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FIXED WING CCW AERODYNAMICS WITH AND WITHOUT SUPPLEMENTARY THRUST DEFLECTION

J. H. Nichols and M. J. Harris

Department of the Navy
David Taylor Naval Ship Research and Development Center

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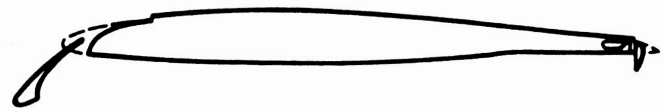
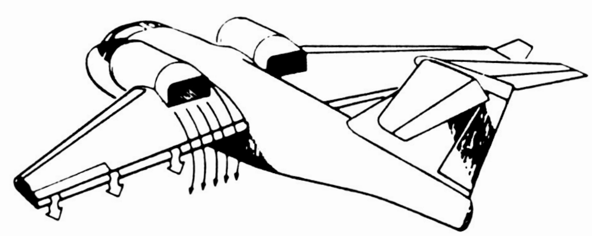


DEVELOPMENT OF ADVANCED HIGH LIFT SYSTEMS

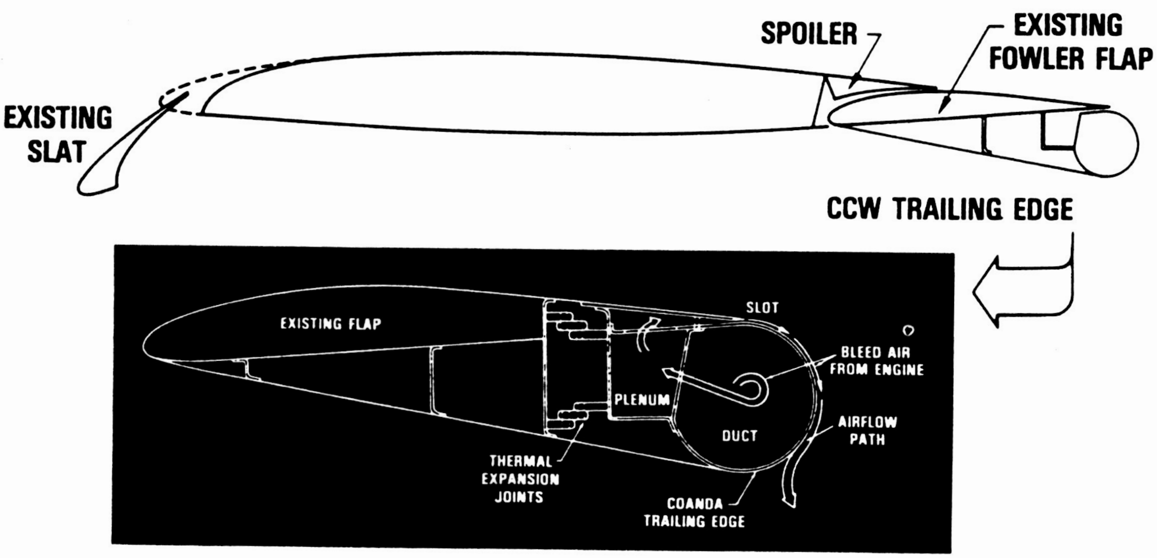


I. Development of high-lift airfoils employing circulation control has been underway at the David Taylor Naval Ship Research and Development Center (DTNSRDC) since 1969. Hybrid systems which combine circulation control with propulsive-lift concepts, like circulation control/upper surface blowing, are also being developed. This presentation will review the highly successful flight demonstration of circulation control on a Navy/Grumman A-6A aircraft and provide an overview of the continuing evolution of circulation control airfoils for fixed-wing applications.

A-6 CIRCULATION CONTROL WING

II. In 1979 a modified A-6A aircraft demonstrated the STOL capability of circulation control. This aircraft is shown as it was modified for this proof-of-concept flight demonstration. Externally the modifications included: a tapered cylindrical wing trailing edge, bleed air cross-over duct under fuselage, Krueger flap on the wing gloves, modified leading edge slats and modified horizontal tail.

