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STO AGARDograph 300
Flight Test Technique Series – Volume 31

AG-300-V31

Reduced Friction Runway Surface Flight Testing – Wet Runway Taxi Test Procedures at Edwards Air Force Base

(Essais en vol sur une surface de piste à frottement réduit – Procédures d'essai de roulement sur piste détrempée sur la base aérienne d'Edwards)

This AGARDograph has been sponsored by the Systems Concepts and Integration Panel.

Published November 2018

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

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- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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AGARDograph Series 160 & 300

Soon after its founding in 1952, the Advisory Group for Aerospace Research and Development (AGARD) recognized the need for a comprehensive publication on Flight Test Techniques and the associated instrumentation. Under the direction of the Flight Test Panel (later the Flight Vehicle Integration Panel, or FVP) a Flight Test Manual was published in the years 1954 to 1956. This original manual was prepared as four volumes: 1. Performance, 2. Stability and Control, 3. Instrumentation Catalog, and 4. Instrumentation Systems.

As a result of the advances in the field of flight test instrumentation, the Flight Test Instrumentation Group was formed in 1968 to update Volumes 3 and 4 of the Flight Test Manual by publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, it was decided that further specialist monographs should be published covering aspects of Volumes 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group (FTTG) was established to carry out this task and to continue the task of producing volumes in the Flight Test Instrumentation Series. The monographs of this new series (with the exception of AG237 which was separately numbered) are being published as individually numbered volumes in AGARDograph 300. In 1993, the Flight Test Techniques Group was transformed into the Flight Test Editorial Committee (FTEC), thereby better reflecting its actual status within AGARD. Fortunately, the work on volumes could continue without being affected by this change.

An Annex at the end of each volume in both the AGARDograph 160 and AGARDograph 300 series lists the volumes that have been published in the Flight Test Instrumentation Series (AG 160) and the Flight Test Techniques Series (AG 300) plus the volumes that were in preparation at that time.

Reduced Friction Runway Surface Flight Testing – Wet Runway Taxi Test Procedures at Edwards Air Force Base

(STO-AG-300-V31)

Executive Summary

Wet runway brake, anti-skid system and aircraft performance testing on new and in-service aircraft is a common flight test requirement that warrants special considerations during test planning and execution to ensure a valid, repeatable and safe wet runway test surface is prepared and that the test is executed safely and efficiently. To meet these needs, the 412th Test Wing at Edwards Air Force Base (AFB), California, USA uses detailed runway wetting procedures, specially equipped ground vehicles and a runway that was specifically designed for the execution of wet runway taxi tests.

Wet runway taxi tests are executed on a wetted runway test section with a width and length tailored to the aircraft size and expected braking distance. The wet runway test section is typically 25 to 50 feet wide and up to 5,000 feet long. There are dry runway safety recovery zones to both sides and beyond the end of the wet runway test section in case the test pilot experiences an unexpected aircraft response. Wet runway taxi tests are not conducted during or after naturally occurring rain as the dry runway safety recovery zones would not be present and the test conditions would not be as controlled or repeatable.

Two fire department water tenders equipped with unique spray bars are used for runway wetting. Continuous friction measuring equipment is used to measure the runway friction before and after each test point to ensure a suitable test surface is prepared and that the water depth does not exceed 1 mm (0.039 inch).

Successful execution of a wet runway taxi test requires close coordination between the continuous friction measuring equipment operator, the fire department water tender drivers, the test conductor and the test pilot to ensure a wet runway test section is properly established and the aircraft enters the wet runway test section as soon as possible.

This report documents the wet runway taxi test procedures used at Edwards AFB as of the date of publication.

Essais en vol sur une surface de piste à frottement réduit – Procédures d’essai de roulement sur piste détrempée sur la base aérienne d’Edwards

(STO-AG-300-V31)

Synthèse

Les essais de fonctionnement des appareils, des freins et du système antipatinage sur piste détrempée sont une exigence courante pour les aéronefs, qu’ils soient nouveaux ou déjà en service. Cette exigence justifie des considérations particulières pendant la planification et l’exécution des essais, dans le but de garantir la préparation d’une surface d’essai valable, reproductible et sans danger et la réalisation d’essais sécurisés et efficaces. Afin de répondre à ces besoins, la 412th Test Wing de la base aérienne d’Edwards, en Californie (Etats-Unis), applique des procédures détaillées de détrempage des pistes, utilise des véhicules au sol munis de matériel spécial et une piste spécifiquement conçue pour l’exécution d’essais de roulement sur piste détrempée.

