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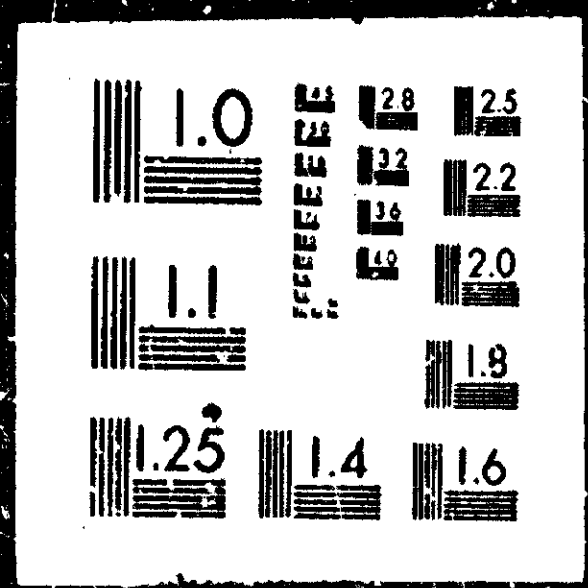

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Special Investigation Report - Large Airplane Operations on Contaminated Runways

(U.S.) National Transportation Safety Board
Washington, DC

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U.S. Department of Commerce
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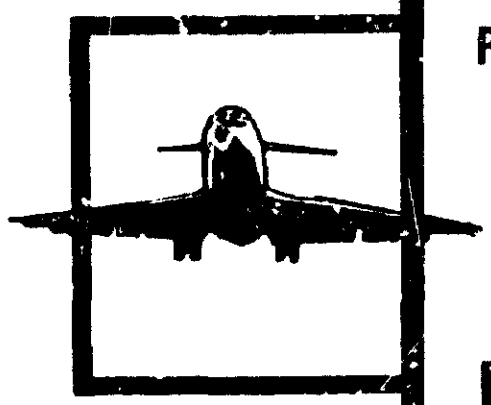

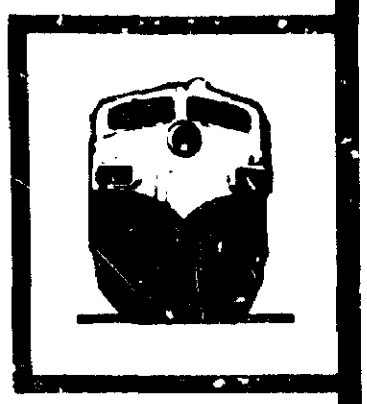

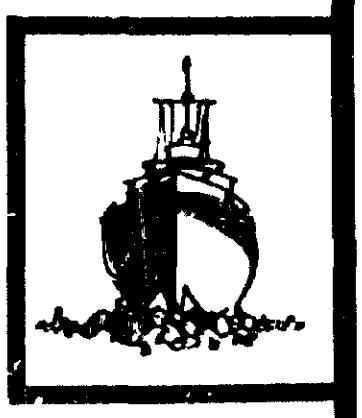

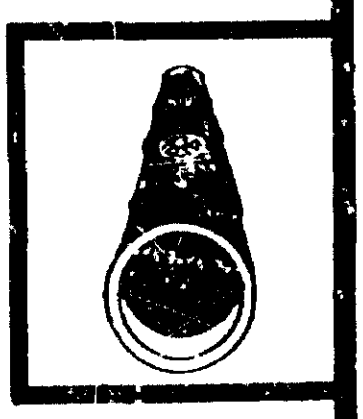

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

LARGE AIRPLANE OPERATIONS ON CONTAMINATED RUNWAYS

NTSB/SIR-83/02

UNITED STATES GOVERNMENT

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16. Abstract

The National Transportation Safety Board's investigation of the fatal airplane accidents involving an Air Florida B-737 at Washington, D.C., on January 13, 1982, and a World Airways McDonnell-Douglas DC-10 at Boston, Massachusetts, on January 23, 1982, focused on the performance capabilities of airplanes while taking off and landing on contaminated runways. These accidents and the accident investigation experience of the Safety Board demonstrated that dealing with the issue of airplane performance in the face of adverse airport conditions is influenced by many elements in the airport-airline-air traffic control relationship. The Safety Board's special investigation examined the issues of maintenance of runway surfaces, the measurement and reporting of runway friction values, the exchange of runway information among ATC, airport personnel and pilots, the airplane certification criteria for operation on contaminated runways, the capability of existing technology to measure runway friction accurately, and the technology available to monitor airplane acceleration.

The investigation buttressed the need for (1) reliable, objective means to measure runway friction during all weather conditions; (2) reliable methods of transmitting that information to pilots; and (3) methods of correlating measured runway friction to airplane performance. As a result of the special investigation, the Safety Board made a number of safety recommendations to the Federal Aviation Administration to resolve the problems associated with airplane performance and contaminated runways.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

Adopted: April 22, 1983

LARGE AIRPLANE OPERATIONS ON CONTAMINATED RUNWAYS

INTRODUCTION

Throughout the history of aviation, flight operations during periods of inclement weather have posed significant safety hazards for pilots. In the early days of aviation, pilots worried about little more than the visibility, the ceiling, and the winds; airport runway conditions were of little importance because the speeds required for takeoff and landing were low, and runway surface contamination 1/ had little effect on early airplane operations.

As the civil aviation industry grew in the early 1950's, airplanes became larger and more complex. Although problems created by contaminated runways increased, these airplanes still took off and landed at relatively slow speeds, and the large reciprocating engines with reversible pitch propellers which responded immediately to the throttle, enabled pilots to control the airplane safely on contaminated runways. The air traffic control (ATC) system, meteorological reporting procedures, and airline dispatch functions concentrated primarily on airborne meteorological conditions and the development of communications procedures for the transmission of en route weather data to pilots.

With the advent of the early jet airplanes in the late 1950's and their refinement throughout the 1960's, came higher takeoff and landing speeds, slower acceleration because of relatively low thrust-to-weight ratios, and delays in engine thrust response to pilot action. Because of the higher speeds required for a successful takeoff, rolling drag caused by contaminants on runways became more significant. Further, the higher takeoff and landing speeds meant that more distance was required in which to stop the airplanes after landing or in the event of a rejected takeoff. Many of these airplanes were not equipped with thrust reversers, and the jet engine thrust reversers which were used initially were relatively inefficient, contributing little to the decelerative force needed to stop the airplane. Consequently, the stopping force developed between the tire-and-runway surface generated by the airplane's wheel brakes became the primary decelerative force. Not only were longer runways with higher friction characteristics needed to accommodate these airplanes, but also the brakes and tires had to provide increased decelerative forces. Hydroplaning on wet runways as a result of the higher speeds and high tire pressures had to be prevented. Antiskid systems were installed on airplanes to control tire slip and to assure the transmission of maximum braking forces between the tire/runway surface. As a result of extensive studies by the National Aeronautics and Space Administration (NASA), runways were grooved in order to decrease the adverse effect of water between the tire and the runway surface on runway friction.

1/ Contaminated runway as used in this report means that ice, snow, slush, water, or rubber deposits have accumulated on the runway to an extent that airplane performance is affected measurably.

While advances in technology during the 1960's and 1970's have contributed much to airplane development, to the air traffic control system, and to airport and navigation facilities, still only limited attention has been paid to airplane performance as it is affected by runway contamination. Admittedly, because of the significant developments in engines, brakes, tires, and runway surfaces, modern airplanes are better equipped to cope with snow, ice, slush, and water on the runway. However, quantitative data relating the airplane's performance to runway condition during a specific landing or takeoff still is not provided to the pilot Further, the pilot has no means of obtaining objective information about the friction values of contaminated runways. Moreover, frequently he does not receive all available information about runway conditions or terminal weather information that is timely and accurate. As a result, while modern technology has made aviation the safest, most reliable means of transportation in the world, pilots daily face potentially dangerous situations in which they land or take off on contaminated runways with no assurance that the runway is adequate for the operation.

The hazards of operations on snow and ice-covered runways were emphasized in the fatal airplane accidents involving an Air Florida Boeing 737 at Washington, D.C., on January 13, 1982 2/ and a World Airways McDonnell-Douglas DC-10 at Boston, Massachusetts, on January 23, 1982. 3/ The latter accident particularly called attention to problems with landings on contaminated runways and demonstrated that operations under these conditions are influenced significantly by an absence of reliable information about runways and airplane performance, and problems in communications between the various elements of the air transportation system -- pilots, controllers, airport management, and airline management.

Information must be continuously gathered and transmitted to flightcrews before they take off or land during inclement weather conditions, requiring both pilots and controllers to report or relay information accurately and quickly. Airport management must maintain runways and taxiways so that operations can be conducted safely in ice, snow, slush, and rain, and it must report the current runway conditions to ATC and local managers of airline tenants. In turn, airport management relies to a significant extent on flightcrew braking action reports to formulate decisions regarding its runway maintenance operations. Air traffic controllers provide the primary communication link between the pilot and airport management, retransmitting to pilots preparing to land braking action reports received from landing pilots, and available runway condition information received from airport management. Additionally, controllers pass runway information to pilots through the Automatic Terminal Information System (ATIS) and through the flight service stations. The airlines, through their flight dispatch offices, brief flightcrews on runway conditions, plan airplane configurations and flying techniques in anticipation of runway conditions, and transmit information during flight to aid flightcrews' landing decisions. Therefore, timely and precise action by each element in the system is critical to the safe operation of airplanes in the terminal area during inclement weather conditions.

In order to explore the problems of large airplane operations on contaminated runways on an industry-wide basis, the Safety Board convened a 3-day public hearing in Washington, D.C., on May 3 1982. Bringing together parties from all segments of industry, the Safety Board collected position papers and heard testimony from 54 witnesses representing the Federal Aviation Administration (FAA). Air Transport

2/ Aircraft Accident Report: Air Florida Inc., Boeing 737-222, N62AF, Collision with 14th Street Bridge, Near Washington National Airport, Washington, D.C., January 13, 1982 (NTSB-AAR-82-8).

3/ Aircraft Accident Report: World Airways, Inc., Flight 30H, McDonnell Douglas DC-10-30, Boston-Logan International Airport, Boston, Massachusetts, January 23, 1982 (NTSB-AAR-82-15).

Association of America (ATA), American Association of Airport Executives (AAAE), Airport Operators Council International (AOCI), the Air Line Pilots Association (ALPA), Allied Pilots Association (APA), Regional Airline Association (RAA), the International Association of Machinists (IAM), Aerospace Industries Association of America (AIA), General Aviation Manufacturers Association (GAMA), National Aeronautics and Space Administration (NASA), the International Airline Passenger Association (IAPA), Transport Canada, the Civil Aviation Authority of the United Kingdom (CAA), and representatives of various airlines, airports, and aerospace firms. (See appendixes A and B.)

Witnesses were asked to address the following five broad issues in their testimony:

1. Airport management informational requirements and procedures for the maintenance of runway, ramp, and taxiway surfaces during inclement weather.

2. The role of airport management, the airlines, ATC, and individual pilots in determining the adequacy of a runway for operational use.

3. The impact of runway surface contamination on airplane certification and operational regulations.

4. The capability of existing equipment to measure runway friction accurately in all weather conditions and to provide useful operational information to pilots.

5. The state of the art in research and development of equipment and techniques to monitor airplane acceleration on contaminated runways.

Through its hearing, the Safety Board heard industry views on the problems associated with large airplane operations on contaminated runways. (See appendix C.) This report presents the Safety Board's conclusions about solutions to the problems. Although it primarily addresses airline operations and large transport-type airplanes used in commercial air transportation, the findings are applicable to the elements of general aviation which use high performance turbojet airplanes since the effects of runway contamination and airplane perforance are similar to those encountered with transport-category airplanes.

IMPROVING OPERATIONS ON CONTAMINATED RUNWAYS

Based upon its review of the various positions presented by the aviation community, the Safety Board has formulated positions on needed action by both FAA and industry to improve safety during operations on contaminated runways. The Safety Board recognizes that airport operators, airplane manufacturers, airlines, and Government research and regulatory organizations have done much during the past 10 to 15 years to improve the safety of takeoff and landing operations during periods of inclement weather. Precision approach aids have been installed, runways have been grooved, airplane braking systems have been improved, tire design has been improved, engine thrust reversers have been made more effective, ground spoilers have been modified to deploy automatically, and pilot training programs have been improved. All of these undoubtedly have contributed to the prevention of accidents. These improvements notwithstanding, the Safety Board believes that the World Airways DC-10 accident at Boston-Logan Airport on January 23, 1982, in particular, indicated that the potential for serious and catastrophic runway overrun accidents remains as long as takeoffs and landings are made on contaminated runways which may provide little or no margin of safety.

The Safety Board's accident investigation experience (see appendix D) and testimony at its public hearing concerning the effect of runway contaminants on airplane operations have demonstrated that two distinct problems exist. First, the airport operator, the flightcrew, and the air traffic controller lacked specific information about the actual coefficient of friction on the runway during any given meteorological condition, and available runway condition information is not exchanged rapidly and efficiently among pilots, controllers, airport operators, and airline management. The Safety Board believes that industry and Government can resolve this problem with current technology and procedures. Testimony at the public hearing indicated that improvements in the development and transmission of runway condition information are being sought by most elements of Government and industry.

The second problem -- formulating data that will correlate the effects of runway contaminants to airplane performance -- will be more difficult to solve. Currently, airplane performance data are established only for dry runway conditions; little data are provided to flightcrews to quantify the effects of runway contaminants on the dry runway acceleration or stopping performance of a particular airplane. Additionally, no established procedures or instrumentation exist which will tell a pilot during the takeoff run that his airplane is accelerating properly to V_1.

In order to provide for optimum safety during operations on contaminated runways, the Safety Board believes that the following actions should be taken:

1) Require through effective certification and inspection requirements, that runway surfaces be maintained in the best possible condition and require institution of procedures which will result in timely removal of contaminants.

2) Refine communications between pilots, ATC, and airport management to keep all parties informed promptly when runway surface conditions change, particularly when braking performance is degraded.

3) Develop a means of quantifying pilot assessments and ground vehicle measurements of runway surface conditions in terms that will allow a pilot to relate the reported conditions to his particular airplane's performance.

4) Provide pilots with sufficient information about their airplanes' performance to enable them to make proper decisions regarding takeoff and landing operations after receipt of reports of contaminated runway conditions.

5) Establish the extreme limits, based on runway surface condition and airplane performance, at which increased runway length safety margins are needed or at which flight operations should be suspended by airport management.

The remainder of this report will discuss each of these actions in detail along with the views of major industry components.

Airports and Runways --Currently, 14 CFR Part 139 - Certification and Operations: Land Airports Serving CAB-Certificated Air Carriers does not prescribe --

- Specific snow/ice conditions in which a runway must be closed;
- Maximum acceptable depth of snow on the runway surface;

- A requirement for the inspection of a runway or closing of that runway upon receipt of a "poor" or "nil" pilot braking action report; or

- A requirement for the the use of a friction measuring device to measure the coefficient of friction under any runway condition.

The Safety Board believes that airport operators should be required to develop airport-specific criteria for removing contaminants from runways in airport operations manuals. Although it is not practical to apply rigid standards for snow removal programs on a national basis, each airport should be required to have objective criteria in the snow removal plan adequate for the environmental and operational needs of the particular airport. Therefore, 14 CFR Part 139 should be amended to require that each airport operations manual specify an amount of snow, slush, or ice above which inspection and/or removal are required before operations at that airport can be continued.

Several parties to the hearing opposed specificity in snow removal plans. Airport management associations stated in strong terms that 14 CFR Part 139, in its broad approach, was sufficient to provide high standards of airport safety. They believed that airports had dealt successfully with the snow removal problem for years before the adoption of 14 CFR Part 139, and that their success could be attributed to the experience and judgment of airport personnel in charge of implementing snow plans. The FAA took a similar position -- stating that varying geographical and meteorological conditions dictate that 14 CFR Part 139 must be very general and essentially must require only that airport operators have an approved snow plan. As a result, there is no standardization or uniformity of snow removal plans at the 778 certificated airports in the United States.

