MD
FLIGHT APPROACH

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PROCEDURAL CHANGE

The April 1984 issue of MD Flight Approach is dedicated to the meteorological hazards that can cause windshear, including microbursts, downbursts, and macrobursts.

FAA Advisory Circular AC-00-50A, dated 1-23-79, was published to provide guidance for recognizing meteorological situations that produce windshear and describes preflight and inflight procedures for detecting the phenomenon as well as pilot techniques that minimize the effect when windshear is encountered on takeoff or landing.

"Windshear Precautions and Encounter Tactics" presented on Page 14 under "Precautions" in the magazine have been reviewed. The following procedures should be used in lieu of those previously published.

The phrase "maximum performance maneuver" is referred to in the procedure for takeoff into suspected windshear condition. The maximum performance maneuver is:

- Increase pitch as required to control vertical speed and altitude. The increase in pitch attitude should be limited to the onset of stick shaker and thereafter to intermittent stick shaker to ensure that stall margin to stick shaker is maintained
- Thrust increase, when it is required, should be immediate to the go-around limit and, if necessary, the throttle levers should be placed at the mechanical stops

The recommended procedure for takeoff into suspected windshear conditions is the following:

1. Use maximum rated thrust: do not use reduced thrust.
2. Use longest available runway with least probability of windshear encounter.
3. Compute takeoff speeds and set speed bugs for the actual gross weight.
4. Compute V_R and V_2 takeoff speeds for the performance-limited gross weight.
5. Compare the performance-limited V_R (Step 4) to the actual gross weight V_R (Step 3). Takeoff into suspected windshear conditions is not recommended and should not be attempted unless the performance-limited V_R (Step 4) exceeds the actual gross weight V_R (Step 3) by at least 10 knots.
6. Prior to V_1:

   If windshear is encountered prior to the actual gross weight V_1, abort the takeoff.

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Correspondence for publication may be submitted to the Publication Editor, J. R. Henningfeld, C1 E61 (41-60), at above address. We, however, reserve the right to judge the material and to edit same.

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7. After V_1 Prior to Liftoff:
   - If engine failure occurs prior to attaining the actual gross weight V_R (Step 3), use it for rotation
   - If engine failure occurs after the actual gross weight V_R (Step 3), rotate at the performance-limited V_R as determined in Step 4
   - All engines operative — Fly to the performance limited gross weight V_R (Step 4)
   - If windshear is encountered — Never rotate later than at point where sufficient runway is available to ensure flight path obstacle clearance. After airborne, implement the "maximum performance maneuver" if necessary
8. After Liftoff:
   - Engine inoperative after liftoff — Fly to the performance-limited gross weight V_2 if feasible (Step 4).
   - All engines operative — Fly to performance-limited gross weight $V_2 + 10$ (Step 4)
   - If windshear is encountered — Immediately implement "maximum performance maneuver"

   Note: When flying to the performance-limited speeds, a push force can be expected to maintain nosewheel contact with the runway to V_R and to maintain the second segment speed.

This procedure is within the intent of AC-00-50A and it provides greater performance and safety margins than the circular.

Laminar

BY
W. E. PEARCE
LFC PROJECT MANAGER

The Douglas Aircraft Company, primarily under NASA's sponsorship, is currently developing a laminar flow control (LFC) system for transport aircraft.

Laminar flow control is a means of reducing surface friction drag by maintaining a smooth flow of air across the external surface. Douglas smooths the air flow across the wing surface by using a unique electron beam (EB)-perforated surface panel as a suction device. As air flows across the millions of perforated holes, it is drawn down into the perforations, moving the transition from smooth to turbulent airflow back toward the trailing edge of the wing.

The overall purpose is to develop a system for aircraft drag reduction that functions reliably over a wide range of environmental conditions. The long-term goal of up to a 20-percent fuel saving, which results in reduced operating costs and increased range endurance, is considered feasible. Douglas has demonstrated the system on a sweptwing model in its low-speed wind tunnel under conditions approaching those of transport aircraft in cruise flight, and a Douglas-designed LFC leading edge, now being flight tested by NASA on its Jet Star aircraft, is performing very effectively.

In the case of aircraft with wings swept for high subsonic cruise speeds, the transition from laminar to turbulent flow (Figure 1) usually occurs very close to the leading edge even with a clean, smooth external surface. The initial transition can be caused by instability of the spanwise flow of the boundary layer along the attachment line at the leading edge (Figure 2). This instability is adversely affected by increased bluntness of the leading edge or increased sweep. The next dominant cause of instability is a cross-flow condition resulting from a chordwise pressure gradient combined with isobar sweep (lines of equal pressure on the wing surface). Finally, there is a natural instability unaffected by wing sweep, which limits the distance for which laminar flow can be maintained. This distance is increased

or decreased by accelerating or decelerating airflow over the surface, respectively, that is determined by the airfoil shape.

Fortunately, the removal of only a small fraction of the boundary layer by surface suction can counteract these influences. The boundary layer stability, provided by suction, also provides increased tolerance to slight

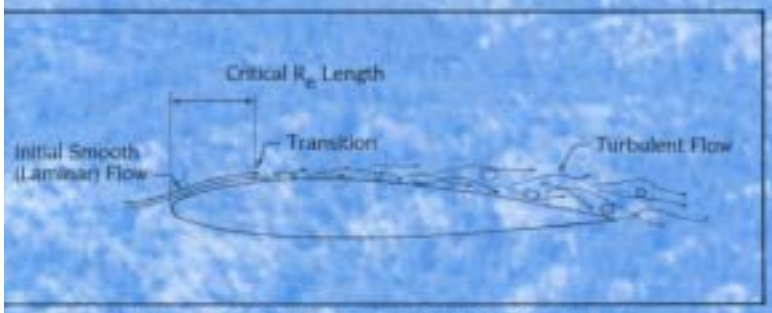


Figure 1. Boundary Layer Transition with Swept Wings

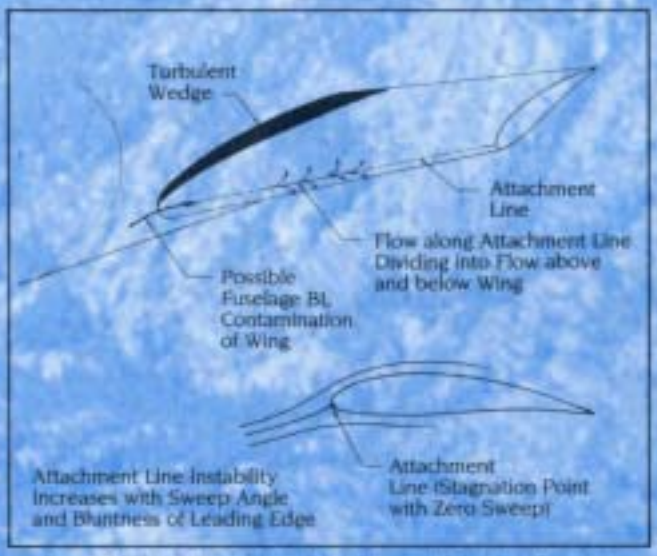


Figure 2. Attachment Line Instability and Fuselage Boundary Layer Contamination

surface imperfections. The use of suction on an airfoil having an acceptable pressure distribution is, therefore, the LFC method selected.

LFC SUCTION SURFACE

Previous LFC suction studies concentrated on multiple slots, resulting in an extensive data base being available. Because of known problems with slots, Douglas decided to pursue the alternative possibilities of using porous or perforated surfaces to take full advantage of recent developments in technology.

Following an initial survey of practical porous and perforated materials, Douglas tested a number of surfaces in the Long Beach wind tunnel with test panels inserted in a flat panel model. The extent of laminar flow was measured as influenced by the level of suction through the surface, and the results were compared with those of a nonporous surface. The alternative surfaces compared included slotted, porous, electron beam-perforated, and strip porosity variations of the latter two, all of which performed satisfactorily during wind tunnel testing.

A slotted surface poses a number of manufacturing and practical difficulties. Slots are difficult to machine to the narrow requirement of 0.076 mm (0.003 in.) in practical, corrosion-resistant materials. Machining must be kept to very tight tolerances to avoid variations along the span, and, since slots are cut after attachment to supporting structures, the release of locked-up stress could cause width and contour variances. Ideally, the slots should follow lines of equal pressure (isobar lines) on the surface, but, with tapered wings, the slots converge and become excessively close together at the tips. To avoid the closeness, some of the slots can be terminated at irregular distances from the tip; however, this arrangement can generate a turbulence condition at the slot ends that defeats the purpose. In addition, should damage occur to the wing, particularly at the vulnerable slots, the repair and alignment with existing slots would present severe problems.

By contrast, the electron beam perforating process proves to be more practical because it provides a more continuous surface with the hole diameter and spacing controlled to achieve the ideal porosity. The hole diameter can be as small as one-tenth of the material thickness; and 800 holes per second can be produced in 0.025-inch-thick titanium.* Figure 3 shows the remarkable accuracy of a 0.0025-inch diameter EB-perforated hole under magnification, and, in Figure 4, the size and pattern of the holes are compared to a standard paperclip. Figure 5 shows the EB hole pattern and the natural hole taper that is a preventative against clogging. Compared with other alternatives, EB-perforated titanium offers additional

* The EB-perforated panels were manufactured by Pratt & Whitney Aircraft to meet Douglas design requirements using improved techniques that Pratt & Whitney Aircraft developed with EB perforating equipment supplied by Steigerwald.