Les essais de roulement sur piste détrempée sont réalisés sur un tronçon d’essai dont la largeur et la longueur sont adaptées à la taille de l’avion et à la distance de freinage attendue. Le tronçon de piste de roulement détrempé mesure habituellement entre 25 et 50 pieds de largeur et jusqu’à 5 000 pieds de longueur. Il est entouré de zones de récupération sur piste sèche des deux côtés et au-delà du tronçon détrempé, au cas où le pilote d’essai serait confronté à une réaction inattendue de l’avion. Les essais de roulement sur piste détrempée ne sont pas menés pendant ou après une pluie naturelle, car dans ce cas, les zones de récupération ne seraient pas sèches et les conditions d’essai ne pourraient pas être contrôlées ni reproduites.

Deux fourgons-pompes tonnes des pompiers, équipés de rampes uniques de pulvérisation, servent à détremper la piste. Un équipement de mesure du frottement continu sert à mesurer le frottement de la piste avant et après chaque point d’essai, pour veiller à ce que la surface d’essai soit adaptée et que la couche d’eau ne dépasse pas 1 mm (0,039 pouce) d’épaisseur.

La bonne réalisation d’un essai de roulement sur piste détrempée nécessite une étroite coordination entre l’opérateur de l’équipement de mesure du frottement continu, les chauffeurs des fourgons-pompes tonnes, le responsable de l’essai et le pilote d’essai, afin que le tronçon d’essai sur piste détrempée soit correctement établi et que l’avion y roule dès que possible.

Le présent rapport documente les procédures d’essai de roulement sur piste détrempée qui sont utilisées à la base aérienne d’Edwards à la date de publication.

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List of Acronyms and Symbols

AC	Advisory Circular
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AGARD	Advisory Group for Aerospace Research and Development
a.m.	antemeridian – before noon
CFME	Continuous Friction Measuring Equipment
cm	centimeters
ETL	Engineering Technical Letter
F	Fahrenheit
FAA	Federal Aviation Administration
Hz	Hertz
LH	Left Hand
mA	milliampere
MLG	Main Landing Gear
mm	millimeter
MPH	Miles Per Hour
Mu	Coefficient of Friction
NATO	North Atlantic Treaty Organization
NLG	Nose Landing Gear
psi	pounds per square inch
RCR	Runway Condition Reading
RH	Right Hand
RPM	Revolutions Per Minute
RTO	Research and Technology Organisation
THA	Test Hazard Analysis
TIH	Technical Information Handbook
UFC	Unified Facilities Criteria
UHF	Ultra High Frequency
USA	United States of America
USAF	United States Air Force
VHF	Very High Frequency
Vmcg	minimum control speed on the ground

Symbols

$\leq$	equal to or less than
$\geq$	equal to or more than
$<$	less than

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REDUCED FRICTION RUNWAY SURFACE FLIGHT TESTING – WET RUNWAY TAXI TEST PROCEDURES AT EDWARDS AIR FORCE BASE

1.0 INTRODUCTION

Wet runway brake, anti-skid system and aircraft performance testing on new and in-service aircraft is a common flight test requirement that warrants special considerations during test planning and execution to ensure a valid, repeatable and safe wet runway test surface is prepared and that the test is executed safely and efficiently. To meet these needs, the 412th Test Wing at Edwards Air Force Base (AFB), California, USA uses detailed runway wetting procedures, specially equipped ground vehicles and a runway that was specifically designed for the execution of wet runway taxi tests. This report documents the wet runway taxi test procedures used at Edwards AFB as of the date of this publication.

Although a limited number of dry runway taxi test points are performed prior to the first flight of a new aircraft, the majority of the taxi tests are executed later in the test program when aircraft performance characteristics are better understood. These later taxi test programs typically include numerous wet runway taxi test points.

Wet runway taxi tests on in-service aircraft are commonly performed to test new design brakes, wheels, tires and/or anti-skid systems due to in-service deficiencies, parts obsolescence, cost reduction efforts or increases in aircraft gross weights.

Wet runway taxi testing at Edwards AFB is executed on a wetted runway test section with a width and length tailored to the aircraft size and expected braking distance. There are dry runway safety recovery zones to both sides and beyond the end of the wet runway test section in case the test pilot experiences an unexpected aircraft response such as a loss or reduction in lateral control, adverse landing gear oscillations or deficient antiskid performance. Wet runway taxi testing at Edwards AFB is not conducted during or after naturally occurring rain as the dry runway safety recovery zones would not be present and the test conditions would not be as controlled or repeatable.