Not all parties agreed, however, that the regulation was adequate. Pilot groups believed that 14 CFR Part 139, in its present form, was inadequate because, in the words of an ALPA spokesman, ". . .it is so imprecise and innocuous that it does not even describe minimum standards outlining what must be accomplished regarding snow and ice control." They advocated that the regulation impose requirements for airport operators during periods of inclement weather when the runways and taxiways were contaminated.

Since each certificated airport must have an approved snow removal plan, specific criteria could be incorporated into each plan by the airport operator based on his judgment and experience and on specific airport operational considerations. While the FAA would still approve snow removal plans, each plan would be tailored to the particular airport. Since FAA surveillance of airports is limited by manpower restrictions - only 27 inspectors are responsible for the 778 certificated airports - inspectors cannot observe the actual implementation of the snow removal plans. The Board believes that specific published criteria regarding snow removal might exert pressure to act. On the other hand, action to meet the present subjective standards may be influenced unduly by operational and economic needs at the expense of safety considerations.

The Safety Board believes that 14 CFR Part 139 should provide both standards and procedural guidelines to airport operators with regard to the contents of airport snow removal plans. Part 139 should require that airport snow removal plans include (1) criteria for closing, inspecting, and clearing contaminated runways based on specified accumulations of contamination, (2) procedures to be followed upon the receipt of "poor" or "nil" pilot braking action reports, and (3) more specific requirements for runway inspections by airport operations personnel.

Pilot Reports.--Pilot braking action reports are the most commonly used method to assess runway conditions. While the braking action report is subjective, it remains the most timely and available source of runway condition information. Airport operators, pilot associations, and airline managements all endorse the need for more uniformity and objectivity in the content of braking reports. Spokesmen for the parties at the hearing suggested that the FAA, ATA, and the airlines begin a program to standardize braking reports. The consensus of the participants was that braking action reports would be less subjective if industry-wide procedures were developed to standardize their meaning. The Safety Board believes that, in addition to the standardizing of procedures to develop pilot braking action reports and a universal understanding of the meaning of the elements of the reports, airline and general aviation pilot training programs should stress the elements which should be contained in pilot braking action reports.

The problems caused by the subjectivity of pilot braking reports are compounded by the lack of specific FAA guidance to airport managers on their use. FAA regional airport certification personnel have no uniform policy concerning the incorporation of braking action reports into airport operations manuals. The Chief, Eastern Region Airport Certification Program, testified at the Safety Board's public hearing into the Air Florida crash that it is his policy that operations should be halted on a runway when a "nil" braking action report is received and that operations should remain halted until the reason for the report is determined and corrected. The New England Region Airport Certification spokesman stated that the region has no policy on the subject. The lack of accurate pilot braking action reports, and the failure of the Boston-Logan airport management to respond adequately to the reports which were submitted, were cited as causal factors in the World Airways accident.

Since pilot braking action reports likely will continue to be a primary source of runway condition information at large airports until runway friction measuring equipment is developed and used operationally, and at smaller airports well into the future, the quality of these reports must be improved. The Board believes that many pilot braking reports probably are based on the pilot's perception of his ability to slow the airplane on the landing runway using all the tools available, rather than the actual braking attained through tire-to-runway friction. For example, if the airplane is light and the runway is considerably longer than that normally required for the landing of the airplane, the pilot may perceive little or no problem in slowing the airplane to a safe turnoff speed, and may so report. Actually, under these conditions, most of the decelerative force is provided by aerodynamic drag and reverse thrust, with little deceleration provided by wheel brakes. Consequently, the pilot may report braking condition to be "fair" or "fair to poor," when actual braking conditions are worse. On the other hand, the pilot of a heavier airplane landing on the same runway will have a smaller stopping margin and will need considerably greater braking force from the wheel brakes; consequently, he could be misled about the actual braking conditions by reliance on reports from pilots of dissimilar airplanes.

The Safety Board believes that immediate action should be taken by the FAA to convene an industry-government group to develop standardized terminology and criteria for pilot braking reports, with the goal of incorporating into certificated air carrier and commuter air carrier flight manuals and pilot training programs more guidance concerning the quality and accuracy of braking reports.

Air Traffic Control.--The role of the air traffic controller is central to the transmission and dissemination of runway surface information to both pilots and airport operators. The two principal methods of relaying information are Automatic Terminal Information Service (ATIS) and individual controller reports. The Safety Board has found that, for various reasons, these methods sometimes are not effective, particularly in heavy workload situations. The investigations of the World Airways accident and the Air

Florida accident revealed that in both cases the ATIS reports did not contain current runway conditions. While ATIS can effectively provide general information about airport runway surface conditions even when the conditions change rapidly, controllers cannot always update the ATIS rapidly enough to provide the most current information. Moreover, under these circumstances, the controller may not, or may not have time to, volunteer the most recent information to pilots, and pilots may rely on outdated ATIS information rather than ask if more current information is available. As a result, essential information may not be provided to pilots during critical phases of flight.

At the Safety Board's public hearing, one witness stated that the transmission of runway condition reports would be more effective if, during periods of runway contamination, when braking action reports are "poor or nil," or conditions are changing rapidly, the FAA would state on the ATIS that "braking action advisories are in effect" and then issue the latest braking action reports when final landing clearance is given. Testimony indicated that doing so would cause the pilot to realize that braking problems might arise and that he should obtain a braking action report before landing. The implementation of this procedure would minimize the chances that a pilot will receive an outdated braking action report.

The Safety Board agrees that the inclusion of such a notice on the ATIS would alert pilots to runway contamination problems and would establish a specific consciousness in pilots and controllers of the runway conditions. Moreover, it could result in additional and more descriptive braking reports from pilots. Most importantly, however, it would ensure that pilots would have the latest runway information in sufficient time to plan the landing or the takeoff Although more radio transmissions between pilots and controllers would be required, the Safety Board believes that the need for critical runway information to assure safety during takeoff and landing on contaminated runways warrants the increased controller and flightcrew workloads. Once the ATC procedures have been changed to modify ATIS broadcasts, the Airman's Information Manual (AIM) must be amended to alert pilots about the meaning of the term "braking advisories are in effect."

Currently, air traffic controllers are only required to retransmit to other flightcrews any pilot braking action reports that have been volunteered by pilots. The Safety Board believes that controllers should actively request pilot braking action reports when the weather conditions are conducive to deteriorating braking conditions. If controllers did so, the most timely information could be made available to both pilots and airport operators, and problems resulting from ATIS-generated delays could be minimized. Additionally, controllers should be instructed to request braking action reports well before a pilot lands so that the reports can be complete, accurate and reflect runway conditions along the entire length of the runway. Controllers also always should inform pilots of the type of airplane which originated recent pilot braking action reports, and should inform pilots when no recent landings have been made by an airplane comparable to the one preparing to land. This information would provide pilots with a better basis upon which to evaluate airplane performance.

In addition to taking a more active role in requesting pilot braking reports, controllers should disseminate "poor" and "nil" braking action reports to arriving and departing flights until airport management has reported that the braking action is "good." This requirement will ensure that the runway condition is known by pilots and would provide an impetus to airport operators to improve the runway condition. Finally, the Safety Board believes that controllers should understand the operational significance of braking action reports and that controllers' training should impart to them knowledge of the effects contaminated runways have on the performance of landing and departing airplanes. The training should relate the effects of size and weight of airplanes to various runway conditions and various meteorological conditions.

Measurement of Runway Friction.--The Safety Board believes that there is a need for the FAA to undertake a program to promote development of means of determining that the concrete or asphalt surfaces of runways are maintained so that dry or wet coefficients of friction are not degraded by wear, rubber deposits, or similar contaminants In this regard, the Safety Board issued two safety recommendations on November 18, 1976, which were were directed toward requiring airport operators to adhere to the guideline material contained in Advisory Circular 150/5320-12 by incorporation of the material into 14 CFR Part 139. In its latest response to these recommendations dated December 9, 1982, the FAA stated that it planned no further action because: "Under the circumstances, we conclude that the imposition of the regulatory requirement recommended by NTSB would be neither appropriate nor justified." The FAA's conclusion was based on its belief that, since the accuracy and repeatability of the reported friction values are highly dependent on the calibration of the equipment, the training and qualifications of personnel, and strict adherence to recommended operating procedures, all of which are difficult and burdensome to achieve, such regulatory action was not appropriate or justifiable.

The Safety Board believes that testimony presented at its public hearing by NASA personnel, by those airport managers who use friction measuring devices for maintenance purposes 4/ on a regular basis, as well as that of representatives of Canada and Sweden, tends to refute the FAA's contention that such devices cannot be used to produce reliable readings The problems expressed by the FAA are valid, but they can be overcome. As a matter of fact, the FAA's own national program to measure runway slipperiness and its followup series of more closely controlled runway friction measurements clearly demonstrates that reliable and repeatable readings can be achieved, especially when used to determine the cleanliness and condition of the concrete or asphalt surface. Therefore, the Safety Board believes that friction data can be developed and applied to formulate a uniform standard so that objective evaluations of the braking quality of a runway surface can be made. In view of this fact, the Safety Board believe that the FAA should measure runway friction at all full certificate airports during the annual inspection of the airport. The friction measurements could be made either by the FAA with FAA equipment or by airport personnel or contract personnel using airport equipment under the supervision of the FAA. When the coefficient of friction falls below the minimum value reflected in Advisory Circular 150/5320-12, Chapter 2, a Notice to Airmen (NOTAM) should be issued. Such a program would lead to the upgrading of the overall quality of runway friction measurement at certificated air carrier airports. Moreover, a continuing friction measurement program would promote standardization of methodology and provide the needed experience to improve the reliability of the equipment and the qualifications of airport personnel to operate and calibrate the equipment. Included in the program for the continuous measurement of runway friction should be provisions for the FAA to monitor the training and qualification of the equipment operators, the calibration and maintenance of equipment, and the airport's procedures for the use of the friction measuring equipment The proper training of operators and valid calibration procedures would upgrade the quality of the program and eliminate many of the problems resulting from unqualified operators.

In their testimony, industry groups took firm positions that the accuracy of existing equipment was not adequate and that there was a need to develop equipment that could be used operationally to measure the degradation of coefficients of friction of runway

4/ Maintenance use — measurement of friction at periodic intervals to determine the effect of rubber deposits or runway surface deterioration on runway coefficient of friction. Operational use — employment of friction measurement device when the runway is covered by snow, slush, ice, or water to determine coefficient of friction for the runway. The data may then be transmitted to pilots.

surfaces as they become contaminated with snow, slush, or ice. Several airport managers pointed out that 14 CFR Part 139 requires that they monitor runway conditions during changing meteorological conditions, but that it does not require that they measure runway friction for either maintenance or operational purposes. Additionally, airport management groups stated that existing technology is inadequate to measure runway friction for operational purposes, because the data produced by current equipment were not repeatable and did not relate to a common standard. Airport management witnesses generally agreed that reliance on reports of braking conditions from pilots and the experience of airport management are adequate and are more reliable and timely than any existing friction-measuring technology. The airport management groups who were opposed to the mandatory use of current mechanical friction-measuring devices stated that they would accept the responsibility of measuring and reporting runway coefficients of friction if a machine that is relatively simple to operate and maintain was available to make the measurement and if such measurements would be significant to the pilot in terms of relating such measurements to the stopping ability of his particular airplane.

The position of U.S. airport management is reflected further in the fact that only about 20 Mumeters 5/ are owned by U.S. airports. Less than half of the 20 Mumeters are actively used, and they are used only for maintenance purposes. A notable exception is Detroit Wayne County Metropolitan Airport, where the Mumeter is used in all weather conditions to provide operational data. According to the manager, the operational use of a Mumeter has been successful and has provided useful runway section information to pilots. Runway friction coefficient values are provided to the tower and to airport tenants through the telewriter. The airport manager stated that the use of Mumeters and the resulting information has been well received by pilots. He endorsed the use of Mumeters because, ". . .basically. . .those machines are calibrated, and. . .they somewhat take away from the human element and those that might be giving a braking action from our own staff. We feel it (Mumeter) is an added factor. It doesn't take a great deal of time to get out and check it, to ascertain if the pilot's view or opinion is correct." He stated that there were no manpower problems or difficulties in getting qualified operators.

Airplane manufacturers generally agreed with airport management on the value of friction measuring devices for operational purposes. According to them, mechanically derived friction data are too inconsistent to establish a credible standard for operational use. Additionally, they stated that existing friction measuring devices do not provide accurate friction data when appreciable water is present on the runway surface. Since wet runways represent a major problem with regard to airplane stopping performance, little credibility could be assigned to the existing friction measuring devices. However, they believe that existing devices could be used for runway maintenance purposes or to provide general advisories to pilots.

General aviation manufacturers do not believe that there is sufficient benefit to be derived from existing runway friction measurement equipment to warrant its use for general aviation operations. They are satisfied that the current reporting and assessment programs of airport management are satisfactory for general aviation purposes. The FAA also does not believe that adequate mechanical technology exists to reliably measure runway friction for operational purposes. Currently FAA believes that runway surface friction problems can best be solved by grooving or otherwise treating runway surfaces.

5/ A Mumeter is a device which provides instantaneous runway friction readings by comparing the revolutions of a canted set of wheels on the device to the revolutions of a freely rotating recording wheel while the Mumeter is pulled along a roadway or runway.

Although pilot associations and the ATA support the use of friction measuring devices, their positions differ with respect to the mandatory use of such devices. Pilot associations recommend regulatory action to require airport management to measure friction and to report the information to flightcrews. In their view, pilots thereby would be able to use the runway friction information in conjunction with expected performance values in the airplane flight manuals. Additionally, they observe that regular and repeated use of runway friction values would expand the operational significance of the values to each pilot.

The ATA has a program to encourage the operational use of friction measuring devices, and it believes that the current equipment is adequate to measure friction on runways to provide advisory information to pilots. The ATA stresses that, while the friction readings cannot be correlated directly to airplane stopping performance, the runway friction advisory information will assist the pilot through repetitious use in relating the information to his airplane's stopping capability on that runway.

Representatives of several foreign governments and one U.S. air carrier indicated at the hearing that they use systems for measuring coefficients of friction on runways contaminated with snow, ice, slush, and water, and for relating the measured values to airplane performance in both general and quantitative terms. However, they admit that the correlations are not precise and they are rarely, if ever, used to impose landing or takeoff weight penalties on airplanes. Further, extensive pilot experience with the systems is required before reliable operational judgments can be made. In other words, the systems used are runway condition advisory systems that have evolved over many years of use and experience. Although the systems are recognized as far from perfect, the users are confident that they are providing useful advisory information to experienced pilots.

The Safety Board recognizes that research is needed to establish the value of the use of runway friction measuring devices for operational purposes when the runway is covered with contaminants, such as snow, slush, or ice, and to establish a correlation between measured values and airplane stopping performance. However, the Safety Board believes that the development of reliable equipment to determine runway condition in quantitative terms for advisory purposes is a realistic objective.

Furthermore, the Safety Board believes that the NASA and the FAA programs related to the development of runway friction measuring techniques should be broadened to determine whether existing systems on an airplane can be redesigned or modified to present quantitative indications of effective braking coefficients to flightcrews. For example, antiskid system modulating pressures or cycling frequencies might be used in conjunction with prescribed pilot braking techniques to calculate and display a quantitative braking coefficient. Also, the potential for using inertial navigation systems to measure deceleration and to provide a quantitative braking coefficient for those airplanes so configured should be explored. Such quantitative pilot reports would allow airport management to monitor deteriorating runway conditions more closely.

