7. RESEARCH PILOTS' OBSERVATIONS OF AIRCRAFT PERFORMANCE ON A GROOVED RUNWAY

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SUMMARY

Braking effectiveness tests of two airplanes have been completed on the landing research runway at NASA Wallops Station. The pilots' observations indicated that transverse-groove surfaces drastically reduced all types of skids on a wet or flooded runway and provided positive nose-gear steering during the landing roll-out. The grooved surfaces also prevented the onset of drift and weathervaning. The overall airplane ground handling and stopping characteristics on the grooved surfaces showed a dramatic improvement over those on corresponding ungrooved surfaces with no observable adverse characteristics from the pilots' point of view.

INTRODUCTION

In March 1968, a flight test program was conducted on the landing research runway at NASA Wallops Station to investigate the differences in wet runway braking effectiveness resulting from grooving various types of surface materials. Previous tests (ref. 1) had shown grooving of the surface to be an effective method for maintaining high friction on a wet surface. The changes in airplane behavior in terms of direct braking effect as well as in cross winds were of particular interest to the pilots, since most hydroplaning accidents involve a loss in directional control or a drift off the side of the runway. Separated test sections on the research runway allowed comparative braking measurements to be made directly during each run and provided the pilots with a unique opportunity to observe the corresponding changes in airplane response to braking and directional control. Pilot observations which form the basis for this paper supplement other measurements of braking performance given in references 2 and 3.

DISCUSSION

Research Airplanes

The test airplanes were a McDonnell Douglas F-4D fighter made available by the U.S. Air Force and an NASA Convair 990 jet transport. These airplanes were selected to provide a range of tire pressures, an important factor in wet runway braking. The F-4D tires were inflated to a pressure of 280 psi, and the 990 tires are normally inflated to a pressure of 160 psi.

The 990 airplane shown in figure 1 has a typical eight-wheel main landing gear and a dual-wheel nose gear. The nose gear is steerable and provides primary directional control during the landing roll-out below 60 to 70 knots. After touchdown, spoilers are used to get the airplane weight on the wheels and the full-power rudder is effective for high-speed directional control.

The antiskid system on the 990 airplane is representative of the systems on current jet transports. Each main gear wheel is braked individually, and the nose gear wheels are braked as a unit in the antiskid mode when full pedal deflection is applied. Transducer-type skid detectors, one for each main gear wheel and a single one for the nose wheels, sense the rate of change of wheel speed. Signals from the detectors are fed to a control box which, in turn, transmits controlling signals to the antiskid control valves. If the deceleration rate of a wheel indicates an impending skid, the associated antiskid valves reduce metered pressure to the affected brakes in proportion to wheel slip until the wheels recover normal speed.

The tires on the 990 were maintained at a pressure of 160 psi which would produce a hydroplaning speed of 112 knots according to reference 1. The 990 landing touchdown speed ranges roughly from 120 to 150 knots.

The F-4D airplane is shown in figure 2. It is a typical fighter configuration with two main gear wheels and a dual-wheel nose gear. No braking is available to the nose wheels. The nose gear is steerable; however, normal operating procedures dictate that nose gear steering be engaged after the rudder is no longer effective for directional control. After touchdown, the horizontal stabilizer in the full-up position adds aerodynamic drag which increases the aircraft weight on the main gear wheels.

The F-4D is equipped with essentially the same antiskid brake system as the 990. A notable difference in the two systems is that the F-4D antiskid control valve reduces metered pressure to both brakes regardless of which wheel is indicating an impending skid, whereas the 990 system only reduces pressure to the affected wheel.

The F-4D landing speed ranges from 135 to 145 knots. Tire pressures utilized during the test would produce a hydroplaning speed of 150 knots.

Landing Research Runway

A diagram of the landing research runway at the NASA Wallops Station is shown in figure 3. The test sections are level and are bounded by 2-inch-high rubber dams to provide an even water depth. Each test section was identified for the pilots by lettered side markers. Approximately 2500 feet of normal runway at each end of the test area provide adequate distance for speed stabilization prior to entering the test sections and for a safe stop or take-off following the data run. Additional information regarding the research runway is available in reference 2.

