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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

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Forwarded to:

Honorable J. Lynn Helms
Administrator
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

SAFETY RECOMMENDATION(S)
A-81-104 through -112,
and -122, and -123

About 1849 m.s.t., June 19, 1980, a McDonnell Douglas DC-9-80, N1002G, skidded off the right side of runway 21R while attempting a simulated hydraulic systems inoperative landing at the Yuma International Airport, Yuma, Arizona. The aircraft came to rest about 6,700 feet beyond the landing threshold of the runway. The aircraft was damaged substantially; however, the three flightcrew members were not injured. There were no passengers. The purpose of the flight was to demonstrate that the aircraft could be flown and landed safely with a complete failure of its hydraulic systems to demonstrate compliance with a special condition to the provisions of 14 CFR 25. The flightcrew consisted of a Federal Aviation Administration (FAA) project pilot, who occupied the cockpit's left seat and flew the aircraft; a McDonnell Douglas engineering test pilot, who occupied the right seat and performed the copilot's duties, but was designated as pilot-in-command by McDonnell Douglas; and a McDonnell Douglas flight test engineer assigned to monitor the aircraft's flight test instrumentation. 1/

The failure of the hydraulic systems was simulated; the flaps and leading edge slats were retracted and the ground spoilers, rudder hydraulic boost, and nosewheel steering were all rendered inoperative. The brake antiskid feature also was disabled to prevent excessive cycling of the brakes, which could result in depletion of brake accumulator pressure and a total loss of brakes during the landing rollout. The approach was normal except for the programmed no-flap/slat configuration. After landing, reverse thrust was applied, and during the rollout directional control of the aircraft was lost. The aircraft skidded 2,800 feet, ground looped, and skidded off the runway. The landing gear then separated, substantially damaging the aircraft.

Flight tests conducted after the accident disclosed that the application of reverse thrust disrupted the airflow over the aerodynamic surfaces of the empennage and substantially degraded the directional stability and controllability of the aircraft

1/ For more information read "Aircraft Accident Report: McDonnell Douglas, Corporation, DC-9-80, N10026, Yuma, Arizona, June 19, 1980." (NTSB-AAR-81-16.)

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during the landing roll. It was also determined that the higher thrust range of the DC-9-80 is modulated over the same angle of thrust lever movement used in the previous, lower-thrust models of the DC-9. Consequently, the DC-9-80 is more susceptible to thrust asymmetry during reverser operation due to minor variations in rigging tolerances and movement of the thrust levers. Such asymmetry in thrust levels can produce directional deviations which, during a normal landing, the pilot can correct with nosewheel steering, rudder, and if necessary differential wheel braking. However, in the certification test, after applying reverse thrust the pilot used rudder to correct a directional deviation because nosewheel steering and brake antiskid were not available. When the rudder failed to correct the directional deviation, the pilot intentionally used asymmetric reverse thrust and manual wheel brakes to make the correction. The application of manual wheel brakes at the high speed associated with the no flap/slat landing configuration, particularly without spoilers to destroy lift, resulted in several tire failures which aggravated the directional control problem.

Although this accident was unfortunate, it did precipitate subsequent tests and analyses which led to procedural changes that will minimize the potential for a loss of directional control during landing with the hydraulic systems inoperative. The McDonnell Douglas Corporation conducted extensive tests to quantify the directional control provided by the rudder at various levels of reverse thrust and at various rollout speeds. Other tests or analyses were conducted to determine the depletion rate of the wheel brake hydraulic accumulator during the landing rollout, using maximum braking. The tests and analyses showed that acceptable directional control and acceptable stopping distances could be attained during a landing with hydraulic systems failed when the brake antiskid system was turned on and the reverse thrust was limited to that obtained with the thrust levers in the reverse idle detent. Consequently, the adverse effect of reverse thrust on rudder control was reduced, and the pilot was provided additional controls (symmetric and differential antiskid braking) for stopping and steering and with protection against the skidding or rupture of the main gear tires. The revised procedures were:

- Make positive main gear touchdown to minimize float;

- Lower the nose immediately after main gear touchdown and after nosewheel touchdown apply the brakes smoothly to full pedal deflection;

- Set thrust symmetrically to the idle reverse detent. Do not use asymmetrical reverse thrust to maintain directional control;

- Use rudder and differential braking as required for directional control. Maintain the maximum possible steady brake pedal deflection to minimize accumulator pressure loss;

- Maintain symmetric idle reverse thrust until the aircraft is stopped, unless higher symmetric reverse thrust is required by existing conditions;

- Maintain maximum possible braking until the aircraft is stopped.

- During reverse thrust operation, should difficulty be experienced in maintaining directional control, reduce reverse thrust as required. Do not attempt to maintain directional control by using asymmetric reverse thrust.