CCW TRAILING EDGE APPLIED TO A-6 FLIGHT DEMONSTRATOR WING SECTION



III. The A-6/circulation control airfoil used in the flight demonstration is shown here in cross section. Air bled from the fifth and twelth compressor stages of the two J52-P-8B turbojet engines on the A-6 is ducted along the wing span in the cylindrical trailing edge. The bleed air exits the cylindrical trailing edge, passes through the plenum and is ejected out through a thin slot in the aft upper surface of the airfoil. The thin jet sheet from the slot adheres to the cylindrical trailing edge, due to the Coanda effect, and flows down around this surface. The jet sheet provides boundary layer control and significant augmentation of the lift generated by the wing.

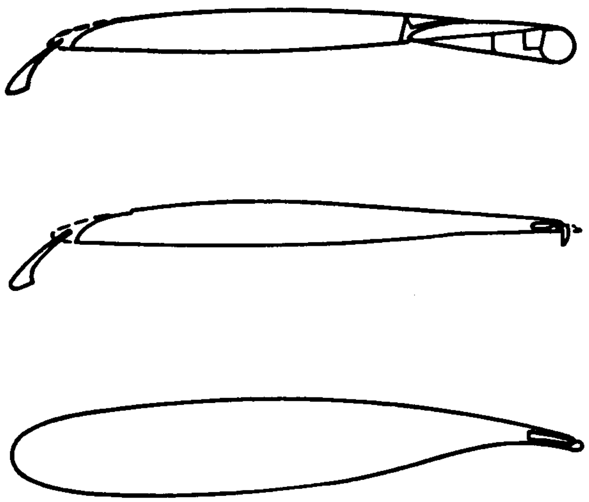
A-6/CCW
STOL PERFORMANCE

	A-6 (30° FLAPS) (REF)	A-6/CCW
85% INCREASE IN $C_{L_{MAX}}$	2.1	3.9 ($C_\mu = 0.30$)
35% REDUCTION IN POWER-ON APPROACH SPEED	118 KTs. ($C_L = 1.49$)	76 KTS (0.75 P_{MAX}, $C_\mu = 0.14$, $C_L = 2.78$)
65% REDUCTION IN LANDING GROUND ROLL	2450 FT	900 FT
30% REDUCTION IN LIFT OFF SPEED	120 KTS ($C_L = 1.41$)	82 KTS (0.6 P_{MAX}, $C_\mu = 0.04$, $C_L = 2.16$)
60% REDUCTION IN TAKEOFF GROUND ROLL	1450 FT	600 FT
75% INCREASE IN PAYLOAD/FUEL AT TYPICAL OPERATING WEIGHT (EW = 28,000 LB.)	45,000 LB.	58,000 LB.

BASED ON FLIGHT DEMONSTRATION RESULTS
TOGW = 35,700 LB., LGW = 33,000 LB.
CORRECTED TO SEA LEVEL, STANDARD DAY

IV. Based on results from the flight demonstration, the A-6/circulation control aircraft achieved an 85-percent increase in maximum lift coefficient when compared to a standard A-6 with Fowler flap deflected 30-deg. This increase in lift coefficient was used to reduce the power-on approach velocity by 35-percent which results in a 65-percent reduction in landing ground roll. During takeoff the increase in lift coefficient provides a 30-percent reduction in lift off velocity which results in a 60-percent reduction in takeoff ground roll. Alternatively, at a takeoff velocity of 120 knots the 85-percent increase in maximum lift coefficient can provide a 75-percent increase in payload/fuel weight.