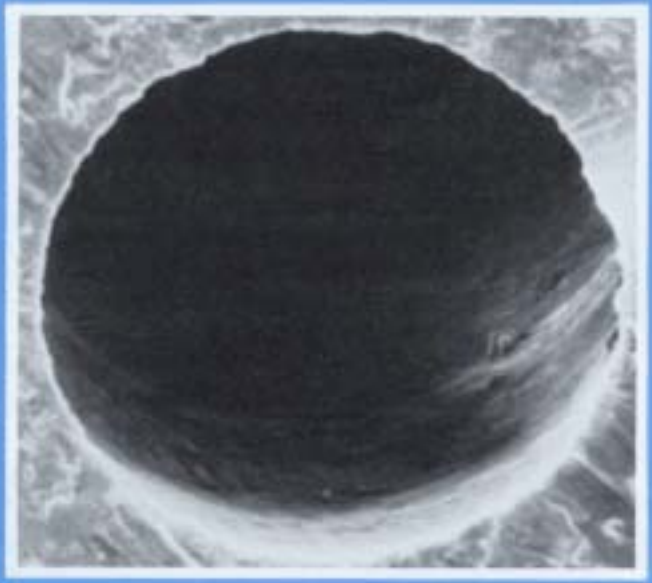


Figure 3. Single Electron Beam-Perforated Hole, 0.0025 Inch (0.063 mm) Diameter

Figure 4. Electron Beam Perforations Compared with Ordinary Paper Clip

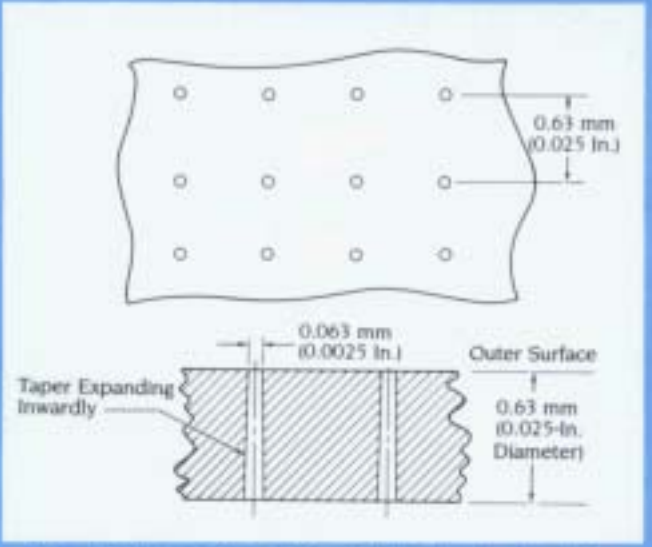


Figure 5. Electron Beam-Perforated Titanium Suction Surface

advantages. Its high strength resists wing bending and contributes to torsional strength and stiffness. Resistance to damage is high, and no loss of LFC occurred during tests when dents made with a hammer were repaired by filling. The porosity is uniform and unaffected by stress or strain; any dirt accumulation can be removed by steam cleaning to restore the original porosity. The perforated titanium is also corrosion-resistant and cost-effective as a suction surface.

SWEPTWING LFC WIND TUNNEL TESTING

After initial wind tunnel testing to compare alternative suction surfaces, LFC capability was demonstrated under the cross-flow conditions existing on a sweptwing. Douglas performed the low-speed wind tunnel testing, and test results are illustrated in Figure 6.

The model chord measured 2.13 meters (7 feet), and the modified tunnel walls simulated an infinite 30-degree sweptwing. The maximum Reynolds number was 4.11 x 10^6 per meter (1.35 x 10^6 per foot), compared with 4.87 x 10^6 per meter (1.6 x 10^6 per foot) for an aircraft flying at Mach 0.75 at 38,000 feet.

Laminar flow was achieved satisfactorily back to 80-percent chord, using suction to 70-percent chord.

An aircraft design study assessed the possible benefits of LFC applied to commercial transport aircraft. The mission format included a 5,000-nautical-mile range, 69,000-lb payload (300 passengers plus cargo), 0.8 cruise, 130 KEAS approach speed, and a 10,000-foot field length.

Because of the unusual wing construction, the study included strength, flutter, and aeroelastic analyses for several aspect ratios. It utilized advanced technology appropriate to the year 1995 and included a graphite-epoxy composite basic wing structure.

The initial configuration was laminarized to 70-percent chord on both upper and lower wing surfaces. The suction pump and drive systems mounted under the wing near mid-semispan reduced suction duct sizes; the propulsion engines located on the aft fuselage reduced engine noise effect on LFC.

For comparison, the study used competitive turbulent flow configuration designed for the same mission and with the same level of advanced technology except for LFC.

The comparison showed that the LFC airplane would require 22 percent less fuel for the same mission, allowing for 2 percent fuel used in providing suction.

Futher consideration of the intial LFC configuration disclosed a number of concerns:

1. Positive protection of the wing leading edge would be required to avoid insect impingement — insect debris as small as 0.1 mm (0.004 inch) above the surface could cause a trailing wedge of turbulence.
2. Access to wing systems would be difficult with LFC on the lower surface.
3. The lower LFC surface would be vulnerable to damage from debris thrown up from the runway.
4. The LFC wing area was 27 percent greater than an equivalent turbulent wing area, due to the relatively poor maximum lift capability of an LFC configuration which did not have a leading edge device.

It became obvious that a leading edge shield for contamination avoidance could be shaped to provide increased lift and could be retracted into the lower surface when not in use. A device of this type is shown in Figure 7. With such a device, laminarization of the lower surface would be impractical due to surface irregularities at the interfaces. However, removal of LFC from the lower surface would overcome the vulnerability and access problems. LFC is less effective on the lower surface, so Douglas engineers considered extending laminar

