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AEROSPACE INFORMATION REPORT

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TIRE SPRAY SUPPRESSION - AIRPLANE
Design Consideration and Testing for

FOREWORD

Changes in the revision are format/editorial only.

1. SCOPE:

This Aerospace Information Report relates considerations for design test procedures and test data evaluation for qualification of tire spray deflection devices.

1.1 Purpose:

The purpose of tire spray deflection devices is to prevent ingestion of water or slush into engines, or to limit ingestion to non-hazardous quantities. A further purpose may be to prevent impacting of the deflected spray into pusher propellers or upon other parts of the aircraft in a harmful manner. These devices may be a part of the tires, or installed on the landing gear or upon other parts of the aircraft. Considerations should cover all applicable ground operating modes including use of reverse thrust, and be extended to cover possible damage to mechanisms, systems, antennae or pitot and static ports.

Ingestion of tire deflected water or slush has caused powerplants to lose power when no precautions were taken. Certification requires establishment of safe and acceptable air vehicle operation.

Past aircraft operation has shown that there is a need to substantiate the capability of aircraft to operate safely from runways having standing water or slush over all or parts of the surface.

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2. REFERENCES:

FAA Advisory Circular No. AC 91-6

NASA Technical Note D-552 dated September 1960 "Studies of the Retardation Force Developed on an aircraft tire rolling in slush or water"

FAA Regulation FAR 25.1091 (c) (2) and (d) (2) "Turbine Engine Air Induction Location"

FAA Regulation FAR 25.1323 (d) "Airspeed Indicating System - Port Locations"

Joint Airworthiness Regulations JAR Code 25.1091

Advisory Circular Joint 4CJ25.1091 (3) (2)

Validation Note No. 3, Special Condition 9 "Take off from Precipitation Covered Runways"

3. HISTORICAL REFERENCE:

Engineers recognized safety implications in jet engines being faced with materials thrown from the wheels of aircraft early in operation of such aircraft. Various studies and engineering approaches to solving problems so related began evolving. Chine tires were one of the most common devices developed to help prevent landing gear propelled water from entering engines.

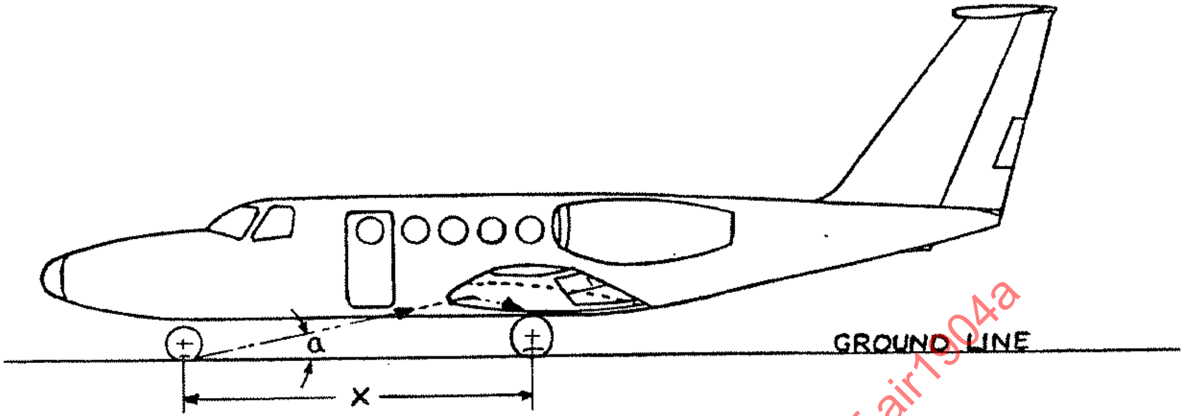
It was found that some aircraft have fortunate geometry and wheel deflected water and slush stayed clear of engines and other sensitive items. Design to purposefully accomplish this end is the ideal.

In several instances, the process of "stretching" an airframe has introduced an ingestion problem that had not existed in original models. Figure 1 illustrates this possibility.

Recent developments in rear mounted propeller driven aircraft have opened a new set of parameters to be considered in water deflection. Portions of the following document may well apply to such aircraft, but at present publication no specific efforts have been so directed. Hopefully, those concerns will be covered by revisions or supplementary efforts.