Airplane Certification, Operational Regulations, and Contaminated Runway Surfaces.--The Federal Aviation Regulations (FAR) and standards are intended to assure the safety of airplane takeoff and landing operations by imposing requirements on airplane manufacturers to demonstrate the takeoff and landing performance of an airplane during its certification, and by defining limitations within which the operator of the airplane must operate during normal service. The regulations which currently apply to modern jet transport operations are set out in the airworthiness standards in 14 CFR Part 25 and the appropriate operating rules in 14 CFR Part 121 or 14 CFR Part 135. These regulations

were derived from earlier Civil Air Regulations adopted in 1959. The current regulations define the considerations for determining the length of runway required for any airplane to take off and land at its operating gross weight, allowing for certain margins of safety.

Although accidents in which an airplane runs off a runway after rejecting a takeoff or after landing are infrequent, they invariably prompt Government and industry safety experts to reexamine the adequacy of safety margins provided by regulation. Both takeoff and landing operations were examined during the Safety Board's hearing. The Safety Board's accident statistics show that the airplane certification and operational regulations pertaining to takeoff and landing performance provid for safe operations under normal conditions. However, in the Safety Board's opinion, the Continental Air Lines DC-10 accident in Los Angeles on March 1, 1978 6/ and the World Airways DC-10 accident at Boston illustrate deficiencies in the regulations which must be addressed. In the Continental Air Lines DC-10 accident, the pilot rejected the takeoff near V_1 because of tire failure, but he was not able to stop the airplane on the runway, which was wet and contaminated with rubber deposits. The airplane continued off the departure end of the runway, where the left main gear failed. The airplane came to rest 664 feet beyond the departure end of the runway and caught fire. Two passengers were fatally injured and 38 passengers were seriously injured in the fire and evacuation. Postaccident tests and analysis showed that the runway contaminants impaired braking capability and to the pilots' inability to stop the airplane on the runway.

The World Airways DC-10 could not be stopped on the icy runway at Boston-Logan International Airport. The analysis of the flight recorder data from the accident airplane and from another wide-bodied airplane which had landed before the World DC-10 showed that the maximum attainable braking coefficient was about 0.08, compared to a dry runway braking coefficient of about 0.50. The FAA-approved landing distance on a wet runway for a 365,000-pound DC-10 using 35° trailing edge flaps is 6,753 feet. However, other analytically derived data provided by the manufacturer for the World Airways DC-10, assuming maximum reverse thrust and ideal piloting techniques, show that for a braking coefficient of 0.08 a runway length greater than 7,500 feet would be required for stopping. Variations in pilot operational techniques, including the proper application of reverse thrust while concerned with directional control on a slippery runway probably would make the actual stopping distance longer.

The major problems is that all of the airplane performance data used to establish operational limitations are obtained under ideally controlled conditions and are not representative of the performance actually attained during normal line operations. The test airplane used during certification is new, its brake and antiskid systems produce peak design performance, the tires are in good condition and at optimum operating pressures, and the test pilot's reaction times to activate deceleration devices, such as ground spoilers and wheel brakes, during a rejected takeoff or after landing may not accurately reflect line pilot performance. 7/ Most significant, however, is that all of the airplane acceleration and stopping performance data are for dry, smooth, hard runway surfaces; yet takeoff and landing operations are frequently conducted on runways covered with water, ice, slush, or snow, or contaminated by rubber deposits. Under some conditions, the effective braking coefficients may be less than 20 percent of those obtainable on dry surfaces. Obviously, the certification standards cannot guarantee that an airplane operating near its maximum gross weight for a given runway can be stopped on the runway

6/ Aircraft Accident Report: Continental Air Lines, Inc., McDonnell Douglas DC-10-10, N68045, Los Angeles, California, March 1, 1978 (NTSB-AAR-79-1).
7/ Aircraft Accident Report: McDonnell Douglas Corporation, DC-9-80 N980DC, Edwards Air Force Base, California, May 2, 1980 (NTSB-AAR-82-2).

if the takeoff is rejected at decision speed and the runway surface is contaminated and slippery. Under these conditions, the airplane may use more than the theoretical or demonstrated runway distance to reach V_1, and consequently, will have less than the theoretical or demonstrated runway distance remaining to stop. Further, because of the reduced effective braking coefficient, the airplane may not be capable of stopping even if the takeoff is rejected before reaching decision speed. The FAA, airplane manufacturers, and air carriers contend that since reverse thrust was not included in the stopping distance determination, its availability provides some safety margin for the rejected takeoff. The Safety Board believes this contention to be faulty since stopping data using reverse thrust are not available and since reverse thrust effectiveness may well be diminished following an engine failure involving directional control difficulties created by asymmetric reverse thrust and a slippery runway.

As to landing on contaminated runways, the FAA, manufacturers, and air carriers also have contended that the safety factors applied to the airplane's certification landing distances are sufficient. For a turbine-powered transport airplane landing on a contaminated runway, the regulations provide for a runway length of 1.92 times the landing distances specified in the approved flight manual which are derived from tests conducted on a dry surface without the use of reverse thrust. Beyond the idealized conditions under which the tests are conducted, the certification flight test procedures used to establish the approved flight manual landing distance data are not representative of landing techniques used during normal line operation Thus, the possibility that even on dry runways, the normal operational landing may infringe upon the runway safety factor cannot be totally discounted.

The Safety Board regards as arbitrary the safety margin for slippery runways established by regulation, since there are no certification tests to correlate the airplane's attainable braking coefficients on surfaces with various types of contamination, and since there is no requirement for the airplane manufacturer to provide data regarding the effective braking coefficients which would be needed to stop the airplane within the distance established by regulation for wet runways. Further, although tests are conducted during airplane certification to demonstrate the functional characteristics of antiskid brake systems under slippery conditions, no tests or analyses are required to quantify the efficiency of these systems on slippery surfaces.

The manufacturers, the airlines, and the FAA continue to cite the safety record amassed by air carrier airplanes as evidence that the existing certification and operational standards provide for continuing safe operations. They note that both takeoff and landing overrun accidents occur only once in more than 2 million operations and that this record is improving. Further, they note that the accidents are seldom catastrophic and generally involve factors other than the runway condition—factors such as rejected takeoff at speeds greater than V_1, high and fast landing approaches, or pilot delays in activating decelerative devices. They attribute the improving safety record to improvements such as runway grooving, the 115-percent wet runway landing requirement, airport bird dispersal programs, improved airplane braking systems, improved tires, increased reverse thrust from fan engines, more precision landing approach aids, and better pilot training programs which make use of sophisticated simulators. The manufacturers and airlines agree that, though accidents are infrequent, methods should be sought to improve the safety of takeoff and landing operations on contaminated runways. They believe, however, that additional certification requirements or more rigid constraints on airplane operating weight for given runway lengths would offer little safety improvement, but would cause a significant economic penalty to the industry. Further, they view the path to improved safety to be through refined operational procedures, improved pilot training programs, and improved runway maintenance practices.

While the AIA representative indicated that he did not believe that measured runway friction could be correlated to airplane performance with sufficient accuracy to make it a reasonable requirement for certification, he noted that airplane manufacturers can, and do, provide data regarding stopping performance for different runway conditions in non-FAA-approved sections of the airplane performance manuals. The GAMA representative also observed that there are no known practical flight testing techniques to measure airplane performance under all runway conditions, but that straight forward analytical methods might be used to calculate the effects of contamination and that additional data could be provided in approved flight manuals. He also noted that GAMA supports all efforts by research agencies to develop more accurate and reliable methods for establishing braking coefficients, rolling-resistance values, and impingment-retardation values for runway contaminants which could be used to provide advisory information to pilots regarding runway length requirements.

Both the manufacturers and the airlines have been strong supporters of the "reduced screen (end of runway) height - reduced V_1 concept" as a means of assuring increased stopping safety margins for rejected takeoffs on contaminated runways. They have urged the FAA to adopt regulatory changes to reduce the required end of runway/clearway crossing height from 35 to 15 feet when operating on contaminated runways so that the reduced V_1 procedures can be used. Using this standard the dry runway required takeoff length would be retained, but the pilots go-no-go decision point would occur at a lower speed with a correspondingly longer distance available for stopping. The United Kingdom has already adopted this concept.

ALPA continues to seek changes to the FAA airplane certification requirements to reflect the effects of runway surface conditions on stopping performance. They believe that a "rational field distance" concept 8/ is needed. ALPA does not believe that reducing the required end of runway crossing height to permit a lower V_1 speed will increase the stopping safety margin sufficiently. They point out that if the takeoff is continued, the reduced safety margin could be even more critical and could in fact result in an accident more serious than a runway overrun after an attempted stop. Instead, ALPA believes that an additional safety factor should be added to the minimum required takeoff runway length (or a corresponding reduction in airplane weight) when the runway is contaminated to compensate for the airplane's reduced stopping performance. The ALPA spokesman at the public hearing suggested that an arbitrary 20 percent factor should be applied unless it is proven by analysis or tests that the factor should be less than 20 percent.

The airline pilots continue to be concerned about the validity of stopping performance data as established during the certification of the present air carrier airplane fleet. One of ALPA's main concerns is that flight test pilot reaction time to an engine failure and response time to activate decelerative devices are faster than may be reasonably expected of airline pilots during normal line operations. This aspect of the certification process has been clarified by amendment 42 to 14 CFR Part 25 which will be applicable to performance data determined for new airplanes. However, ALPA believes that performance data for older airplanes should be updated to reflect more realistic pilot response times. (An ALPA representative also indicated that the stopping performance of older airplanes needs to be upgraded by retrofitting them with modern antiskid braking systems.)

8/ The ideal situation where the airplane's stopping performance would be related to the actual condition of a contaminated runway and the airplane takeoff or landing weights would be adjusted accordingly.

For reported or measured runway friction information to be fully useful, flightcrews must have more data regarding the stopping performance of their airplanes. The Safety Board is aware that, even though airplane manufacturers are not required to demonstrate landing performance on runways other than dry, hard-surface runways for U.S. certification, the manufacturers of some airplanes have demonstrated performance and have provided data for wet runway performance to meet United Kingdom certification requirements. Furthermore, some manufacturers provide operators with estimated stopping performance data for low braking coefficients and for no-brake conditions. For example, such data are provided for the DC-10, and some operators use these data to derive tables or graphs that portray the stopping distances required for various reported braking action conditions.

The Safety Board's review of some major operators' manuals disclosed that the presentations of such data are not standardized, and in some cases, the landing distances for similar airplane weights and runway conditions derived by various operators differ significantly. The Safety Board recognizes that actual demonstration of airplane stopping performance as a function of runway surface friction coefficient is not practical. However, we believe that manufacturers can extrapolate data from dry runway stopping performance to predict theoretical stopping performance for braking coefficients of typical wet and icy runway surfaces. We believe that such data are needed by flightcrews and should be required. Further, the FAA should assure that the analytical assumptions used to derive such data reflect antiskid brake system efficiency and any other landing gear or brake characteristics which can affect stopping performance on slippery surfaces. To accomplish this, the FAA should require manufacturers to demonstrate antiskid brake system performance on surfaces with low friction coefficients by actual flight test or by laboratory simulations.

The Safety Board believes that the inclusion of analytically derived stopping performance data in present airplane performance manuals is less helpful than it could be because the data are not made available generally to flightcrews in a form that is useful for quick reference when needed for takeoff and landing decisions. Therefore, the FAA should require that the data be presented to flightcrews in a form which allows correlation to runway friction coefficients obtainable from ground measuring devices. In the interim, the data should be categorized in accordance with accepted braking action terminology -- good, fair, poor, and nil -- (elsewhere we have pointed out the need for additional guidance regarding the meaning of these terms).

Furthermore, the Safety Board believes that it is feasible to use analytically derived airplane stopping performance data to establish airplane weight limitations for operations on slippery runways for which friction measurements are available. The Safety Board is not convinced of the validity of the airplane manufacturers' and airlines' view that such requirements would impose severe economic penalties, since only those scheduled flights which operate from slippery runways at or near maximum allowable gross weight limits would be affected. Therefore, the Safety Board urges NASA and the FAA to continue research in the measurement of runway friction coefficients and their correlation to airplane stopping performance so that stopping distances on contaminated runways eventually can be accurately predicted. To date, NASA and FAA research has related the stopping performance of eight different airplanes to various ground friction measuring devices. This progress indicates that further correlations, which ultimately could be used to provide operational data to pilots, are achievable.

The Safety Board believes that, to increase the safety margin during takeoff on contaminated runways, flightcrews should be provided data for the lowest V_1 speed which would produce the existing accelerate-go safety margin (35 feet end-of-runway crossing

height) during takeoffs where the available runway length exceeds the minimum balanced field requirements. The Safety Board, however, rejects the view that an allowable reduced end-of-runway crossing height with a further reduced V_1 speed, as advocated by the manufacturers and the airlines, is an acceptable alternative to an increased runway length safety margin under slippery conditions. The Board is concerned that the reduced margin would present a hazard during a continued takeoff following an engine power loss at or just after V_1 because takeoff positioning variations or subnormal takeoff acceleration due to slow thrust application, contaminant retardation, or tire failure could not be predicted adequately.

Acceleration on Contaminated Runways.--The accelerate-stop performance and, thus, the field length and decision speed computations are based upon the demonstrated and theoretical acceleration of the airplane using normal takeoff power. If for any reason, airplane acceleration is less than that used for the computation, the runway distance traversed to achieve V_1 will be increased and, therefore, the length of runway available for stopping will be decreased. Thus, with subnormal acceleration, such as during the takeoff of the Air Florida Boeing 737, there is no assurance that the airplane can be brought to a stop from V_1 on the remaining runway even if the runway surface is clean and dry. Consequently, a takeoff may have to be rejected at an airspeed much lower than V_1 when airplane acceleration is subnormal, and in order to assure adequate stopping distance the pilot must be able to recognize the subnormal acceleration rates early in a takeoff roll.

There was extensive testimony at the public hearing about the development and use of takeoff performance monitoring systems. The doubts and concerns about the technical feasibility and complexity of a takeoff performance monitoring system are well founded. Essentially, witnesses for the airlines and the manufacturers stated that there were too many variables to be integrated into an acceptable takeoff peformance monitor system before the system could function satisfactorily. They feared that such a system would ultimately result in high speed aborted takeoffs, and therefore, would be more of a hazard than an aid to the pilot. The airlines and the manufacturers are satisfied that the V_1 concept and the reliability of transport airplanes minimize the potential for acceleration-stop accidents. These organizations do not believe that there is a pressing need to develop additional technical equipment or technology on the subject. The FAA agreed with the position of industry on takeoff acceleration monitors. The FAA spokesman stated ". . .all the concepts so far proposed have drawbacks which may lead to false alarms and potential problems, such as causing unnecessary high speed aborted takeoffs or pilot distraction during the critical period. Unless the issues are resolved and systems are successfully demonstrated for application to line service, the V_1 concept is the most desirable system for takeoff safety management."

Hearing participants generally agreed that, if available and reliable, a better means of indicating acceptable takeoff progress would be an important asset to flightcrews. Representatives of ALPA and APA strongly advocate early development of acceleration monitoring systems to provide an early indication of unacceptable takeoff progress, thereby avoiding high speed rejected takeoffs and the accompanying high risk of overrun accidents. These representatives also believe that the technology to develop such systems is available today.

The Safety Board is aware of some progress in developing a takeoff acceleration monitoring system. One system, which is in the developmental stage, can, according to a company spokesman, provides ". . .early, and continuous warning of significiantly substandard all-engines acceleration up to the V_1 point, without being so sensitive as to induce unnecessary rejected takeoffs." He further stated that an FAA evaluation of the system indicated "considerable development potential." Other takeoff monitor systems included the use of inertial navigation systems and a ground-based monitor system.

Notwithstanding the position of the airlines, the FAA, and the airplane manufacturers, the Safety Board believes that two important considerations point to the need of addressing the development of takeoff acceleration monitoring systems. First, given the uncertainity of airplane stopping performance on a contaminated runway, flightcrews must know the status of airplane performance during takeoff roll. The provision of this information to flightcrews may be significant in only a very few instances; however, the potential for a serious accident in each of these instances is very high and warrants the provision of a means to monitor takeoff performance accurately. Second, the Safety Board believes that appropriate technology can be developed for takeoff acceleration monitoring systems if proper industry emphasis is forthcoming. The Safety Board is not convinced that the problems cited by industry are insurmountable in the face of today's technology and the aviation industry's engineering and development capability. Instead, the Board believes that a concerted effort by various elements of the aviation community could overcome the technical hurdles involved and would lead to the implementation of a takeoff performance monitoring system that could make a significant contribution to flight safety.