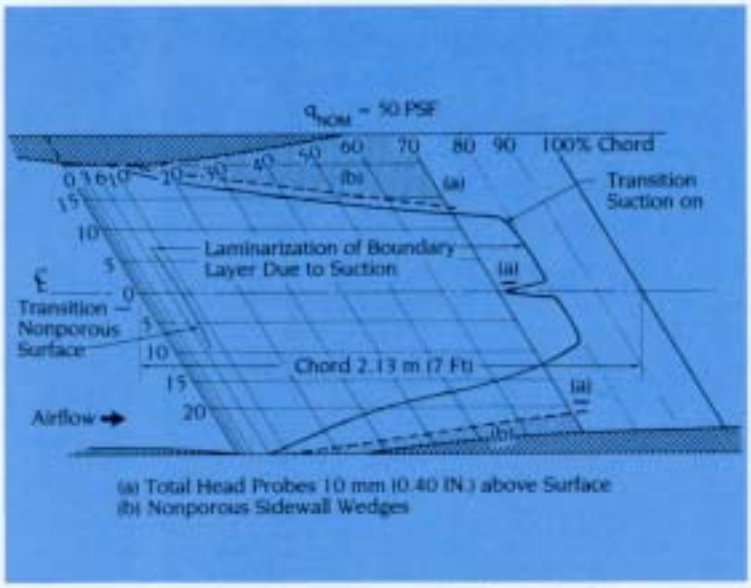


Figure 6. Effect of Suction to 70-Percent Chord on Transition

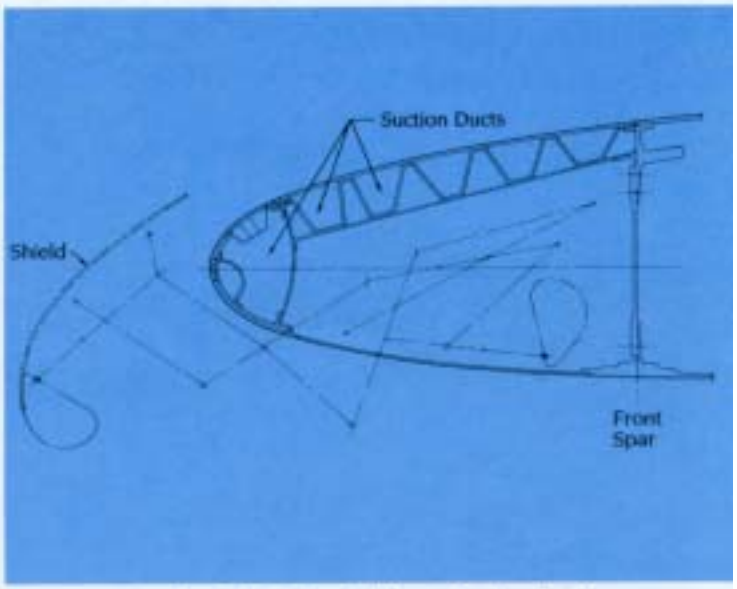


Figure 7. Leading Edge Design with Upper Surface Suction

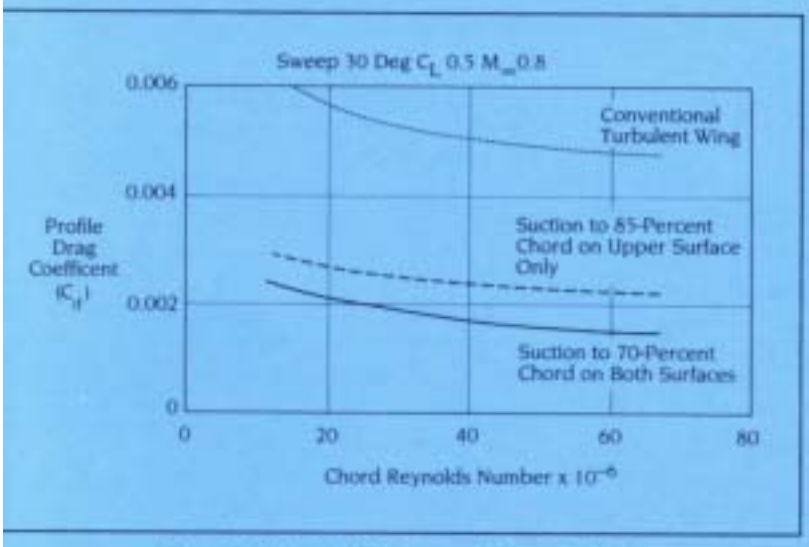


Figure 8. Effect of LFC Extent on Wing Profile Drag

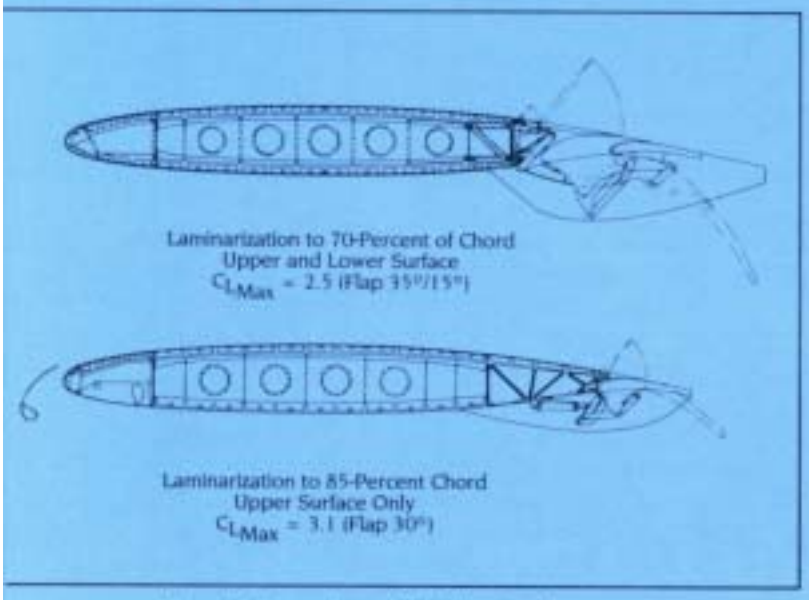


Figure 9. Comparison of LFC Wing Sections

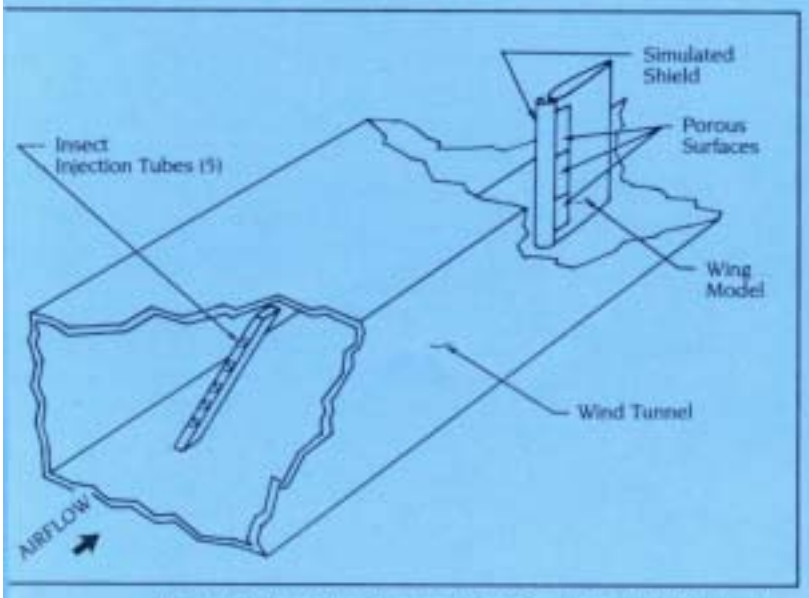


Figure 10. Insect Impingement Tests Conducted in NASA-Lewis Icing Tunnel

flow to 85-percent chord on the upper surface as possible compensation. The effect on drag is shown in Figure 8. It seemed possible that the small increase in drag coefficient could be more than compensated by the simpler LFC system and increased maximum wing lift. Even with a smaller flap aft a wing with a leading edge device can provide 24 percent more lift (Figure 9).

A wind tunnel test in the NASA-Lewis icing tunnel (Figure 10) confirmed the shielding effect of the leading edge device and provided data for use in analyzing insect trajectories, based on existing programs developed for ice accumulation.

The revised LFC configuration with suction only on the upper wing surface to 85-percent chord is shown in Figure 11. The improvements over the previous configuration are presented in Table 1. From every aspect considered, the configuration with LFC on the upper wing surface only (USO) is superior. In addition, practical design objectives of reduced vulnerability to both insect contamination and foreign object damage plus normal wing access to systems are obtained.

The effect of LFC on direct operating cost (DOC) is shown as a function of fuel cost in Figure 12. Based on recent fuel prices, the DOC of the USO aircraft would be 6 to 8 percent less than for an equivalent aircraft without LFC, and the USO aircraft is again superior to the aircraft with suction on both upper and lower surfaces (U + L).

LFC LEADING EDGE FLIGHT TEST

The leading edge region of the wing is most critical under adverse environmental conditions. To test the effectiveness of the LFC surface protection systems, a Douglas LFC leading edge has been installed on the NASA JetStar, and the test results to date are very encouraging. The test section (Figure 13) is located within a glove fairing designed to provide a pressure distribution similar to that desired for LFC. The protective shield uses only a simple hinge (Figure 14), and, for this test, installation is designed to avoid significant asymmetric lift when extended only on one side of the aircraft. The relatively small shield is equipped with a supplementary spray system to provide additional protection for the upper surface if necessary. Preliminary flight test results indicate that even the small shield may be sufficiently effective for contamination avoidance without the spray, and laminar flow has been achieved over the test section under cruise design conditions.

	LFC on Both Wing Surfaces to 70% Chord	LFC on Upper Surface Only to 85% Chord	Change (Percent)
Wing Area m^2 (FT^2)	331 (3,560)	288 (3,100)	−13.0
Weight (OEW) kg (LB)	97,900 (215,830)	93,690 (206,550)	− 4.3
Thrust/Eng SLS kN (LB)	145.4 (32,690)	139.8 (31,430)	− 3.9
Fuel Burned kg (LB)	49,745 (109,670)	49,260 (108,600)	− 1.0
Initial Cost ($ Million)	48.39	46.52	− 3.9

Table 1. LFC Aircraft Configuration Suction on Upper Wing Surface to 85-Percent Chord

	WING	HORIZ	VERT
Area m^2 (FT^2)	288 (3100)	80.3 (864)	52.7 (567)
Aspect Ratio	10	5	1.1
Taper Ratio	0.25	0.4	0.7
Sweep	30 Deg	30 Deg	40 Deg
Thickness Ratio	0.108 Avg	0.11	0.11
Tail Volume Coefficient	—	1.24	0.068