CCW CONFIGURATION DEVELOPMENT



A-6/CCW

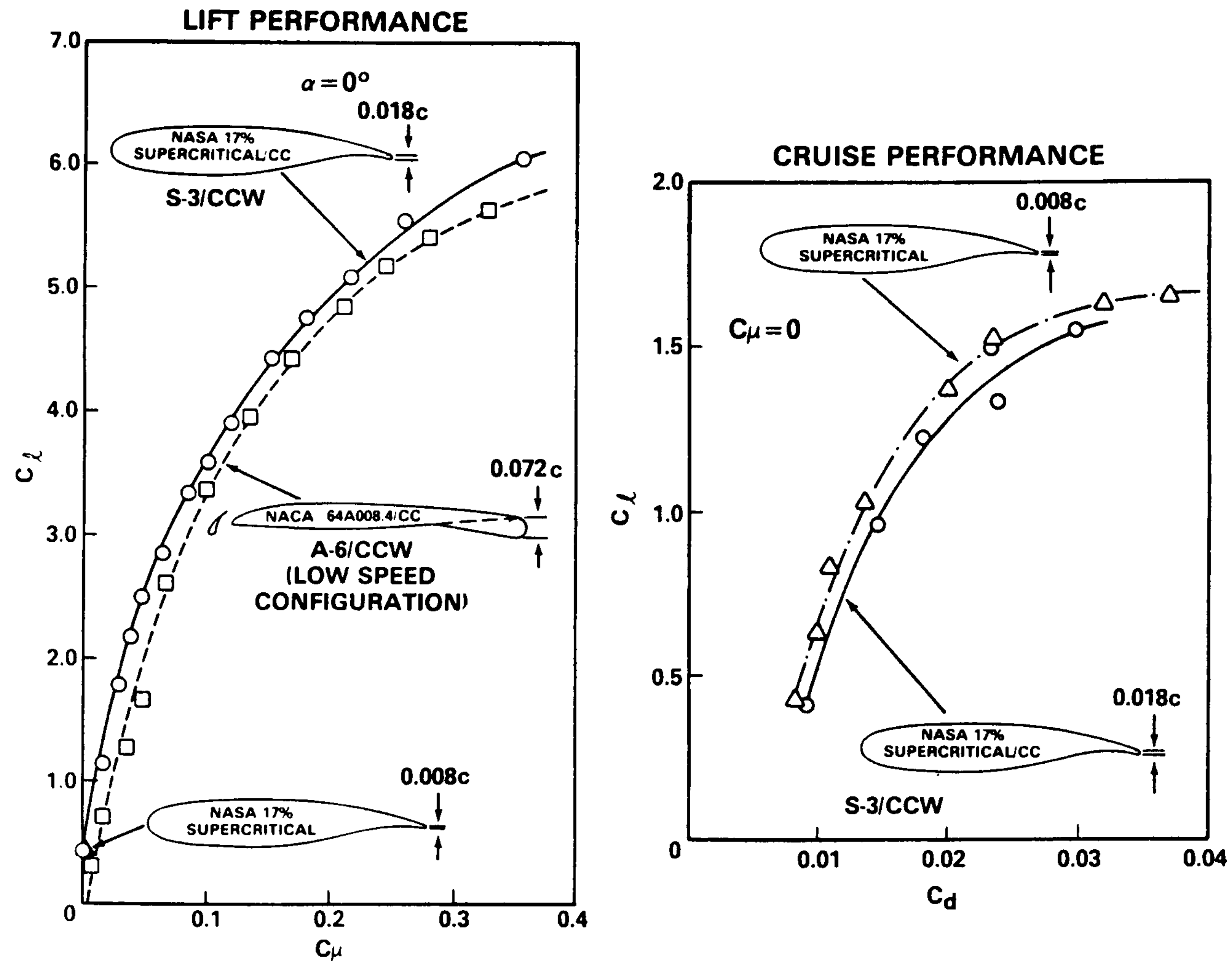
A-6 DUAL RADIUS FLAP

THIN T.E. SUPERCRITICAL/CCW

V. The radius of the cylindrical trailing edge used in the flight demonstration was 3.65-percent of the local wing chord. This relatively large surface could not remain deployed during cruise flight. Several concepts were proposed for converting this airfoil from the high-lift configuration to the cruise configuration. These concepts included: inflatable trailing edges, flaps which rotate nearly 180-deg exposing the cylindrical surface and complex mechanical systems which rotate or translate the cylindrical surface forward into the airfoil