4. DESIGN CONSIDERATIONS FOR SPRAY SUPPRESSION:

(Consider the effect of spray in all likely modes of operation.)



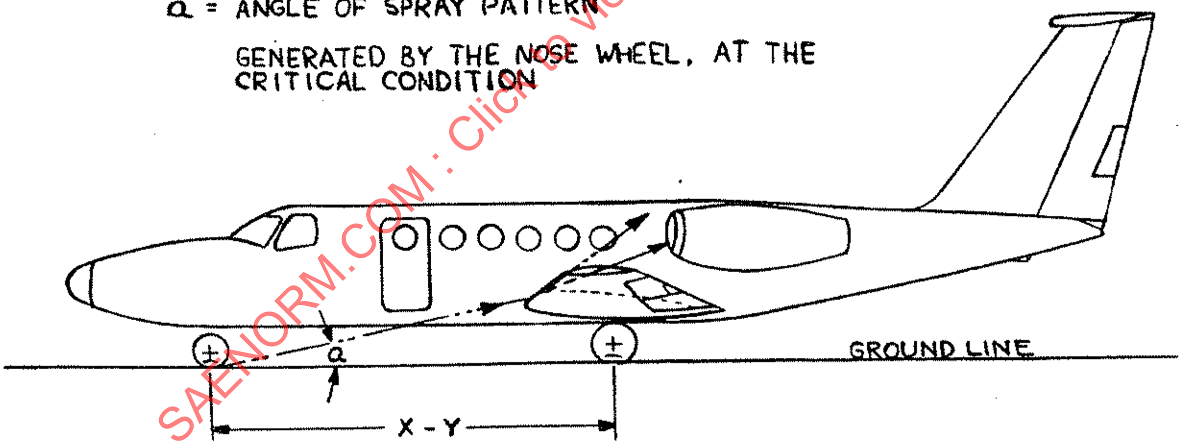
ORIGINAL MODEL

X = WHEELBASE
X - Y = STRETCHED WHEELBASE

GENERATED BY ADDING A FUSELAGE PLUG BETWEEN THE MAIN & NOSE GEAR

a = ANGLE OF SPRAY PATTERN

GENERATED BY THE NOSE WHEEL, AT THE CRITICAL CONDITION



STRETCHED MODEL

FIGURE 1

4.1 Deflection of Spray Necessitated By:

a) Engine performance (surges, loss of thrust, inlet blockage)

b) Static port performance (icing, blockage)

c) Mechanisms (impact damage, clogging, freezing)

d) Landing (in case of thrust reverser performance)

e) Takeoff performance (slush drag)

A loss of takeoff performance when operating from slush-covered runways has been recognized as evidenced by Federal Aviation Administration (FAA) Advisory Circular No. AC 91-6. Jet transports, with high takeoff speeds and low acceleration characteristics can be exposed to drag forces that may inhibit takeoff. The term "slush drag" is used to encompass either slush or water drag. Research into the problem showed that slush, or any other fluid which can remain on a runway in sufficient depth, causes drag on the aircraft in two ways. First, there is a direct drag on the wheels as they displace fluid from their path, while second, the intense spray formed by this process causes drag by impingement on the aircraft structure. National Aeronautics and Space Administration (NASA) research and experience show that the total impingement drag can be great enough for certain airplane types to cause marginal takeoff capability in 1 inch of slush and to cause takeoff refusal in 1.5 to 2 inches depth of slush. See Figure 2.