Test Procedure

Braking effectiveness data were obtained for ground speeds ranging from about 50 to 150 knots. The wheel rotational speed signal from the antiskid system operated a meter which was previously calibrated to read ground speed by timing the airplane between measured points along the runway at constant meter readings. The meter was placed directly in the pilot's view to allow him to establish desired speeds prior to entering the test sections. The tests involved accelerating to the test speed from a standstill to the take-off position or landing short of the test section and adjusting speed by referring to the ground speed indicator. This speed, or a slightly higher speed, was held until about 100 yards before the appropriate test sections. At this point, power was reduced to idle and the spoilers extended. The timing was such that the engines would be spun down to idle thrust before entering the test area. The brake pedals were abruptly applied to maximum deflection while the wheels were still on the dry reference section and were maintained through two wet or flooded test surfaces, one grooved and one ungrooved. When feasible, the stop was completed and a brake and tire check was made before the next run. At the higher speeds, a take-off was made directly after the run to cool the brakes and tires. One hundred twenty-five braking runs including 75 landings were made with the 990 airplane; 72 runs and 25 landings were made with the F-4D airplane.

For the slush tests, the 990 turbocompressor air inlets, lower rotating beacon, and antennas were shielded since previous FAA slush tests indicated the vulnerability of these areas to impact damage. The airplane withstood this abuse well and required no additional maintenance. Slush tests were not conducted with the F-4D airplane.

Although most of the effort was directed toward obtaining braking effectiveness data, other measurements and observations were made. For example, the braking tests were repeated with new conventional tread tires so that the results could be compared with the results obtained with bald tires. In addition, treaded and bald tires were placed in alternate positions on one four-wheel truck to determine whether the clearing effect of the forward wheel would make a difference in rear wheel braking corresponding to tread wear on the rear tire. The results would determine the effectiveness of moving worn tires to the rear truck wheels. Landing touchdowns were also made in each flooded test section to measure wheel spin-up characteristics.

Test Observations

The three physical phenomena associated with wet-pavement skidding – thin-film lubrication (viscous hydroplaning), dynamic hydroplaning, and reverted rubber skids – were repeatedly encountered during these tests. Dynamic hydroplaning was consistently encountered at high speeds, even to the point of preventing wheel spin-up at touchdown on a flooded surface. Reverted rubber skidding occurred several times with the 990 following a phase of dynamic hydroplaning and at lower speeds. There were no reverted rubber skids with the F-4D. Viscous hydroplaning occurred even at taxi speeds on the smooth wet concrete surface, and it was very noticeable to the pilots because the speed was low enough to prevent antiskid operation.

The data in time history form from a typical braking test with the 990 are shown in figure 4. The time history selected is for dynamic hydroplaning at about 110 knots on a flooded ungrooved surface followed by a phase of high brake effectiveness on the flooded grooved surface. The first trace at the top of the figure is a time history of the nose-gear-wheel rotational speed, with the rotational-speed traces of the four right main gear wheels below. The brake pressure traces are in the same sequence, and a longitudinal-acceleration trace is included at the bottom of figure 4 to show the braking effectiveness.

The point of brake application is clearly shown by the rise in brake pressure. The rise in the nose-gear-wheel brake pressure verifies that the brake pedals are fully deflected since nose-gear-wheel braking is only obtained through the antiskid system with full pedal deflection. At this point, the wheels are on a dry ungrooved surface and very little change in rotational speed can be seen, yet a deceleration of nearly 0.5g is indicated. This deceleration corresponds to a very abrupt stop in an automobile when full brakes are applied on a dry surface. In less than a second, the airplane traveling at over 150 feet per second entered the wet ungrooved section and, as the acceleration trace shows, the retardation has almost returned to the no-braking level because the wheels started to skid. The wheel rotation rate falls nearly to zero even though the antiskid system rapidly released the brake pressure. Even without brake pressure, all wheel rotation had ceased and the airplane is sliding free in a condition of dynamic hydroplaning.

When the nose wheels are hydroplaning, they have lost their steering effectiveness and, as observed in runs where a cross wind existed, a yawing moment and lateral drift would be produced. The yaw can be controlled to some extent at this speed (but not at lower speeds) by use of the rudder; however, the drift would continue. A change in heading with the rudder does not appreciably alter the path of the airplane as it translates toward the side of the runway.