The DC-9-80 certification test was completed successfully using these revised procedures.

The Safety Board remains concerned, however, that the inclusion of the revised procedures in the Aircraft Flight Manual does not place sufficient emphasis on the aircraft characteristics which led to revision of the procedures. Further, we note that although the pilot is advised to maintain symmetric idle reverse thrust until the aircraft is stopped, he is permitted to use higher levels of reverse thrust if required by such conditions as a shorter runway length than desired or rain, snow, or ice causing slippery runway conditions. Therefore, he could end up in a difficult situation where directional control is decreased as reverse thrust levels are increased. Finally, reverse thrust asymmetry could develop because of the high gain of the thrust reverser levers and could contribute to an initial loss of directional control.

Although the new procedures tell the pilot to reduce reverse thrust when directional control problems are encountered, they do not inform the pilot about the quantitative loss of rudder effectiveness accompanying increased levels of reverse thrust nor do they alert him to the possibility of thrust asymmetry. During a high-speed hydraulics-out landing, especially under adverse conditions, the pilot may not have sufficient available runway to correct for directional control problems if they develop. Further, although the effects of reverse thrust on directional controllability during landing rollout are more critical with the aircraft's hydraulic systems failed, the Safety Board believes that the pilot's knowledge of these effects is equally important for normal landings. Therefore, we believe that: (1) data quantifying rudder effectiveness during reverse thrust operation should be provided in the Aircraft Flight Manual along with a statement cautioning the pilot to carefully maintain symmetric reverse thrust; and (2) an explanation of the airplane's directional stability and control characteristics during reverse thrust operation should be provided in the training manuals and training programs.

In addition, the stability and control characteristics associated with reverse thrust have not been incorporated in DC-9-80 flight simulators approved for landings. Full vertical stabilizer and rudder effectiveness are programmed into the simulators regardless of reverse thrust levels. Normal landings, hydraulics-out landings, and other emergency landings are regularly practiced in approved flight simulators because of the danger and costs associated with practice in actual flight. Consequently, pilots could develop incorrect habits and impressions from the simulators. The Safety Board believes that this negative training should be avoided and that DC-9-80 landing-approved simulators should be updated to include the correct stability and control characteristics associated with the use of reverse thrust as quantified in McDonnell Douglas Corporation report MDC-J9005.

The Safety Board determined that earlier DC-9 series airplanes (-10 through -50) also encounter substantial losses of vertical stabilizer and rudder effectiveness during the application of reverse thrust, although not to the extent of the DC-9-80. Examination of the Aircraft Flight Manuals of various carriers disclosed that they do not provide any discussion of the effect of reverse thrust on the effectiveness of the rudders. In addition, the landing-approved simulators for these airplanes do not incorporate the correct stability and control characteristics during reverse thrust operation. Therefore, the Safety Board believes that similar data describing the directional stability and control characteristics of DC-9 series -10 through -50 aircraft during reverse thrust operation are needed in the Aircraft Flight Manuals, training manuals, and training programs for these aircraft. We further believe that landing-approved simulators for DC-9 series -10 through -50 airplanes should be updated to include the stability and control characteristics associated with the use of reverse thrust as quantified in McDonnell Douglas Corporation report MDC-J9005.

The hydraulics-out landing procedures for the earlier DC-9 series aircraft have remained unchanged despite what has been learned from the DC-9-80 accident. Analysis of the DC-9-80 procedures indicates that the procedures have the potential for improving the directional stability and controllability of these earlier model aircraft. The major difference between the DC-9-80 and earlier models which would affect the procedures is the brake hydraulic accumulators and the antiskid systems. The Safety Board believes that the hydraulics-out landing procedures for the DC-9-80 should be used for the DC-9 series -10 through -50 where possible and within the limits of the respective brake hydraulic accumulators and antiskid systems.

To comply with 14 CFR 25.1435, Hydraulic Systems, a Special Condition was established for the DC-9-80 certification. This special condition titled "Hydraulic System Failure" required that: "The airplane must be shown by flight tests to be capable of continued safe flight and landing with a complete failure of the hydraulic systems." This special condition is not adequate because it is not quantitative or realistic, and it relies solely on a subjective assessment by a test pilot. The Safety Board believes that the certification requirements for aircraft for which this special condition applies should be changed to: (a) include a quantified level of directional control following touchdown in terms of yawing moment or yaw acceleration for appropriate rollout speeds; (b) require that the applicant demonstrate that these values can be obtained using those controls which are available and using the procedures which are to be specified for this condition in the aircraft's approved flight manual; and (c) demonstrate or calculate landing distances for this special condition and include them in the aircraft's flight manual.