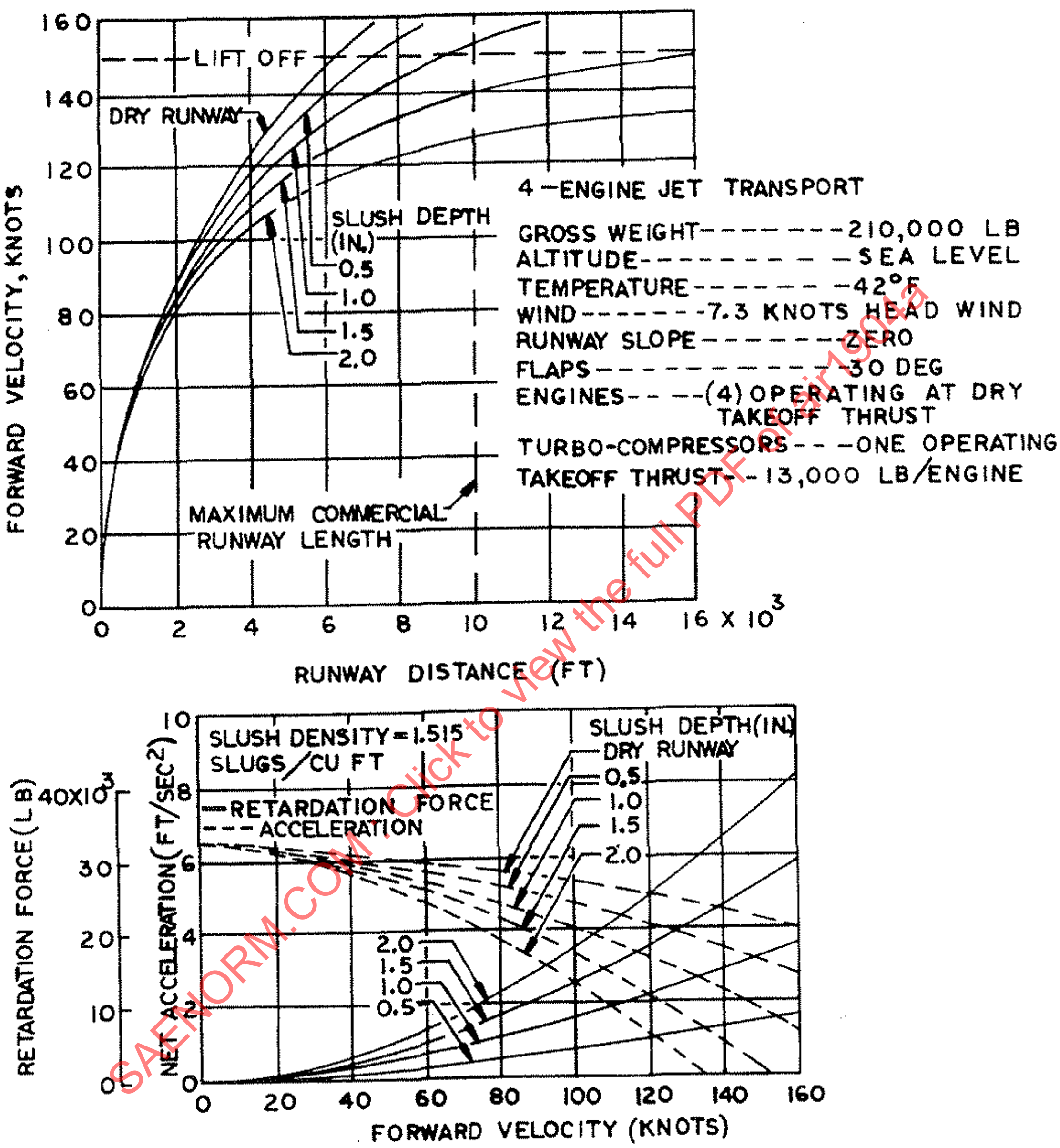
Generally, the slush drag effects on the tires increase parabolically up to the tire hydroplaning speed, and then drop off as the tire rides up on the water or slush during total hydroplaning. While it might seem that total slush drag on the aircraft would lessen at this point, such may not be the case. The amount of impingement drag on the airframe caused by the intense spray that is sent up from the hydroplaning tires may exceed the tire drag, and thus the acceleration of the aircraft could be reduced appreciably at this point. These factors may place a large responsibility on the design of tires and landing gear to be able to deflect water and slush clear of the airframe.

f) Erosion or structural damage to rear mounted (pusher) propellers.

4.2 Spray Geometry:

Current technology to compute spray geometry is not recognized. Research has been started at NASA which may form the basis for such tools. Since spray geometry cannot be determined by analysis it must be demonstrated by test. Preliminary design should consider previously demonstrated aircraft and make allowances for adjustments that may be required from test results.

