APPLICATION OF PNEUMATIC LIFT AND CONTROL SURFACE TECHNOLOGY TO ADVANCED TRANSPORT AIRCRAFT

by

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TRANSPORTATION BEYOND 2000:
ENGINEERING DESIGN FOR THE FUTURE

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Introduction

The application of pneumatic (blown) aerodynamic technology to both the lifting and the control surfaces of advanced transport aircraft can provide revolutionary changes in the performance and operation of these vehicles, ranging in speed regime from Advanced Subsonic Transports to the High Speed Civil Transport, and beyond. This technology, much of it based on the Circulation Control Wing blown concepts, can provide aerodynamic force augmentations of 80 to 100 (i.e. return of 80-100 pounds of force per pound of input momentum from the blowing jet). This can be achieved without use of external mechanical surfaces. Clever application of this technology can provide no-moving-part lifting surfaces (wings/tails) integrated into the control system to greatly simplify aircraft designs while improving their aerodynamic performance. Lift/drag ratio may be pneumatically tailored to fit the current phase of the flight, and takeoff/landing performance can be greatly improved by reducing liftoff/touchdown speeds and ground roll distances. Alternatively, great increases in liftoff weights and payloads are possible, as are reductions in wing and tail planform size, resulting in optimized cruise wing designs. Furthermore, lift generation independent of angle of attack provides much promise for increased safety of flight in the severe updrafts/downdrafts of microbursts and windshears, which is further augmented by the ability to sustain flight at greatly reduced airspeeds. Load-tailored blown wings and blown wing tips can also reduce tip vorticity during high-lift operations and the resulting vortex wake hazards near terminal areas. Induced drag due to lift can also be decreased. Reduced noise may also be possible as these jets can be made to operate at low pressures and reduce noise-producing turbulence.

The following presentation will support the above statements through discussions of recent experimental and analytical research and development of these advanced blown aerodynamic surfaces, portions of which have been conducted for NASA. Also to be presented will be predicted performance of advanced transports resulting from these devices. Suggestions for additional innovative high-payoff research leading to further confirmation of these concepts and their application to advanced efficient commercial transport aircraft.

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"TRANSPORTATION BEYOND 2000"
September 27, 1995
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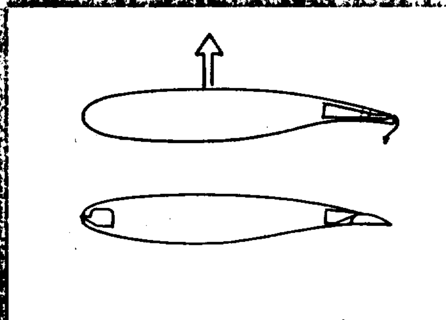
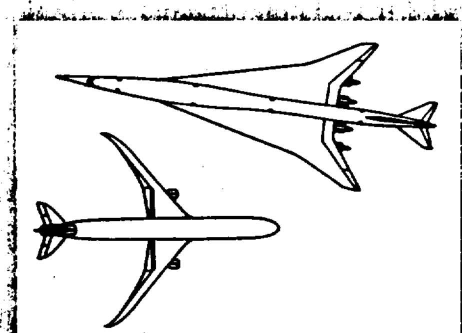


PNEUMATIC AIRFOILS

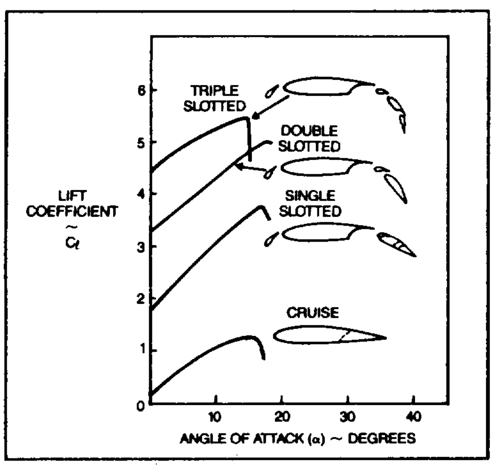


ADVANCED TRANSPORT AIRCRAFT

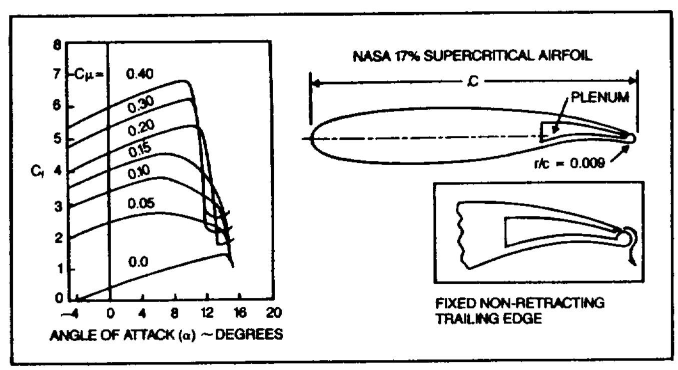
- **No-Moving-Part Aerodynamic Force Augmentor**
- **Pneumatic Control Surfaces**
- **Safety of Flight**
- **Simplicity & Synergism: Aero/Propulsion/Stability & Control**

Comparison of Circulation Control Wing and Mechanical High-Lift Systems

The application of tangential blowing to round or near-round trailing edges of helicopter rotor blade sections has been under development and flight testing for a number of years. Very high lift augmentation, ($\Delta C_l/C_\mu$= 80-100 without any moving flap components) was verified during two-dimensional (2-D) wind-tunnel testing. This suggested the application to high-lift systems of fixed wing aircraft. As shown in the figure below, the application of a trailing edge radius equal to 0.9 % wing chord produced maximum lift coefficients nearing 7.0, and values of 6 at α=0°. The real potential is the very low blowing coefficient (C_μ= mass flux x jet velocity/qS) at which these values are achieved; these coefficients could conceivably be obtained from direct bleed of existing engines (to be discussed later). An interesting comparison between the blown airfoil and the multi-element mechanical high-lift systems is shown. It required double or triple-slotted flaps and mechanical leading edges to achieve lift performance comparable to the blown no-moving-part CCW/Supercritical section shown. The following figures show the confirmation of blown high-lift augmentation during flight test and further airfoil/wing developments as background. These lead up to recent developments of advanced pneumatic high-lift and control-surface configurations and applications.



MULTI-ELEMENT MECHANICAL HIGH-LIFT AIRFOILS



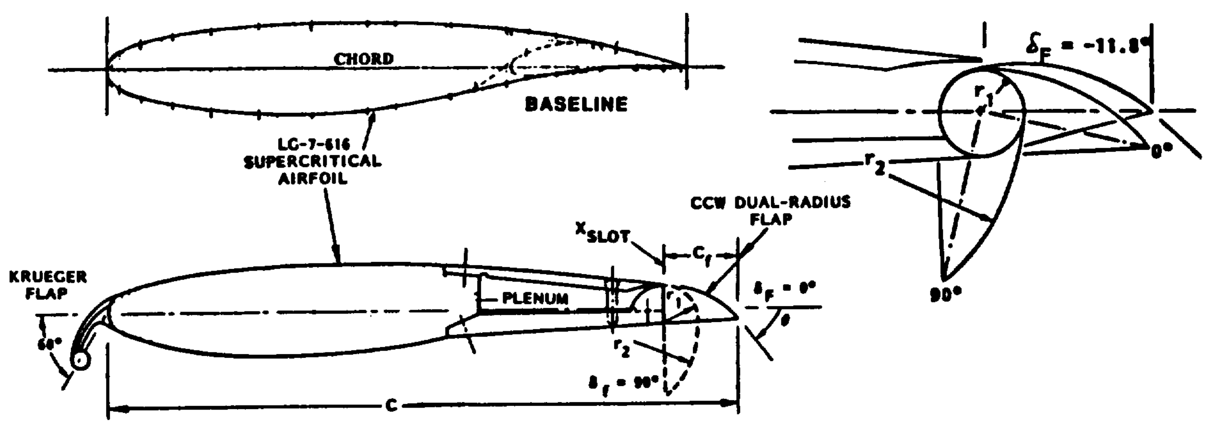
NO-MOVING-PART CCW/SUPERCRITICAL AIRFOIL

The Flight Test of the CCW Concept on the A-6/CCW Flight Demonstration Aircraft

After a series of 2-D airfoil and 3-D developmental wind-tunnel investigations, a fixed Circulation Control Wing (CCW) trailing edge was installed on a Grumman A-6 Intruder flight-test aircraft for a proof-of-concept program. The high-lift system was fixed to the existing wing with air supply lines connected externally to the existing J-52 turbojet engine bleed ports. In this somewhat limited configuration a maximum C_μ of 0.26 was available. Flight test results confirmed an increase of 85% in maximum lift coefficient relative to the existing Fowler-flap/leading-edge-slat high-lift system; but more importantly, an improvement of 140% in usable approach/takeoff lift coefficient was confirmed. Limited STOL performance testing showed reductions in approach takeoff speeds of 30-35% and ground roll reductions of 60-65% relative to the standard A-6. Actual measured ground rolls of 600-700 feet and flight speeds as low as 65 knots showed that a light-weight A-6/CCW could have operated from a big-deck aircraft carrier without use of catapult or arresting gear. Also, the new system allowed up to a 75% increase in A-6 liftoff payload for the same ground roll.

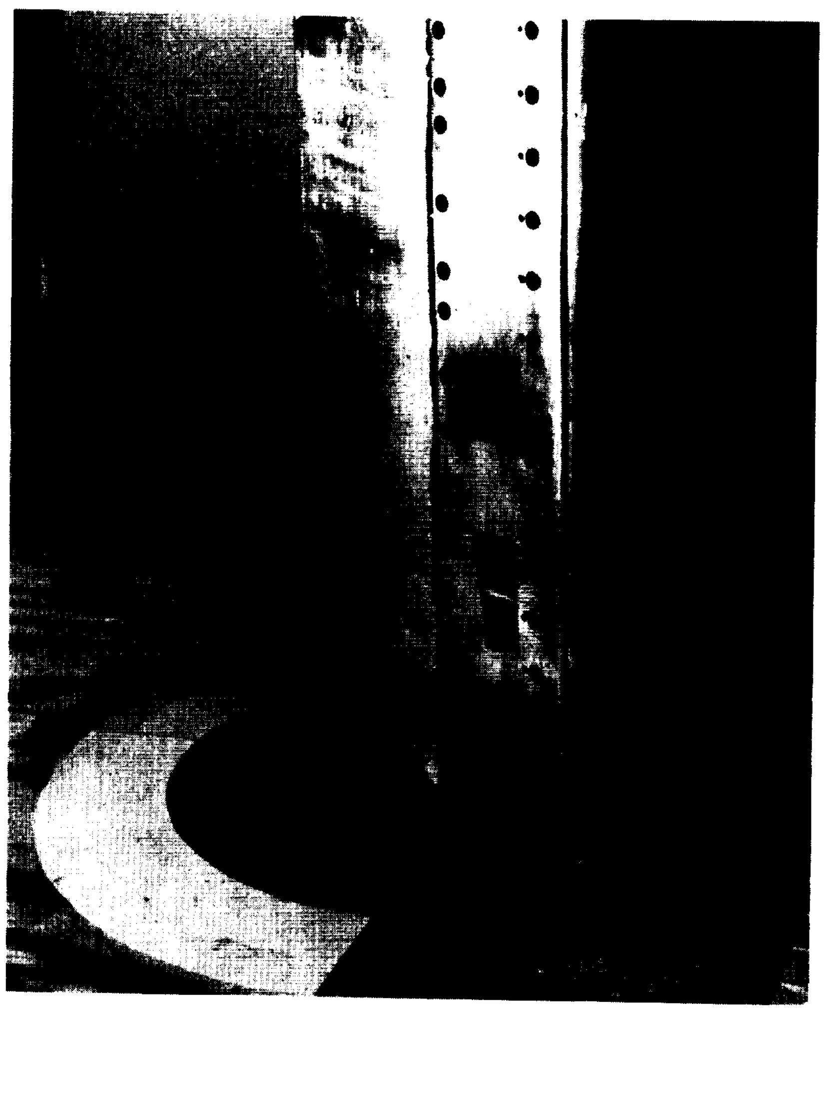
Dual-Radius Circulation Control Wing Configuration with Krueger Leading-Edge Device