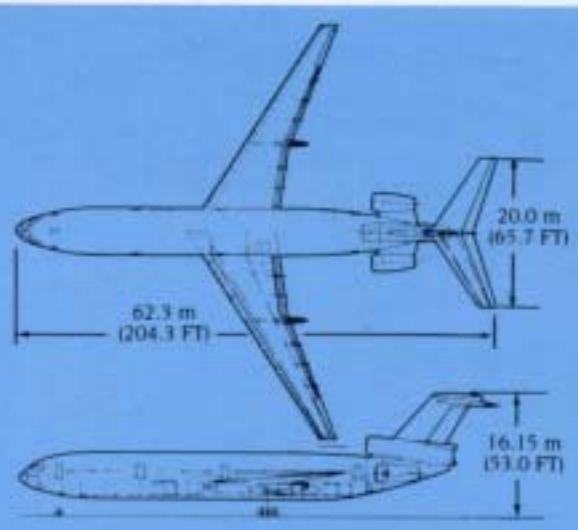


Figure 11. Upper Airfoil Surface Laminarized to 85-Percent Chord

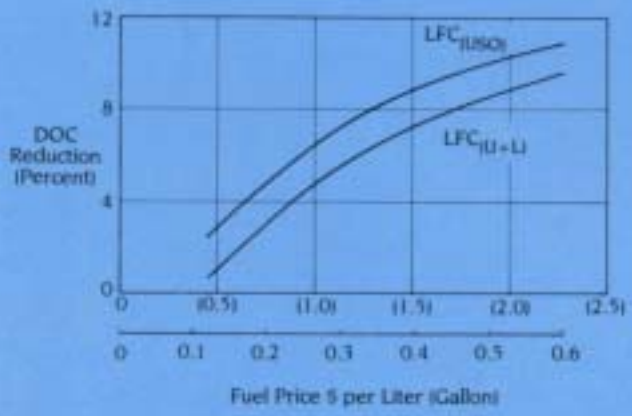


Figure 12. Reduction in DOC Due to LFC

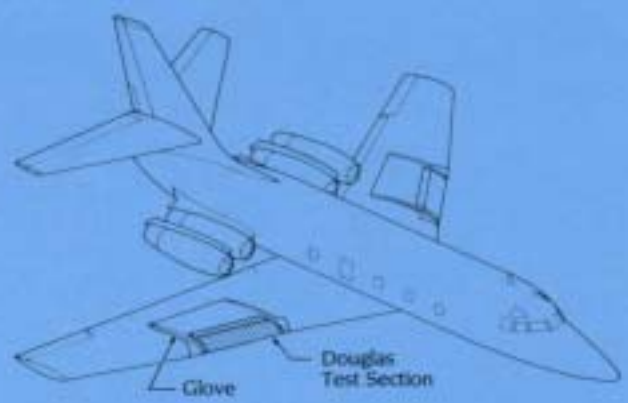


Figure 13. NASA Jet Star LFC Test Airplane

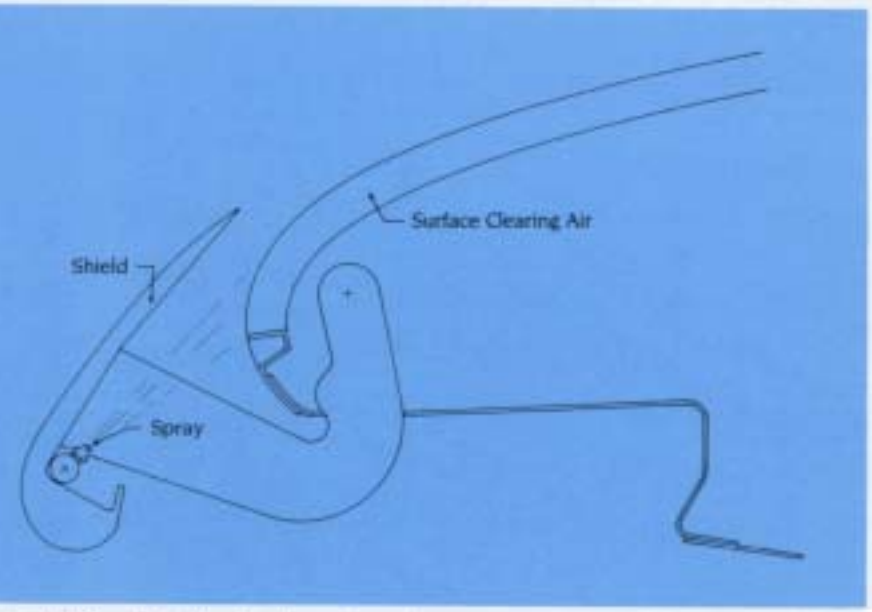


Figure 14. Contamination Avoidance Concept

LFC HIGH-SPEED SWEPTWING WIND TUNNEL TEST

The Douglas LFC system is to be tested at high Mach and Reynolds numbers on a 2.13-meter (7-foot) chord sweptwing model. The tests will be made in the NASA Langley 2.44-meter (8-foot) pressurized tunnel at Mach number up to 0.82 and at Reynolds numbers ranging from 8×10^6 to 40×10^6.

Perforated suction glove panels will be installed on the upper surface in place of previously tested slotted panels to test their effectiveness for achieving LFC over the full chord length.

HYBRID LAMINAR FLOW CONTROL (LFC)

A simpler alternative approach to achieving LFC on sweptwings is now being investigated. Suction is used in the leading edge region to counteract attachment line and crossflow instabilities, and a favorable pressure gradient is used further aft to maintain laminar flow over the main wing box region.

This system, known as Hybrid LFC (HLFC), is illustrated in Figure 15. Its advantages are reduced suction power requirements, simplification of the suction system, uncompromised wing structural efficiency and fuel volume, and reduced initial cost and maintenance requirements.

Studies have shown that to test and prove HLFC for transport aircraft a glove could be added to the upper surface of a DC-9 wing to obtain the desired pressure distribution, and a suction leading edge with a high-lift shield could replace the existing leading edge (Figure 16). With its clean wing unencumbered by engine noise and nacelle interference, the DC-9 would be an ideal vehicle for LFC testing.

Current indications are that the use of a reliable and effective electron beam-perforated suction surface on the wing protected by a high lift shield may provide the breakthrough needed to make LFC a practical reality on transport aircraft. Flight testing with a sufficiently representative transport aircraft (such as the DC-9) to prove the effectiveness of LFC should pave the way to substantial performance and economic benefits in the future.

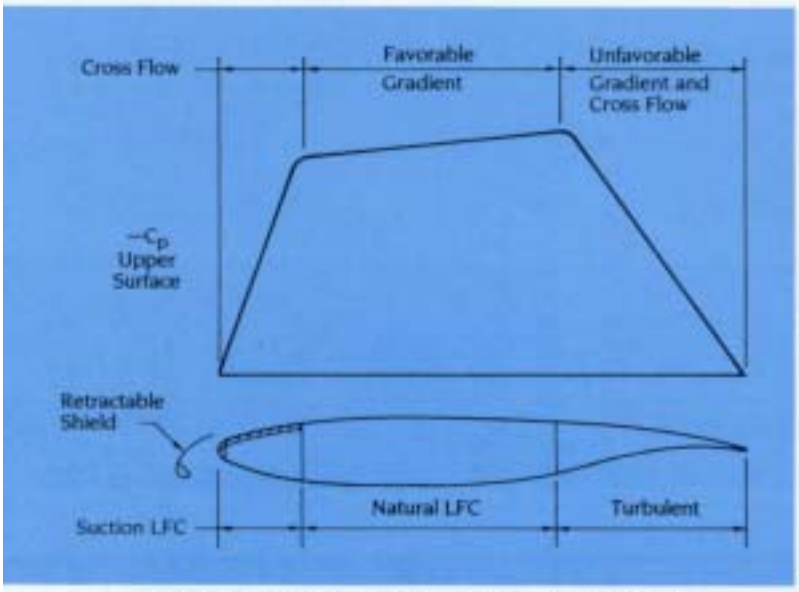


Figure 15. Natural LFC on Swept Wing with Suction at Leading Edge

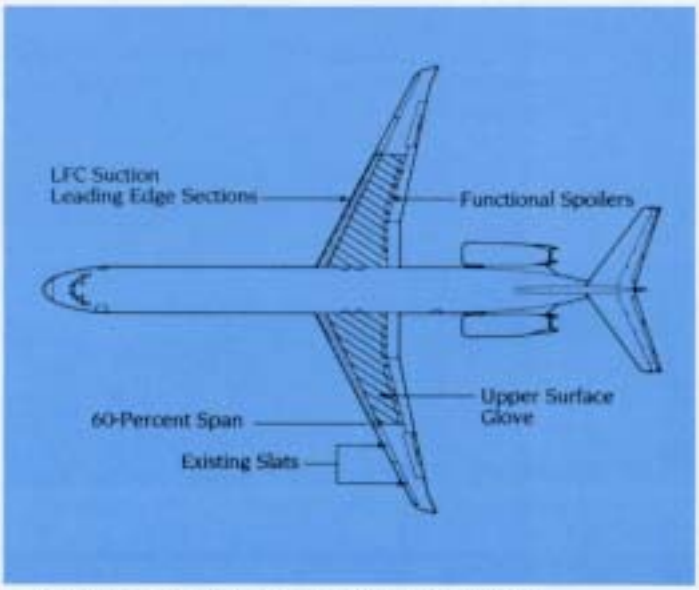


Figure 16. Flight Test Aircraft Hybrid Laminar Flow

POWERBACK PROCEDURE

Backing transport aircraft away from the blocks under their own power dates back approximately 40 years when reversible pitch props made their debut. The primary function of the powerback procedure was to augment braking during landing rollouts. While the operation proved effective enough in its braking function, it deprived the engines of necessary air for cooling and achieved only moderate success as an accepted procedure.

With the advent of turboprop engines, overtemping virtually disappeared, bringing about renewed interest in powerback, mostly in military operations. More recently, powerback has crept into the turbojet operation and is gaining recognition as an effective means of backing away from the blocks.

In the early '80s, Eastern Airlines initiated powerback procedures with its transport aircraft. Eastern's success encouraged Republic Airlines to explore powerback with its own fleet. Subsequently, Republic Airlines received FAA approval to powerback its 727s, DC-9 Series 10, 30, 50, and MD-80s. Now, both operators use powerback at many of their stations to perform many operations daily.

Advocates say the advantages of powerback lie in time savings at pushoff. Realistic figures for a powerback departure show a 2.5-minute saving over the tug or

pushback operation. As time savings accumulate, more departures can be accomplished during peak periods at multiple operation airports. An example of the savings can be seen by multiplying the 2.5-minute savings by a realistic 200 daily departures, times 30 days, producing a dramatic monthly savings in block-to-block time. Advantages in dollar savings come with not paying for standby tug service.

Powerback is not without drawbacks. Requests for powerback clearances by resident airlines are approved by the airport authority only after careful consideration and survey of specified gates at designated stations. Powerback would be limited on ramps with excessive gradients. Other ramps, even though level, would be limited if they were covered with ice, slush, snow, or other contaminants. Other restrictions include excessive ground traffic in the immediate area and poor visibility due to rain and fog. Powerback would be restricted in any area where standard safety practices would be impaired.

In the interest of safety, most operators require a coordinator and a wingman* to work with the captain during a powerback operation. The ground crew wear acceptable ramp clothing and protective eye goggles to prevent possible injury from swirling particles of ramp debris (Figure 1). Ground crews should caution other personnel in the area of the powerback operation and direct them away from potentially hazardous areas. (Winds generated by deployed reversers and spooled up engines have been recorded up to 14 knots at the wingtips and up to 23 knots at the aircraft's nose.)

In preparation for a powerback operation, the wingman positions himself aft of the left wingtip where he can observe the entire area around the aircraft (Figure 2), protecting the aircraft from traffic hazards and potential engine damage from foreign objects. The coordinator positions himself forward of the aircraft's nose in full view of the captain (Figure 3).

Semaphore-like arm signals** convey ramp conditions between the wingman and coordinator. A thumbs-up signal by the captain communicates to the coordinator that clearance has been received to powerback; the coordinator returns with a salute noting message understood. For clarity of signals the coordinator and wingman use luminous, vermilion-colored, elongated shades over a flashlight lens. For added visual cues at night, the shades are lighted.