On the research runway when the wheels entered a grooved section which is also flooded, there was an abrupt buildup in retarding force, as shown in figure 4, even though full brakes had been applied continuously. The feeling of applying full brakes on a dry surface is repeated when entering the flooded grooved section from the ungrooved surface with full brakes applied. The wheels spin up on the grooved surface, and brake pressure is applied by the antiskid control unit with a corresponding increase in the retarding force. A deceleration level almost equivalent to the dry surface value is obtained, and nose-gear steering returns.

The pilots were appreciative of the fact that during these tests there were grooved sections on which to recover from skids and a long section of dry runway to complete the stop or to take off to cool the brakes. On the ungrooved flooded surface, the pilot was helpless. No braking technique had any significant effect, since under these conditions wheel rotation had often ceased even without brake pressure. Some directional control remained through use of the rudder, but the cross-wind drift could not be stopped by any process until some side force could be generated through wheel friction. The improved braking on a transverse-groove surface was impressive, but the fact that the wheels could generate a side force to prevent lateral drift was considered to be equally important to the pilot. There can be few worse feelings to a pilot than when his airplane is skidding out of control on a wet runway.

The tests were made in a sequence involving first the dry reference surface and then the wet ungrooved surface which led to an entry into the wet grooved surface in a skid. Since the prevailing winds gave a consistent cross-wind component, occasionally over 15 knots, a lateral drift occurred during many skids. The drift was straightened out by the grooved surface so abruptly that there was concern over the magnitudes of the associated side loads on the landing gear. Accordingly, the tests were altered so that the airplane entered the grooved surface first. This procedure tended to reduce the aircraft speed at the end of the drift with a consequent reduction in landing-gear side loads.

Five types of ungrooved surfaces were used in the tests. The subjective differences in braking on them were difficult to determine when they were flooded. When the surfaces were just damp, the textured sections gave noticeably better braking, especially at the lower speeds. The measured data which are presented in reference 2, however, provide a definitive comparison between the surfaces.

The difference in braking effectiveness between new tires with a tread pattern and bald tires was not readily apparent to the pilot. Again, the measured data of reference 2 must be studied to reveal the advantages of tread pattern.

Incidentally, one tire was damaged due to a miswired brake control valve, and hydroplaning damage and wear required several other tire changes. The brake control valve was newly overhauled with the internal wiring reversed. This service error caused the skid signal to release brake pressure on the opposite wheel so that one wheel of the pair had full pressure applied and the other was free rolling. There is no way to detect this condition in the cockpit or even from tire wear obtained by landing on dry runways, because until a skid is sensed, the brake pressure would be applied evenly. This problem is mentioned as a matter of interest; however, it should be pointed out that the overhaul was not provided by the manufacturer of the antiskid controls for this aircraft.

CONCLUDING REMARKS

The grooved runway surfaces drastically reduced all types of skids, including dynamic hydroplaning, and allowed positive nose-gear steering during the landing rollout. The grooved surfaces also prevented the onset of drift at touchdown in a flooded area because wheel spin-up provided high cornering forces.

The overall airplane ground handling and stopping characteristics on the grooved surfaces showed a dramatic improvement over those on corresponding ungrooved surfaces with no observable adverse characteristics from the pilots' point of view.