The Safety Board believes that a joint government-industry task force should be formed under the leadership of the FAA at an early date to establish a program and guidelines for the development of a takeoff performance monitoring system. Moreover, this effort should be coordinated with other development and evaluation efforts pertaining to headsup displays, flight guidance and control systems, and other related avionics systems in order to take advantage of advances in these areas and to assure integration of all takeoff performance monitoring functions.

CONCLUSIONS

1. Airlines, ATC, airport management, and pilots each play a crucial role in the development and transmission of information relating to runway conditions during periods of inclement weather.

2. Because of the small number of FAA airport inspectors compared to the total number of certificated airports, the FAA must rely on airport management to conduct snow removal operations without continuing FAA surveillance.

3. The lack of specific requirements in 14 CFR Part 139 for airport snow removal programs can result in ineffective local snow removal programs.

4. The requirements of 14 CFR Part 139 should be amended to require that airport snow plans include both standards and procedural guidelines for airport operators, specifically criteria for closing, inspecting, and clearing contaminated runways, procedures to be followed upon receipt of "poor" or "nil" pilot braking action reports, and more specific requirements for runway inspections by airport operations personnel.

5. When pilots report braking action as "nil" or "poor to nil," airport management should be required to determine and correct the reason for the reduced runway friction before further airplane operations are permitted on the runway

6. While braking action reports are subjective, they remain the most timely and most available source of runway condition information.

7. The timing, form, and content of braking action reports must be standardized in order to minimize subjectivity.

8. The role of ATC is central to the transmission and dissemination of runway surface information to both pilots and airport management.

9. The ATIS should not be the sole means for transmiting runway condition reports during periods of rapidly changing runway conditions.

10. Air traffic controllers should anticipate the need and request braking action reports from pilots well before they land so that the pilot can make an evaluation of the entire landing roll.

11. Controllers should understand the operational significance of braking action reports, and their training should include information regarding the effects of contaminated runways on the performance of landing and departing airplanes.

12. Industry groups do not agree on the reliability and adequacy of existing runway friction measuring devices.

13. The use of mechanical friction measuring devices to measure runway coefficients of friction is an attainable, reasonable objective; friction data should be developed and used to establish a basis for objective evaluations of the braking quality of a runway surface.

14. Few friction measuring devices are currently used at U.S. airports; some airport managers who use friction measuring devices reportedly have used them successfully.

15. All parties agree that friction measuring devices could be used for assuring that the concrete or asphalt surface friction is not degraded, although airport management believes runway maintenance tests can be conducted equally well without the expensive and complicated equipment.

16 Airport management does not believe that adequate technology exists to measure runway friction with sufficient accuracy and reliability for such measurements to be used for operational purposes.

17. Pilot groups and the ATA support the use of friction measuring devices to provide, at a minimum, advisory information to pilots for assessment of takeoff and landing performance.

18. The FAA should measure runway friction during inspections of all full certificate airports and require that a Notice to Airmen (NOTAM) be issued when the coefficient of friction falls below the minimum value reflected in Advisory Circular 150/5320, Chapter 2.

19. The problem of measuring the coefficients of friction of contaminated runways and correlating measurements to airplane stopping performance is a complex one because of the large number of variables that must be accurately accounted for.

20. Several FAA and NASA projects for the measurement of runway coefficients of friction and correlation of the measurements to airplane stopping performance indicate that such correlation is an achievable goal.

21. Sufficient research has been completed to warrant further testing to establish correlations between runway friction measurements and airplane performance.

22. During airplane certification, the FAA should require manufacturers to show through analytically derived data the airplane's stopping performance on surfaces with coefficients of friction representative of typical wet and icy runways.

23. Measurements of runway coefficients of friction and their correlation to airplane performance will have to be both accurate and consistent before their use will be accepted voluntarily by the aviation industry.

24. The FAA should adopt rules which will provide adequate runway length safety margins in relation to existing runway conditions.

25. Techniques of time-distance and time-to-V_1 are not accurate methods of measuring airplane acceleration on the takeoff roll and have not found general acceptance.

26. The development of an accurate and reliable takeoff performance monitoring system would permit pilots to assess subnormal takeoff acceleration in time to effect a safe rejection of the takeoff.

RECOMMENDATIONS

As a result of this investigation and the investigations of the World Airways and the Air Florida airplane accidents, on December 23, 1982, the National Transportation Safety Board issued the following recommendations to the Federal Aviation Administration:

> Amend 14 CFR 139.31 and 14 CFR 139.33 to require that airports certificated under 14 CFR 139 and located in areas subject to snow or freezing precipitation have an adequate snow removal plan, which includes criteria for closing, inspecting, and clearing contaminated runways following receipt of "poor" or "nil" braking action reports and to define the maximum snow or slush depth permissible for continued flight operations. (Class II, Priority Action) (A-82-152)

> Use a mechanical friction measuring device to measure the dry runway coefficient of friction during annual certification inspections at full certificate airports and require that a Notice to Airmen (NOTAM) be issued when the coefficient of friction falls below the minimum value reflected in Advisory Circular 150/5320-12, Chapter 2. (Class III, Longer-Term Action) (A-82-153)

> Require that full certificate airports have a plan for periodic inspection of dry runway surface condition which includes friction measuring operations by airport personnel or by contracted services and which addresses the training and qualification of operators, calibration and maintenance of the equipment, and procedures for the use of the friction measuring equipment. (Class III Longer-Term Action) (A-82-154)

> Convene an industry-government group to develop standardized criteria for pilot braking action assessments and guidance for pilot braking action reports for incorporation into pilot training programs and operations manuals. (Class II Priority Action) (A-82-155)

> Amend air traffic control procedures to require that controllers make frequent requests for pilot braking action reports which include an assessment of braking action along the length of the runway whenever

weather conditions are conducive to deteriorating braking conditions and that the requests be made well before the pilot lands. (Class II, Priority Action) (A-82-156)

Amend air traffic control procedures to require that controllers disseminate "poor" and "nil" braking action reports promptly to airport management and to all departing and arriving flights until airport management reports that the braking action is "good." (Class II, Priority Action) (A-82-157)

Stress in initial and recurrent air traffic controller training programs, the importance of transmitting all known contaminated runway condition information to departing and arriving flights, that a "fair" or "poor" braking report from a pilot may indicate conditions which are hazardous for a heavier airplane, and that departing and arriving pilots should be informed when no recent landing by a comparable airplane has been made (Class II, Priority Action) (A-82-158)

Amend air traffic control procedures to require that Automatic Terminal Information Service broadcasts: (1) be updated promptly after receipt of reports of braking conditions worse than those reported in the current broadcast, and (2) when conditions are conducive to deteriorating braking action, include a statement that braking action advisories are in effect. (Class II, Priority Action) (A-82-159)

At such time as air traffic control procedures are amended to require Automatic Terminal Information Service (ATIS) broadcasts to be modified, amend the Airman's Information Manual to alert pilots that when advised on ATIS that braking action advisories are in effect they should be prepared for deteriorating braking conditions, that they should request current runway condition information if not volunteered by controllers, and that they should be prepared to provide a descriptive runway condition report to controllers after landing. (Class II, Priority Action) (A-82-160)

Require that air carrier principal operations inspectors review the operating procedures and advisory information provided to flightcrews for landing on slippery runways to verify that the procedures and information are consistent with providing minimum airplane stopping distance. (Class II, Priority Action) (A-82-161)

* * * * *

Amend 14 CFR 25.107, 25.111, and 25.113 to require that manufacturers of transport category airplanes provide sufficient data for operators to determine the lowest decision speed (V_1) for airplane takeoff weight, ambient conditions, and departure runway length which will comply with existing takeoff criteria in the event of an engine power loss at or after reaching V_1. (Class III, Longer-Term Action) (A-82-163)

Amend 14 CFR 121.189 and 14 CFR 135.379 to require that operators of turbine engine-powered, large transport category airplanes provide flightcrews with data from which the lowest V_1 speed complying with specified takeoff criteria can be determined. (Class III, Longer-Term Action) (A-82-164)

Amend 14 CFR 25.109 and 14 CFR 25.125 to require that manufacturers of transport category airplanes provide data extrapolated from demonstrated dry runway performance regarding the stopping performance of the airplane on surfaces having low friction coefficients representative of wet and icy runways and assure that such data give proper consideration to pilot reaction times and brake antiskid control system performance. (Class III, Longer-Term Action) (A-82-165)

Amend 14 CFR 25.735 to require that manufacturers of transport category airplanes determine and demonstrate the efficiency of brake control systems on surfaces with low friction coefficients representative of wet and icy runways by using simulation techniques incorporating dynamometer tests and actual brake system components, or by actual flight test. (Class II, Longer-Term Action) (A-82-166)

Amend 14 CFR 121.135 to require that air carriers and other commercial operators of large transport category airplanes include in flightcrew operations manuals takeoff acceleration retardation data in accordance with guidance provided in Advisory Circular 91-6A and stopping performance data on surfaces having low friction coefficients, beginning immediately when such data are available from airplane manufacturers. (Class II, Priority Action) (A-82-167)

In coordination with the National Aeronautics and Space Administration, expand the current research program to evaluate runway friction measuring devices which correlate friction measurements with airplane stopping performance to examine the use of airplane systems such as antiskid brake and inertial navigation systems to calculate and display in the cockpit measurements of actual effective braking coefficients attained. (Class III Longer-Term Action) (A-82-168)

Convene an industry-government group which includes the National Aeronautics and Space Administration to define a program for the development of a reliable takeoff acceleration monitoring system. (Class II, Priority Action) (A-82-169)

The Administrator. Federal Aviation Administration, (FAA) responded to Safety recommendations A-82-152 through A 82-169 on April 1, 1983. The FAA said that in response to recommendation A-82-152 a Notice of Proposed Rule Making (NPRM) will be issued to address the changes in 14 CFR Part 139 which were contained in the recommendation. With regard to recommendations A-82-153 and -154, the FAA is considering several alternative proposals for action involving the use of friction measuring devices for evaluating runway pavement surface conditions. The FAA will have a plan by July 1 1983.

The FAA stated that action had already been undertaken on recommendations A-82-155 and -169. A Joint Aviation/Industry Landing and Takeoff Performance Task Group was formed to address the issues raised in the subject recommendations, as well as their takeoff performance issues.

The FAA intends to modify FAA Handbook 7110.65C, paragraph 49 to respond to recommendation A-82-156. Additionally, to address recommendation A-82-157, the FAA will modify FAA Handbook 7210.3F, paragraph 430, to establish responsibilities for the prompt exchange of braking action reports between the tower and airport management. Handbook 7110.65C, paragraph 980 and paragraph 1010 will be amended to provide procedures which will ensure the timely relay of current braking action reports.

The Air Traffic Service has requested that the FAA Academy develop training materials which will provide training concerning braking action reports. Additionally, FAA handbooks are being reviewed to determine which procedures may be amended to enhance the effective gathering and timely distribution of runway braking action reports.

In response to recommendation A-82-159 the FAA proposes to include procedures within FAA Handbook 7210.3F, paragraph 1230, that will clarify the need to update broadcasts based on braking action reports. They are considering procedures for inclusion of the statement "braking action advisories are in effect" when appropriate runway conditions exist. The FAA stated that in response to recommendation A-82-160, the Airman's Information Manual will be revised once the air traffic procedures are modified as suggested in the preceding recommendations.

In response to recommendation A-82-161, Suggested Procedures When Landing on Slippery Runways, the FAA is evaluating the suggested procedures in Air Carrier Operations Bulletin 7-76-33 to determine if they remain valid in view of current information.

In response to recommendations A-82-163, -164, and -165, the FAA stated that they will respond to these recommendations once they have completed the review of the results of the Transport Airplane Takeoff Performance Requirements Conference, and the Joint Aviation/Industry Landing and Takeoff Performance Task Group.

The FAA did not agree with recommendation A-82-166. They said their disagreement was because of the variability in methods of measuring and comparing braking efficiency, and because of the FAA's lack of confidence in simulations for use in predicting braking performance.

The FAA did not concur with recommendation A-82-167 for the same reasons they did not accept recommendation A-82-166.

In response to recommendation A-82-168 the FAA and NASA are formulating a test program which was to be accomplished by NASA starting in April 1983. Congress has allocated fiscal year 1983 funding for that program. They stated that this effort would fulfill the intent of recommendation A-82-168.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES E. BURNETT, JR.
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ G. H. PATRICK BURSLEY
Member,

/s/ DONALD D. ENGEN
Member

April 22, 1982

APPENDIXES

APPENDIX A

**WITNESSES BEFORE THE
NATIONAL TRANSPORTATION SAFETY BOARD
PUBLIC HEARING ON
THE EFFECT OF RUNWAY SURFACE
CONDITIONS ON AIRCRAFT PERFORMANCE
MAY 3, 4, 5, 1982**

(In order of appearance): Some witnesses appeared more than once

1. Captain J. J. Ruddy
   Air Line Pilots Association

2. Mr. Roger Fleming
   Assistant Vice President - Operations
   Air Transport Association of America

3. Mr. Robert C. Davidson
   President, Los Angeles Department of Airport
   American Association of Airport Executives

4. Col. Leonard L. Griggs
   Director of Airports
   Lambert-St. Louis International Airport
   Airport Operators Council International

5. Mr. William C. Coleman
   Director of Aviation
   Boston Logan International Airport

6. Mr. Daniel J. Norton
   Airport Manager
   Detroit Metropolitan-Wayne County Airport

7. Mr. Booker Burley
   Hartsfield Atlanta International Airport

8. Mr. Richard Rebadow
   General Manager
   Greater Buffalo International Airport

9. Mr. Daniel C. Orcutt
   Executive Director
   Indianapolis International Airport

10. Mr. William Depuy
    Federal Aviation Administration
    Engineering and Certification Branch
    New England Region

11. Mr. Harry Hink
    Federal Aviation Administration
    Office of Airport Standards

12. Mr. Dean Broadfoot
Chief, Flight Standards
Transport Canada

13. Captain Knut Anfindsen
Air Line Pilots Association

14 Captain Robert Blyth
Allied Pilots Association

15. Captain Henry Nash
Chief Pilot, Washington National Airport
USAir

16. Captain Michael Yocum
Vice President, Flight Operations
Pennsylvania Commuter

17. Mr. Walter Mitchell
Federal Aviation Administration
Air Traffic Service

18. Mr. Alan Steven
Vice President, Operations
Regional Airline Association of America

19. Mr. Allen Rossmore
International Association of Machinists
Dispatchers Union

20. Captain Kenneth Healey
Senior Vice President, Flight Operations
World Airways

21. Mr. Edward E. McKellar
Director, Flight Control Planning
Delta Airlines, Inc.

22. Captain William Melvin
Air Line Pilots Association

23. Mr. Vern Ballenger
Director of Engineering
Air Transport Association of America

24. Mr. Charles Bautz
Air Transport Association of America

25. Mr. Donald Schelp
Aerospace Industries Association of America

26. Mr. Stanley J. Green
Vice President and General Counsel
General Aviation Manufacturers Association

27. Mr. Edward Hirzell
Director of Research
Hydroaire, Inc.

28. Mr. Darrell Pederson
Certification Division
Federal Aviation Administration

29. Mr. Thomas Imrich
Federal Aviation Administration

30. Mr. Leslie Bramhall
Civil Aviation Authorities
United Kingdom

31. Mr. Thomas Yager
National Aeronautics and Space Administration

32. Mr. Augie Stasio
Air Line Pilots Association

33. Captain Mel Volz
Vice President, Flying
United Airlines

34. Mr. Vern Benning
M. L. Aviation, Inc.

35. Mr. Gerald P. Fitzgerald
Chairman, Technical Committee
American Association of Airport Executives

36. Mr. David Stamey
Executive Director
Airline Passengers Association

37. Mr. Hector Dalutolo
Federal Aviation Administration

38. Mr. Harold Hoekstra
Miles Phoenix, Inc.

39. Captain Edward Halpin
Allied Pilots Association

APPENDIX B

WRITTEN COMMENTS SUBMITTED FOR THE RECORD OF THE PUBLIC HEARING ON THE EFFECT OF RUNWAY SURFACE CONDITIONS ON AIRCRAFT PERFORMANCE, MAY 3, 4, 5, 1982

The following organizations submitted written comments for the record of the public hearing on "The Effects of Runway Surface Conditions on Aircraft Performance."