Design should consider geometry of spray related to:



EFFECT OF SLUSH DEPTH ON THE TAKEOFF DISTANCE REQUIRED FOR A FOUR-ENGINE JET TRANSPORT OPERATING AT 210,000 LBS GROSS WHT WITH 13,000 POUND THRUST ENGINES

(FROM NASA TN D-552)

FIGURE 2

4.2 (Continued):

a) Engine capabilities (compare to engine manufacturer's limits)

1. Tire bow wave (usually predominant at lower speeds)

2. Tire side spray

3. Tire "rooster tails" (usually predominant at higher speeds) (see Figures 3 and 4)

4. Slugs of water or slush. (Concentrated versus evenly dispersed ingested material. Engines are not certified for concentrated ingestion.)

NOTE: Spray geometry is affected by hydroplaning and should be examined at all certified ground operating speeds.

b) Airplane parameters to consider in design.

1. Airplane velocity effect on tire shape (centrifugal forces on tire)

2. Tire pressure

3. Tire wear and tire tread profile design

4. Tire position in relation to other aircraft components, engines, wings, empennage, fuselage, etc.

5. Location of critical ports and mechanisms relative to spray patterns

6. Flight deck visibility effects

7. Aircraft loading variations

c) Water/slush depth to be certified for safe operation.

1. May be greater for some missions than others - requires a variety of devices to cope with all.

2. Based on AC91-6 and FAR 25.1091, FAA will certify water depth for which testing has been shown to be safe for all operating conditions.

3. Also of interest may be Advisory Circular No: 20-XX, title "Water Ingestion Testing", which FAA is preparing but is only in draft form at this writing.

WATER SPRAY TYPES AND PATTERNS

- SIDE OR FIREHOSE SPRAY
  - SPRAYS OUT FROM SIDE OF TIRE
  - DENSE, CONCENTRATED STREAM OF WATER
- BOW WAVE
  - SPRAYS OUT FROM FRONT OF TIRE
  - USUALLY A FINE MIST
  - SPRAY ANGLE DIMINISHED AS HYDROPLANING SPEED IS APPROACHED
  - BOW WAVE DISAPPEARS ABOVE HYDROPLANING SPEED
  - MOST SEVERE AT 60 KTS OR LESS
- ROOSTER TAIL, DUAL WHEELS
  - CAUSED BY IMPINGEMENT OF 2 SIDE SPRAYS ON EACH OTHER FROM TWO CLOSELY SPACED WHEELS
  - DENSE STREAM OF WATER
- α = SPRAY ANGLE AT CRITICAL CONDITION

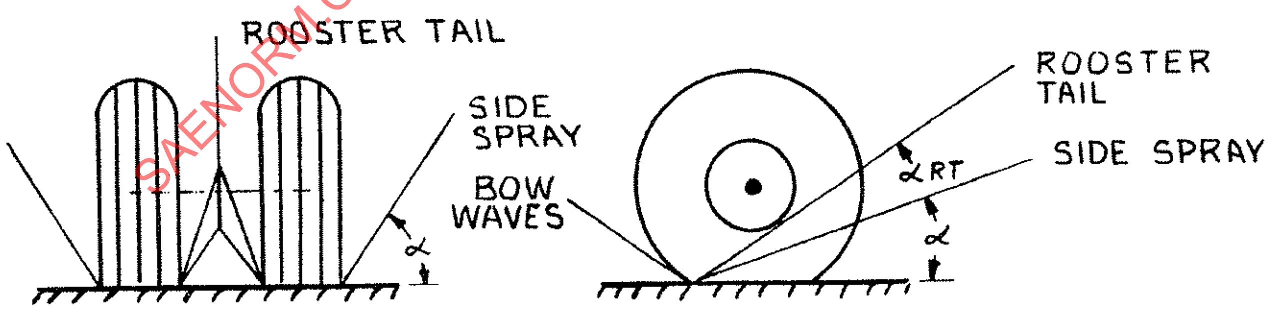


FIGURE 3

- ROOSTER TAIL SINGLE WHEEL
  - CAUSED BY ADHESION OF WATER TO TIRE, AND THROWN OUT OF GROOVES BY CENTRIFUGAL FORCE
  - WIDE SPRAY ANGLE
  - LIGHTER CONSISTENCY
  - GENERALLY HIGHER SPEED RANGES
  - CHARACTERISTICALLY SPLASHES OFF AIRPLANE AND MAY REDIRECT INTO ENGINE
  - α = SPRAY ANGLE AT CRITICAL CONDITION