Although Edwards AFB is in the Mojave Desert, it has been the site of many successful wet runway taxi test efforts. For example, from 2013 to 2016, more than 110 wet runway taxi test points were successfully executed on new and in-service aircraft. This merging of a dry desert environment and an outstanding wet runway taxi test capability is due to the unusually flat, wide and long runway (04R/22L) and more than 50 years of experience in wet runway taxi test execution. Runway 04R/22L was specifically designed to support wet runway testing with a reduced transverse grade (lateral slope) and no runway grooves. Whereas a typical runway is designed to shed water, runway 04R/22L was designed to retain enough water to allow for safe and efficient wet runway taxi test point execution. A description of runway 04R/22L is in Annex A.

More information on wet and dry runway taxi test procedures can be found in RTO AGARDograph 300, Flight Test Techniques Series – Volume 14, Introduction to Flight Test Engineering, Chapters 9, 13 and 17 [1]; and AFFTC-TIH-81-1, Aircraft Brake Systems Testing Handbook [2]; which is available at http://www.dtic.mil/dtic/tr/fulltext/u2/a101516.pdf.

2.0 WET RUNWAY TAXI TEST OVERVIEW

Wet runway taxi test methodology closely mirrors that used for dry runway taxi tests with the additional considerations discussed in this report. Wet runway taxi test points are normally limited to the Normal or Low Caution brake energy operating zones where wheel thermal fuse plug release and thermal damage to the brakes, wheels, tires and/or axles is not likely to occur. Dry runway taxi tests typically include test points in the Danger brake energy operating zone where thermal damage is likely to occur.

Wet and dry runway taxi tests usually have similar test objectives, evaluation criteria and instrumentation requirements. Typical test objectives and evaluation criteria are shown in Table 1. Typical test instrumentation requirements are provided in Annex B.

Table 1: Typical Wet Runway Taxi Test Objectives and Evaluation Criteria.

Test Objective	Evaluation Criteria
Evaluate aircraft performance under wet runway conditions	Stopping Distance
	Aircraft Stability
	Pilot Qualitative Assessment
Evaluate anti-skid performance under wet runway conditions	Anti-skid Efficiency
	Anti-skid Response
	Landing Gear Loads
	Landing Gear Dynamic Stability
	Pilot Qualitative Assessment
Evaluate brake performance under wet runway conditions	Brake Response
	Brake Dynamic Stability
	Brake Reliability
	Brake Temperature

The beginning and end of the wet runway test section are designated in terms of the runway length remaining markers (boards). For example, a 3,000-foot long wet runway test section could be defined as from the 12 to 9 boards. To minimize the possibility for confusion, the ends of the wet runway test section are usually marked by high visibility markers such as orange traffic cones or other approved devices on the side of the runway. The wetted runway test section is easily seen by the pilot due to the difference in runway surface color and sheen.

The wet runway test section is typically 25 to 50 feet wide and up to 5,000 feet long. The water depth at time of aircraft entry into the test zone is approximately $\leq$ 1 mm (0.039 inch). The required wet runway test section widths and lengths are specified in the test plan which typically includes the length of the runway zones listed in Table 2.

Table 2: Wet Runway Taxi Test Zones.

Runway Zone	**Runway Condition**	**Purpose**
Accelerating Zone	Dry	The pilot accelerates to the throttle chop speed and retards the throttle(s).
Coasting Zone	Dry or Wet	Thrust decays and aircraft decelerates into wet runway test section.
Wet Runway Braking Zone	Wet	Pilot applies brakes as directed in the test plan – Predicted wet runway deceleration rate is used to determine zone length.
Dry Runway Braking Zone	Dry	Safety stopping zone beyond wet runway test section – Predicted moderate braking deceleration rate is used to determine zone length.
Runway Remaining Zone	Dry	Safety zone of at least 2,500 feet beyond the dry runway braking zone.

An illustration of a sample wet taxi test runway setup plan with zone lengths and placements is shown in Figure 1. Taxi test zones and figures such as Figure 1 help optimize placement of video cameras and ground test support vehicles and assists in test safety planning.