1. American Association of Airport Executives
2. Airport Operators Council International
3. Atlanta International Airport
4. Massachusetts Port Authority
5. Greater Buffalo International Airport
6. Air Transport Association of America
7. Regional Airline Association of America
8. Aerospace Industries Association of America
9. Greater Aviation Manufacturers Association
10. The AOPA Air Safety Foundation
11. Air Line Pilots Association
12. Allied Pilots Association
13. Aircraft Dispatchers Lodge 2485
    International Association of Machinests
    and Aerospace Workers
14. Flight Dispatchers, Meteorologists and Operations Specialists Union
15. Federal Aviation Administration
16. Transport Canada
17. United Kingdom Civil Aviation Authority
18. Department of the Air Force
19. National Aeronautics and Space Administration
20. Ransome Airlines
21. World Airways, Inc.
22. United Airlines, Inc.
23. Pennsylvania Airlines, Inc.
24. Delta Airlines, Inc.
25. USAir
26. Hydro-Aire Division, Crane Company
27. International Airline Passengers Association
28. Miles Phoenix, Ltd.
29. M. L. Aviation Company, Ltd.

APPENDIX C

SUMMARY OF BACKGROUND INFORMATION AND PUBLIC HEARING TESTIMONY ON LARGE AIRPLANE OPERATIONS ON CONTAMINATED RUNWAYS

Background Information and Airports and Airport Management

The airport system in the United States is almost exclusively privately owned, or owned by local governments, rather than by the Federal Government. In most other countries, the airport system is operated by the government. The FAA's role is essentially one of system planner, a source of funding for many airport projects, and in the case of certificated airports, 9/ a regulator. The FAA also does the overall planning for current and future airport needs. The FAA owns/operates only Washington National Airport, Dulles International Airport, and an airport at its Technical Center in Atlantic City, New Jersey. In the United States, cities and counties or semi-autonomous authorities formed by these entities, typically own airports. In addition, the State of Alaska and a few other States own a limited number of airports; overall there are about 6,290 public-use airports in the United States. Private airports -- those closed to commercial or general aviation traffic without approval of the owners -- number about 9,186 airports. Until May 1973, the operations of airports in the United States were not governed by Federal regulations, and airport management had developed and grown utilizing standards developed by the airport owners themselves.

Historically, the safety record of airports has been good. Data for 1970 through 1980 regarding 14 CFR 121 and 14 CFR 135 air carriers indicate that there were 3,106 accidents for the combined group of carriers. Of this total, 561 resulted in one or more fatalities. Airport and airport facilities were cited as a cause or a factor in only 13 percent of the 2,321 14 CFR 135 accidents and 8 percent of the 785 accidents recorded by 14 CFR 121 operators. (See Table 1.)

Table 1.--Selected Airport/Cause/Factor Data From National Transportation Safety Board Accident Statistics.

14 CFR 135 Accidents			Condition	14 CFR 121 Accidents		
Cause	Factor	Total		Cause	Factor	Total
7	33	40	Wet Runway	15	16	31
7	33	40	Ice/Slush on Runway	2	6	8
5	50	55	Snow on Runway	1	7	8
3	16	19	Snow Windrows	1	1	2
4	25	29	Poorly Maintained Runway Surface	0	2	2
0	5	5	Ice/Slush on Ramp/Taxiway	0	2	2
1	3	4	Snow on Ramp/Taxiway	0	3	3
27	165	192		19	37	56

9/ Certificated airport is one which is regulated by 14 CFR 139. An airport must be certificated in order for air carrier airplanes to serve the airport.

14 CFR 139 -- Snow/Ice/Contaminant Removal.--Procedures used at airports for snow and ice removal have evolved from more than 40 years of operating experience by the airport industry. During this period, the FAA had little influence on the manner in which snow plans were developed. When 14 CFR 139, Certification and Operations: Land Airports Serving CAB (Civil Aeronautics Board) - Certificated Air Carriers, became effective in May 1973, the regulation set forth general requirements for the operation of certificated airports. 10/ As the title of the regulation states, only those airports serving CAB - certificated air carriers need be certificated. As a result, about 778 airports are regulated under 14 CFR 139, which includes all of the airports served by air carriers and most of the airports served by commuter airlines. The 778 certificated airports are further divided into full 11/ and limited 12/ certificated airports. There are 521 airports which have full certificates, requiring the airport to meet all the requirements of 14 CFR 139. The 257 airports holding limited certificates need only meet certain portions of 14 CFR 139. The annual FAA surveillance of the 778 certificated airports is done by 26 FAA airport inspectors.

The requirements for ice and snow control are general, and in essence require only that the airport operator remove from the runway pavement areas of snow, ice, standing water, and other contaminants as "promptly and as completely as practicable." (Rubber deposits were included as a contaminant.) The 257 limited certificate holders are not required to meet these provisions. The regulation requires that the airport operator have a system to detect and assess on-airport hazards such as ice and snow, and have in place appropriate procedures to disseminate information on airport conditions affecting the safe operation of airplanes The procedures require methods of reporting the presence and depth of snow, ice, slush, or water on runways and taxiways.

In order to comply with 14 CFR 139, airport operators must insure that the general requirements of the regulation are contained in its FAA-approved airport snow plan. The airport operator has great latitude in developing airport procedures for the control of ice and snow. The FAA spokesman stated that standardization and uniformity of snow plans is not efficient, since each airport has operational and meteorological differences which do not lend themselves to uniformity. Therefore, each snow plan is approved by the local FAA airport inspector based on an analysis of the specific conditions and anticipated needs.

Industry representatives testifying at the Safety Board's hearing gave diverse opinions on the adequacy of 14 CFR 139. The airport management associations stated in strong terms that the regulation, in its broadly structured approach to snow and ice control, was sufficient to provide high standards of airport safety. Their position was that airport managers have dealt successfully with the snow problem for years before the adoption of 14 CFR 139. The ultimate success of any snow plan was attributed to the experience and judgment of airport personnel in charge of the snow plan. Additionally, various airport associations have sponsored snow removal education programs, and the Air Transport Association of America (ATA) published a snow removal handbook in 1971. Some of the airport managers who testified stated that pilot associations and airlines have worked with airport management to insure that snow removal plans at different airports were satisfactory The position of airport management toward more specific guidance in 14 CFR 139 was represented in the following statement by the president of the American Association of Airport Executives (AAAE):

10/ The Safety Board is conducting a special study of airport certification and operation to be completed in early 1983.
11/ Full certificate — issued to airports providing service to large, schedule CAB-certificated air carriers.
12/ Limited certificate — issued to airports providing service to large, unscheduled and small scheduled and unscheduled CAB-certificated air carriers.

> Under 14 CFR 139 there are certain requirements and generally speaking airport management considers airport certification as sort of a stamp of approval on the various safety and housekeeping procedures that would be followed regardless of Federal certification. The FAA realizes that no rigid rules can be established to cover the various situations from airport to airport. It is for this reason that the airport manager prepares the certification manual tailored to that particular airport. The FAA approves the manual and its surveillance is to assure compliance with the provisions of the manual.

The FAA spokesman addressed the lack of specific requirements or objective standards for airport snow and ice control in 14 CFR 139. The FAA, citing the need for individual airport programs, had allowed the airport operators to develop plans they considered adequate. In most cases, a plan is routinely approved by FAA airport inspectors. The FAA's annual inspection of an airport snow removal plan is basically a review of a written document, which usually has no objective standards upon which to make operational decisions. Since FAA does not usually inspect for actual implementation of snow plans, it cannot insure that effective snow removal will actually be used during snow and ice conditions. The airport operator is responsible for the effective implementation of the snow plan.

The regulation of certificated airports by the FAA is much different from the regulation by Canada and many International Civil Aviation Organization (ICAO) member countries. The primary reasons are the nature of the ownership of the airports, and the initiative of government and airport authorities to develop technology and procedures to assess objectively airport operational conditions. In contrast to 14 CFR 139 requirements, the following procedures regarding snow/ice control programs are followed by Transport Canada and many other nations:

(1) A priority system which limits the snow depth at various segments of the airport. For example, priority area No. 1, the duty runway, and taxiway must be completely clear of snow and ice throughout the snow storm. The maximum allowable accumulation of snow in priority area No. 1 is 1/2 inch, and in priority area No. 2, the maximum is 2 inches. Priority area No. 2 is the secondary runway and taxiway.

(2) Transport Canada provides different types of friction measuring devices to 90 airports. Coefficient of friction values for snow and ice-covered runways are provided to pilots.

(3) A runway friction measurement program has been established to monitor runway friction at Canadian airports.

(4) A landing distance correction table is provided to pilots which alters the landing distance required on a dry runway to account for reduced runway friction caused by snow, slush, ice, or other runway contaminants.

Snow Removal Procedures --The sufficiency of current snow/ice removal procedures and chemicals was endorsed by most spokesmen for airport management groups and the airline industry. Witnesses noted that snow removal at some airports had been less than satisfactory in the early 1960's. However, industry-sponsored symposiums, the ATA program to develop a snow-removal handbooks, and pilot associations' efforts have resulted in upgraded snow removal programs at U.S. airports.

Airport managers cited several common snow and ice removal techniques. The most effective was a combination of snow plows, machine-driven brooms, or snow blowers, and a final application of fine sand over the runway. Normally, the removal procedure must be repeated whenever the depth of snow on the runway approaches 2 inches. Some airport managers use chemicals to melt snow and ice. The drawback to chemicals is the 15- to 30-minute waiting period for the chemicals to work. Additionally, the chemicals must be removed from the runway before operations can continue because the chemicals create a slippery runway. The manager of the Greater Buffalo International Airport stated that his policy is to bring on three-shifts of workers, 24-hours a day from November through April. This workforce enables the manager to have a continuous operation to clear runways when snow is falling and, as a result, "keeps the runways clear and bare during the entire winter season." All airport managers cited the tremendous expense involved in snow removal programs as a result of the overtime payments for personnel, the cost of chemicals, the cost to operate removal equipment, and the cost to remove the snow from other airport areas when necessary.

The only relatively new technological advance related to snow removal reported by airport managers was runway sensors. Runway sensors are electronic devices implanted in the runway and around the airport. These electrical devices allow airport management to monitor the surface ambient air so that ice prevention or clearing procedures can be implemented at precisely the right time. Worldwide, many large airports have installed runway sensors; however, only about 20 of these are in the U.S. Managers of airports with runway sensors reported that they have proven both cost-effective and useful as a runway-condition evaluation tool, enabling airport management to monitor runway surface in order to determine the most efficient time to apply chemicals or sand. One manager stated that the savings on sand and chemicals in 1 year covered the cost of the installation of the sensors.

Despite the availability of equipment to clean runways efficiently, several airline industry and pilot witnesses testified that at some airports the technology is not used properly. The reason given generally for poor snow removal programs was lack of preparation and ineffectual implementation by airport management. Although the number of airports having inadequate programs is small, the problem is difficult to deal with because snow removal programs are administered at a local level. Since 14 CFR 139 is not specific in outlining the requirements of a snow removal program, the effectiveness of any program is contingent upon its implementation by the airport manager. Testimony by witnesses indicated that where problems of this nature exist, remedial action is usually generated only through the combined efforts of airline tenants, pilot associations, and FAA airport inspectors.

Snow Removal and Closing of Runways.--The decision to close a runway for snow removal operations, or even the decision to begin snow removal operations in other parts of the airport, must be made by the airport manager, but the manager's decision may be influenced by airport snow committees. The criteria which affect the decision are contained, to some extent, in the airport operations manual and the snow plans. Snow committees are composed of representatives of tenant airlines who are on call to assist airport management during periods of snow. They inform the airport manager about runway and taxiway conditions and advise him when he is faced with a decision to open or to close a runway. However, the primary bases for the decision is the assessment of the operational conditions and the judgment of the airport manager or snow director. Testimony by most witnesses indicated that each situation varies so widely that it is impossible to impose standard criteria regarding activation of snow removal plans or the closing of runways.

Large Certificated Airports vs. Small Certificated Airports.--The requirements of 14 CFR 139 for snow removal and for the maintenance of paved areas are identical for all certificated airports, regardless of the number of runways or the scheduled air carrier traffic count. Unlike the crash-fire-rescue regulations, which are based on the size of the airplanes using an airport and the number of scheduled operations per day, snow and ice removal programs under 14 CFR 139 are approved based on the ability to provide a safe operating surface at the airport.

Testimony indicated that problems with snow removal programs are more prevalent at small airports. There were several reasons for this. First, smaller airports usually have only one air carrier runway. Airport management is under more pressure not to close the runway for cleaning than management at airports with multiple runways. Second, snow removal is costly, which could have a greater impact on a small airport with limited revenues Third, if an airport does not own snow removal equipment, it must contract for the personnel and equipment. Problems of timeliness, reluctance to keep the contracted company at the airport between snow falls, and the adequacy of equipment can become problems. In the latter case, rubber-tipped snow plows or brooms for sweeping the runway are not generally used for clearing snow from road surfaces, and therefore, a contractor may not possess such equipment for snow removal at the airport. Additionally, contract snow removal companies are in heavy demand during snow periods, which adversely affects reaction time to a request from an airport. Finally, special techniques are required to remove snow and ice safely from a runway surface; these skills and techniques are developed from experience on airports, and contract snow removal companies may not have such experience.

At the hearing, ALPA cited another potential problem at small certificated airports -- adequacy of communications. An ALPA spokesman stated that at a smaller airport an electrowriter is less likely to be available to disseminate runway condition reports. A spokesman for a commuter airline was asked about the timeliness and accuracy of information on runway conditions at small airports compared to that at large airports. He stated: "At the smaller community airports we become more self-sufficient for obtaining our information and (we) have our station personnel obtaining and working closely with airport management to be sure that we always have the most up-to-date information."

The operational problems created by snow and ice conditions at an airport with a single air carrier runway are not limited exclusively to small airports. One witness pointed out that of the largest 65 air carrier airports in the U.S., 18 have runway configurations such that when the main air carrier runway is closed, air carriers cannot land. Nine of these 18 airports are in the "snow belt," 13/ and include LaGuardia, Washington National Airport, Baltimore Washington International, Indianapolis International Airport, Greater Buffalo International Airport, Bradley International (Hartford Connecticut), Nashville Metro Airport, Standiford Airport (Louisville, Kentucky), and Rochester Municipal Airport. According to the manager of Indianapolis International Airport, "It is these nine airports which really have the critical problem of keeping their runways open during adverse weather conditions."

Development and Transmission of Runway Condition Data.--The ATA and ALPA described several problems in the system used to develop and transmit information to pilots. An ALPA spokesman attributed the problems to the lack of FAA leadership in its failure to sponsor development of reliable friction measuringequipment, and the failure to have more efficient NOTAM (Notices to Airman) systems. The ATA spokesman believed

13/ The snow belt is the geographical area in the middle to northern section of the United States.

that improvements in the information generation and dissemination system could be realized by use of a friction measuring device and dissemination of information through a snow desk or command post. However, he stressed that the development and distribution of runway condition information must be a shared endeavor among airport management, the airlines, the pilots, and the ATC system.