The one disadvantage of the round or near-round CCW configuration was high base drag in cruise. An alternate configuration known as the Dual-Radius CCW airfoil was developed at David Taylor Naval Ship R and D Center and at Lockheed Aeronautical Systems Company-Georgia. As shown here applied to a 17% supercritical airfoil, this short-chord flap rotated up to 90° about a lower surface hinge point, exposing a small-radius (r_1) CCW surface. The upper surface of the small flap (normally 10-11% chord, but as low as 5% chord has been demonstrated) was a second much larger radius (r_2) which provided excellent jet turning when deflected to flap angles as high as 90°. When retracted, a sharp trailing edge existed for cruise, and the large upper surface radius yielded little if any aft flow separation. The airfoil shown here was tested extensively at LASC-Georgia. A mechanical Krueger leading-edge flap deflected 60° was initially installed to keep the leading edge flow attached at the very large supercirculation and high upwash produced by the blown trailing edge. Results are shown on the following pages.



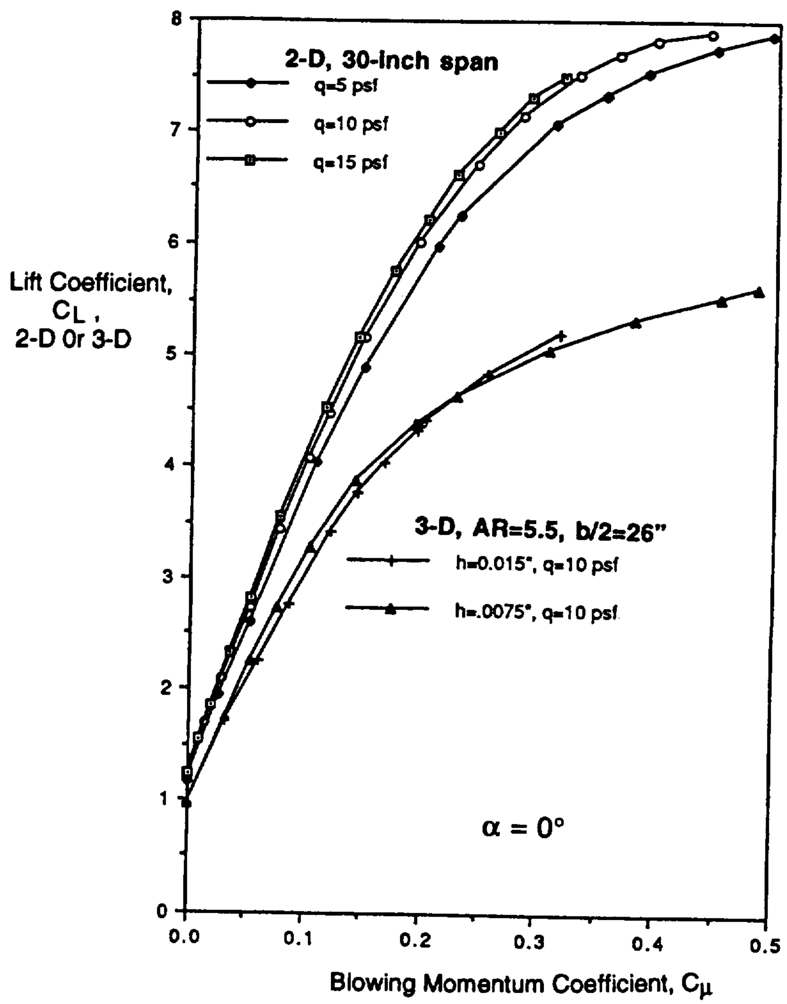
Aft View of Dual-Radius CCW Airfoil Showing Jet Turning and Attachment to 90° CCW Flap

This picture shows a 2-D airfoil with the dual radius CCW flap installed, mounted in the subsonic Model Test Facility research wind tunnel at GTRI. The CCW flap is deflected 90°, which allows turning of the tangential jet to as much as 130-135°down from the aft chordline. Jet attachment is shown by the tuft. Note that the very high flow entrainment and supercirculation allow this airfoil to generate positive large lift at very large negative angles of attack. This test setup allowed various flap deflection angles to be evaluated. It also allowed the 2-D airfoil to be withdrawn through the floor to produce a 3-D rectangular planform wing of constant airfoil section to investigate three-dimensional loading and tip effects.



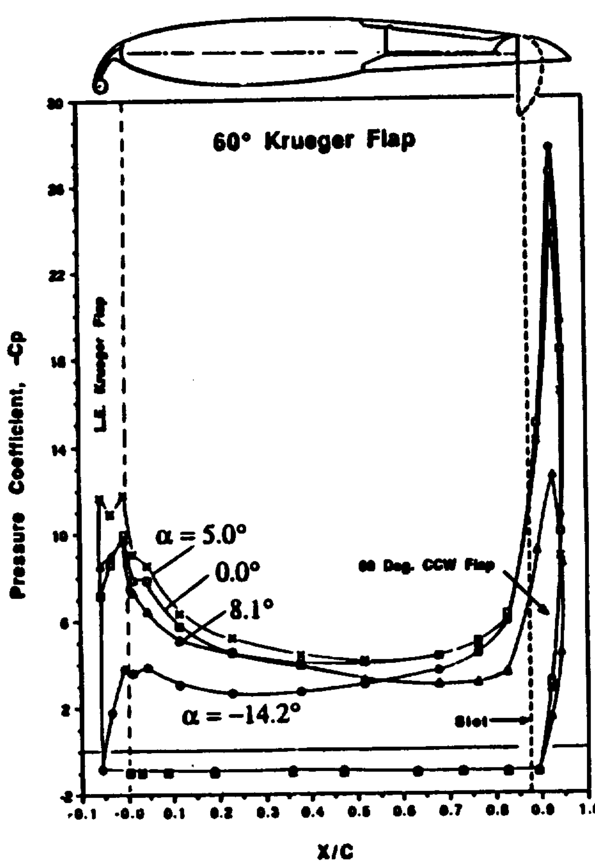
2-D CCW Lift Comparison Showing 3-D and Tip Vortex Effects

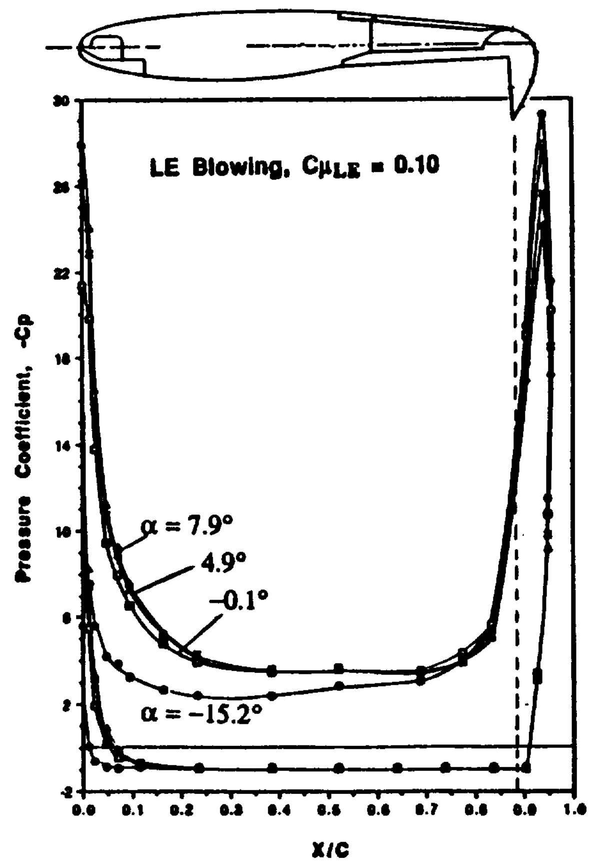
These data show lift performance at $\alpha=0°$ for both the 2-D dual-radius-CCW airfoil with a 60° Krueger LE flap and 90° CCW flap and an aspect-ratio 5.5 semi-span wing created when this airfoil model was retracted through the tunnel floor. Two-dimensional lift values of nearly 8 were generated for C_μ of 0.4. The lift improvement of this dual-radius flap over the previous round CCW trailing edge is approximately 35% and is accompanied by greatly reduced cruise drag (to be discussed later). The 2-D lift improvement represents a factor of 2 to 4 increase over the mechanical flaps of previous slides at $\alpha=0°$. Note also the lift reductions that occur due to tip vorticity and span wise effects when the airfoil is converted to a 3-D semi-span wing. Nevertheless, the resulting C_L values of greater than 5 at $\alpha=0°$ are still appreciable.



