord, a conservative approach, and the
study assumed no laminar flow would be
used during climb.

Fuel Use Reduced

Results were a 25% net reduction in
fuel consumption over the conventional
advanced design. Direct operating costs
of the two were identical at a fuel price of
25 cents/gal., but the laminar-flow con-
trol aircraft was markedly superior at 50
cents/gal. It also was able to use smaller
and cheaper engines, but on the whole
would cost about $2 million more per
copy than the advanced conventional air-
craft.

In general, the fuselage of aircraft
would also benefit from laminar flow
control, but there are additional prob-
lems with turbulence tripers—protru-
sions and irregularities such as wind-
shields, doors and hatches. An alternative
is fuselage blowing, thus avoiding a penalty in
ram drag.

Braslow outlined a basic three-phase
program aimed at proving the economics
of laminar flow control:

- **Phase 1**—Investigations would in-
volve surface materials and main-
tainability, and the disciplines of aerody-
namics, acoustics and structures.
- **Phase 2**—"If everything still looks
go" at this point," Braslow said, "we'd
put more emphasis in subsystems. Air-
pumps for the suction are an example.
- **Phase 3**—Demonstrate and validate
laminar flow control in flight, with a re-
search vehicle based on an existing air-
craft with a new wing and perhaps a new
tail where suction would be applied.

"Everybody agrees that you have a hell
of a payoff with LFC," he said, "but the
question is, 'Can you do it on a day-to-
day basis?'"

![Graph of CD vs. Mach Number](image)

Second generation supercritical airfoil (solid line) has been refined to eliminate the drag
creep exhibited by the earlier version (broken line)—the slow steady increase in drag coeffi-
cient before the drag-rise Mach number is reached. First supercritical wings designed for
possible eventual production are being flown on USAF's two advanced medium STOL
transport rivals, the McDonnell Douglas YC-15 and the Boeing YC-14.