The following elements were cited by most witnesses as necessary to the development of sound information on runway conditions:

- o Continuous monitoring of runway surface conditions by airport personnel.
- o Assignment of experienced airport personnel to conduct monitoring.
- o Aggressive solicitation of pilot braking action reports by ATC and airport management.
- o Centralized point to monitor information on runway conditions.
- o Specific and rapid corrective response by airport personnel when braking action reports indicate deteriorating conditions.
- o Standardized pilot braking action reports.

During periods of snow, ice, and rain conditions can be assessed visually by airport management, mechanically through use of a mechanical friction measurement device, or by pilot braking action reports. Few airports use mechanical devices since their accuracy and reliability has not been accepted by airport management. Therefore, visual inspection by airport management and pilot braking action reports were cited by witnesses as the most reliable indicators of the need to remove snow or ice.

ATA has developed general terms for use by pilots to describe the quality of braking. The terms are "good," "fair," "poor," "nil," or a combination of these terms. (See appendix E.) However, their attempt to standardize terms has not contributed significantly to the accuracy of pilot reports. Pilot and airport management testimony confirmed that even with the ATA definitions, pilot braking action reports often vary based on pilot technique, type of airplane, and type of runway contamination. The pilot perspective of braking reports was summarized by an airplane pilot as follows:

> "...the terms are so subjective, if you take the man with his 727 that lands exactly on the speeds as prescribed, he may very well say the braking action is fair. Perhaps due to conditions, the next man along the line will land at a higher speed trying to compensate for winds, and he would describe it as poor to nil..."

All airport operators who testified said that they relied on pilot braking action reports for a first-hand assessment of runway conditions. Though they agreed that the braking reports were subjective, airport managers believed that they were generally a real-time measurement of actual runway conditions. One airport manager stated that pilot braking action reports actually tend to confirm the runway assessment made by airport operations personnel. Airport operators generally agreed that reliance on braking action reports, visual inspections, and use of airport vehicles on the runway was superior and more timely than the use of mechanical friction-measuring devices to determine the condition of the runway surface.

Each airport operator reported different reactions to specific braking action reports, underscoring the lack of standardization and the subjectivity associated with the reports. Washington National Airport and Detroit Metropolitan Wayne County Airport have a policy that when a report of "nil" braking action is received, the runway is closed until airport personnel determine the reason for the "nil" report. Other airports managers reported less specific procedures, but stated that a "nil" report would cause their operations personnel to monitor the runway condition closely.

All participants -- airport management, pilot associations, and airline management -- endorsed the need for more precise guidance for making braking action reports. Participants suggested that ATA and the airlines through their training programs initiate a movement to resolve the lack of standardization. With regard to pilot's braking action reports, the reports were preceived as being more accurate when the pilot was told before the landing is made that he would be asked to submit a braking action report upon completion of the landing. Testimony indicated that when pilots were asked for braking reports after the landing was completed, the reports were sketchy and inaccurate. The consensus of the witnesses was that each airport and ATC facility should have procedures to request braking reports from pilots when certain weather conditions exist, that the request should be made before the airplane has reached the final approach fix, and that the report should reflect conditions in the touchdown, rollout, and exit areas of the runway.

The Airlines, Air Traffic Control, and the Individual Pilot

All witnesses agreed that the pilot has the final responsibility to make the decision to use a runway given existing conditions, and that his decision must take into consideration all of the physical, meteorological, and procedural factors available at the moment he elects to take off or to land. There was, however, a significant difference in positions between the pilot groups and airport management as to how runway surface conditions should be evaluated. The former maintained that airport management should provide mechanically-derived runway friction values rather than simply reports of the contamination on the runway and evaluations of contaminated conditions by other pilots. Airport management was adament that the pilot was the best judge of the condition of the runway surface, especially in rapidly changing meteorological conditions. The airport management group summarized its position on the use of pilot braking action reports rather than mechanical devices for condition assessment in the following statement:

> By relying on these reports, we are turning to the most qualified people who are the experts in aircraft operations and they are in the best position to make a value judgment. The introduction of information obtained by less qualified people operating friction measuring equipment, merely dilutes and diminishes the experienced opinion.

Clearly, until new equipment or procedures are introduced to provide additional runway data, there will be no fundamental change in the positions of these parties. In the absence of new equipment, however, the established roles for the pilot, the airline, and ATC in the existing system must provide timely, accurate runway condition information. Witnesses from each of the parties, however, admitted that the system depends on after-the-fact reporting of runway conditions and that often there are delays in the development and transmission of the information.

Functions and Responsibilities of the Airline Dispatcher.--The airline dispatcher's authority and responsibilities are established by 14 CFR 121 -- Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft. The dispatcher has joint responsibility with the pilot-in-command for the operation of a flight in compliance with applicable regulations and the air carrier's operations specification. Once the flight has departed, the dispatcher has the responsibility to monitor the progress of the flight and the destination airport's condition, and to issue information necessary to assure safety of the flight.

While a flight is en route, the dispatcher has more time than the flightcrew to maintain a watch on the destination airport. Additionally, the dispatcher normally has access to more sources of information than the crew. The dispatcher evaluates and forwards such information as field condition reports, braking action reports made by airport personnel, braking reports made by pilots, and reports of any potentially hazardous weather conditions. All parties considered the function of the dispatcher important since the dispatcher can monitor current airport conditions constantly and can function as a central information source for flightcrews.

The testimony indicated, however, that when runway conditions change rapidly, the dispatcher's value is diminished. Moreover, communications with the dispatcher decrease as an airplane arrives in the area of the destination airport, because the flightcrew is too busy during final preparations for landing to communicate with dispatcher. Additionally, once in the terminal area, the most current runway condition information is available through ATC, other pilots, and company station personnel. The reduction of information from the dispatcher to flightcrews and the increased information from ATC at this phase of flight was recognized by the parties as commonplace and to be expected. The shift of informational sources to reliance on local communications during the approach and landing phase of flight was articulated by an airline witness as follows:

> The cockpit crew, faced with a complex task even under the most favorable conditions, is unable to maintain continuous, meaningful contact with dispatch. During approach and landing, communication must first and foremost be with air traffic control. ATC is charged with the duty of communicating information which may affect flight safety. Cockpit chatter and radio communications must be kept to a minimum to assure a manageable crew workload and maximum concentration on the task of landing. As a practical matter, the cockpit crew expects to receive information relating to flight safety from air traffic control. They rely on air traffic control to perform its duties in a professional manner, and they rely on the accuracy of air traffic control's messages and field condition reports which are broadcast to incoming traffic.

Role of Air Traffic Control.--The ATC system is the primary means of transmitting current runway and airport information to the pilot. The controller, unlike the dispatcher, does not evaluate or analyze runway condition reports; however, he has the crucial responsibility to observe and to report current runway information to pilots.

The controller has two primary sources of information on current runway conditions -- airport management and pilots who have recently used the runway. In both cases, the data the controller receives is subjective and subject to rapid obsolescence with changing runway and meteorological conditions. As a result, the controller must retransmit runway condition reports immediately if they are to be of value to the pilot. Procedures for transmiting this information exist at all terminal ATC facilities. However, several witnesses noted that the information is not always passed to the pilot in a timely manner, and they cited other instances where the ATC system had failed completely to transmit critical runway and weather data to pilots.

Witnesses cited as a problem the inconsistent manner in which braking action reports are submitted to ATC. There is no regulatory requirement for pilots to submit braking action reports, although many airlines have internal procedures and requirements on the subject. As a result, submission of braking action reports can be inconsistent, even during very poor conditions. For example, 15 airplanes landed on runway 15R at Boston-Logan International Airport in the 2 hours it was open before the World Airway DC-10 crashed. Five of the 15 flightcrews made braking action reports to the controller. Two pilots reported braking as "fair to poor," two others reported it as "poor," and one pilot reported "poor to nil." One departing pilot reported the runway was extremely slippery as he attempted to position his airplane. Most witnesses stated that braking action reports are useful when (1) they are submitted regularly, and (2) the request for the report is made to the pilot before the landing airplane reaches the final approach fix. All witnesses stated that in the absence of an objective measurement of runway friction, pilot braking action reports remain the best source of current information.

A second problem with braking action reports centers on the manner in which ATC disseminates information. Airport control tower operators are required to issue factual information as reported by airport management and by pilots about the condition of the runway surface. ATC procedures specify that the controller "issue airport condition information necessary for an aircraft's safe operation in time for it to be useful to the pilot." Included in the instructions to the controller is the requirement to tell pilots of braking conditions caused by snow, ice, slush, or water, and other pertinent airport conditions. However, the manner and thoroughness with which the reports are relayed to pilots varies between facilities, and witnesses considered the procedures to be unsatisfactory at some facilities.

The testimony at the public hearing did not indicate that there was a lack of ability to transmit information during periods of changing runway conditions. ATIS tapes can be employed to pass runway conditions; but because of the time required to update the ATIS the ATIS information generally will not reflect the most recent runway data if new pilot reports or airport inspection data are submitted to ATC. The most current information comes from the controller, who receives and can request the latest pilot braking reports.

Aircraft Certification, Operational Regulations, and Contaminated Runway Surfaces

Takeoff.-- In accordance with 14 CFR 121 and 14 CFR 135, the airplane manufacturer determines and demonstrates the airplane's takeoff performance in terms of the takeoff speed, takeoff distance, accelerate-stop distance, and takeoff flightpath. It must be demonstrated that a multiengine transport airplane can tolerate the loss of power of one engine after beginning the takeoff roll and, depending upon the airplane's speed when engine power is lost, either stop safely within the remaining length of the runway, or continue the takeoff with power from the remaining engines and achieve a safe height by the time it reaches the end of the runway. Additionally, it must be demonstrated that the airplane can continue to climb at a specified minimum gradient with the power available from the remaining operating engines.

During certification, the manufacturer must establish the takeoff decision speed (V_1) for the full range of airplane operating weights. Generally V_1 speed is established as the speed at which the pilot could react to an engine power loss and either continue the takeoff or reject the takeoff, using minimum total runway length in either event. The minimum runway length required to satisfy these conditions alone is said to be "balanced," if the distance to accelerate to V_1 with all engines operating and then to continue takeoff with one engine inoperable is equal to the distance to accelerate to V_1 with all engines operating and then stop. While this "balanced" runway length is the theoretical minimum

length of runway needed for takeoff, other constraints can create the need for a longer length of runway. For example, the established V_1 speed must be high enough to allow for development of aerodynamic forces sufficient to maintain directional control with asymmetrical engine power. Furthermore, the current requirements of 14 CFR 25 stipulate that the minimum runway length cannot be less than 115 percent of the distance required for the airplane to take off with all engines operating and achieve a safe height by the time it reaches the end of the runway end. If these criteria are limiting, the V_1 accelerate -go and V_1 accelerate-stop distances probably will not be balanced.

In establishing the accelerate-stop distance for the airplane, the manufacturer must demonstrate the stopping performance using the decelerative devices which are "safe and reliable." The FAA has excluded the use of reverse thrust for stopping during the certification demonstrations. All of the certification accelerate-stop performance tests are conducted on dry, smooth, hard surfaced runways.

The data derived during the airplane manufacturer's certification tests are included in an FAA-approved flight manual for the airplane. Minimum takeoff runway length data are provided in terms of airplane gross takeoff weight and other variable factors, such as altitude, temperature, wind, and runway gradient. The operator will then use the approved flight manual data to develop procedures that assure compliance with the appropriate operating rules. For takeoff the carrier must prescribe minimum runway lengths, that are consistent with the runway length criteria contained in the flight manual. However, no additional safety margin is required. Generally, the air carriers will apply flight manual data to the operational runways at those airports into which they operate to prepare airport analysis charts for quick reference by the flightcrews. These charts show the maximum weight at which the airplane can be operated from a specific runway under existing ambient conditions and with different airplane takeoff flap configurations. There are no requirements that carriers consider the effects of runway contamination (water, ice, or snow) on retarding the airplane's takeoff acceleration or degrading its stopping performance in preparing this guidance for their flightcrews. However, FAA Advisory Circular (AC) 91-6A, dated May 24, 1978, provides information, guidelines, and recommendations concerning the operation of turbojet airplanes when water, slush, and snow are on the runway AC 91-6A acknowledges that airplane manufacturers often provide adjustment factors to be applied to FAA-approved Flight Manual data for varying runway conditions. These adjustments are in the form of maximum weight reduction in maximum weight and corresponding reductions in the V_1 speed for operations from a given length runway that is contaminated with standing water, slush, or snow. These data may be provided to flightcrews by an air carrier but are not required by the FAA. Consequently, the data are not usually provided and only rarely have the data been put into quick reference form.

Landing.--The regulations pertaining to landing performance require that the airplane manufacturer determine the horizontal distance necessary to land and bring the airplane to a complete stop from a point 50 feet above the landing surface. The specified procedures allow for a steady gliding approach at an airspeed 30 percent above stall to a 50-foot height. The manufacturer can use procedures to minimize air distance as the airplane descends below 50 feet; however, the landing must be made without excessive vertical acceleration. The ground roll stopping distance is demonstrated using "safe and reliable" decelerative devices. As with takeoff accelerate-stop, the FAA has excluded the use of reverse thrust. These tests also are conducted on a dry, smooth, hard-surfaced runway.

The landing distance data from the certification tests are those which appear in the FAA-approved Flight Manual. Unlike the case of takeoff requirements, however, the operator of large transport category airplanes under the operating rules of 14 CFR 121 or

14 CFR 135 must apply a safety factor to the FAA-approved Flight Manual landing distance data in his operating manuals. The operator must assure before dispatch that the weight of the airplane on arrival would allow a full stop landing from a point 50 feet above the runway threshold at the destination within 60 percent of the effective length of the landing runway. Thus, the minimum runway length for landing is 1.67 times the minimum landing distance developed in the airplane certification tests. Additionally, for turbine-engine-powered airplanes, a further margin must be applied if the runway is forecast to be wet at the time of arrival. Under these conditions, the required available runway is 15 percent longer than would be required if landing on a dry surface. Thus, an air carrier's landing airport analysis charts must provide dispatchers and flightcrews with the maximum weight at which the airplane can be landed on a destination runway for various landing flap configurations on both a dry or a wet runway surface.

Industry Recognition of Problem.--Recognition that existing regulatory standards do not provide positive assurance that an airplane can be stopped safely on a slippery runway has periodically prompted industry to examine other approaches to establishing certification standards and different operational practices. The "rational field length" distance concept frequently has been advanced. In theory this is the ideal solution in which the airplane's stopping performance would be related to the actual condition of a contaminated runway, and the airplane takeoff or landing weight limits would be adjusted accordingly. The FAA and the manufacturers contend that an airplane effective braking coefficient as it relates to a contaminated runway surface depends upon too many variables to make certification testing meaningful. The most significant problem appears to be the ability to repeatedly produce and measure a defined coefficient of friction on a given runway surface. The experience of the United Kingdom seems to substantiate the position of the FAA and the manufacturers. For nearly 25 years, manufacturers seeking U.K. certification were required to demonstrate the airplane's braking performance on a "wet" runway, and both accelerate-stop and landing distances were determined on that basis. The test condition was intended to represent an "average, wet, well-soaked" runway which was defined in terms of braking force coefficients measured by a skidding trailer type of friction measuring vehicle. The U.K. recently concluded that the water depth, runway texture, and friction measured by the vehicle were of a low order of accuracy and the test results were too broad to justify continuation of this certification requirement. It is interesting to note that the the U.K. permitted the use of reverse thrust in the wet runway certification tests and for many airplanes so certified, the U.K. regulatory wet runway landing distance was less than the safety margin provided in U.S. operations. The U.K. still insists, however, that some form of wet runway factor is essential in computing safe runway lengths for both takeoff and landing. Currently, it is considering using analytical methods to establish accelerate-stop and landing distances assuming that the wet surface braking coefficient is 50 percent of the effective coefficient attained on dry surfaces.