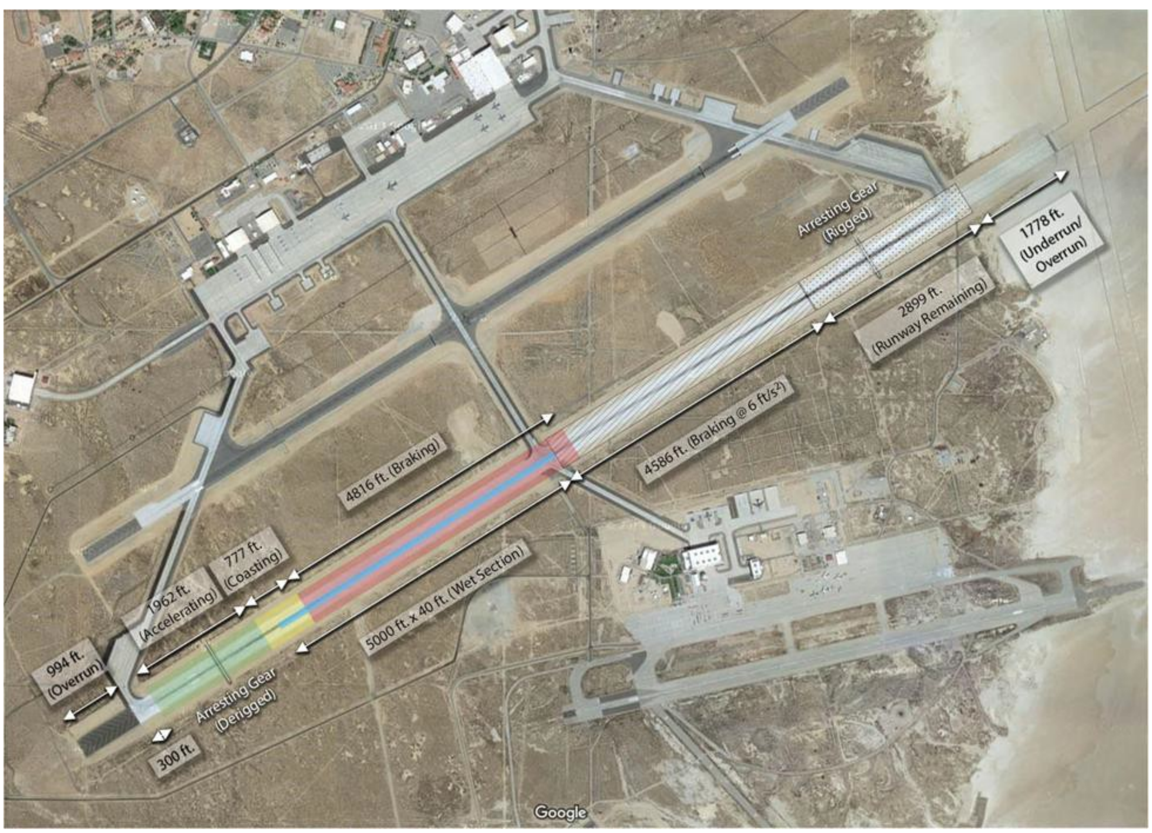


Figure 1: Sample Wet Runway Taxi Test Zones.

High speed video is normally taken from two or more locations along the wet runway test section to record tire skid indications and landing gear dynamics such as gear walk. A 2 to 6 inch (5 to 15 cm) wide witness mark is typically painted on the tire and wheel as shown in Figure 2 to provide a visual benchmark during video review. The witness mark normally extends onto the wheel to document any tire slip on the wheel.

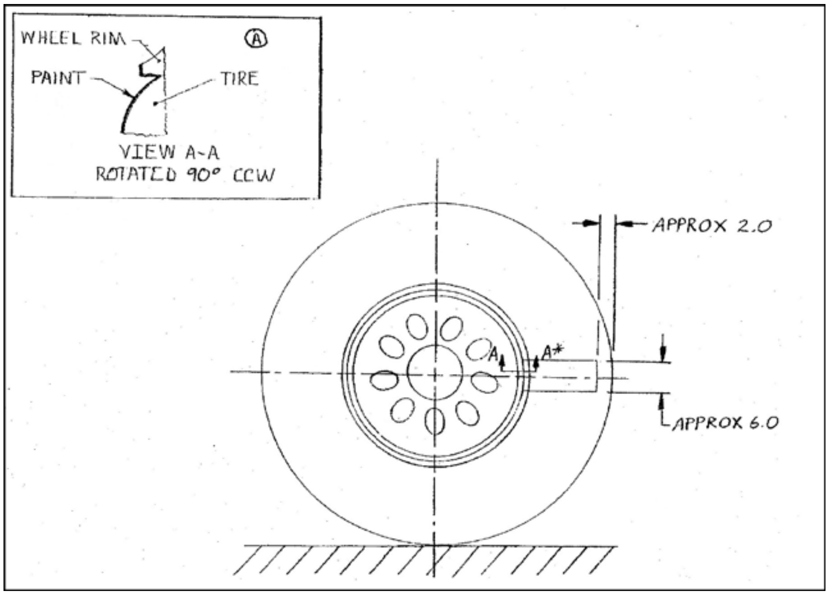


Figure 2: Typical Tire Witness Mark.