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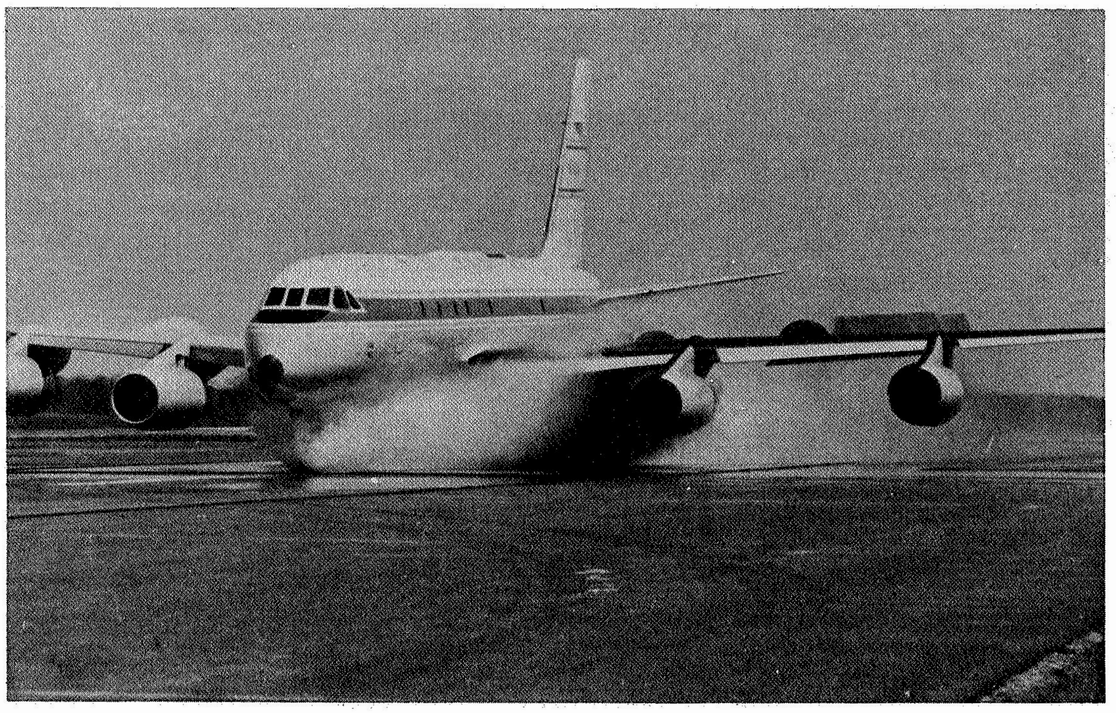

Figure 1.- The 990 test airplane.

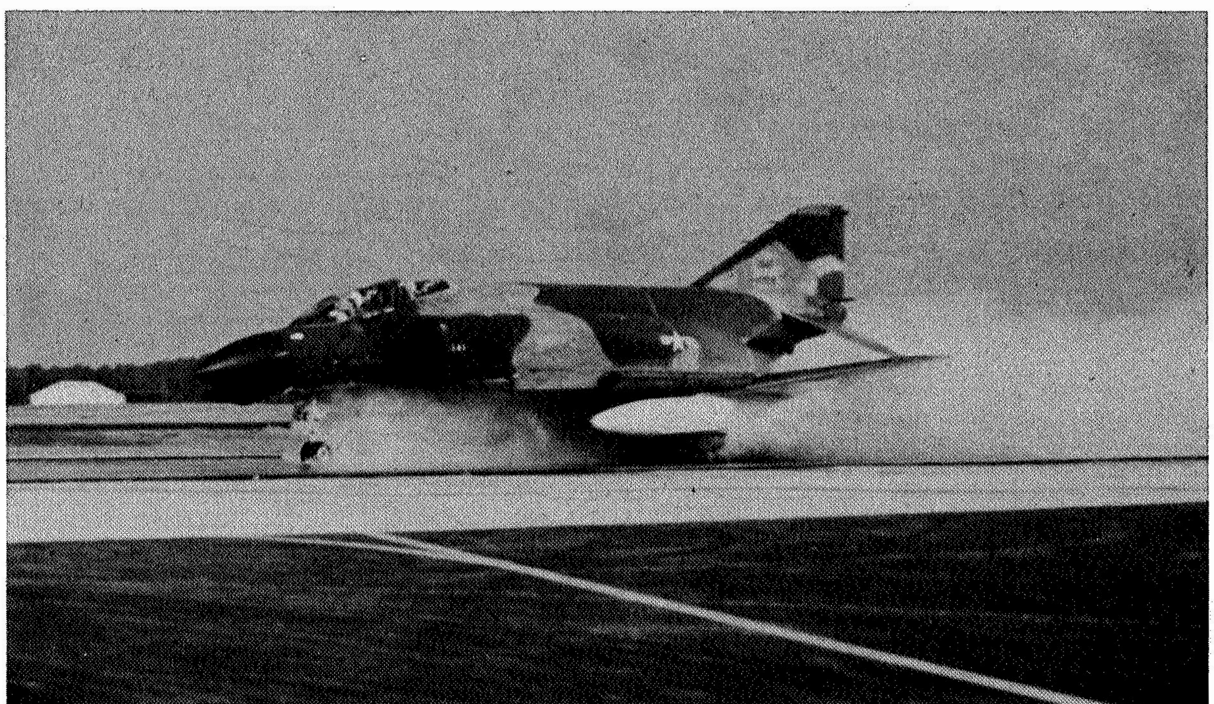

Figure 2.- The F-4D test airplane.