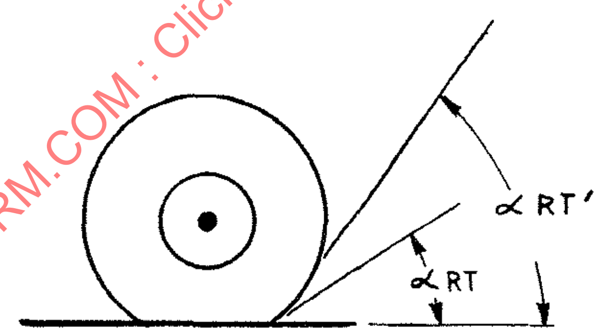


FIGURE 4

4.3 Placement of Spray Suppression Devices:

a) Depends on source, type and severity of spray problems

b) Must maintain reasonably constant relationship to tire/runway interface

c) Must accommodate strut deflections and changing aircraft geometry relationships; such as, wing flaps, spoilers and thrust reversers

d) Must consider aerodynamic effect and stowage space if stowed

1. Consider possible inlet distortion (power plant airflow) impact

2. Assure space in wheel wells for safe gear operation - or other airframe or equipment clearances

4.4 Devices Should Consider:

a) Chine tires:

1. Shape and placement, compatibility with tire technology

2. Effects of centrifugal forces (may change shape of chine)

3. Chine to runway clearance variations due to loading changes (tire deflection affects chine effectiveness)

4. Compatibility with normally expected variations in tire rolling radius due to variations in tire pressure, loads, tread wear, growth and manufacturing tolerances

5. Tire profile definition by airplane manufacturer so that multiple procurement sources may be approvable on the basis of similarity (may control recapping also)

6. Compatibility with recapping procedures

7. Compatibility with maintenance methods

8. Compatibility with tow bars, spotting dollies, and other ground support equipment

9. Specifications for tires may be prepared to control variables and eliminate the need for qualification water testing due to different vendors and/or minor product changes. There is precedent for this procedure.

10. Both single and dual chines may be considered - single chines normally accompany dual wheel assemblies.

4.4 (Continued):

11. Some aircraft may be towed with nose gear torque links disconnected allowing greater than normal turning angles. Chine/deflectors should clear obstructions in such cases.

b) Deflector:

1. Proper shape, size, placement and strength
2. Capability of being retracted (if applicable)
3. Compatibilities with normally expected variations in tire rolling radius due to variations in tire pressure, loads, tread wear, growth, manufacturing tolerances, flat tire (interference with deflector)
4. Reasonable accessibility for jacking, tire changes, etc.
5. Minimum drag
6. Compatible with icing conditions
7. Ease of installation and maintenance

4.5 Consider Operational Compatibility for Either Chine or Deflectors:

a) Any cornering constraints?

b) Effect of runway contact; such as, chine damage effect on tire balance

c) Damage sources

1. Airport equipment overruns
2. Foreign objects
3. Pavement drop-offs and steep ramps
4. Carrier deck hardware; cables, deck grooves, platheads, etc.

d) Positive assurance of inability of a damaged device to jam gear in wheels-up configuration.

e) Consider effect of both grooved and ungrooved runways (if satisfactory on ungrooved runway probably okay on grooved runways). Tests are normally run on ungrooved surfaces.

f) Loss of steering effectiveness due to hydrodynamic lift (if used on steerable gear).

g) Compatible with uplocks, downlocks, and sensitive items around the landing gear.

4.6 Slush Versus Water Deflection:

Testing in specially prepared facilities where ice has been shaved into a test trough to create a thick slurry or slush has been done. The Civil Aviation Authority (British) and Canadian Department of Transport have experience in this area with research and/or certification requirements placed on airframe manufacturers.

Reference to NASA Technical Note D-552 may be useful in regard to slush effects. That study focused on drag and indicates that water and slush have similar effects. Comments from airframe manufacturers indicate that water and slush are dynamically similar and that testing in water will adequately demonstrate performance for an equal depth of slush. It is evident that test conditions in water are more controllable due to the temperature effects on slush and the provisions to shave ice and manufacture slush.