As a consequence of its investigation of this DC-9-80 accident, the Safety Board became aware of the deficiencies discussed above. Further, as a result of testing and analysis by the manufacturer, it became evident that the effects of reverse thrust on the directional stability and controllability of an aircraft can be quantified. The Safety Board is fully aware that several models of aircraft other than the DC-9 have engines with thrust reversers mounted in proximity to their vertical stabilizers, and we believe that some of these aircraft may also encounter a loss of vertical stabilizer and rudder effectiveness when reverse thrust is used during landing rollout. Therefore, we further believe that these aircraft should also be examined to determine if this potentially adverse characteristic is present; if it is, landing procedures and appropriate manuals and training materials should be revised as necessary to minimize the effect of the characteristic.

14 CFR 121, Appendix H, establishes requirements for simulators which must be achieved to obtain approval for certain types of flightcrew training in simulators. The type of training that can be conducted is based on the sophistication of the simulators, which are identified as Phase I, II, or III simulators. A Phase III simulator is the most sophisticated of the three. These simulator requirements are further amplified in Advisory Circular 121-14C, Aircraft Simulator and Visual System Evaluation and Approval, dated August 29, 1980. All of the Phase I, II, and III simulators are approved for landing training. However, according to Appendix H, only Phase III simulators must contain aerodynamic modeling for aircraft (for which an original type certification is issued after June 1, 1980) which includes the "reverse dynamic thrust effect on control surfaces." Phase I and II simulators have no similar requirement. Consequently, many landing-approved simulators are programmed for full vertical stabilizer and rudder effectiveness regardless of the levels of reverse thrust used during landing rollout. The Safety Board believes that pilots could develop incorrect habits and impressions from these simulators and that, therefore, these simulators should be updated to include representative stability and control characteristics associated with the use of reverse thrust during landing rollout.

Accordingly, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Incorporate the following information into the DC-9-80 Aircraft Flight Manual under the abnormal hydraulics-out landing section and the normal landings on wet/slippery runways section:

The maximum rudder effectiveness available is substantially reduced during reverse thrust operation as follows:

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	25
1.6 EPR (Reverse)	minimal

*/Rudder effectiveness also decreases with decreasing airspeed.

When reverse thrust levels above reverse idle are used, carefully monitor and maintain symmetric reverse thrust to avoid adverse yawing moments. (Class II, Priority Action) (A-81-104)

Incorporate the following information into the DC-9-80 training manuals and training programs under the flight control and landing sections:

When thrust reversers (located just forward of the vertical stabilizer) are used during landing rollout, the exhaust gases from the engines are deflected by the thrust reverser buckets in such a manner that the free stream airflow over the vertical stabilizer and rudder is blocked, reducing the effectiveness of these surfaces. At a nominal airspeed of 100 KIAS, the reduction in rudder effectiveness with increasing symmetric reverse thrust levels is shown below.

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	25
1.6 EPR (Reverse)	minimal

*/Rudder effectiveness also decreases with decreasing airspeed.

On a dry runway, directional control is easily maintained by differential antiskid braking and nosewheel steering. However, under adverse conditions such as a slippery runway with rain, snow, or ice, when crosswinds reduce the braking effectiveness of the gear on the upwind wing, or when a high-speed landing is made with both hydraulics systems out (i.e., flaps/slats retracted, ground spoilers, rudder hydraulic boost, nosewheel steering all rendered inoperative, and brake antiskid systems limited by hydraulic accumulator pressure), the vertical stabilizer and rudder will be the primary source of directional stability and control during the high speed portion of the landing rollout. Under these conditions, it is important to make allowance for the adverse effects of reverse thrust on the effectiveness of the vertical stabilizer and rudder.

The cockpit thrust reverser levers in the DC-9-80 are more sensitive (i.e., command increased amounts of thrust per degree of movement) than previous DC-9 models because of the greater thrust range of the engines on the DC-9-80. The higher sensitivity of the cockpit thrust reverser levers make selection of symmetric reverse thrust more difficult than on previous models; therefore, careful attention should be given to selecting and maintaining symmetric reverse thrust levels to avoid adverse yawing moments. (Class II, Priority Action) (A-81-105)

Require that DC-9-80 landing-approved simulators incorporate actual aircraft characteristics including the decrease in vertical stabilizer and rudder control effectiveness as a function of engine reverse thrust levels. The flight test data used should be taken from McDonnell Douglas report MDC-J9005. Figure 14, Yawing Acceleration Due to Maximum Rudder, Power ON, and figure 15, Yawing Acceleration Due to Maximum Rudder, Manual, should be used for symmetric reverser configurations for thrust values from forward idle to 1.3 EPR reverse. Data similar to that in figure 71, Effect of Reverse Thrust on Directional Control, should be derived and used for all speeds and symmetric reverse thrust settings. Control effectiveness from a symmetric 1.3 EPR to a symmetric 1.6 EPR should decrease to zero. For asymmetric reverse thrust conditions, the data in figure 20, Controllability with Asymmetric Reverse Thrust, should be used. (Class II, Priority Action) (A-81-106)

Incorporate the following information in the DC-9 series -10 through -50 Aircraft Flight Manuals under the abnormal hydraulics-out landing section and the normal landings on wet/slippery runways section:

The maximum rudder effectiveness available is substantially reduced during reverse thrust operation as follows.