Blown Leading Edge Effectiveness on CCW Airfoils, $C_\mu = 0.28$

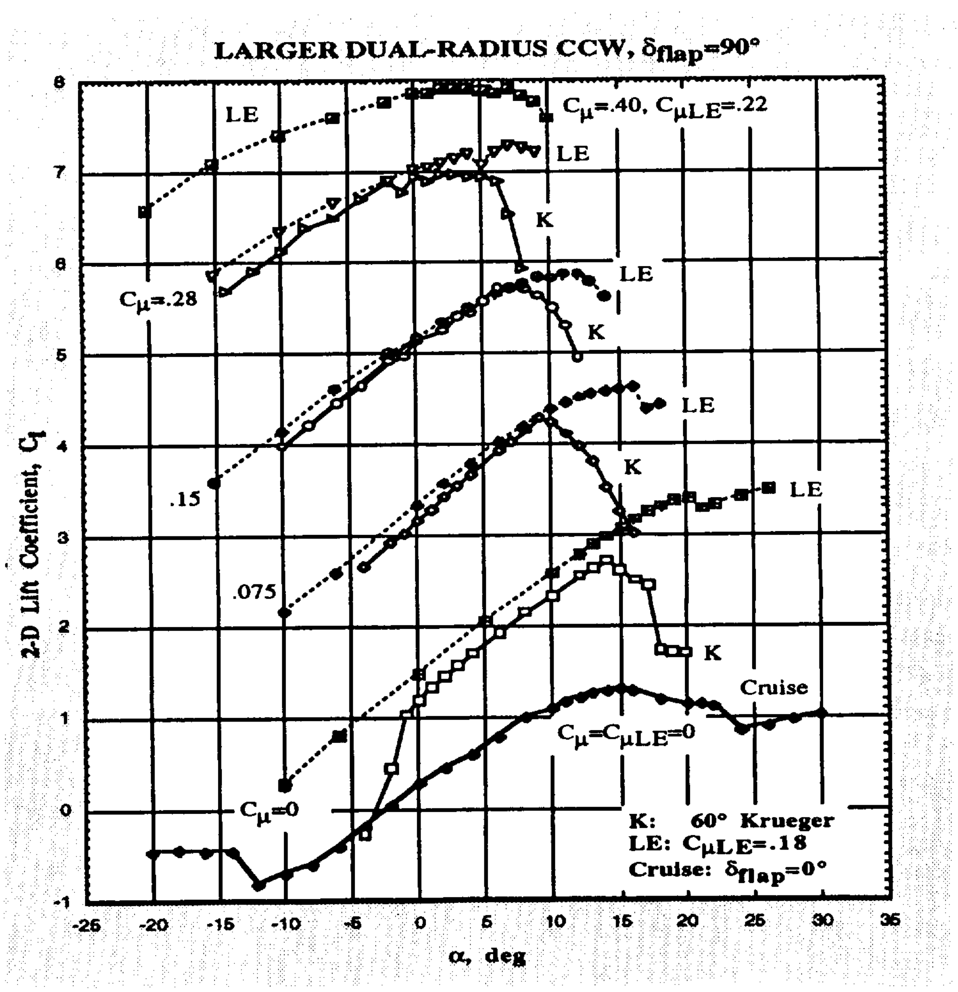
An effective leading edge (LE) device is essential to retain LE flow attachment at high angle of attack and high supercirculation levels. Whereas the mechanical Krueger LE device at 60° deflection had been an effective device in the previous tests, its ability to perform at high incidence and high lift reached limitations. The pressure distributions below at an intermediate $C\mu$ confirmed that a LE separated region formed and expanded as incidence was increased. It was desired to eliminate this problem, as well as the mechanical LE device, from the pneumatic airfoil. Thus a blown LE was installed in the present dual-radius airfoil model. Its effect in eliminating LE separation is shown in the pressure distributions below. Not only does the LE flow remain attached for all conditions shown, but also, the leading edge effectiveness can be adjusted without moving parts merely by varying the blowing rate. Thus, leading edge stall protection could be coupled to trailing edge supercirculation generation merely by coordinating two separate valves. Also, unlike LE flaps or slats, there is no lower-surface LE stall occurring at lower wing incidence. The LE blowing is merely terminated to return the airfoil to cruise conditions; blowing is thus transparent in leading-edge operation.





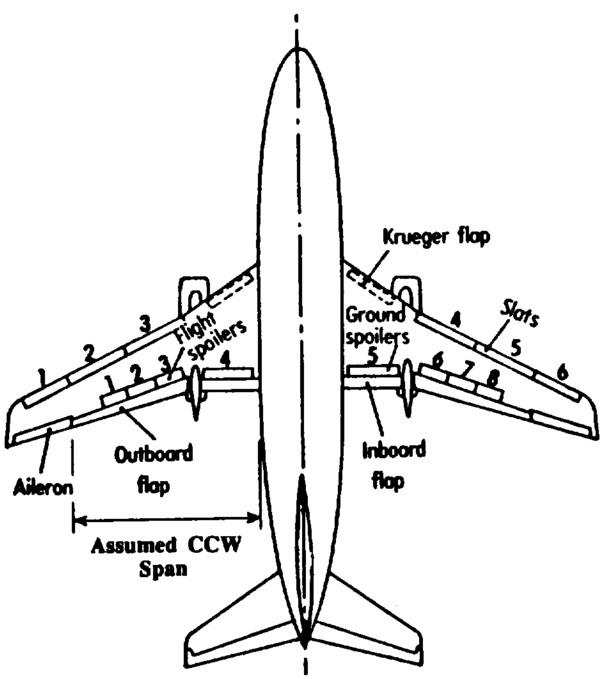
Blown Leading Edge Lift and Stall Improvements

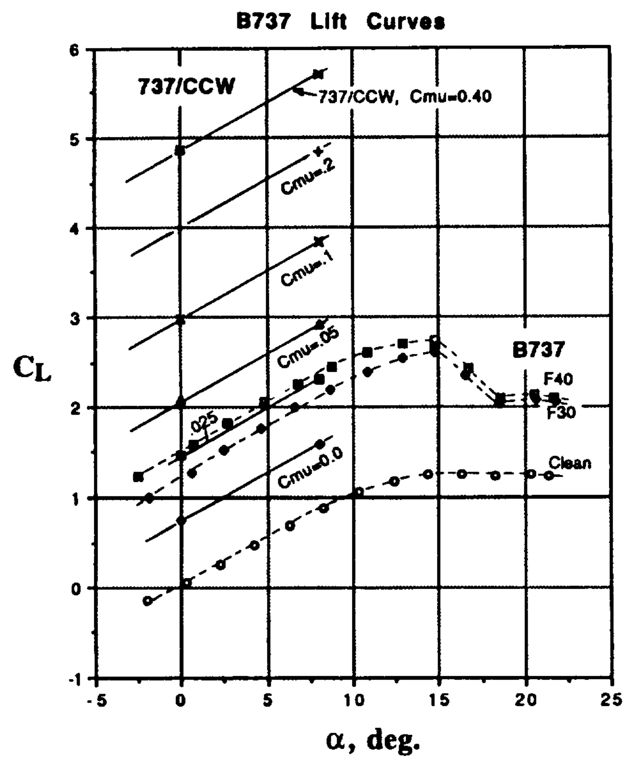
Blown airfoil lift curves are shown below to compare the Krueger flap mechanical leading edge (identified as K) with the blown leading edge (LE) of the previous page. For reference, the clean cruise airfoil is also shown. Note here the Krueger lower surface stall at $C_\mu=0$, and that for any constant value of trailing edge C_μ, the LE blowing shows significantly higher stall angle, as well as, greater lift at lesser incidence. This is because, unlike mechanical LE devices at low incidence the LE blowing itself adds to the supercirculation of the airfoil. Leading edge blowing alone was found to traverse all the way to the trailing edge dual-radius flap and remain attached to at least a portion of the flap arc, thus augmenting lift. Thus, a non-moving pneumatic LE and a short-chord dual-radius CCW trailing edge yielded very high lift augmentation even at $\alpha=0°$.



Boeing 737 and 737/CCW High-Lift Systems

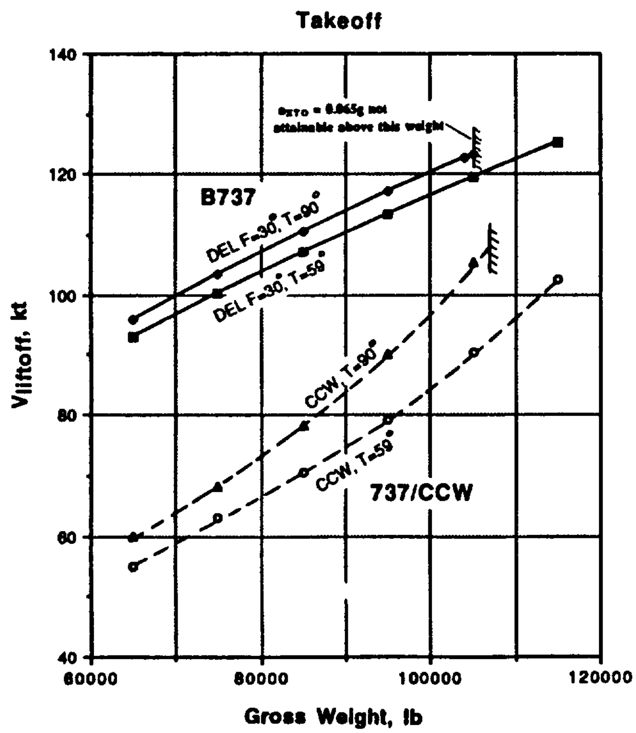
To evaluate the payoffs of the dual-radius CCW airfoil, its 2-D characteristics were analytically applied to modify the aerodynamic characteristics of a current day commercial transport, the 737. The airfoil configuration used was the dual-radius CCW with the Krueger LE flap of the previous slide, and with the flap at 90°. Details of this analysis are provided in AIAA Paper 93-0644 by Englar, et. al., but results are summarized in the next few slides. For a fair comparison, the CCW flap spans only the existing 737 flap span, as shown below, although full-span blowing would provide much better aerodynamic performance. The resulting lift curves are also shown below. Since accurate prediction of full-scale blown aircraft stall angle would be difficult at this point, it was assumed that the 737/CCW and the baseline 737 aircraft took off and landed at comparable incidence (α) values. Significant increase in lift capability due to CCW is seen for both the takeoff and landing conditions.