Another concept proposed by industry to better define the stopping distance safety margin during takeoff operations on contaminated runways would require a change in operational rules and procedures. Currently, the certification determination of accelerate-go distance and the operating regulation require that the airplane reach a height of 35 feet above the surface by the time it passes above the end of the runway or clearway. 14/ By permitting manufacturers to calculate anaccelerate-go distance,assuming an engine power loss at the critical engine failure speed, based upon a lower required height while keeping the present dry runway length requirements, a lower

14/ Clearway is an area under the control of airport authorities beyond the runway not less than 500 feet wide centrally located about the extended centerline of the runway with an upward slope not exceeding 1.25 percent above which no object nor any terrain protrudes.

V_1 speed could be established. Thus, the speed during takeoff at which the pilot would no longer attempt to stop the airplane because of an engine failure would be reached sooner in the takeoff roll and an additional increment of runway would be available for stopping the airplane. Using this procedure the manufacturer would provide not only a new normal V_1 speed for takeoff on dry runways but also a further reduced V_1 speed for takeoff from contaminated runways. This concept was discussed extensively at the FAA's Transport Airplane Takeoff Performance Requirements Conference of November 16-20, 1981, but the matter has not yet been resolved.

The ALPA representative offered a divergent view from those of the manufacturers and the airlines on several issues. He did not believe that it is appropriate to cite the safety record in terms of accidents per total number of operations. Rather, he observed that a better measure would compare accidents to the number of "high risk" operations -- the number of takeoff and landing operations on contaminated runways with the airplane at or near to its maximum gross weight for the runway. For comparison, a spokesman from one airline estimated that about 10 percent of their takeoff and landing operations are conducted at or near maximum allowable weight. His statement did not indicate how often these were conducted on a contaminated runway.

An ALPA representative also indicated that positive actions are needed to upgrade the stopping performance of older airplanes by retrofitting them with modern antiskid braking systems. A spokesman from an antiskid brake system manufacturer observed that the modern brake systems are far more effective than systems designed in the 1960's. Current designs have benefited from computer simulation wherein tire and brake data are developed from dynamometer testing and are combined with an airplane's structural attributes and an actual brake control system to evaluate airplane stopping performance for postulated runway conditions. The simulation includes effects of tire and brake heating, spotty runway conditions, and changes to airplane configuration and attitude. The spokesman noted that while current antiskid systems are effective in maintaining optimum braking on both dry and wet or slippery surfaces, some earlier designs became less effective on slippery surfaces when they were most needed. He also observed that the most efficient brake system cannot stop an airplane effectively if the runway coefficient of friction is nil. Both the antiskid brake manufacturer's spokesman and the representative from the U.K. Civil Aviation Authority expressed concern that older, cheaper, and less efficient antiskid systems will still be installed since there is no definitive requirement regarding braking system efficiency on slippery surfaces.

Current Friction-Measuring Technology

Although the problem of measuring the coefficient of friction of a contaminated runway and correlating the measured values to airplane performance may appear to be one that could be solved readily with modern technology, this special investigation revealed that the problem is complex and is not amenable to easy solution, modern technology notwithstanding. The complexity of the problem is directly related to the numerous variables involved in airplane stopping performance and in the accurate measurement of the coefficient of friction. These variables include: (1) underlying runway surface condition, (2) tire composition, (3) tire tread condition and design (4) tire inflation pressure, (5) tire surface friction shearing stress, and (6) relative slip speed between tire and runway surface. The problem is further compounded by the wide variety of runway surfaces and the wide variety of contaminants that can affect a given runway during a relatively short period of time. Finally, in correlating runway friction coefficients with airplane stopping performance, the correlation must be related to each particular airplane and its configuration and to the particular runway to be used.

Currently, there are mechanical devices which are used at some U.S. airports to measure the coefficient of friction on contaminated runways. These devices are used at many European and Canadian airports with success. Vehicles available to measure runway friction include the Mumeter, the diagonal braking vehicle, the SAAB friction tester, and the Jones decelerometer. These vehicles, if properly maintained, calibrated, and used, are capable of accurately measuring coefficients of friction of runways for maintenance purposes. However, most users testified that all of the devices have limitations which reduce their practical value when used on snow, ice, or slush. Further, none of them can duplicate the dynamics of airplane tires in terms of speed, tire design, and tire loading. Some progress has been made by NASA to correlate the friction measured by these vehicles to airplane performance. As a result, the operational use of the devices have been essentially rejected by airport managers.

The industry positions were discussed earlier in the study. Airport management groups stated that the existing technology is inadequate to measure runway friction because the data produced by any of the current equipment was not repeatable and did not relate to a common standard. Furthermore, they stated that use of measuring devices was time-consuming and required too much technical support for the benefit produced.

A spokesman for the aircraft manufacturers generally agreed with airport management on the limited value of friction measuring devices, and he made three specific points. First, despite 20 years of research, airplane performance still cannot be related to mechanically measured friction values. Therefore, friction measuring devices cannot and should not be used to impose weight limitations on transport airplanes. Second, there is not enough consistency in friction data to establish a credible standard for using friction information. Third, he said that existing technology does not adequately provide friction data when appreciable water is present on the runway surface. Since wet runways represent a major problem with regard to airplane stopping performance, little credibility could be assigned to existing friction measuring devices. However, he believed that existing devices could be used for runway maintenance purposes or to provide general advisories to pilots.

Pilot associations and the ATA supported the use of friction measuring devices, although the pilot groups advocated that the requirement should be in the applicable regulations. Pilots wanted airport operators to provide coefficient of friction values to flightcrews before a landing or a takeoff on a contaminated runway. The flightcrew would used the information as a runway advisory in conjunction with data in airplane flight manuals.

The ATA program encourages the use of friction measuring devices. They believe that the current devices are adequate to provide advisory information to the pilots. The ATA had started an airline runway friction measuring program in 1971. The intent of the programs was (1) to encourage airport management to purchase a friction measuring device, (2) to encourage airports to adopt procedures to qualitatively assess runway conditions whenever the runways were other than dry, and (3) to get the qualitative assessment to the pilot in a timely manner as advisory information. The ATA spokesman acknowledged that the friction readings could not be correlated directly to airplane stopping performance. However, he stated that the runway friction information would assist the pilot in his assessment of the runway surface conditions.

Both groups cited examples of airlines which had incorporated coefficient of friction information into flight manuals to relate measured friction values to likely airplane braking action performance. Both groups recognized the current inability to specifically correlate measured friction to airplane performance. However, ALPA believed that it is

possible to predict airplane stopping performance based on runway friction measurements and stressed that further testing of new friction measuring technology could provide the solution to this problem. ALPA urged that NASA and the FAA assign a high priority to research programs related to the correlation of runway friction measurements to airplane stopping distances and to pilot braking techniques on contaminated runways.

The U.S. Air Force uses a full range of friction measuring devices to provide operational data on runway conditions to pilots. However, airport and airline management do not believe the U.S. Air Force program is applicable to commercial operations because of the need to maintain high volume commercial schedules. Further, the exclusive Air Force ownership of airports with generally longer runways provides latitude not available to the civilian segment of aviation. Finally, the civilian segment does not have the Air Force's high level of confidence in the friction measuring devices. Although the reason for the lack of confidence in existing friction measuring devices is the general unreliability and lack of standardization, the cost of the equipment and the need for trained operators are also factors.

A spokesman for NASA reviewed the efforts of that agency to correlate runway friction measurements with airplane ground handling performance. NASA has made progress in correlating dynamic brake vehicle measured friction to DC-10 and Boeing 747 airplanes through the evaluation of airplane stopping performance from digital flight data recorder (DFDR) data. Further, ground vehicle measurements have been related to the performance of eight different instrumented airplanes under controlled runway conditions. Methodology for predicting airplane performance on a wet runway surface has been developed and has been established for 10 different airplanes. Finally, NASA has demonstrated that different measuring devices could be correlated to each other to establish a single, common base of data. Further, tests currently in progress to evaluate the combined viscous/dynamic hydroplaning theory of predicting airplane stopping performance may provide confirmation of a sufficiently accurate method of predicting performance for future operational use. NASA is also experimenting with the possibility of developing an airplane braking system that will continuously measure the runway coefficients of friction during landing rollout or on rejected takeoff, and through an onboard computer will provide the pilot with a cathode-ray tube display of the airplane's stopping capability.

The manufacturer of the Mumeter stated that the Mumeter did meet the accuracy and reliability standards necessary for both maintenance and operational use. He cited the experience with the Mumeter in those countries where it was used regularly, the U.S. Air Force experience, and testimony of airport operators who use the equipment successfully. Spokesmen for NASA stated that the Mumeter did not require exceptional technical skill to maintain or to operate.

Future Technology and Techniques to Monitor Airplane Acceleration on Contaminated Runways

Spokemen for Government and most segments of the aviation industry indicated that little effort is being directed toward the development of acceleration monitors to measure airplane performance during takeoff. Essentially the industry appears satisfied with the V_1 concept. The position of ATA was that the reliability of current generation transport airplanes has reduced the potential for takeoff-acceleration accidents. As a result, ATA believes that there is not a pressing need for additional technology on the subject; GAMA and AIA spokesmen concurred.

There was general agreement among hearing participants that, if available and reliable, a better means of indicating acceptable takeoff progress in air carrier flight operations than is currently available using takeoff reference speeds would be an important asset to flightcrews. Representatives of ALPA and Allied Pilots Association (APA) strongly advocated early development of acceleration monitoring systems to provide an early indication of unacceptable takeoff progress, thereby avoiding high speed rejected takeoffs and accompanying high risk of overrun mishaps. These representatives also expressed the belief that the technology to develop such systems was available today.

While other industry and Government participants agreed on the need for such systems, they were not as confident regarding their current technical feasibility. In written comments submitted before the hearing, and later amplified during hearing testimony, the AIA stated the following regarding techniques to monitor airplane acceleration on contaminated runways:

> The technology to monitor airplane acceleration is readily available. However, knowledge of airplane acceleration is not sufficient to determine the adequacy of the airplane performance. It is the integrated result of acceleration in terms of speed and runway position (runway remaining) that must be compared to the performance predicted for that particular takeoff to derive guidance of the crew. It is believed that there is as yet no adequate means of providing meaningful information to the pilot for takeoff decisions based on aircraft acceleration.
>
> The manufacturers will continue to follow and actively participate in the development of new or improved systems to monitor takeoff progress and when such technology is mature it will almost certainly be applied in their new designs. The AIA is equally firm, however, in its belief that the incorporation of immature technology must be guarded against to prevent any erosion of the excellent operational safety record that has been established.

The ATA representative testified that although his organization has not been involved actively in programs to develop acceleration monitoring devices, it is aware that such systems have been considered by the industry. He expressed the view that a highly sophisticated system would have to be developed in order to cope with the many variables involved in day-to-day takeoff operations. Moreover, he contended that some of these variables cannot be accurately quantified; therefore, the actual takeoff performance monitored by an automated system would often differ from the expected reference airplane performance. He further contended that "whenever the indicated performance is less than the expected performance, there will either have to be a substantial margin applied to the go-no-go decision criteria, or unnecessary takeoff aborts will result. Increased exposure to unnecessary high speed aborts may also increase exposure to overrun accidents, thus defeating the purpose of such a device."

On the other hand, excessive margins in the go-no-go criteria would also negate the value of a performance monitoring device. Perhaps this dilemma is part of the reason why no such device has yet secured widespread endorsement in the airframe manufacturing and airline communities.

The testimony of FAA's representative closely paralleled the ATA's views. He expressed concern over the number of variables involved and the complexity of a system which would comprehensively account for them. He contended that "all the concepts so far proposed have drawbacks which may lead to false alarms and potential problems, such as causing unnecessary high speed aborted takeoffs, or pilot distraction during the critical period. Unless, the issues are resolved and systems are successfully demonstrated for application to line service, the V_1 concept is the most desirable system for takeoff safety management."

At the invitation of the Safety Board, the U. K. Civil Aviation Authority submitted a position paper on the subject of airplane acceleration monitoring on contaminated runways. CAA views were similar to those of other hearing contributors regarding the need for a monitoring device, as well as the difficulty and complexity of developing such equipment. But beyond that, the CAA also included an explanation of why the technical problems were formidable and thus affords some insight into the hurdles that must be overcome before such a device can be developed. The relevant text is presented below:

Our view is that a device which has the ability to detect deficient performance on takeoff could make a significant contribution to flight safety and should be encouraged. There are reservations, however.

The problematical nature of take-off acceleration monitors arises from:

(i) the possibility that they may provoke an increasing number of aborted take-offs and that the hazard introduced by these might overweigh any benefit and

(ii) the difficulty of defining the level of "acceptable" acceleration.

For (i) not to happen, then (ii) must be set at exactly the right level, and we are not sure what this level should be. There is a common misconception that a reference level of performance exists - the so-called "book" performance given in the Flight Manual - and that this performance derives from a Newtonian type equation of motion. We do, of course, begin with a Newtonian type equation - the gross performance of the aeroplane - but all the parameters in the equation (weight, thrust, drag, friction etc.) vary in real life in a "normal" fashion, and we assume standard deviations for all these statistical variables. The operational variables (wind, temperature, altitude etc.) are accounted for at the time of take-off. The wind component carries a 50% factor of pessimism, the temperature is assumed known, and the airport altitude (strictly pressure altitude) is often assumed to be geographical altitude in dispatch weight calculations. From consideration of the statistical variables and the operational variables we produce, for example, a scheduled all-engines take-off distance in the Flight Manual which, if used on a day-to-day basis, should be exceeded on only about one in a million take-offs. We expect the same remote probability of a low speed over-run on landing; or in an abandoned take-off.

In the case of the all-engines take-off distance, the scheduled distance derived from the above considerations happens to be 1.15 times the gross distance. The acceleration required to achieve this factored distance could be the "reference" acceleration of the monitor, so that the pilot would be warned of sub-standard performance only when this level of

acceleration was not being achieved, i.e., on roughly one in a million take-offs. Even this is not as simple as it sounds, for the monitor can only react to what has already happened, or to what is happening instantaneously some of the statistical variables it knows nothing about, e.g. ASI (air speed indicator) error and it cannot predict, for example, handling errors, the time at which the pilot initiates rotation or the speed at the screen height. These variables, all of which are accounted for in the scheduled distance are beyond the scope of an acceleration monitor.

The achieved take-off distance on a given day results from the mean values of a number of parameters, all of which are varying, in an assumed manner in the scheduled performance, and in an unknown manner on the day. The monitor cannot cope with mean values because it cannot predict.

Thus, how do we prevent the monitor from sounding an alarm early in the take-off from a runway assumed to be level, but on which there is initially a substantial uphill gradient? And how do we ensure that the instrument will sound an alarm early enough during a take-off in deep slush, where the additional drag varies as V_2, and where the acceleration may be acceptable at low speeds?

This together with such additional problems as take-off from non-limiting runways, and the widespread use of reduced thrust for takeoff, convinces us that the problem of monitoring acceleration on take-off is insoluble unless very complex devices incorporating considerable real time computation capacity are used.

Notwithstanding the technical difficulties envisioned by the several hearing participants, one company had developed a concept for a takeoff monitoring system which it contends offers the potential to overcome the technical difficulties and operational shortcomings of other systems. At the Safety Board's hearing, a company representative explained the proposed system -- TOPIS -- Take-off Performance Indicating System.

The company contends that its system will "provide early, and continuous, warning of significantly sub-standard all engines acceleration up to the V_1 point, without being so sensitive as to induce unnecessary RTO's" (rejected takeoffs). The company contended that "it should be advisory only and should indicate when the point has been reached from which it would be hazardous to initiate an RTO." The company maintained that FAA's evaluation, under flight conditions, proved that the TOPIS system worked and met these objectives. The evaluation also reportedly revealed that the system "possessed considerable development potential to cover a number of other functions — e.g. wind shear, landing roll, deceleration guidance, net flightpath position, etc."

As indicated earlier, based upon available information, the TOPIS system represents a developmental approach which has acknowledged limitations and which has had only limited testing. At best the concept is sometime away from a solution to the takeoff performance monitoring problem.