Assuming all other criteria are met for a powerback maneuver, including cockpit configuration, communications begin with the wingman. From his wingtip position, he keeps his arms down by his sides until he is certain ramp conditions are safe; if he should cross the wands over his head (Figure 4), he is advising the aircraft to remain static or stop. When the wingman has surveyed the area and deemed the ramp safe for powerback, he will

*Titles may vary between airlines.

**Some arm positions/signals may vary between airlines.

Figure 1.

Figure 2.

Figure 3.

give the all-clear signal by extending his arms outward (Figure 5). These communications are between the wingman and coordinator only. The captain will not move the aircraft until, first, clearance is received from ground control, and second, an all-clear is signaled by the wingman.

When ground control advises the flight crew they are cleared for powerback, the captain gives a "thumbs up" (Figure 6) to the coordinator who responds with an all-clear salute (Figure 7). (Depending on lighting conditions and/or visibility, the captain may opt to flash the landing light(s) in lieu of thumbs up.) The all-clear means the area is safe to begin the powerback maneuver, but it is not a clearance to move the aircraft. That clearance will come only when the coordinator rotates both hands/wands in a rolling motion in the direction he wishes the aircraft moved (Figure 8).

At that point the pilot moves the reverser levers to reverse thrust detent. Appropriate cockpit lights illuminate and the reversers deploy. Next comes brake release as both pilots place their feet flat on the floor and leave them there throughout the reverse roll. The pace of the coordinator and the rate he rotates the wands tell the pilot the speed he should back the aircraft. Constant eye contact between the pilot and coordinator is essential. It is also essential that one pilot keep his eyes on the instruments. DC-9 procedures call for a maximum of 1.3 EPR for powerback (Figure 9). If 1.3 is reached and the aircraft does not move, the powerback maneuver should be discontinued. Once the aircraft is moving, 1.3 EPR may move the aircraft faster than required, in which case thrust should be reduced. It may even be possible to reduce one engine to idle detent and the aircraft will still roll at a sufficient rate.

There may be times when tires have become flat-spotted under heavy loads and 1.3 EPR will not move the aircraft off the spot in reverse. Some crews have been successful in first moving the aircraft forward, off the spot a foot or so, then initiating powerback from that point. As in all cases, *caution* must be exercised. This is not a universal procedure, or a procedure published by Douglas Aircraft Company or the FAA.

If turning the aircraft is included in the maneuver, the coordinator signals by pointing downward with the wand that indicates the direction the tail of the aircraft is to go while continuing to rotate the other wand. To increase the turning rate, the coordinator increases the cycle motion of the rotating wand.

Stopping the aircraft's rearward motion requires a contrasting *come forward* signal by the coordinator. He holds the wands in the same manner as for backing the aircraft, but he reverses the rotating motion and moves slowly backward.

Seeing the signal, the pilot places the reversers in the forward thrust position, allowing the forward thrust to stop the backward motion. It is very important during this transition for the pilots to keep their feet firmly on the floor preventing the use of brakes to arrest the backward motion. Depending on the load and center of gravity, brake application here could tip the aircraft back, causing a tail strike.

If at any time throughout the operation the wingman sees an impending problem which affects the maneuver, he signals the coordinator with a quick arms-to-side movement, who signals the captain to stop the aircraft. If the movement is in reverse, the same stopping procedure applies as before. If the movement is forward, the pilot makes sure the throttles are in idle, then may apply the brake. With the aircraft secured, the captain awaits the next signal — right turn, left turn, backup, or come forward. The captain responds according to the signal. When the taxi area is clear, the coordinator gives the take-over signal, and the aircraft is taxied out of the area.

Standard signals apply even in unusual situations. As an example — a chock is wedged behind a tire and cannot be removed by hand — the thumbs-up and all-clear have been given, and the coordinator signals to come forward. The captain releases the brakes and responds with forward thrust. When the pressure is off the chock, the coordinator quickly extends his hands to the stop signal. When the chock has been removed, the coordinator gives the standard hand/wand rotating signal for backup, and the captain responds with brake release, reverse thrust, and feet on the floor.

Powerback is a proven technique which has time saving, economic benefits. If the procedure in the Flight Crew Operating Manual is followed, it can be mutually beneficial to flight operations and to maintenance.

Figure 4.

Figure 7.

Figure 5.

Figure 8.

Figure 6.

Figure 9.

FUSELAGE AND NACELLE STRAKES — WHY?

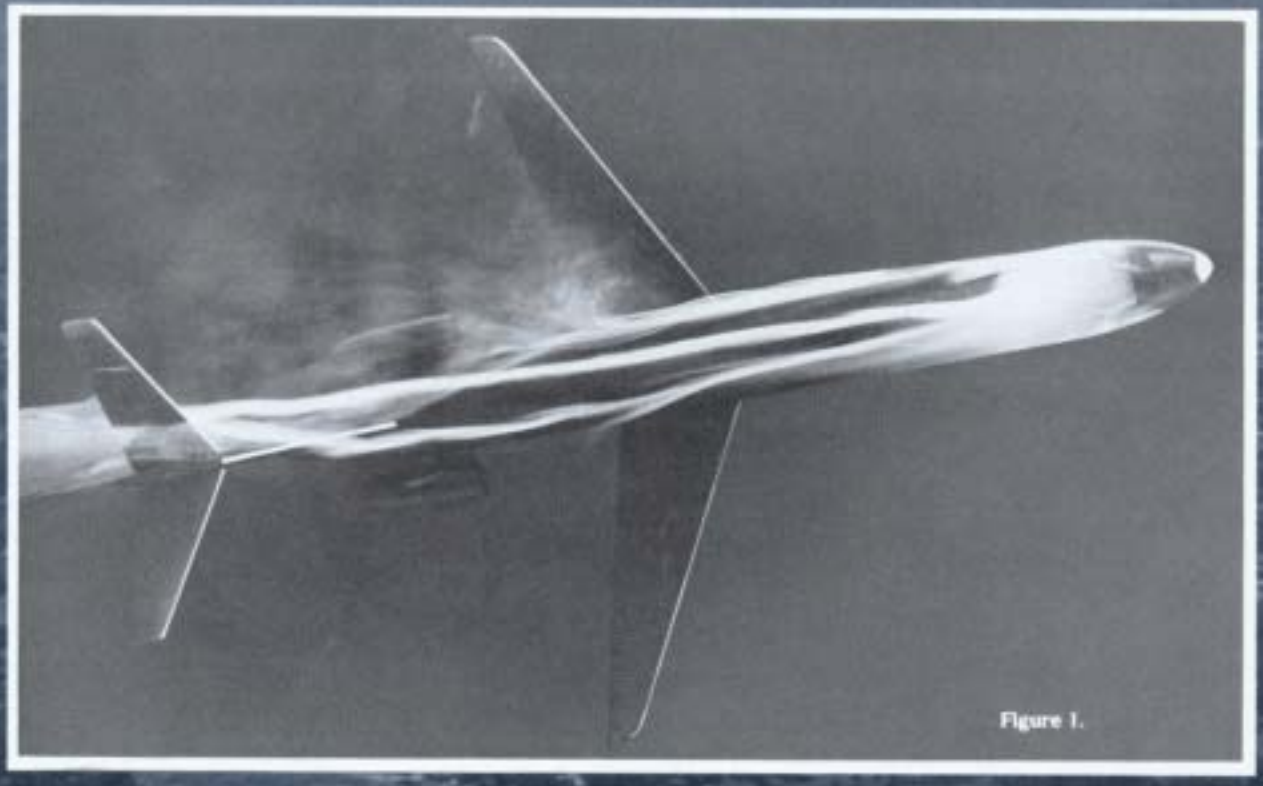


Figure 1.

Fuselage strakes have been included in the DC-9-50 and MD-80 family of aircraft to improve the directional stability of these long-nosed Douglas aircraft when flying in a sideslip at high angles of attack. Nacelle strakes were added to the MD-80 to provide additional recovery capability in the event of a deep stall.

Flying at high angles of attack and in a sideslip, transport aircraft develop vortexes at the lower forward fuselage. These vortexes flow up and along the fuselage side passing the vertical tail as pictured in Figure 1. The vortex flow can degrade directional stability, and handling qualities are affected accordingly.

As illustrated in Figure 2A, when the center of the vortex transits low on the vertical stabilizer, as with early short fuselage DC-9s, the resultant side force assists the vertical stabilizer in counteracting the sideslip. As the DC-9 fuselage grew longer, the vortex center moved progressively higher on the vertical stabilizer (shown graphically in Figure 2B and Figure 3). The resultant force from this higher vortex acts in opposition to the stabilizing force of the vertical, thereby degrading directional stability.

With the DC-9-30 development, Douglas installed a rudder limiter to prevent the airplane from reaching sideslip angles where directional stability was affected. To assure directional stability in the approach configuration, the limiter confines the rudder to ± 17 degrees with the flaps extended up to 5 degrees.

The rudder limiter was successful on the Series 30 and 40 DC-9s, but it did not entirely satisfy the Series 50 requirements. As the fuselage reached Series 50 length, the vortex center moved to a height on the vertical tail that the rudder restrictions compromised other handling qualities. Therefore, an alternate method of providing adequate directional stability that would assure good handling qualities on the Series 50 was necessary.

The answer evolved as *fuselage-mounted strakes* that were developed and optimized during wind tunnel testing. The testing also revealed the lower forward portion of the fuselage as the most favorable location for the strakes. In that location, strakes generate vortexes that alter the local flow past the vertical tail, providing good directional stability over the greatest range of angles of attack, sideslip, and flap deflection. In addition, wind tunnel testing showed the final configuration did not degrade longitudinal stability or stall recovery, nor adversely affect lift and drag. The Series 50 strake design proved suitable for the longer MD-80 and was carried over without modification.