5. QUALIFICATION REQUIREMENTS:

Test procedure must be defined; test data acquisition procedure established. Test data reduced and evaluated (reports, film editing). Test data presented for qualification.

5.1 United States Requirements:

FAA 23.1091(c)(2) Turbine Engine Air Induction Location

FAA 25.1091(d)(2) (Same as above)

FAA 25.1323(d) Airspeed Indicating System - Port Locations

FAA Advisory Circular AC91-6 Basis for 1/2 inch depth most commonly used

"Water, Slush and Snow on the Runway"

Some commercial operators have found a need for operation in fluids deeper than 1/2 inch. Then qualification and safe operation must be provided for up to a maximum operational fluid depth limit recommended.

Current industry effort to standardize water testing is reflecting the following thinking:

Water Depth: Airplanes should be capable of operating on wet runways with areas of standing water without creating adverse engine and APU operating characteristics due to water ingestion. FAA Advisory Circular 91-6A recommends that takeoffs should not be attempted when standing water, slush, or wet snow greater than 1/2 inch in depth covers an appreciable part of the runway.

The following water depth test criteria may become the standard for demonstrating compliance with §§ 23.1091(c)(2) and 25.1091(d)(2):

5.1 (Continued):

(i) Heavy turbojet powered airplanes. Turbojet powered airplanes with maximum gross weights over 75,000 pounds (typically Part 121 operators) generally operate at larger airports with well maintained runways where puddling of water is not normally a problem. One-half inch water depth would be the required test criteria for this class of airplane.

(ii) Light turbojet powered airplanes. Turbojet powered airplanes with maximum gross weights of 75,000 pounds or less (typically Part 91 operators) often operate at smaller airports with runways that are not as well designed and maintained. Puddle depth may vary to a larger degree due to runway unevenness. Three-quarter (3/4) inch water depth may become required test criteria for this class of airplane.

An applicant seeking an airworthiness approval may demonstrate the airplane's capability by testing in standing water of the required depth for his/her class of airplane. Upon a successful demonstration, the airplane would be approved without an operating limitation on runway depths. If the airplane can demonstrate successfully only at some shallower water depth, then the shallower depth would become a limitation on that airplane's operation.

Military requirements may differ from commercial policy depending on aircraft operating role and missions.

5.2 United Kingdom Requirements (and Other Nations Recognizing Joint Airworthiness Regulations (JAR) Codes):

JAR 25.1091 gives requirements for aircraft exceeding 12,500 pounds gross weight. See Advisory Circular - Joint (ACJ) 25.1091(3)(2), Aerodrome Licensing for water shedding (13 mm depth basis). See also Validation Note No. 3, Special Condition 9, "Take off from Precipitation Covered Runways".

6. TEST AIRCRAFT CONFIGURATION AND INSTRUMENTATION:

6.1 The aircraft being tested must be equivalent to the configuration intended for production with consideration given to the following:

6.1.1 The effect of center of gravity location or locations should be explored in preliminary tests - if a critical or most adverse configuration is found, that should be the test configuration. It is advisable then to publish information on the effects in the flight manual.

6.1.2 Tire and shock strut pressure servicing tolerance should be reviewed for significant effect on water trajectory, if any.

6.1.3 Tires representative of those being certified for use must be used in test. Small variations have been found to be significant.

6.1.4 Minimize variables to be tested for economic reasons, i.e., tire pressure and wear effects probably can be eliminated from testing by rationalization or test planning.

6.2 Test Aircraft Instrumentation:

6.2.1 A movie or video camera, on the aircraft and trained on the critical engine inlet, is often used for certification information. During development it may be useful to install a camera at the following locations: 1. Above and outboard of the tire; or looking down at the tire, or looking at the engine from the tire area. 2. Ahead of the wheel looking aft at the tire. 3. On top of the vertical stabilizer, looking forward and down. Spray shapes and paths can then be studied to assist in designing deflection devices.