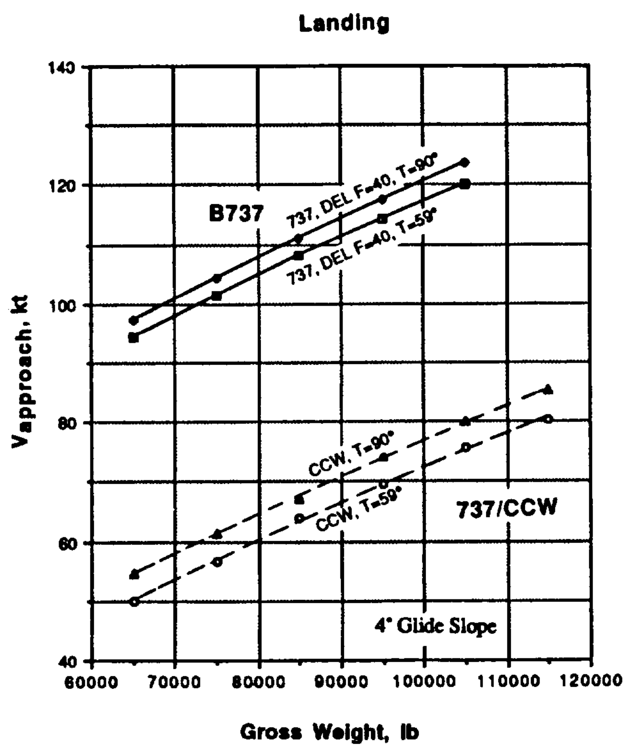




Predicted Boeing 737 and 737/CCW Takeoff and Approach Speeds

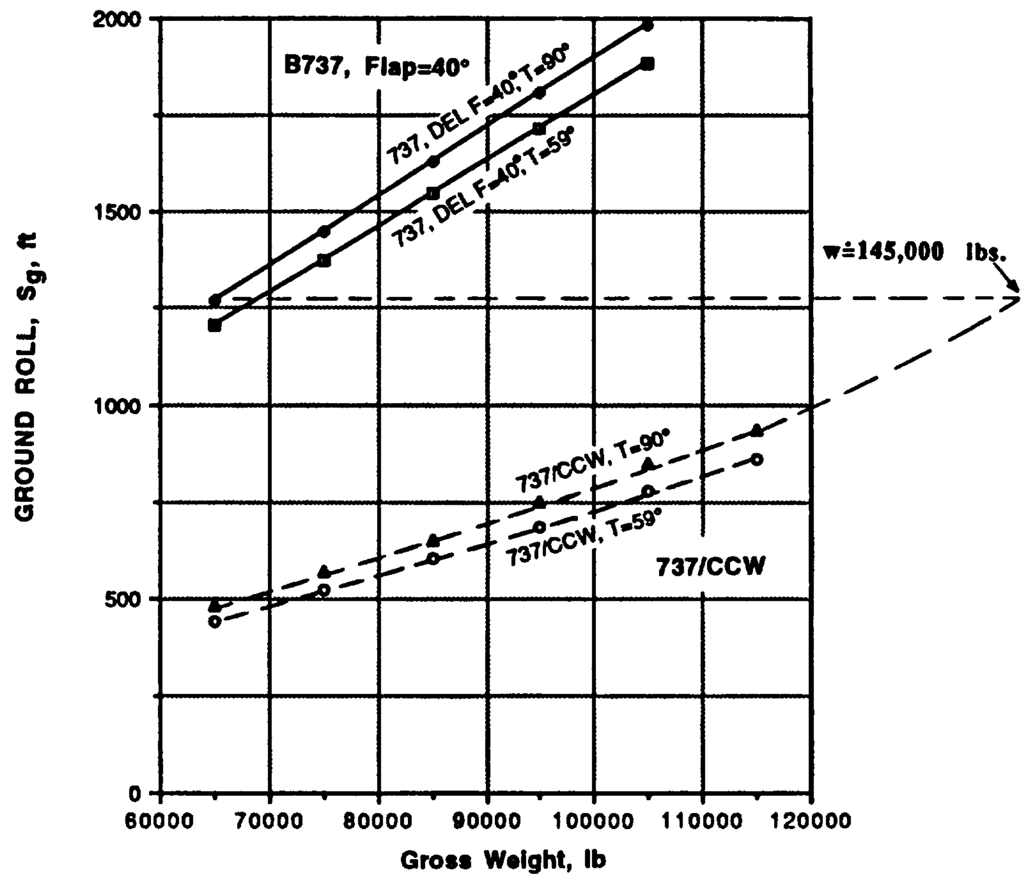
Terminal area speeds of the conventional 737 are a function of gross weight, flap angle and temperature, as shown below. Corresponding 737/CCW speeds vary with available blowing instead of flap angle which is fixed here at 90°. Available blowing corresponds to bleed of existing fan bypass air. Blowing reduces liftoff speeds by between 15 and 40%, depending on aircraft weight and temperature. Approach speeds were decreased by 36 to 47% by blowing. One imagines that these could be even greater reductions if more air were available, say from an onboard APU dedicated to high lift in terminal area operations, but to heating, air conditioning and/or pressurization at other times.





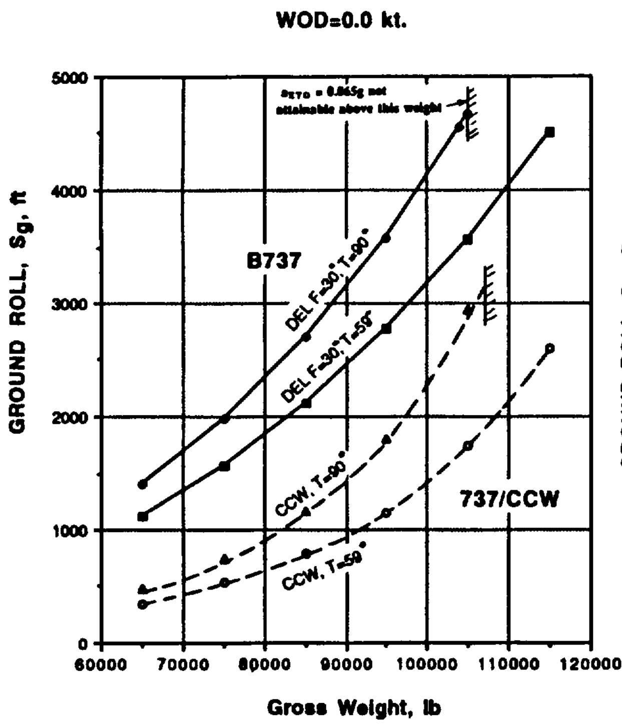
Predicted B737 and 737/CCW Landing Ground Rolls, 0 knot Headwind

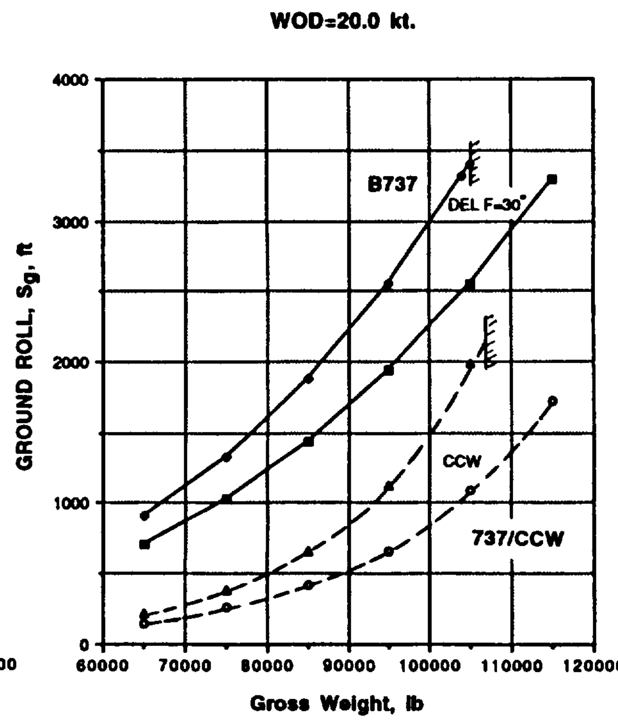
Using the previous reduced approach speeds due to blowing, landing ground rolls with braking after a 4° equilibrium approach are reduced by 54-76%, as shown below. An alternate payoff here is to land in the same ground roll distance as the conventional 737 and use the extra landing/lift capability to support extra payload without re-sizing the wing area. For instance, at the 1300-foot ground roll of a 65,000 pound 737, a 123% overload capability is available for the 737/CCW. (No comment is made here on where that extra payload would be stored on the aircraft or if the structure could sustain it, but merely that there is sufficient wing lift to support that extra weight).



Predicted 737 and 737/CCW Takeoff Ground Rolls at Sea Level

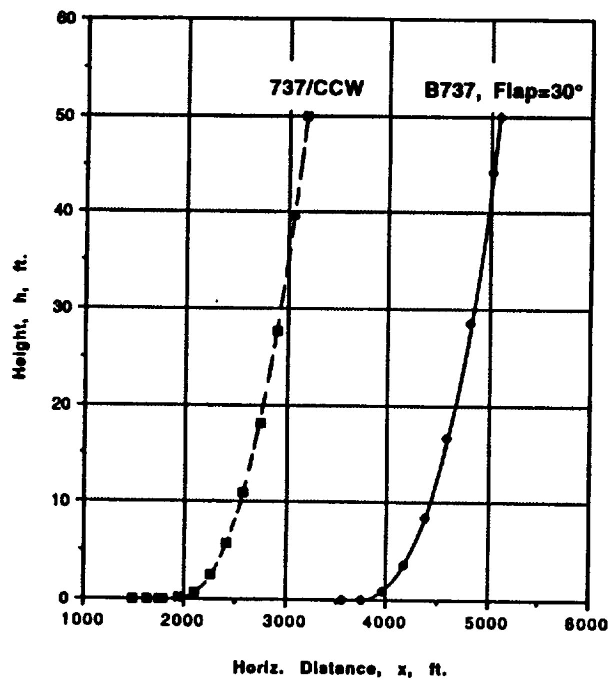
This data applies to previously mentioned takeoff speeds, available with and without blowing, and includes thrust loss due to bleed where appropriate. Blowing has been reduced where necessary to assure that a minimal acceleration at liftoff of 0.065g was available, a Navy one-engine-out restriction. Ground roll reductions from 37 to 80% result, with the greatest reductions being at lighter weights. Again, increases in gross weight that could be lifted airborne at a constant ground roll distance show very large improvements for the blown aircraft over the conventional configuration.



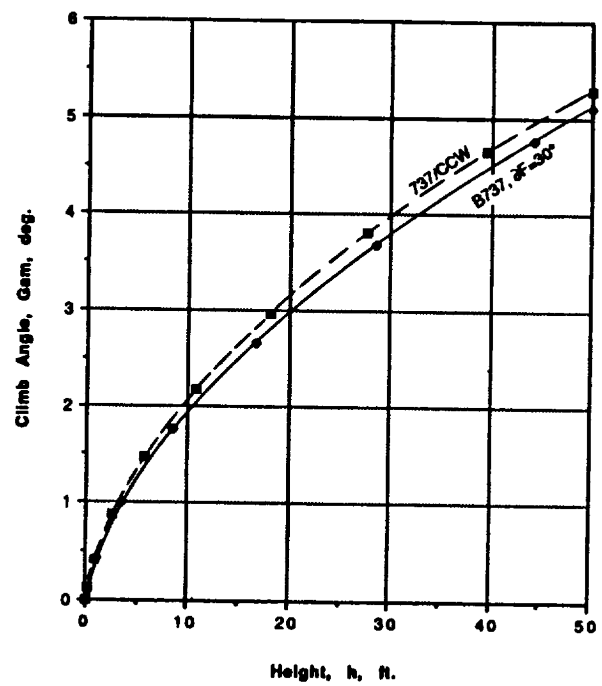


Predicted B737 and 737/CCW Takeoff Flight Path and Climb Angle, Gross Weight=105,000 pounds, Temperature=59°, 0 knot Headwind

These predictions are shown for a heavier value of gross weight, and reveal the reduced distance to climb over a 50 foot obstacle, as well as the slightly larger climb angle available from the blown aircraft. It should be noted here and for the previous slides, that all blown takeoff performance is for the 737/CCW with a 90° flap deflection, which is clearly a high-drag configuration which would probably not yield good L/D values on takeoff. Improved performance should result if the blown flap angle and blowing were optimized for both takeoff and landing.