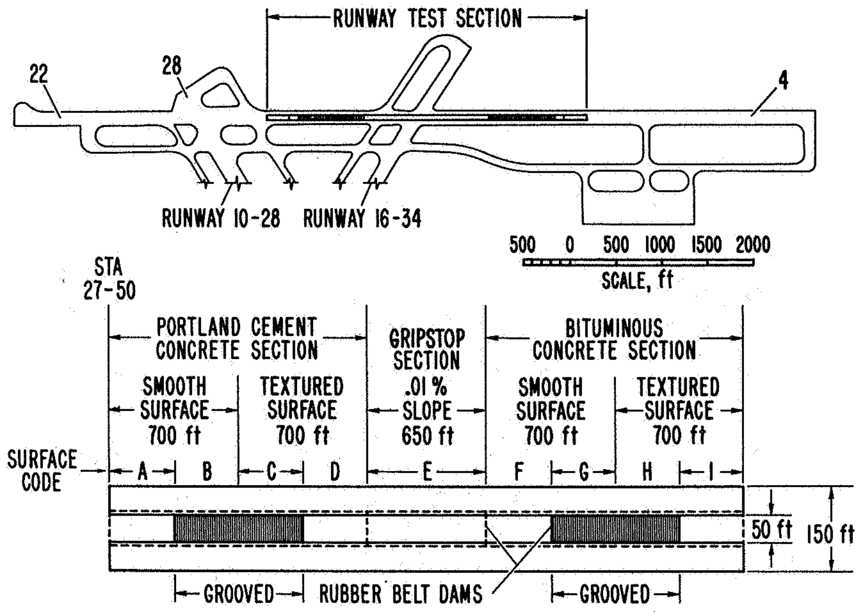

Figure 3.- Schematic view of landing research runway at NASA Wallops Station.

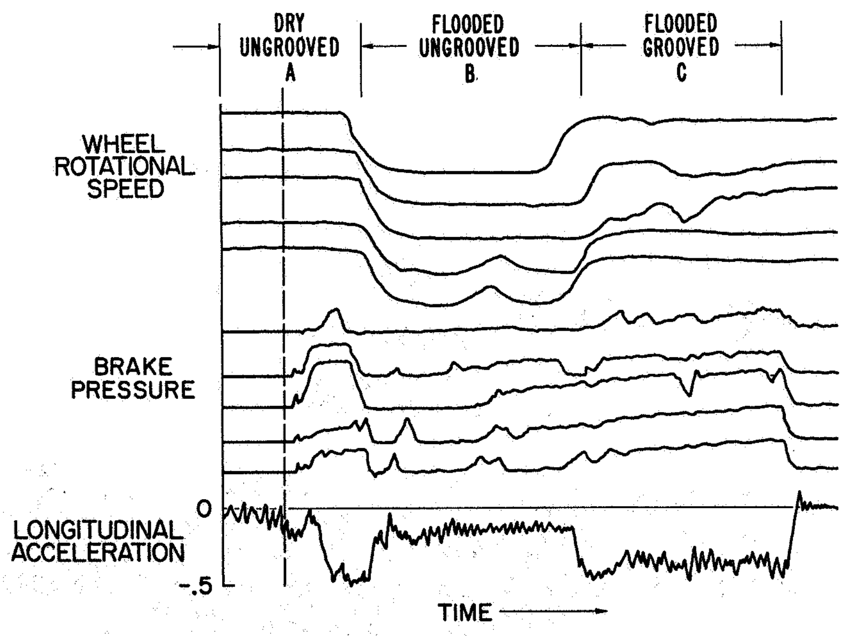

Figure 4.- Typical 990 test data.