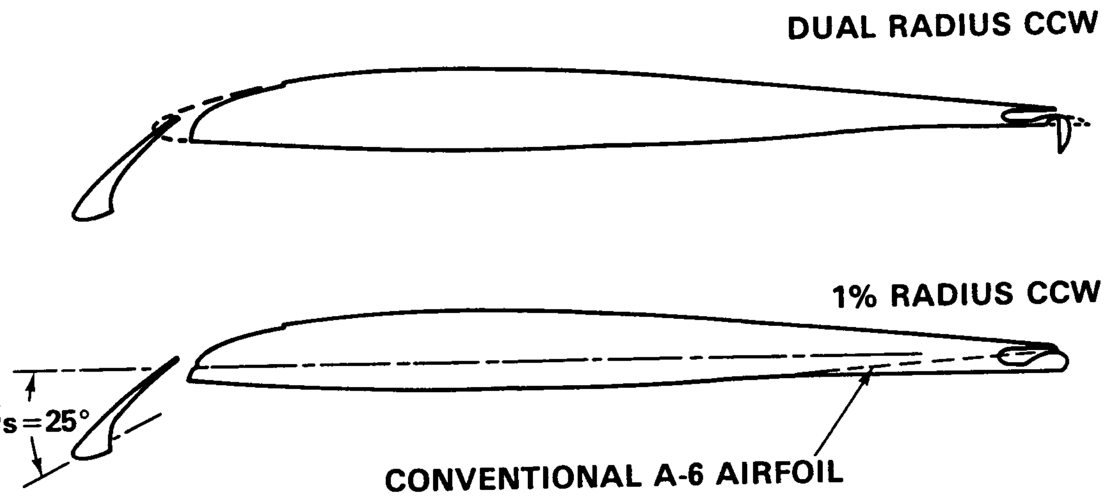
Two mechanically simple alternatives to the large radius trailing edge used in the flight demonstration, which are being developed at DTNSRDC, are the dual radius circulation control flap and circulation control trailing edges with a radius small enough so it can remain deployed and still have minimal impact on cruise flight.

CCW AIRFOIL PERFORMANCE



VI. The concept of a circulation control trailing edge which has a base thickness less than two-percent of the wing chord was successfully demonstrated on a supercritical airfoil. Wind tunnel investigations have confirmed the capability of this combination of supercritical airfoil and small radius circulation control trailing edge to achieve, at STOL velocities, lift coefficients equivalent to the lift coefficient achieved in the A-6/circulation control flight demonstration. This combination also results in an airfoil which converts from high-lift configuration to cruise configuration by simply terminating the flow of bleed air to the blowing slot. Since this trailing edge remains deployed during cruise flight no retracting mechanism is needed.

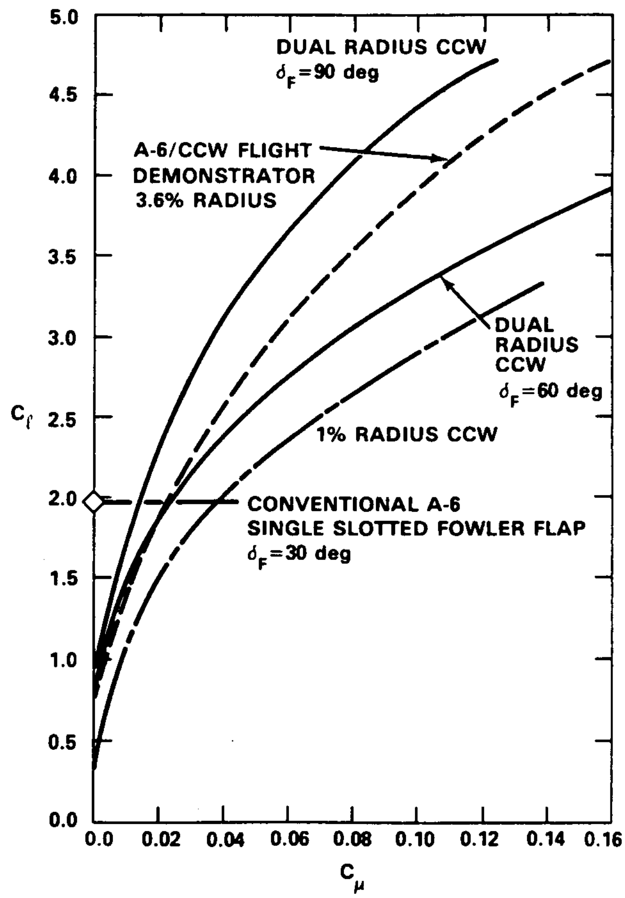
A-6/CCW
CRUISE CONFIGURED AIRFOILS



VII. A circulation control trailing edge with a radius of one-percent of the wing chord was also evaluated on the A-6 airfoil along with the dual radius circulation control flap. The dual circulation control flap is a short chord flap which, when rotated from 60 to 90 deg, provides a circulation control trailing edge. The dual radius flap currently being evaluated is 3.5-percent of the wing chord. Dual radius refers to the two arcs which make the upper surface of this flap. In this case the flap leading edge radius is one-percent of the wing chord and the flap trailing edge radius is four-percent of the wing chord.