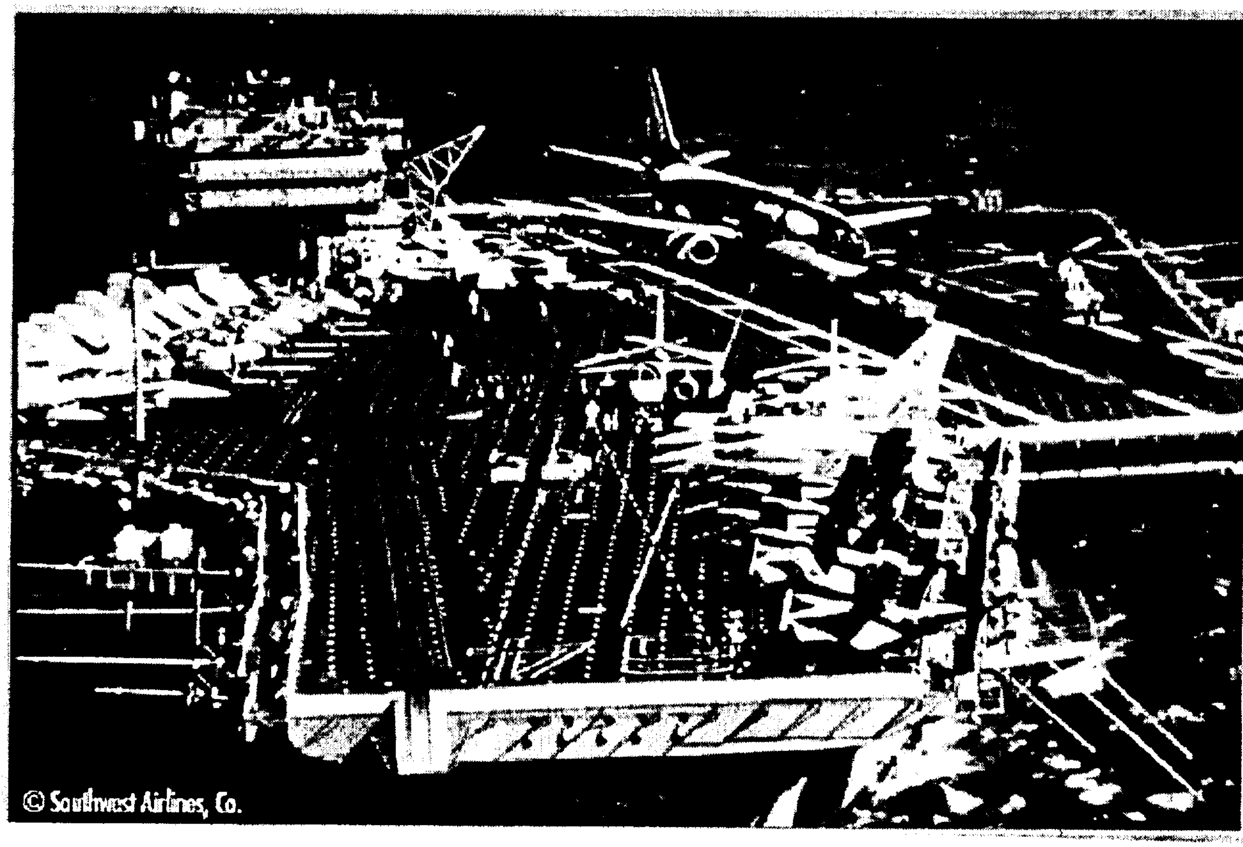
FLIGHT PATH



CLIMB ANGLE

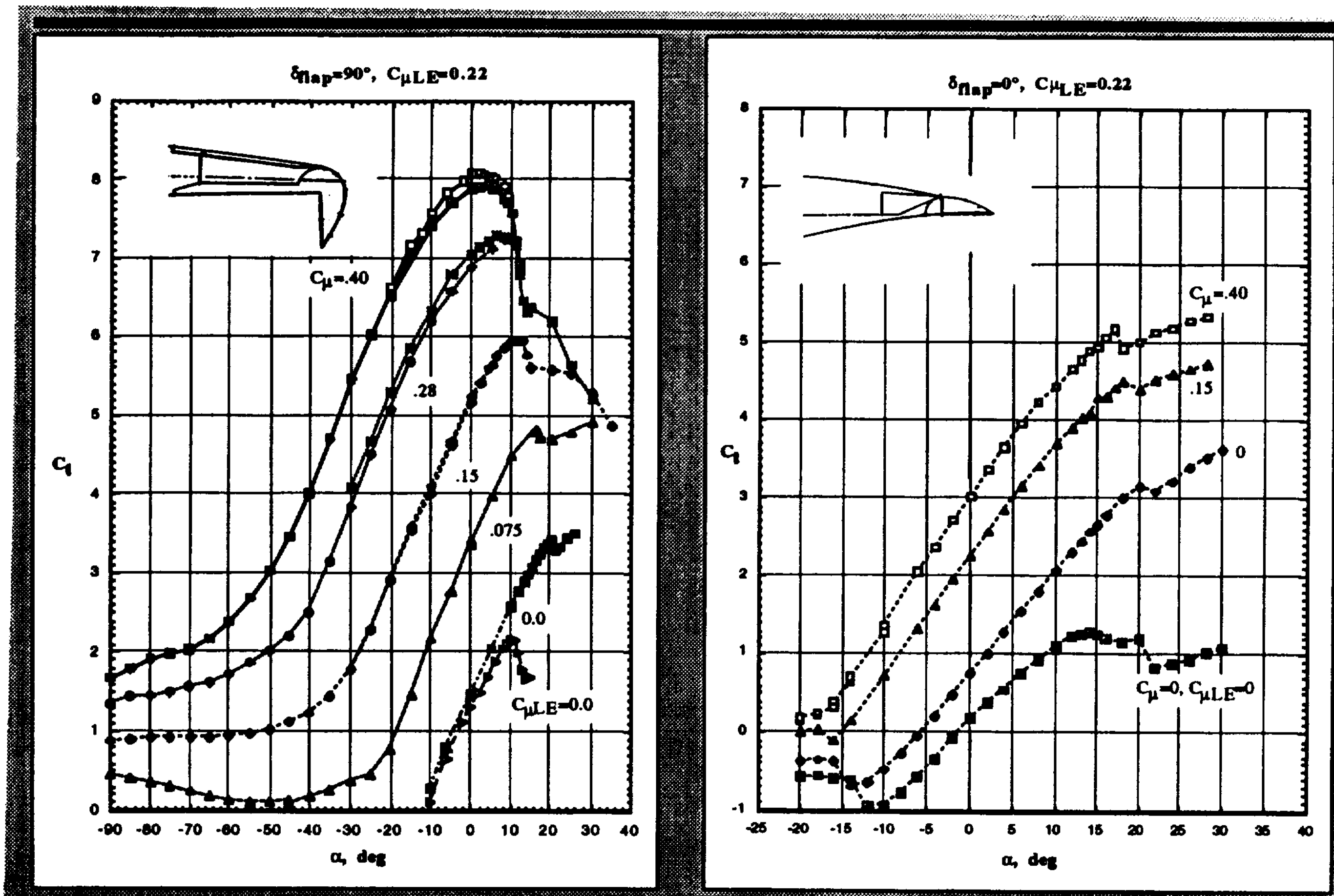
Short Field Capability for Pneumatic Commercial Aircraft (??)

Thanks are due to Southwest Airlines Company for this interesting picture which we downloaded from their World Wide Web home page. The previous data indicates that these ground roll distances, implied in jest here by the airline, are already possible for a light weight 737-CCW commercial aircraft. Given optimization of the flap angle and addition of leading edge blowing, ground rolls of these short distances should be possible for a much larger range of weights for pneumatic commercial airliners.



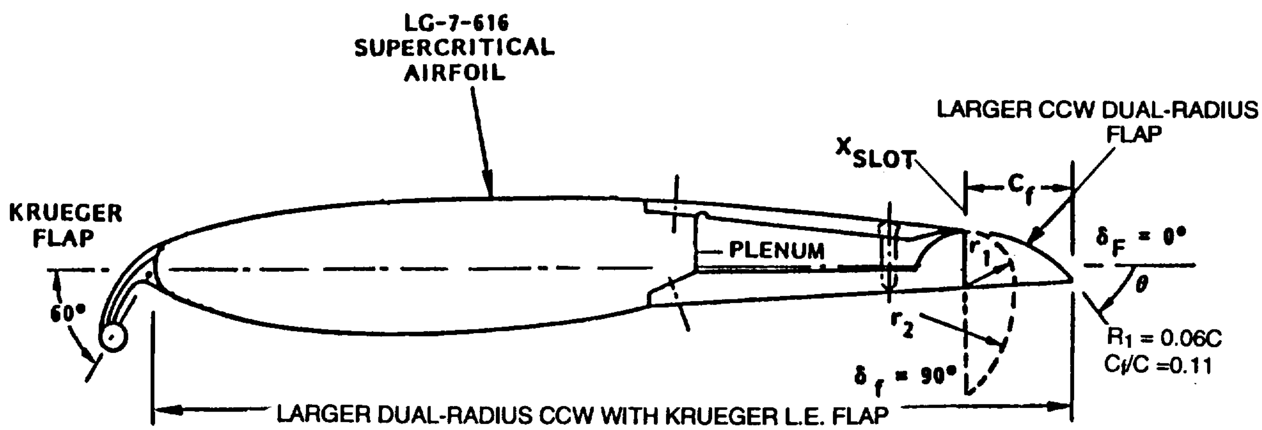
Safety of Flight: Extended α and Lift Ranges, (Larger Dual-Radius CCW Airfoil)

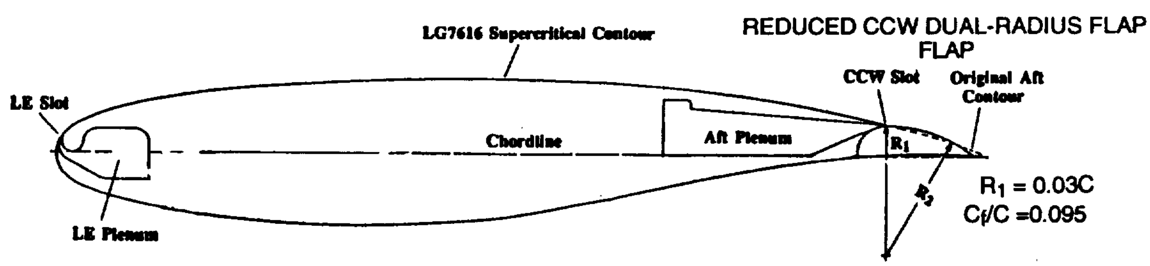
Safety of flight of commercial aircraft is essential in severe weather, including the high updrafts and downwash angles found in microbursts and windshears. Blowing will provide a very interesting safety feature not previously mentioned. At GTRI, we have experimentally evaluated the dual-radius CCW airfoil over a very large range of negative and positive angles of attack. These data were intended to look at blown wings for a tilt-rotor aircraft experiencing large downwash angles over the wing upper surface. These results are shown below, where leading edge blowing is applied to both figures. The left figure is with the CCW flap deflected 90° and shows that for all trailing-edge blowing of $C\mu$=0.075 or more, positive lift coefficient is generated all the way to α=-90°, and beyond. On the high positive incidence extreme, a lift coefficient of 5 or more is generated out to α =30°, even though stall may be exceeded at higher blowing. Thus, positive lift is possible over 120° angle of attack range for the flap-down configuration. The right figure is data for the cruise airfoil, i.e. flap retracted to 0°. Here, C_l up to 5 is possible without any surface deflected, using only blowing. With these blown airfoils, it is physically possible to maintain a high lift coefficient value on approach or takeoff even if the aircraft undergoes large changes in α due to windshear or microbursts. For instance, using the 90° flap, the aircraft can maintain a section lift coefficient of 5.0 with the aircraft dropping incidence from α=+30° to -32°, merely by increasing flap C_μ from 0.075 to 0.40.