Another innovative approach intended to alleviate the takeoff performance monitoring problem warrants brief mention here.

In late September 1982, the Safety Board received a letter from an airline captain in which he outlined his personal experience and ideas for utilizing an aircraft's

Inertial Navigation System for monitoring takeoff progress in those aircraft equipped with such systems. (See appendix F.) Although his approach has not been formally tested and validated, his account of the use of the system in everyday line operations appears to have credibility and warrants further consideration and evaluation to determine its suitability for more widespread application in air carrier operations. Most importantly however, this system indicates that despite the general reluctance of industry to examine a takeoff monitor system, there is interest and activity by some elements of the user group in this area. This interest is further underscored by the emergence of ground based takeoff monitor systems that the Safety Board has reviewed in recent months.

Flightcrew Practices and Procedures for Assessing Takeoff Acceleration.--Aside from intracockpit technology, there have been other procedures and techniques employed in the past to monitor takeoff performance. In past years there have been three primary methods used to measure airplane acceleration during the takeoff roll: (1) time-distance based on runway markers; (2) timed acceleration rate to the V_1 speed, and (3) the use of doppler or Inertial Navigation Systems (INS). An ATA spokesman in testimony at the hearing concerning acceleration checks alluded to the Safety Board's safety recommendation (A-71-3) and to some activity in the aviation community which followed its issuance. He stated the following:

> As a result of the NTSB recommendation, in early 1971, the FAA asked the ATA Flight Operations Committee to update its comments on the use of distance-to-go runway markers as a means of supplying acceleration rate information to V_1 speed to flightcrews on takeoff. In addition, the airlines were asked to explore the feasibility of developing an acceptable acceleration time check on aircraft having inertial navigation systems (INS) to determine if procedures could be developed that would enable flightcrews to make a go-no-go decision with regard to the airplane's acceleration to V_1 speed. The Flight Operations Committee reviewed this subject in detail and concluded that any attempt to use distance-to-go runway markers or use the INS system for acceleration rate information to V_1 speed was not feasible for airline operations. Of more serious concern in utilization of such techniques was the fear of increasing exposure to unnecessary high speed aborts and subsequent exposure to abort over-runs. It was the opinion of the Flight Operations Committee, based on individual investigations and experience, that acceleration checks during takeoff roll could cause more exposure to accidents than the procedure might prevent.

In addition to the ATA spokesman, several other witnesses at the hearing stated they believed that the use of runway distance markers would increase crew workload and cause distraction from normal cockpit duties, and that such divided attention between the inside and outside of the cockpit could adversely affect safety as well as complicating necessary crew coordination.

Additionally, representatives of a number of aviation organizations testified regarding the extent to which speed and distance checks are currently used in turbojet operations to assess takeoff performance. Without exception, spokesmen from ALPA, ATA, APA, and several airlines indicated they knew of no carrier which regularly uses such checks. Similarly, GAMA and AIA representatives indicated that to their knowledge none of their member companies use or advocate such techniques. Although some military operations still use runway markers to provide specific information on distance, use of time-to-speed and time-to-distance checks elsewhere in aviation operations appears to be rare. In any case, there was a consensus among hearing participants that the operational use of current on-board systems or equipment was not widespread in the aviation industry; nor was the use of such equipment viewed as offering a ready-make solution to the problem of assessing takeoff progress.

APPENDIX D

HISTORY OF SAFETY BOARD CONCERN WITH LARGE AIRPLANE OPERATIONS ON CONTAMINATED RUNWAYS

The National Transportation Safety Board's interest in runway contamination has been longstanding. The Safety Board has conducted a number of takeoff and landing accident investigations involving problems caused by contaminated runways, hydroplaning, and airplane acceleration and deceleration. In late 1970, interest in takeoff acceleration checks was heightened as a result of an air carrier takeoff accident involving a Capitol International Airways, Inc., DC-8. The Safety Board's investigation of the accident indicated that the airplane failed to accelerate at a normal rate during takeoff from an icy runway because the airplane's parking brake was engaged. On January 1, 1980, a Falcon 10 crashed during takeoff from Meigs Field, Chicago, Illinois, when the parking brake was left engaged in an intermediate position. In analyzing the Capitol International Airways Accident, the Safety Board expressed the view that the takeoff might have been rejected successfully had the flightcrew been able to assess the airplane's acceleration rate more accurately under the given operating conditions. As a result of the Safety Board's investigation and analysis of the accident, it recommended that the Federal Aviation Administration (FAA):

> Determine and implement takeoff procedures that will provide the flightcrew with time or distance references to enable the pilot in command to make a 'go-no-go' judgment with regard to the airplane's acceleration rate to the V_1 speed, particularly for critical length runways, and for runway surface conditions that may impede acceleration. (A-71-3)

Neither the FAA nor the airline industry supported this recommendation because both believed that acceleration checks during the takeoff roll could cause more accidents than the checks would prevent.

Also as a result of its investigation and analysis of the Capitol International Airways DC-8 accident in May 1972, the Safety Board reiterated its recommendation that FAA "require the installation of runway distance markers at all civil airports where air carrier aircraft are authorized to operate." The Board again urged the FAA to "require the use of takeoff procedures which will provide the flightcrew with time and distance reference to associate with acceleration to V_1 speed." In its report on this accident, the Board pointed out that an added benefit of runway distance markings would be a positive indication to the crew of the amount of runway available for takeoff. Crew confusion that existed regarding runway distance available from a displaced threshold would have been eliminated.

In 1973, the Air Line Pilots Association (ALPA) petitioned FAA to require distance-to-go markers at 1,000-foot intervals on runways used by turbine-powered airplanes. The petition did not, however, include a proposal to require the use of an operational procedure in connection with the proposed markers. In response to ALPA's proposal, the FAA issued an Advance Notice of Proposed Rulemaking (ANPRM) on the subject in May 1973. The FAA withdrew the ANPRM in 1977 after receiving significant industry opposition to it.

In 1973, the Safety Board as a result of its investigation of another accident recommended that the FAA ". . .expedite its research program to determine the friction characteristics of wet runways, not only for its effect on the landing certification

requirements for aircraft, but also for the certification of runway surfaces under the new Airport Certification Regulations." This recommendation followed a Northwest Airlines B-747 takeoff accident at Miami, Florida, on December 15, 1972. The accident occurred when the takeoff was rejected because of a bird strike to the No. 4 engine. The airplane was not able to stop on the runway because of the low coefficient of friction of the runway and a malfunction of the No. 3 thrust reverser which restricted the use of the Nos. 1 and 2 thrust reversers on the left wing side of the airplane.

The Safety Board made additional recommendations to the FAA concerning runway slipperiness and hydroplaning following a Piedmont Airlines Boeing 737 accident in October 1973. The probable cause of the accident was ineffective braking action caused by dynamic hydroplaning on a rain-flooded runway; the airplane ran off the end of the runway. As a result of this accident, the Safety Board made seven recommendations including a request that the FAA establish a monitoring system for runway slipperness and runway contamination. The FAA did not adopt this recommendation because it ". . .believed that, for the present, runway grooving is the most practical solution to the problem."

On November 27, 1973, an Eastern Airlines McDonnell Douglas DC-9-31 ran off the end of the runway during a landing at Akron-Canton Regional Airport, North Canton, Ohio; hydroplanning was a factor. The Safety Board requested NASA to conduct slipperiness and drainage tests on the accident runway. The NASA tests indicated that the slipperiness level of the runway was such that the landing velocity (reference speed plus 8-knot tailwind) "increased the wet stopping distance without reverse thrust from 3,109 feet to 5,068 feet."

On March 31, 1976, a Japan Air Lines Boeing 747 was damaged severely when it was blown off an icy taxiway at Anchorage, Alaska, and slid into a ditch. The airplane was out of service for a long time and the cost of repairs was reported to have been $6 million.

On November 18, 1976, the Safety Board issued two safety recommendations following two incidents at Washington National Airport in which Eastern Airlines Boeing B-727's ran off the end of the runway; one during an aborted takeoff and the other after landing. The runway was wet during both incidents. The recommendation called on the FAA to require compliance with ". . .all portions of AC (Advisory Circular) 150/5320-12, (Methods for the Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces) applicable to the testing and maintenance of paved runway surfaces be required as a condition of continuous certification of all airports utilized by turbine-powered air carrier aircraft, and (guidance) be incorporated into 14 CFR 139 [as requirements] (A-76-136)."

The FAA did not implement the recommendation because of "insufficient standards and authentic guidance material" to measure runway friction. However, in partial response to the recommendation, the FAA contracted for a National Runway Friction Measurement Program which was completed in December 1980. In this program, the friction of runways at 268 airports was measured using a Mumeter.

The contractor's final report to FAA concluded, in part, that "the basic concepts of Advisory Circular 150/5320-12 are supported by the data. Corrective maintenance action is recommended for runways with friction values less than the recommended value of 0.50." Other principal conclusions were:

- The airport survey reports produced for each of the 268 airports after each testing, provided timely input for airport maintenance purposes.

- The purpose and objectives of the National Runway Friction Measurement Program were achieved. Mumeter measurements and pavement condition survey data obtained in this program have yielded a rational and useful analysis of runway friction.

- The Mumeter is a rapid and effective device for measuring surface friction when operated in accordance with the manufacturer's instructions.

- A Mu value of 50 or greater has long been generally accepted as providing adequate runway friction under most operating conditions. This program did not disclose data to support any other value. It must be understood that as friction decreases the relative safety decreases, but it is gradual and time-related, that is, when the Mu value decreases from 50 to 49 the pavement does not go from totally adequate to totally inadequate.

Despite the selection of the Mumeter as the measuring device for the FAA's national program and its use at two FAA-owned airports for runway maintenance purposes (Washington National and Dulles International), the FAA continues to maintain that no reliable friction measurement device exists which could be used for the operational measurement of friction on runways contaminated with snow, ice, or waters.

The Safety Board addressed the issue of the reduced airplane acceleration-stop performance on wet runways in a series of recommendations issued November 17, 1978. The recommendations followed an accident involving the rejected takeoff of a Continental Airlines DC-10 at Los Angeles International Airport on March 1, 1978. These recommendations resulted in an FAA-sponsored technical review in November 1981 of the operational and certification rules governing the takeoff and accelerate-stop distance requirements for transport category airplanes.

In addition to the accidents in which contaminated runways and accelerate-stop issues were implicated, other similar accidents have illustrated the need to examine these safety issues. On January 21, 1981, a Cessna Citation overran a snow-covered runway during a landing attempt at Bluefield, West Virginia; five persons were killed. The Safety Board's investigation found that the manufacturer's airplane flight manual lacked sufficient information concerning landing distances on slippery runways.

APPENDIX E

DEFINITIONS OF PILOT TERMS

With the exception of "nil," which is described as bad or not braking action, FAA provides no information for the other adjectival terms. The 1980 edition of the Air Transport Association's Snow Removal Handbook describes the terms for their members as follows:

Good - More braking is available than will be used in an average airline type deceleration. If a max energy stop were attempted, some distance in excess of certified stopping distance would be expected.

Fair - Sufficient braking and cornering force is available for a well flown approach and landing using light braking. However, excess speed or long touchdown would result in an extremely low safety factor depending on runway length and crosswind component. Careful planning and good judgement are required.

Poor - Very careful planning, judgment and execution are absolutely essential. Crosswind becomes a "priority one" consideration. While a safe and successful approach, landing and stop can be accomplished if all factors are favorable, there is little room for error. Care must be exercised in every facet of the operation and a very careful evaluation of all existing conditions is necessary.

Nil - Extremely slippery with poor directional control even while taxiing. This is the kind of report we would envision during a freezing rain condition if nothing were done to the runways or taxiways.

APPENDIX F

EXCERPTS FROM LETTER RELATING TO AN INERTIAL NAVIGATION SYSTEM ACCELERATION MONITOR SYSTEM

An Inertial Navigation (or Reference) System, (INS or IRS) can be programmed to display acceleration, (instantaneous rate of change of groundspeed with time). Pan Am's INS units read out in terms of milli-g (one thousandth of the acceleration due to gravity). To put it in perhaps more familiar terms, one milli-g (mg) equals a change of one knot groundspeed in 52.5 seconds. During takeoff, typical accelerations range from about 170 mg to over 250 mg. It is a very sensitive unit of measure, and the INS gives a very reliable readout, as can easily be seen by comparing all three of the INS sets in our aircraft, and realizing that the INS can't navigate at all unless the acceleration is known to a fraction of one milli-g.

Acceleration varies during takeoff, usually reaching a peak at about 70 knots, then dropping off gradually as speed increases with attendant higher drag and changing engine output, to become at the rotation speed something like 80 percent of the peak value. For all the various Weight, Altitude, Temperature, Thrust, Wind, and Runway conditions there are typical curves of acceleration which must be achieved to yield the nominal takeoff, and there are also minimum curves below which a safe takeoff simply can't be made. I have only rough approximations of such curves, but it is straightforward engineering to generate fully valid ones.

Each acceleration curve can be characterized adequately for the purpose by the peak value observed at low speed. If the peak value is substandard there are two viable choices:

1. If it is a reduced thrust takeoff, and the peak acceleration is just a little low, add thrust and recheck.

2. If insufficient thrust is available, abort the takeoff. From a speed of 80 kts near the start of a takeoff roll, most airplanes will slow to taxi speed on the runway without any braking or reverse thrust.

I have been using some empirically observed check values for several years now, and have added thrust just once that I can remember, and never aborted due to insufficient performance. But then it has been 12 years between Capitol and Air Florida, so I didn't expect to need this method personally -- nobody does, and that's part of the problem, isn't it?

I am not prepared to offer the numbers for use with this method, because I am not satisfied that mine are valid. However, I am convinced that the method is sound and could readily be quantified. If it is desired only to meet minimum FAR takeoff performance requirements, then the enclosed format would be sufficient. Of course, in most situations there is excess performance, so it might also be desired to compare actual acceleration against nominal, not just against minimum. That would be even more simple, but require a different format of presentation.

The advantages:

1. Accurate readout very early in the takeoff roll.

2. It is adequate to make one check, and it can be done in a non-critical time of the takeoff.

3. Detects all major forms of performance deterioration, whether involving deficient thrust, excess weight, or excess drag. (The most significant exception would be aerodynamic drag, which would not be expected to show strong effects until a higher speed. Most forms of brake and tire drag would be covered.)

4. Gives readout which is directly related to the extra length of runway which is being used up, because distance to a given speed is inversely proportional to the average acceleration. (For example, the FAR calls for a minimum runway length equal to the all-engine operating takeoff distance plus 15%, which means that if deceleration is deficient 15%, takeoff is just possible in the full runway length *if* all engines keep operating.)

5. This method would remove much of the hazard from reduced thrust takeoffs, because it would be a final check that the thrust setting was indeed sufficient, not a result of mistaken computation. This would not be an economic penalty, because nearly all reduced thrust deficiencies could be made good, and the takeoff continued safely.

Deficiencies are:

1. Takeoff performance depends somewhat on the along-track wind component at the rotation point. (The wind elsewhere in the roll is of minor consequence.) This method will not predict the wind at rotation.

2. This method will not assure that the airplane is on the correct runway. Assurance that the chosen runway is long enough (even if it isn't the intended runway,) is the main advantage of "distance-to-go" markers. Such markers are not useful for performance checks, but it is nice to look up and see "10" if you are depending on 10,000 feet of runway.

3. The location of the readout is not ideal for instrument scan, but a good readout could easily be added to the panel.

Other uses might be made of the acceleration readout:

o To check braking action on the runway, 4 feet per second deceleration (minimum autobrakes) is about "N (Negative) 120" mg on the INS; 6 fps (medium autobrakes) is about "N 200" mg.

o In flight, if you have something near zero mg, you have sufficient thrust set to maintain the current flightpath angle at the current *groundspeed*, (which will also maintain the current *airspeed* if there isn't any windshear). This makes possible more precise throttle control.

END
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