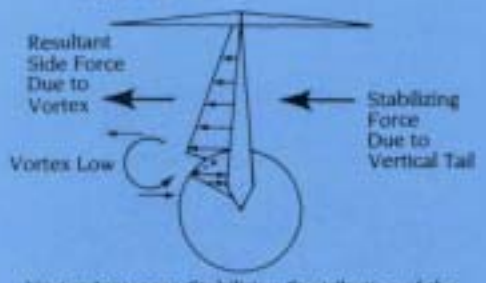
MD-80 *nacelle strakes* enhance stall recovery at angles of attack above the normal stall region. When the horizontal tail enters the wing wake in these "higher-than-normal" regions, T-tailed airplanes may encounter deep-stall conditions where stall recovery by conventional means becomes difficult.

Preliminary designs of the MD-80 exhibited acceptable recovery characteristics with flaps up but marginal in some flaps-down configurations. Wind tunnel data suggests several options, including an increased horizontal span, use of spoiler deployment, or additional fuselage, or nacelle strakes. The nacelle strake design chosen for production improves the flow across the horizontal tail where it increases stabilizer and elevator effectiveness (at very high angles of attack) sufficient to provide nose-down pitching moment for stall recovery. Thirty-eight nacelle strake configurations were evaluated before the final design was chosen.

With the addition of fuselage and nacelle strakes, the exceptional handling qualities of the long-nosed DC-9s have been retained on the MD-80s without the necessity of a stability augmentation system.

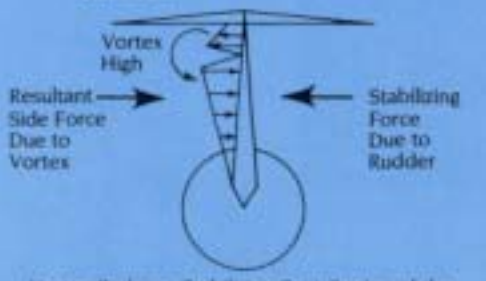
EFFECT OF FUSELAGE VORTEX ON DIRECTIONAL STABILITY

Figure 2A.



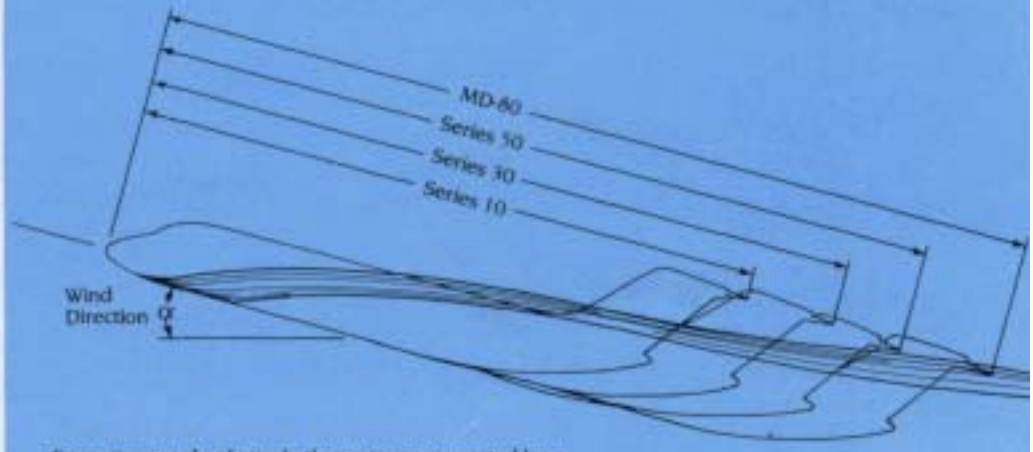
Vortex Increases Stabilizing Contribution of the Vertical Tail

Figure 2B.



Vortex Reduces Stabilizing Contribution of the Vertical Tail

Figure 3.



For a given angle of attack, the vortexes generated by a long-nosed airplane will pass at a higher point along the vertical stabilizer than those of a shorter aircraft — the longer the nose, the higher the transiting vortexes.

More than a decade ago, DC-10 operators initiated a reduced thrust plan as a means to reduce engine wear during takeoffs. Since then, the combined efforts of operators and manufacturers have contributed toward effective development and acceptance of reduced thrust as an operational procedure. Within this 10-year timeframe, monitoring indicates a maintenance cost savings of approximately five percent for each one percent thrust reduction. The relationship of five to one is valid in the region of full-rated thrust; however, this relationship decreases with increased thrust reduction.

A review of present operational methods, safety, and realized operational benefits seems timely in view of the fact this subject was last discussed in DC *Flight Approach* No. 24, September 1975.

Two primary methods are employed today by DC-10 operators. They are the variable reduction (assumed temperature) method and fixed reduction — based on either percentage of thrust or temperature increment. Both methods are based on the variation of thrust with temperature for any given altitude.

Most of today's commercial jet engines are flat-rated for constant thrust to a given temperature breakpoint. The thrust then decreases until the maximum certified temperature for the given pressure altitude is reached (Figure 1).

Since airplane performance is directly proportional to thrust, and aircraft certification is based on the thrust characteristics of a particular configuration, it becomes evident (Figure 1) how it is possible to take advantage of DC-10 excess performance.

Excess performance is available whenever the takeoff temperature capability exceeds the breakpoint and actual ambient temperature (shaded area in Figure 1). When this condition exists, it is possible to perform a reduced thrust takeoff. Assumed temperature method, the most commonly used, takes advantage of any available excess performance, whereas the fixed method

REDUCED THRUST FOR

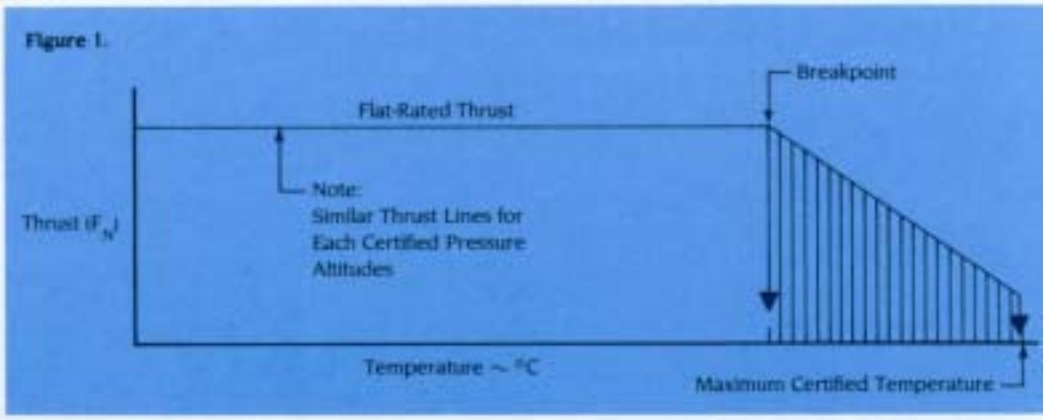
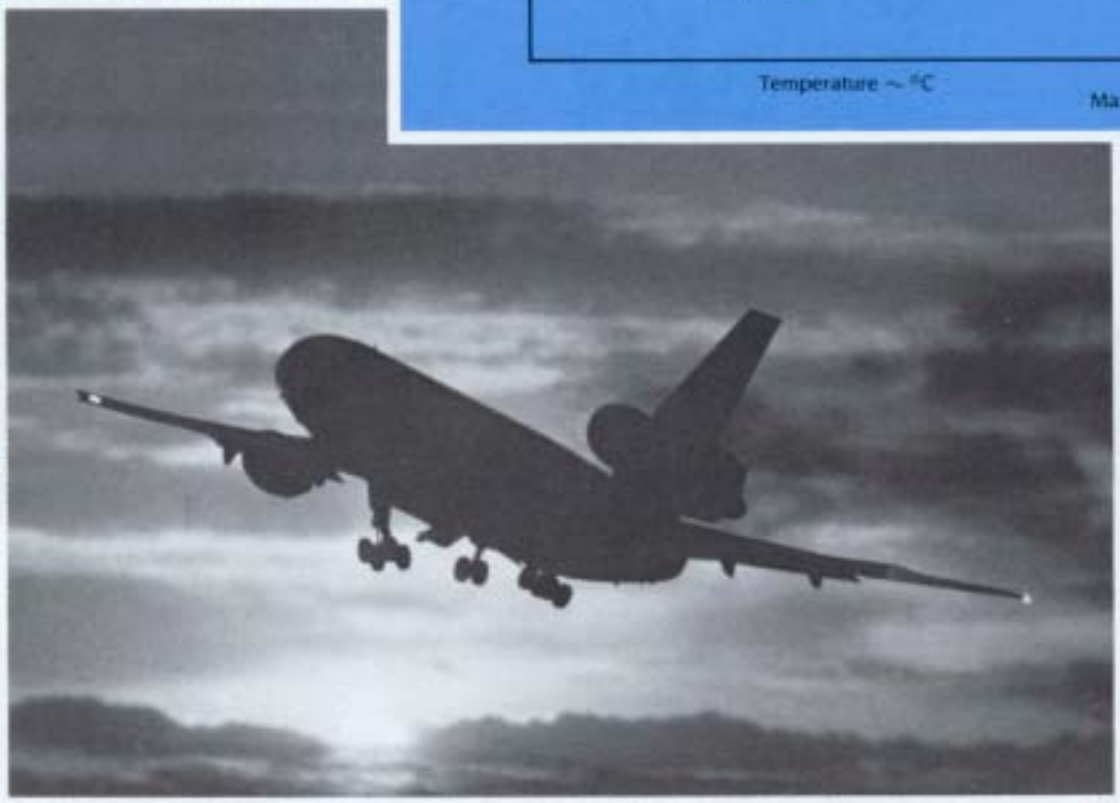


Figure 1.