Advanced Dual-Radius CCW/Supercritical 2-D Airfoils

The ultimate goal in the development of pneumatic airfoils is to design one with very high-lift capabilities, no cruise drag penalty, few or no moving parts, and minimal changes to the baseline cruise airfoil configuration. The dual-radius CCW configuration with leading edge blowing as previously discussed was close to this goal. However, to ensure excellent CCW jet turning, an enlarged trailing edge radius had been chosen which exceeded the original supercritical airfoil contour. A more recent configuration is shown below, the small dual-radius CCW airfoil. Here the initial radius (R_1) has been cut in half relative to the previous airfoil so that the undeflected flap falls within the cruise airfoil contour. This produces an initial radius of 3% wing chord and a flap chord of less than 10% wing chord. Again, leading-edge blowing is employed. The same CCW airfoil as previously tested has been modified into this configuration. The following slides will present representative data. It should be noted that the plenums shown are probably oversized relative to actual aircraft application. Here they had to contain pressure recording equipment and static pressure tubing while still not distorting plenum flow.

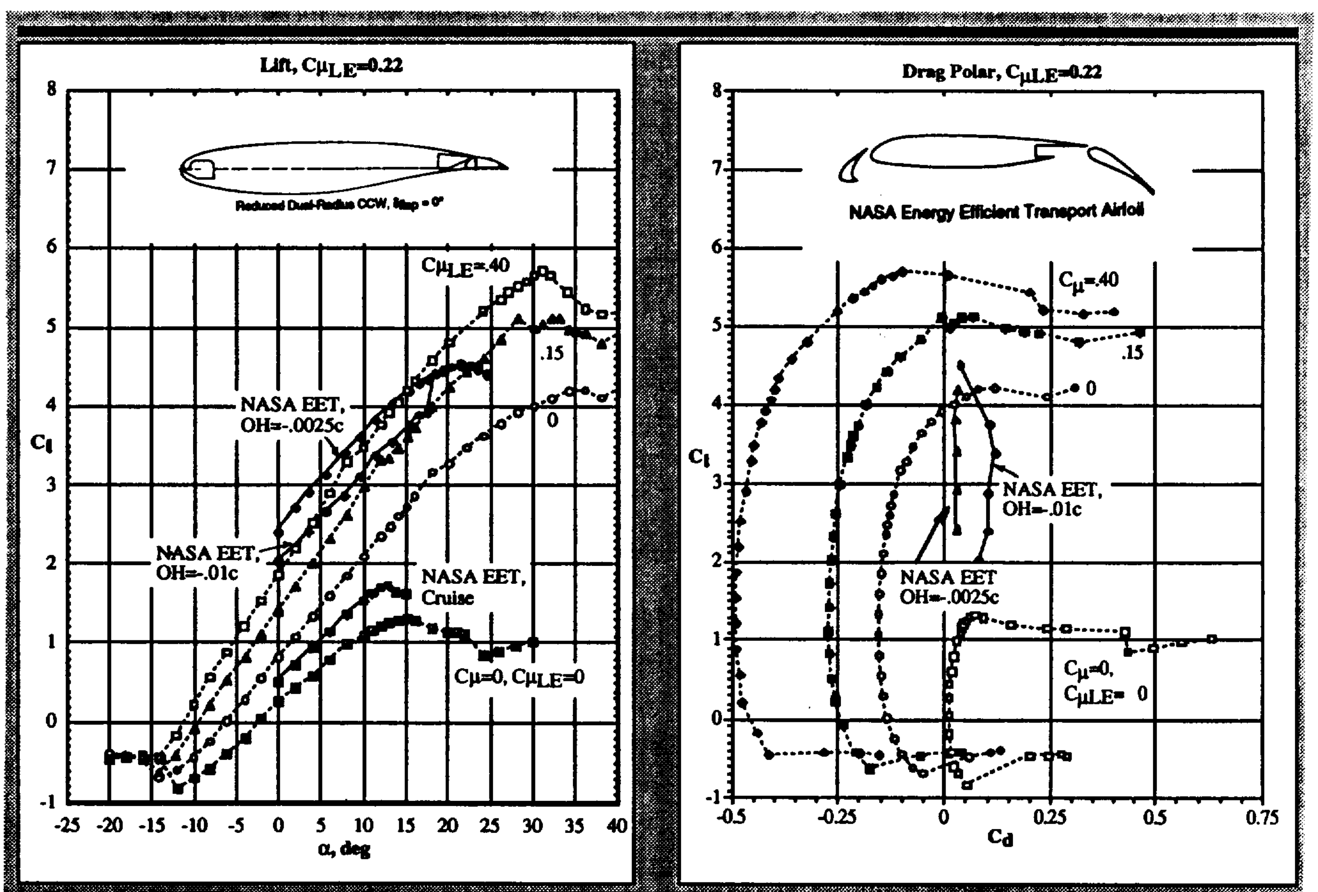




SMALL DUAL-RADIUS CCW WITH L.E. BLOWING

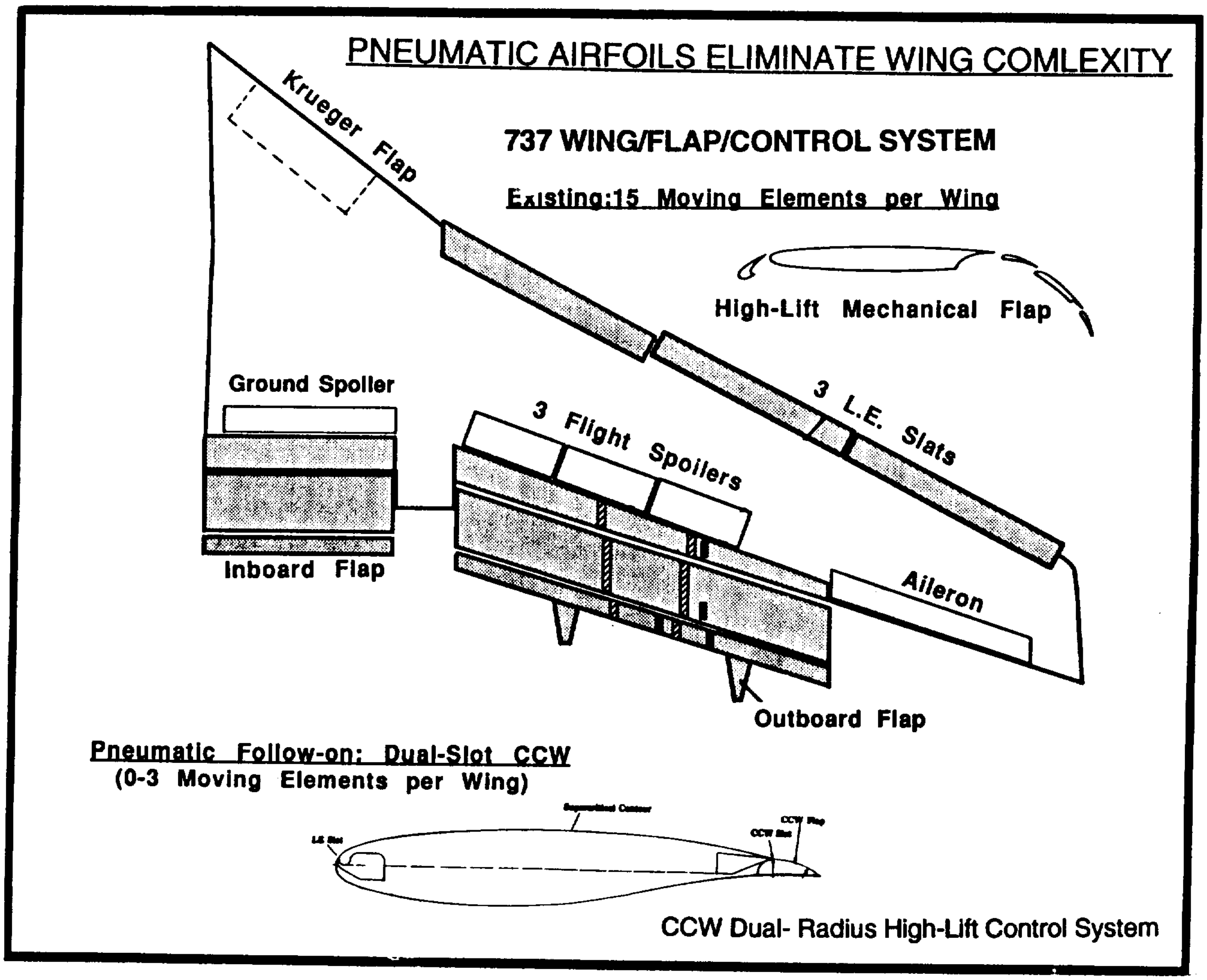
Force Amplification of Small Dual-Radius CCW Airfoil δ_{flap}=0°

At this point, only the undeflected-flap configuration has been evaluated in the tunnel with blowing, but the results are quite enlightening since this represents the cruise airfoil. For reference in the data below, we have included the recent NASA Energy Efficient Transport (EET) airfoil, from AIAA Paper 95-1858. This is a single-slotted flap/slat high-lift airfoil, where the less complex single-slotted flap is used to reduce parts count, complexity, cost, and noise due to turbulence over multi-element flaps. Its cruise airfoil is a 12% thick supercritical airfoil and test Reynolds number ran from 9 to 16 million. The current CCW airfoil is a 17% thick supercritical design with high-lift test Reynolds number less than one million. The results below show that the smaller CCW flap performed better than the larger CCW configuration, probably because of the increased aft camber of the supercritical airfoil. Note that this new airfoil with no moving parts can produce lift coefficients of nearly 6. That compares favorably with the NASA EET airfoil, which, by necessity, is subject to considerable high-lift system optimization, including flap and slat angle, gap, overhang, Reynolds number, etc. Observe the considerable loss in lift performance and drag increase which result when the flap overhang varies slightly from the optimized value (OH=-0.0025c). The unblown minimum cruise drag of the CCW airfoil falls in the very acceptable range of around 0.0112-0.0113. (The corresponding cruise drag for the larger dual-radius CCW airfoil at the same conditions was 0.0156-0.0160). The addition of blowing to the cruise airfoil reduces the measured drag to negative values. The negative drag increment produced is on the same order of magnitude as the C_μ applied; that is, there is high thrust recovery from the blown surfaces. The implication here is that airfoil efficiency (l/d) can be very high and can be adjusted during flight by variation in blowing. The fact that this no-moving-part blown airfoil generates greater lift from blowing values on the order of C_μ =0.1 than the flapped and slatted mechanical airfoil, speaks very highly for this new configuration. It also suggests the possibility of no-moving part blown surfaces to replace aileron, spoiler, rudder, and elevator control surfaces on conventional aircraft.