6.2.2 A wheel speed (RPM) measuring device is useful to observe hydroplaning effects.

6.2.3 A Distance Measuring Unit has been found useful in correlating aircraft position in the test run where powerplant anomalies occur.

6.2.4 When the airplane testing shows that water is entering the engine inlet, powerplant operations parameters, including power variations should be recorded. Records of engine power variations should be compared with engine manufacturer's data to determine whether or not they represent harmful excursions or shorten engine life, provided no other detrimental aircraft performance is experienced.

NOTE: A test track of sufficient length to stabilize power indications has been necessary when water ingestion occurs.

6.2.5 The record of powerplant operations should be compared to responses of the airplane powerplant instruments to determine if those instruments are accurately indicating engine parameters when spray ingestion is occurring.

6.2.6 The use of water-soluble "paint" e.g., a colored cleanser paste, painted onto parts of the aircraft that are washed by the spray, is valuable in determining spray pattern and density. A photo record before and after each test run followed by repainting has been found helpful.

7. TEST SITE REQUIREMENTS:

7.1 A stationary high-speed movie or video camera tape should be used to record the water spray pattern during aircraft passes. This camera can record water being ingested as evidenced by steam being expelled. Care should be exercised in concluding that spray which appears in line with powerplants is actually ingested. Cross-checks with film from the cameras looking at the inlet from different angles may verify that the spray enters or clears the engine inlet.

7.2 Test Trough:

Width of the test trough should be sufficient to assure the aircraft can be kept in the trough during test runs. A very narrow trough could deflect spray giving false information. Wider troughs may aggravate the problem of water depth control measurement. Testing may include the necessity for including both the main and nose gear at one time, in which case the trough should be wide enough to keep both nose and main gears in the water during test runs.

7.2 (Continued):

The trough length should be sufficient to stabilize the spray pattern for all speeds and test conditions. It should be noted that for speeds below 150 knots, a 20-foot long trough has been found adequate in cases where all spray from each individual gear is deflected clear of hazardous contact with the aircraft. Again, the longer trough aggravates water depth control due to wind and possible pavement slopes. Soft flexible cross dams in the trough may be used to help control water depth variation due to slope variations and wind. Recent testing has tended to longer troughs - 100 to 150 feet is common practice in current certification. (FAA indicates a desire for trough lengths that will allow the aircraft to be in the water for approximately one second.) If water ingestion is present a trough length of 400 to 500 feet may be required to allow power plant stabilization at high speeds.

The most common water depth is 1/2 inch. This is due to the practice in reference to the FAA Advisory Circular AC91-6, that allows certification without aircraft operating restriction if testing in 1/2 inch is successful. As indicated earlier, other factors may dictate a greater or lesser water depth. As indicated earlier, other factors may dictate a greater or lesser water depth. Measurement of water depth can be a very difficult element of qualification testing since test surface flatness tolerances of ±.25 inch are not easily located. Runway slope, crowns and wind all affect depth in any specific area. It is suggested that water depth should be stipulated along the path of the tire in test (as determined by trough entry and exit observations) and one foot either side of that line. The depth recorded for test should then be an average along this path. No depth along the path should be less than 1/2 that average. Depth variations of ±0.10 inch have been found to be critical. Water depth control may be a very significant factor in successful testing. Near zero wind conditions are often sought for testing.

NASA has constructed a water test facility at Wallops Island which has been used to some advantage for the ingestion Certification Testing. A runway has been provided with provisions to trap controlled water depths over long distances (500 - 1,000 feet). Arrangements can be made there for technical assistance, recording equipment and runway and service access. This facility has not been satisfactory in all known instances but surely is to be considered as a test site.

8. TEST PROCEDURE:

8.1 Runs Through Trough:

Certification testing involves run through the above described water trough at speeds ranging from 10 knots to a speed beyond the maximum approved $V_{lift\text{-}off}$ (high altitude, hot day). Testing usually is done in speed increments of 10 to 20 knots in order to determine the speed range for any hazardous quantity of water ingested into the engine or other ports and critical areas. In addition to normal airplane attitudes, any special handling techniques likely to be used if likely to be affected by spray, should be tested; such as, the effect of max/min elevator authority, etc.

In cases where the aircraft being tested demonstrates clear margins for deflected spray, the spectrum may be abbreviated.