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TAKEOFF—AN UPDATE

can only be used when a specified or greater excess performance is available.

It is understandable why some crews are reluctant to use reduced thrust since they believe that this procedure uses the entire runway available; however, this in fact is not true. Just the opposite is true as is evident in Tables 1 and 2.

Airplane performance is at a limiting condition only when the assumed temperature equals the actual ambient temperature. In terms of takeoff field-length performance, a reduced thrust takeoff has inherent protection as shown in Table 1. This protection is directly proportional to the difference between the assumed and actual ambient temperature.

The unaccounted for excess field length when using reduced thrust for takeoff is the result of operating under the actual ambient, *not* the assumed, temperature conditions, Table 1. The temperature difference between assumed and actual has a significant effect on field length performance due to the resulting lower than assumed true airspeed during the takeoff. This true airspeed difference does not significantly affect climbout performance (Table 1). The inherent field length performance safety margin is directly proportional to the percentage of takeoff thrust reduction and exists in all properly executed reduced thrust takeoffs.

Since the early days of reduced thrust takeoffs, improvements to procedures and equipment have simplified implementation. Prior to discussing the implementation, however, it is pertinent to review applicable DC-10 criteria.

DC-10 operators must establish a periodic check on the availability of full-rated takeoff thrust to assure that deteriorated engines are not being used. This check can be accomplished at less than full takeoff thrust by using specified maintenance manual procedures that will prevent unnecessary engine wear. The flight director mode should not be used for reduced thrust takeoff when the airplane gross weight is less than W_{MC}, a weight at which the airplane performance initially becomes minimum control speed limited. In addition, reduced thrust takeoffs are not permitted from runways that are contaminated with water, ice, slush or snow; and the anti-skid and slat functions of takeoff warning must be operative.

Takeoff speeds for reduced thrust takeoffs (except V_{MCG}) must be increased to the assumed temperature, assuring V_2 at 35 feet above the takeoff surface in the event of an engine failure at V_1. FAA requires V_{MCG} be determined for the actual ambient temperature, assuring directional control will not be compromised in the event the pilot elects to increase thrust to maximum allowable during takeoff.

Crew members often question the procedure of determining takeoff speeds at the assumed temperature since the procedure results in higher takeoff speeds with less than full takeoff thrust. The increase in V_1 is required to maintain the balanced field-length concept with less than full-rated thrust. The increased V_R is necessary to achieve V_2 at 35 feet if an engine fails at V_1 with less than full-rated thrust, as depicted by Figure 2.

The FAA criteria for runway surface condition have been recently changed to prohibit reduced thrust operation from a contaminated runway. Most operators, and Douglas, use reduced thrust from *dry* runways only. Consider, for instance, a situation where a reduced thrust takeoff is planned and, as the airplane initiates taxi for takeoff, it begins to rain. The first problem the crew encounters is to define the runway surface condition: is it merely wet or is it contaminated?

A wet runway is neither dry nor contaminated. A contaminated runway has standing water, slush, snow, or ice on its surface, and a wet runway surface exhibiting a mirror-like surface should be considered contaminated.

DC-10 with CF6-50 Engines

	Temperature	
Actual	60°F	108°F
Assumed	108°F	108°F
FAR Field Length	9,740 ft	9,740 ft
• Distance to 35 feet (Engine Fail @ V_1)	8,850 ft	9,450 ft
• Distance to 35 feet (All Engines) × 1.15	9,025 ft	9,740 ft
• Climb Gradient Gear Up. One Eng. Inop.	2.7%	2.7%

Table 1.

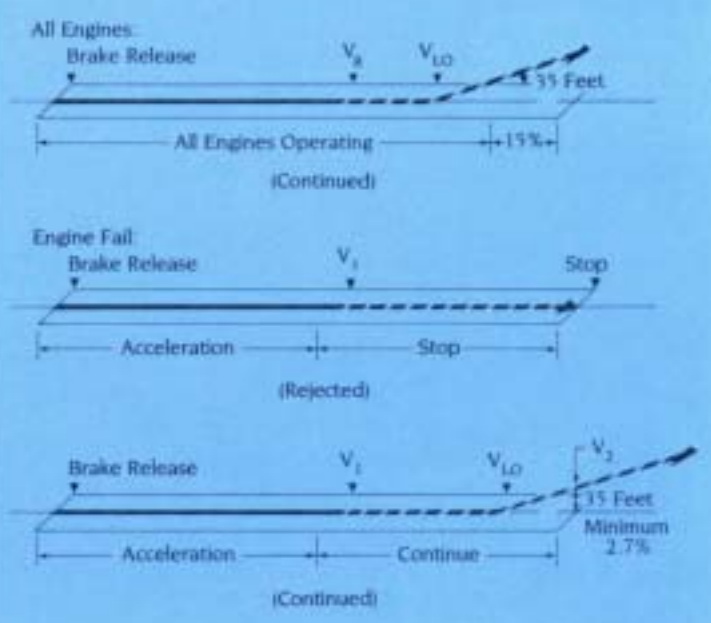


Figure 2.

Takeoff performance *must* be totally recomputed prior to departure from a contaminated runway. For the wet runway condition, full takeoff thrust is recommended and may be used with takeoff speeds corrected for the planned reduced thrust takeoff. Table 2 compares resulting performance of various conditions based on the following given data:

DC-10-30 with CF6-50C2 Engines

Gross Weight:	500,000 lb
Available Runway:	10,300 ft
Pressure Altitude:	Sea Level
Ambient Conditions:	Standard

DC-10-30 Takeoff Distance Comparison

Condition	Takeoff Distance (Feet)	Approximate Protection (Percent)	Temperature of Ambient	Temperature of Assumed	Temperature of Speed Basis
A	10,300	0	120	→	→
B	9,220	10	60	120 →	→
C	8,610	16	60 →	→	120
D	7,880	23	60 →	→	→

Table 2.

Condition A: the assumed and ambient temperatures are equal at 120°F.

Condition B: same conditions except the ambient temperature is 60°F, which is less than the performance limiting temperature, allowing reduced thrust to be used. This results in an actual takeoff distance of 9,220 feet or approximately 10-percent protection in field length.

Condition C: it begins to rain and the crew elects to increase thrust to full takeoff but uses the takeoff speeds corrected to the assumed temperature. The thrust increase by itself improves the performance protection an additional 6 percent over condition B or 16 percent better than the performance-limited condition A.

The final condition D: full thrust is used and the speeds are recalculated for the actual temperature of 60°F, resulting in a 23-percent improvement over condition A. Condition D is the base condition; the reduced thrust cases diminish the safety margin from this point.

FAA regulations require V_{MCG} be determined for full takeoff thrust as protection in the event of a V_{MCG}-limited reduced thrust takeoff and where the pilot elects full takeoff thrust. The above rule prohibits use of the flight director takeoff mode in combination with reduced thrust at gross weights of W_{MC} or less. If the FAA had *not* required that V_{MCG} be determined at the actual temperature, the flight director takeoff mode could be used for *all* takeoffs provided SB 22-107 is incorporated.

To review the takeoff speeds, the following graphic and mathematic relationships will help explain how V_{MCG} affects flight director climbout speed programming. Flight directors incorporating Service Bulletin 22-107 command V_2 + 10 KIAS for all engines, V_2 for engine failure at or below V_2, existing speed for engine failure between V_2 and V_2 + 10 KIAS, and V_2 + 10 KIAS for engine failure above V_2 + 10 KIAS.

Flight directors not incorporating Service Bulletin 22-107 should not be used in the takeoff mode. They program V_2 + 10 KIAS for all engines and V_2 for engine inoperative.

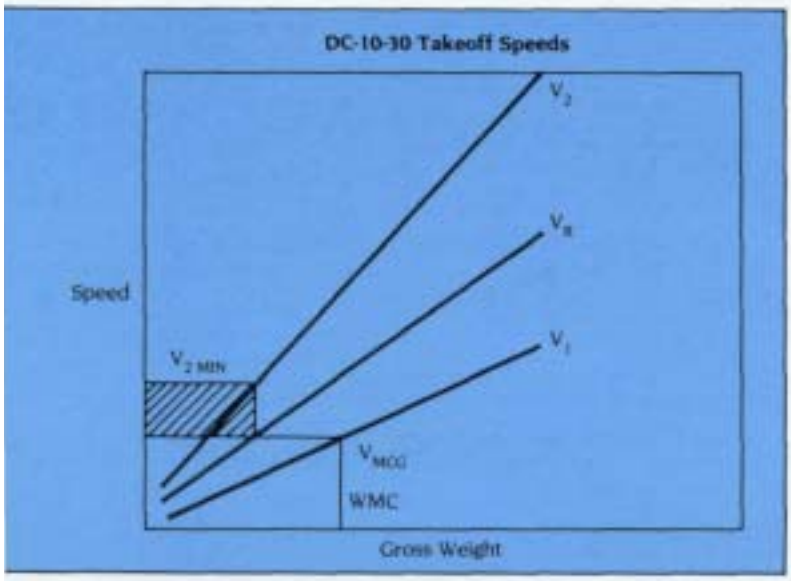


Figure 3.

Basically, takeoff V speeds are directly proportional to takeoff gross weight until limited by minimum speeds (Figure 3).