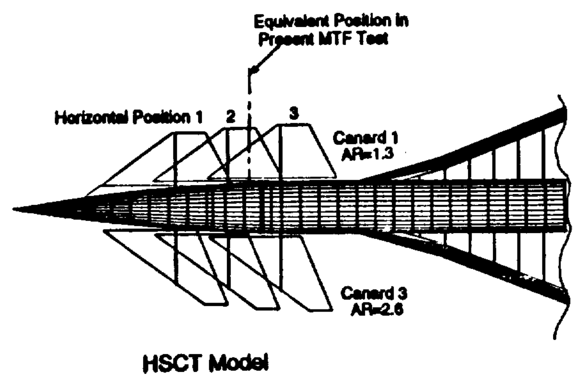
Pneumatic Airfoils Eliminate Wing Complexity

All of the previous data strongly suggest that these new blown airfoils can generate very high lift capability along with reduced drag without use of moving surfaces, or at most, using a small single-element blown flap. This suggests the possibility of simplification of wing complexity and weight. This slide shows a current day commercial transport's wing, which includes 15 moving elements per side for lift generation, stall delay, roll control, and direct lift control. We have seen that the no-moving-parts dual-radius CCW can provide equal or greater lift generation and stall prevention by using blowing. It is also suggested that incremental direct lift and roll control can also be provided by blowing alone. Should even greater lift or roll control be necessary, the small CCW flap can be deflected. Thus it is possible to provide an integrated wing capable of lift, drag, roll, yaw, pitch, and possibly side force control variation without moving surfaces. The improvements in weight, maintainability, safety of flight, and reduction of complexity are evident. In addition, the use of blowing can augment certain of these forces and moments to values which are not obtainable by mechanical surfaces.



Blown Canard on Generic High Speed Civil Transport Model

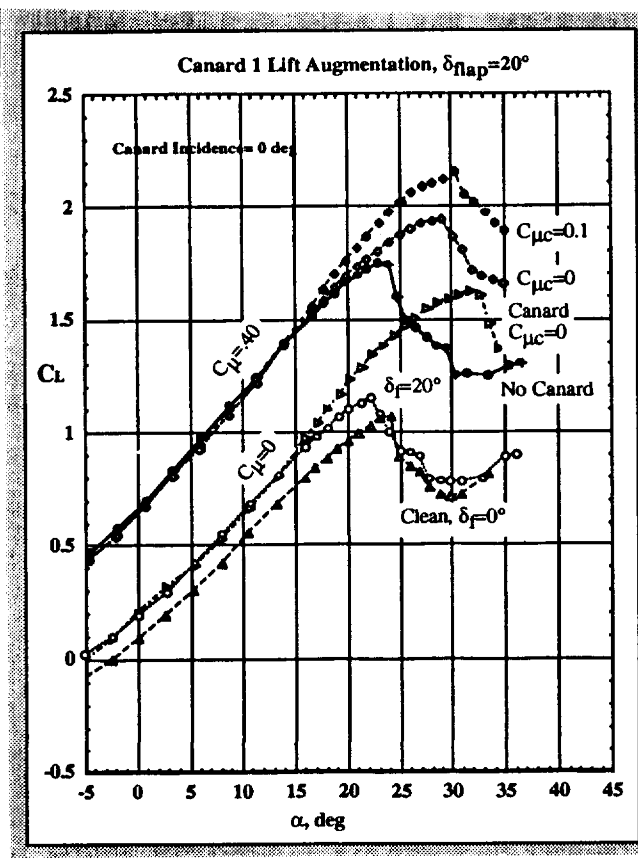
Pneumatic technology is not limited to advanced subsonic transport aircraft. Current designs for proposed High Speed Civil Transport configurations employ highly swept wing designs and achieve high lift augmentation by leading edge vortex generation. This, however, usually requires approach and takeoff at very high angles of attack. This has required additional tail power and such unusual features as nose droop on some designs. Recently, GTRI has investigated for NASA the application of pneumatic technology to HSCT configurations to provide alternative means of lift and angle of attack control. Blown circular-cylinder canards had been applied to National Aerospace Plane configurations to provide pitch control for takeoff, and strong control of wing vortex burst had been discovered to result as well. The same concept was applied here to a generic HSCT configuration. Two blown canards were applied to a half-span NASP model which had a wing planform very similar to HSCT planforms. These canards included Canard 1 (AR=1.3 with forward-swept trailing edge) and Canard 3 (AR=2.6, with aft-swept trailing edge) as shown below. Each of these canards had an aft-blowing slot and a dual-radius-type trailing edge flap. This flap was deflectable, but all of the data shown here were obtained with 0° deflection. The picture shows the higher-aspect-ratio canard with blowing mapped by a tuft. Flow visualization showed that when blowing was applied, the downwash behind the canard delayed vortex burst on the wing because of reduced upwash over the wing leading edge.

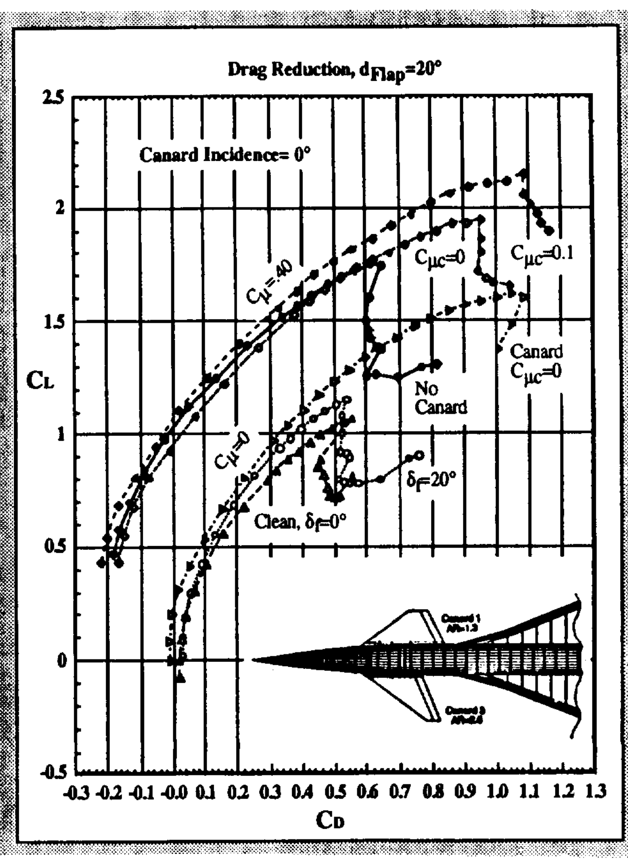


Blown Canard Planforms

Blown Canard Effect On Generic HSCT Lift and Drag

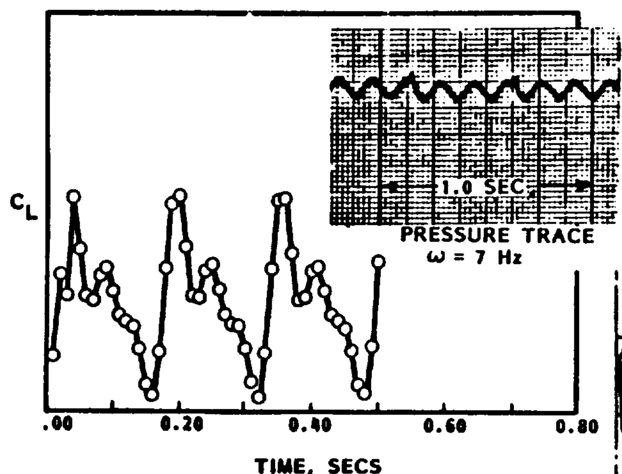
The generic HSCT model was tested subsonically over a large range of angle of attack for both canards and for several flap configurations on the wing trailing edge. The sketch here shows the locations of both canards relative to the wing leading edge. (Of course, on this half-span model, only one canard was tested at a time). The lower aspect-ratio canard was found to be the more effective of the two, probably because its forward-swept blowing slot aligned the jet sheet more effectively with the wing leading edge and vortex. The lift and drag data shown here are presented for no wing blowing and for a wing C_{μ} =0.4. Also, a 20-degree plain flap was applied to the wing trailing edge, both with and without blowing. The unblown canard provides an increase of approximately 33% in lift and 27% in stall angle over the clean cruise configuration due primarily to delay of wing vortex burst. Addition of blowing to the low-deflection wing flap increases lift by 65% with no change in stall angle. However, the real payoff occurs from adding the blown canard to the blown wing. Here, maximum C_L increases by 103% and the associated stall angle by 29% over the clean configuration. These are improvements achieved without canard deflection. Trimming of the airplane needs to be evaluated by use of both canard and tail deflection (the present wind tunnel model is tailless). An additional advantage from these blown configurations is terminal area operation at much lower angle of attack. The maximum lift C_L=1.06) of the clean configuration occurs at α=24°, while wing blowing or canard presence achieves that same C_L at α=8°. Significant drag reduction is also possible. At the maximum lift of the clean configuration, wing blowing alone (C_{μ}=0.4) reduces the drag from C_D=0.56 to 0.02. This is a combination of blowing thrust recovery and lower aircraft angle of attack. At that same drag value for the clean configuration, the lift can be increased from C_L=1.06 to 1.8 (67%) by use of wing and canard blowing. Conceivably, adjustment of canard and wing blowing could optimized L/D values for both takeoff and landing.



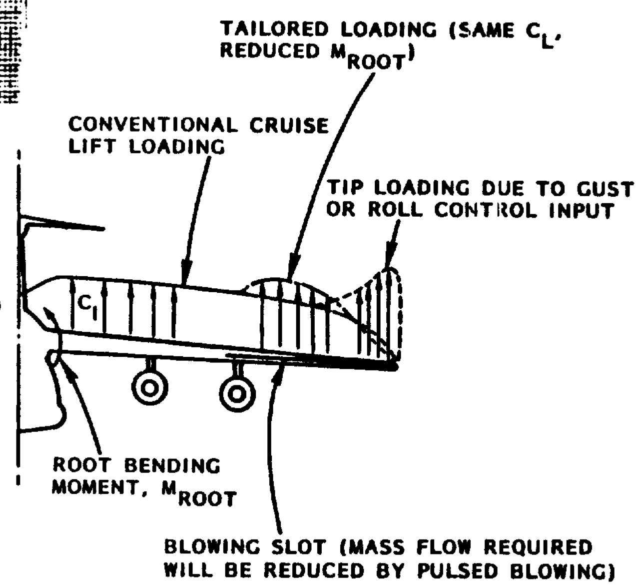


Cyclic Blowing and Load Tailoring

Additional opportunities exists for pneumatic lift and control of both low-speed and high-speed transports. It has been shown during earlier pneumatic applications to helicopters that pneumatic blowing could be made to vary quite rapidly (30 cycles per second or more). Recent applications to fixed-wing aircraft show additional benefits. From a control standpoint, aerodynamic response at 30 cycles per second is quite beneficial. We have also found that cyclic blowing can reduce the amount of mass flow required from the engine to augment aerodynamic forces. For instance, a time-averaged lift can be obtained at an average mass flow which is less than the constant mass flow value required for the same lift under steady-state conditions. From a controls standpoint, it is also possible to pneumatically tailor both the spanwise lift loading (and thus the induced drag) as well as the lifting surface root bending moments. It is possible to provide an elliptic spanwise slot distribution and thus an elliptic lift distribution with the associated minimum induced drag. It is also possible to reduce tip loadings due to gusts by adjustment of blowing values near the wing tip.