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	45
1.6 EPR (Reverse)	15

*/ Rudder effectiveness also decreases with decreasing airspeed.

(Class II, Priority Action) (A-81-107)

Incorporate the following information in the DC-9 series -10 through -50 Training Manuals and Programs under the flight control and landing sections:

When thrust reversers (located just forward of the vertical stabilizer) are used during landing rollout, the exhaust gases from the engines are deflected by the thrust reverser buckets in such a manner that the free stream airflow over the vertical stabilizer and rudder is blocked, reducing the effectiveness of these surfaces. At a nominal airspeed of 100 KIAS, the reduction in rudder effectiveness with increasing symmetric reverse thrust levels is shown below.

Engine Thrust Setting	Maximum Rudder Effectiveness Available (percent)*/
Forward Idle	100
Reverse Idle	65
1.3 EPR (Reverse)	45
1.6 EPR (Reverse)	15

*/ Rudder effectiveness also decreases with decreasing airspeed.

On a dry runway, directional control is easily maintained by differential antiskid braking and nosewheel steering. However, under adverse conditions such as rain, snow, or ice making the runway slippery, when crosswinds reduce the braking effectiveness of the gear on the upwind wing, or when a high speed landing is made with both hydraulic systems failed (i.e., flaps/slats retracted; ground spoilers, rudder hydraulic boost, nosewheel steering, brake antiskid all rendered inoperative; manual brake system limited by hydraulic accumulator pressure) the vertical stabilizer and rudder will be the primary source of directional stability and control during the high speed portion of the landing rollout. Under these conditions it is important to make allowance for the adverse effects of reverse thrust on the effectiveness of the vertical stabilizer and rudder. (Class II, Priority Action) (A-81-108)

Require that DC-9 series -10 through -50 landing-approved simulators incorporate actual aircraft characteristics including the decrease in vertical stabilizer and rudder control effectiveness as a function of engine reverse thrust levels. The flight test data to be used should be taken from McDonnell Douglas Corporation report MDC-J9005. Data similar to that in figure 71, Effect of Reverse Thrust on Directional Control, should be derived and used for all speeds and symmetric reverse thrust settings. (Class II, Priority Action) (A-81-109)

Conduct an engineering evaluation of the DC-9 series -10 through -50 brake hydraulic accumulators and antiskid systems to determine if the brake antiskid systems can be left on during hydraulics-out landings. Revise where applicable the hydraulics-out landing procedures for the DC-9 series -10 through -50 airplanes to correspond with those developed for the DC-9-80 within the capabilities of the respective brake hydraulic accumulators and antiskid systems. (Class II, Priority Action) (A-81-110)

Examine all aircraft models with aft pod-mounted engine/thrust reversers to determine if vertical stabilizer and rudder effectiveness is lost or reduced when reverse thrust is used during landing rollout. If this adverse characteristic occurs, revise landing procedures, appropriate manuals, and training materials as necessary to assure that maximum directional control is maintained during the landing rollout. (Class II, Priority Action) (A-81-111)

Revise certification requirements for those aircraft for which safe flight and landing following a partial or total hydraulic system failure must be demonstrated to: (a) include a quantified level of directional control following touchdown in terms of yawing moment or yaw acceleration for appropriate roll out speeds; (b) require that the applicant demonstrate that these values can be obtained using those controls which are available and using the procedures which are to be specified for this condition in the aircraft's approved flight manual; and (c) demonstrate or calculate landing distances for this special condition and include them in the aircraft's flight manual. (Class II, Priority Action) (A-81-112)

Ensure that Phase I, II, and III simulator requirements for other model aircraft as defined in 14 CFR 121, Appendix H, specifically include the representative degradation of directional control associated with the effect of reverse thrust on the aerodynamic control surfaces if the simulated aircraft has such characteristics for normal and abnormal configurations or systems condition, and revise Advisory Circular 121-14C accordingly. (Class II, Priority Action) (A-81-122)

Ensure that air carrier training and proficiency check programs required by 14 CFR 121 include a demonstration of directional control characteristics during landing rollout when conducted in accordance with the training and checking permitted using a Phase I, II, or III simulator as provided for in 14 CFR 121, Appendix H. (Class II, Priority Action) (A-81-123)

KING, Chairman, DRIVER, Vice Chairman, and GOLDMAN and BURSLEY, Members, concurred in these recommendations. McADAMS, Member, did not participate.

Francis H. McAdams

By: James B. King for
Chairman