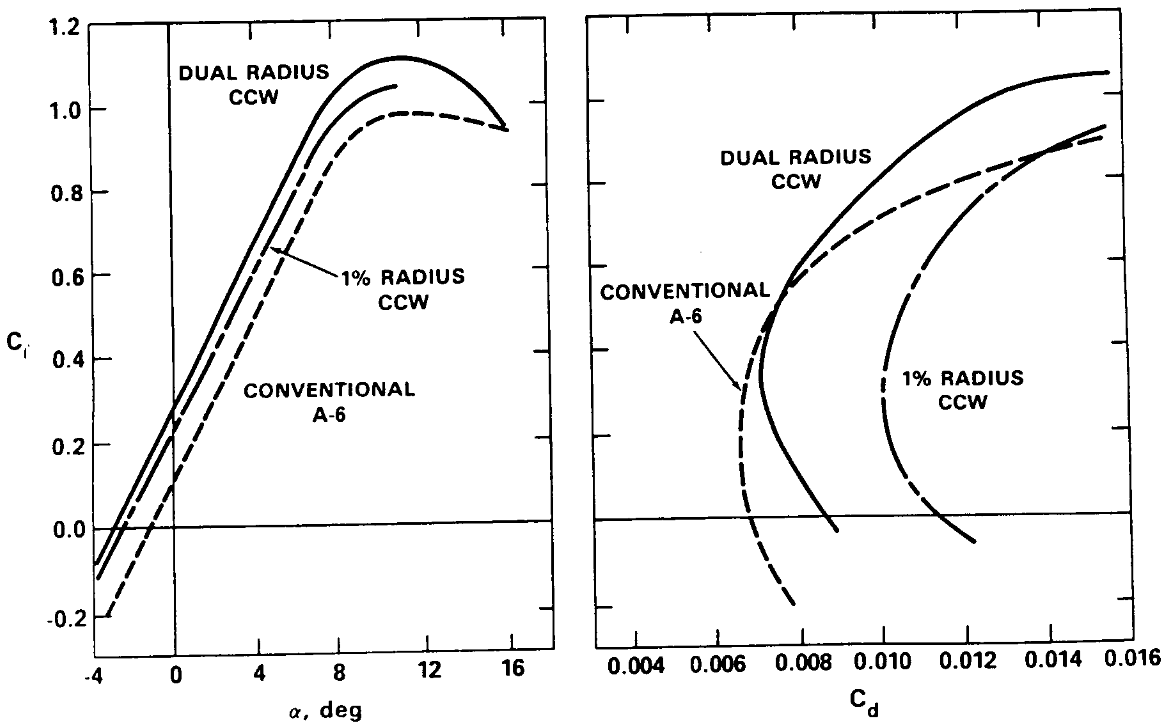
COMPARISON OF BLOWN LIFT AUGMENTATION

$\alpha_g = 3$ deg
$\delta_{Slat} = 25$ deg



VIII. The A-6 airfoil with either the one-percent radius circulation control trailing edge or the dual radius circulation control flap achieved lift coefficients at relatively low blowing levels which are higher than can be achieved with a single slotted Fowler flap deflected 30 deg. With the dual radius circulation control flap deflected 90 deg, lift coefficients achievable at low to moderate blowing levels are higher than the lift coefficients achievable with the large radius circulation control trailing edge used in the flight demonstration.

CLEAN AIRFOIL COMPARISON (NO BLOWING)



IX. The mechanical system required to rotate the dual radius circulation control flap would be equivalent to the system required for a simple single slotted Fowler flap. The undeflected dual radius circulation control flap would have no significant impact on cruise performance. The dual radius flap provides a means of mechanically varying the wing chamber independent of the circulation control blowing.

The impact of the one-percent radius circulation control trailing edge on cruise performance is significant enough to require that this surface be retracted during cruise flight. Retracting the small radius circulation control trailing edge would be considerably simpler than the large radius surface used in the flight demonstration.

Conclusions:

The concept of circulation control has been successfully demonstrated in flight using an A-6 aircraft.

Circulation control can provide an aircraft with STOL performance of heavy-lift capability.

For ship based Naval aircraft the lower takeoff and landing velocities result in reduced deck gear and wind-over-the-deck requirements.

Circulation control airfoil can be mechanically less complex and light weight compared to multi-element high-lift airfoils.