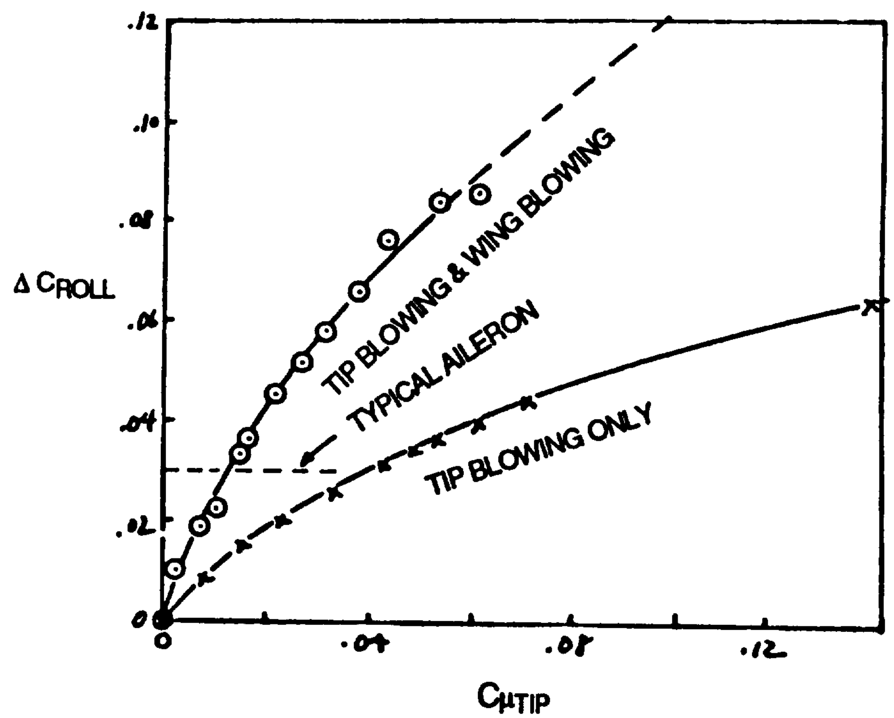


LIFT VARIATION



CC Wing For Roll Control And Drag Reduction

Pneumatic treatment at the wing tips can provide significant returns from both an aerodynamic and a safety-of-flight standpoint. By use of a proprietary blowing geometry at the wing tip, it is possible to induce a flowfield exactly opposite to that generated by a typical wing tip vortex. This blown flowfield offsets and neutralizes the conventional tip vortex, whose strength would otherwise increase proportionately with wing lift. Measured drag on a rectangular planform wing with this pneumatic tip has shown drag reductions up to 14%, which effectively results from an effective increased aspect ratio of the wing. This additional loading of the tip can be used as a roll control device. The data below show that tip blowing alone can double the incremental roll obtained from a typical mechanical aileron. It is also possible to combine tip blowing and asymmetric wing blowing to produce greater lift asymmetries and incremental roll, increasing roll by up to four times that obtainable from an aileron.



Challenge to American Aerospace Technology

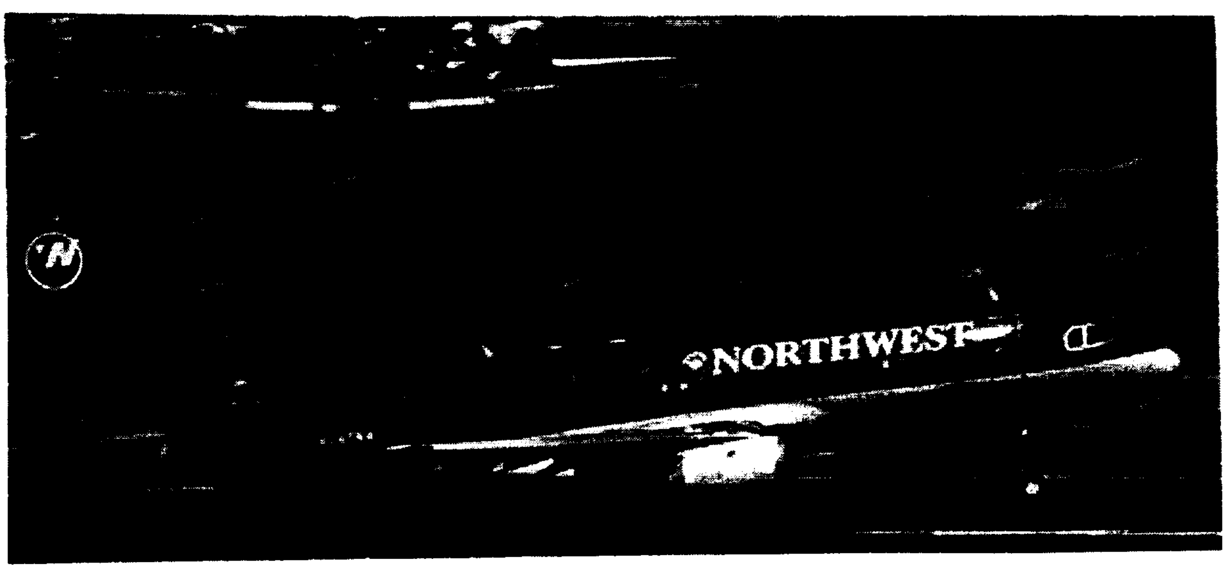
The American commercial aircraft industry is under challenge from foreign competitors in terms of both Advanced Subsonic Transports (AST) and the High Speed Civil Transport (HSCT). For example, during its first commercial flight in June 1995, the latest Boeing airliner, the 777, was already competing against two similar foreign aircraft, the A330 and A340 (by the European consortium Airbus Industrie including member companies from Britain, France, Germany and Spain). The American MD-11 aircraft faces similar competition. US airlines are already buying and flying a number of these foreign-built aircraft (see below). American industry has yet to produce even a prototype HSCT, but the British/French consortium built the Concorde supersonic transport which has been flying commercially (with flights into the US) since 1976. ***American advanced transport technology is behind.*** Even though numerous research programs have been conducted over the years and promising technology developed, a concentrated efficient integration of these technologies (including thorough environmental and economic impact analyses) has not been completed. The next generation of efficient commercial aircraft must exhibit superior performance; satisfy all noise and environmental requirements; and exhibit adequate economic potential by satisfying the interests of airlines and by offering an affordable ticket price to the passenger. In order to achieve all these objectives, the designer must, early in the design process, account for cost of operation and reliability/maintainability. **State-of-the-art aerodynamic, propulsive, control, noise, and operational technologies need to be developed, and a logical means to effectively integrate these into promising advanced US designs needs to be employed. Advances in pneumatic technology and its application to American transport designs can yield major benefits to our industry.**

ValuJet nearing purchase of new jets

Airbus A319 is insider favorite

(Atlanta Journal-Constitution, 9/20/95)

Northwest Airlines Airbus A320



Application Towards Efficient Future Transport Systems

The slide below suggests how the research community might employ the major advantages of pneumatic technology to enhance a number of the advanced transport configurations being discussed in this NASA workshop. The main emphasis should be placed on developing an aerodynamic/propulsive force and control system taking maximum benefit from the force/moment augmentations possible from these advanced no-moving-part pneumatic systems at low blowing rates. Clever integration of this technology can provide a simple, reliable efficient aircraft able to adjust its configuration pneumatically to optimize it for each particular phase of flight.

Application Towards Efficient Future Transport Systems

- **Integrated Force Generation , Control Surface, Safety of Flight & Performance Optimization Systems**
- **Integrated Aero/Propulsive/Stability & Control on Advanced Simple Aircraft**
- **Safety of Flight - Wave Vortex**
  Microburst/Wind Shear
  α - Independence
  Very Low Flight Speed
- **Terminal Area Operations : Noise Reductions (Footprint, Airframe)**
  : Improved Gross Weight and Payload
  : Reduced Flight Speeds & Take Off/Landing Distances
- **Very Large Transport : Gross Weight Increase, Terminal Area Downsize**
- **HSCT - Wing & Control System Integration; Not α - dependent; Noise Reduction**
- **Lift/Control on Unique Configurations: Blended Wing Body**
  Oblique Wing
  Corporate-Supersonic Transport
  Rotary Wing (Simplicity; efficiency; max speed)

What's Needed??

Proof of concept verification of much of this pneumatic technology has already occurred, and patents exist or have been applied for. Immediate research and systems analysis that need to be accomplished near-term are shown below. Applications to near-term designs such as the Advanced Subsonic Transport and the High Speed Civil Transport should take precedence. Integration of aerodynamic, propulsion, stability & control, and acoustics teams into a unified design effort is essential.

WHAT'S NEEDED??

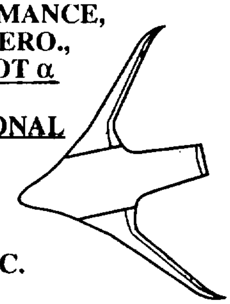
- **High Speed Performance of Pneumatic Airfoils**
- **Mission Integration; System Analysis; Payoffs & Penalties; MDO**
- **Experimental /CFD Evaluation for Particular Configurations/Applications**
- **Full-Scale Proof-of-Concept on Subsonic Commercial Transport**
  Has Already Been Proof-of-Concept Flight-Tested on Military Aircraft
- **Operations Analysis, New Uses:**
  - **Noise Abatement**
  - **Wing Downsize**
  - **Systems Synergistic Integration**
- **HSCT - Configuration Optimization**

Pneumatic Aerodynamic Technology --- Where Do We Go From Here?

Major efforts to pursue in order to take advantage of this major breakthrough in aerodynamic technology are shown below. Let's apply this pneumatic technology to integrated systems to optimize aircraft design and performance pneumatically, not mechanically. Let's take advantage of an existing research data base and undertake a large-scale effort to apply this technology to near-term aircraft designs. This could motivate the American aircraft industry to include this technology in their designs, before the European and Far East competitors do.

PNEUMATIC AERODYNAMIC TECHNOLOGY --- WHERE DO WE GO FROM HERE?

- A VIRTUAL BREAKTHROUGH IN MOST AREAS OF AVIATION:
  - * AERODYNAMICS, PROPULSION, PERFORMANCE,
  - * STABILITY AND CONTROL, UNSTEADY AERO.,
  - * ACOUSTICS, STRUCTURES; BLOWING NOT α



- OPTIMIZE CC AIRFOIL PERFORMANCE & OPERATIONAL LIMITS:
  - * LOW & HIGH SPEED
  - * AERODYNAMIC PARAMETERS
  - * GEOMETRIC PARAMETERS
  - * AIR SOURCES, PROPULSION, DUCTING, ETC.
- SYNERGIZE SYSTEMS:
  - * COMBINE AERO., PROPULSION, CONTROL, ACOUSTICS, PERFORMANCE, ETC.
  - * SYNERGISTICALLY INTEGRATE FROM THE OUTSET, NOT AS AN AFTERTHOUGHT
- OVERCOME POLITICAL/EMOTIONAL AERODYNAMICS:
  - * WE HAVE A 22+ YEAR DATABASE -- LET'S PUT IT TO GOOD USE!!