$V_{2\ MIN}$ is indirectly a function of V_{MCG} at the W_{MC} gross weight or less. Minimum takeoff safety speed is determined as follows:

DC-10-30
MINIMUM CLIMBOUT SPEED

$$V_{2\ MIN} = V_{R\ MIN} + (V_{2\ BASIC} - V_{R\ BASIC}) \text{ where}$$

$$V_R = V_1 \text{ and } V_1 = V_{MCG}$$

Thus:

$$V_{2\ MIN} = V_{MCG} + (V_{2\ BASIC} - V_{R\ BASIC})$$

Thus, in the case of reduced thrust W_{MC}-limited takeoff, the takeoff pitch guidance would command too slow a $V_{2\ MIN}$, since V_{MCG} is derived by the flight director system from the measured linear acceleration (at existing reduced thrust). The flight director-determined V_{MCG} when substituted in the above equation directly affects $V_{2\ MIN}$.

The following alternate flight director procedure may be used for all takeoffs in place of the takeoff mode for DC-10s with flight director not incorporating SB 22-107 and for reduced takeoff at gross weight less than W_{MC}:

> Prior to brake release, arm heading select and select vertical speed of approximately 2,000 feet per minute, which will bias the pitch command bar for climb:

> *Operators with ATS authorized for takeoff . . . no ATS for takeoff blank.

> After the airplane is airborne and the required takeoff safety speed is attained, select IAS HOLD:

> *Operators with ATS authorized for takeoff . . . no ATS for takeoff blank.

Airport analysis further reduces the crew workload and chance of error by providing the necessary information in a simplified condensed format as shown in Table 3.

Implementing reduced thrust takeoff effectively into everyday DC-10 operation has been significantly simplified by the takeoff flex mode (T.O. FLEX) on the thrust rating computer (TRC). The T.O. FLEX mode allows the operator to preselect the calculated assumed temperature; the TRC will automatically display the reduced N_1 takeoff value as a function of the actual total air temperature (TAT) and the preselected assumed temperature when the T.O. FLEX mode is selected. The T.O. FLEX mode allows use of autothrottles for reduced thrust takeoffs since the TRC and N_1 limit indices (autothrottle targets) are automatically positioned to the reduced thrust value, thus requiring no change between auto and manual modes during flight.

The availability of computerized airport analysis data also greatly simplifies the flight crew procedure to calculate assumed temperature. The use of computerized airport data provides a direct reading of assumed temperature for actual takeoff weight and airport conditions. Airport analysis data are available in several formats for both fixed flap and optimum flap operation.

Some operators use a fixed percentage deration and usually implement it by using a temperature increment from the actual performance limited temperature. Any fixed takeoff thrust reduction method is not as effective, since it cannot be used as often. Since many takeoffs fall between full-rated and the fixed reduction, a full-rated takeoff would have to be performed. With the variable

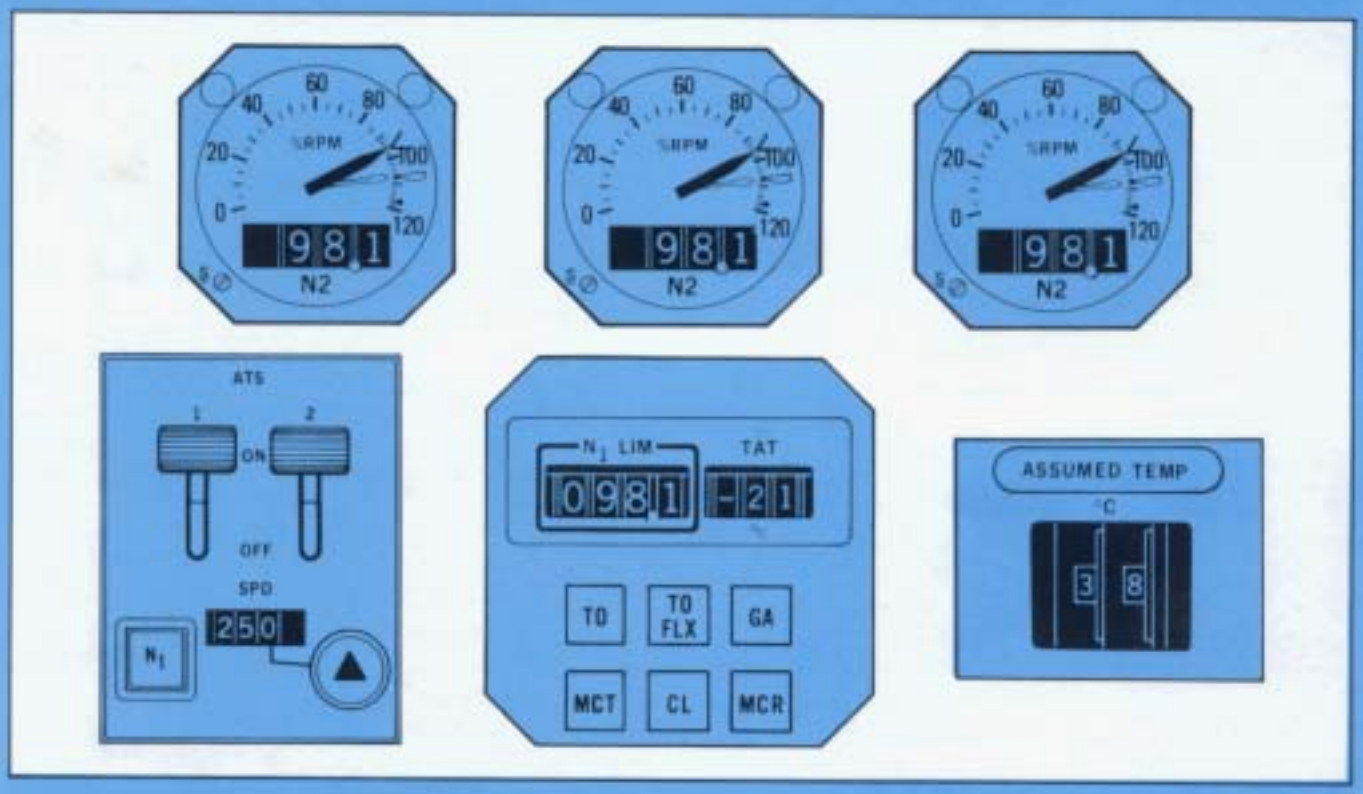
thrust reduction method, it is possible to take advantage of any available excess performance.

In conclusion, we wish to emphasize a statement in our opening paragraph: Engine manufacturer monitoring indicates a maintenance cost savings of approximately five percent for each one percent thrust reduction in the engine turbine area. The relationship of five to one decreases as percentage of thrust reduction increases and, of course, is more pronounced close to full-rated thrust.

A properly executed takeoff with reduced thrust is simpler with today's airport analysis, safer than a performance-limited takeoff, and it is cost effective.

TEMP DEG C	−10 KNOTS	0 KNOTS	10 KNOTS	20 KNOTS
30.0	527.8(20.0) 149/158/172 192/242/276	555.7(20.0) 157/165/178 198/248/283	565.3(19.7) 160/167/180 200/250/285	572.0(18.8)ST 162/170/182 201/251/287
32.0	522.6(20.0) 148/158/171 191/241/274	Gross Weight 532.4(18.9) V_1 154/162/174 V_R V_2 193/242/277 VFR	Opt. Flap V_{SR} V_{MM}	568.0(18.0) 162/170/182 200/251/286
34.0	517.3(20.0) 147/157/170 190/239/273			562.0(17.3) 161/169/181 198/249/284
36.0	511.6(20.0) 147/156/168 188/238/271	538.7(19.4) 155/163/175 194/244/278	547.2(18.1) 158/166/177 195/246/280	555.1(16.5) 161/169/180 197/248/282
38.0	505.7(20.0) 146/155/167 187/236/269	532.4(18.9) 154/162/174 193/242/277	540.9(17.5) 157/165/176 194/244/279	548.0(15.5) 160/168/179 195/246/281

Table 3.



The straight scoop

The flight ramp at the Douglas Aircraft Company in Long Beach is an awesome sight for the airplane buff. Shiny new twin-jets and trijets freshly painted in airline colors await delivery to the carriers of the world. At any time, an American Airlines MD-80 may sit flashing silver in the sun next to a deeply purple-shaded Federal Express DC-10. Planes destined for Alitalia, Finnair, TWA, and dozens of other carriers create a color spectrum that rivals any painter's palette.

To this rainbow of colorful aircraft on the Douglas flight ramp an anomaly has recently come. A Douglas plane, yes, and certainly new looking, but instead of jets it is propeller-driven, the wings are not swept, and no empennage like that has come off an assembly line in 30 years.

But today there is a new — or at least like-new — Douglas DC-2 waiting on the ramp. Its existence owes much to the devotion of many Douglas employees and retirees who have spent two years recreating the past by restoring the aircraft to the condition in which it first flew in the 1930s.

This ship, now christened the Donald W. Douglas, first rolled down the runway in 1935 as No. 77 of the 156 DC-2s built. It began its career with Pan American World Airways and was later transferred to its Mexican affiliate, Mexicana, in October 1937. Three years later it became part of the Aviateca of Guatamala fleet. After 13 years in Central America, No. 77 next flew in Montana for the Johnson Flying Service which used it for aerial spraying and to carry fire jumpers, cargo, and the occasional passenger. In 1973, the plane was traded to Stan Burnstein as partial payment for a DC-8. The following year, Mr. Burnstein donated the DC-2 to the Donald Douglas Museum and Library in Santa Monica, California.

The Douglas Aircraft Company Management Club arranged to bring No. 77 to the Long Beach plant for restoration in 1982. Since then, members of a newly formed Douglas Historical Foundation have devoted thousands of hours — a labor of love — into restoring this DC-2. Now, on the 50th anniversary of the DC-2, No. 77, one of only seven remaining DC-2s in the world, is ready to fly again.

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