3.0 WET RUNWAY TAXI TEST PROCEDURES

Before taxiing onto the runway, the aircraft tire and brake temperatures are measured and compared to limits in the test plan and/or safety package to help ensure that post-test tire and brake temperatures will be within predictions. The intent of these predictions is to help determine if the aircraft is safe to taxi and if it is safe for the ground crew to approach after the test point is completed. The increase in tire and brake temperatures due to the kinetic energy absorbed during the stop is typically predicted using dynamometer and modelling data provided by the brake or antiskid manufacturer and/or the aircraft flight manual brake energy charts.

If the pre-test tire or braking cooling time is expected to be longer than the test team can tolerate, for example due to aircraft weight reduction because of fuel burn or due to runway access time restrictions, then the aircraft can be towed to end of the runway hammerhead for engine start and pre-flight checks.

The aircraft is then taxied onto the runway and the runway wetting team assumes their positions at both ends of the planned wet runway test section. After the pilot and all test team members are ready for test point execution, the runway is wetted using two specially configured fire department water tenders and the procedures described in this report.

Continuous Friction Measuring Equipment (CFME) is used to measure the runway friction in terms of Runway Condition Reading (RCR) immediately after the wetting procedure is complete. The CFME provides a continuous graphic record of the pavement surface friction characteristics and is operated in accordance with

FAA Advisory Circular (AC) number 150/5320-12C Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces [3] and the CFME manufacturer's operator's manual.

The RCR is a non-dimensional number that is used in USAF flight manuals to predict aircraft stopping distances. For the CFME used at Edwards AFB (a MK6 Mu-Meter) the RCR is equal to the coefficient of friction (Mu) multiplied by 32.2 and rounded up. It is important to note that the Mu measured by CFME is not the same as the Mu that will be experienced by the aircraft as the CFME tires are significantly different than aircraft tires. The RCR measurements are used to ensure the wet runway test section is suitable for test point execution. Runway 04R/22L has a wet runway RCR of 12 to 23 depending on the water depth and a dry runway RCR of 24 to 26 depending on measurement location.

If the wet runway test section RCR is within the allowable minimum and maximum limits, then all ground vehicles quickly exit the runway and the test conductor clears the pilot to immediately execute the test point. If the RCR is too low, then the test is delayed for 2 to 4 minutes while the RCR rechecked to allow excess water to dissipate. If the RCR is too high, then the test is delayed for approximately 20 to 30 minutes to allow more water to be sprayed onto the test section and the RCR is rechecked.

The pilot then advances the throttle(s), accelerates to the throttle chop speed and retards the throttle as specified in the test plan. The wet runway test section is normally positioned so that the aircraft will be decelerating from approximately 5 to 10 knots above the brake application speed as the aircraft enters the wetted area. The deceleration rate will slightly increase after the aircraft has entered the wet runway test section due to the water contaminant drag.

The pilot applies the brakes, control surfaces and speed brakes after the aircraft enters the wet runway test section at the ground speed specified in the test plan. The brake application speed is typically in knots ground speed to better control the brake kinetic energies and the post-test brake, tire and wheel temperatures.

After the aircraft comes to a complete stop, data are reviewed in a mission control room to ensure the aircraft is safe to taxi and then the aircraft is cleared to taxi off the runway. The pilot parks the aircraft in accordance with the test plan procedure and records observations on a pilot questionnaire as shown in Annex C.

The CFME measures the RCR after the aircraft clears the wet runway test section so the approximate RCR at the time of test can be determined. The rate of RCR change with time is assumed constant between the pre-test RCR measurement and the post-test RCR measurement. This relationship is considered valid if the time interval between the two measurements is less than 15 minutes. A sample of the pre-test and post-test runway friction measurements is shown in Annex D.

4.0 TEST SAFETY CONSIDERATIONS

Safety planning for wet runway taxi tests typically use the same minimizing procedures for dry runway taxi tests except for additional considerations for possible directional control instabilities and extended stopping distances. The pilot is usually briefed to release the brake pedals if the aircraft approaches the sides of the wet runway test section or experiences an unacceptable yaw or drift. Should such an event occur, the aircraft is allowed to exit the side or end of the wet runway test section with brakes released and then normal to light braking is used to stop the aircraft on the dry runway safety recovery area.

A nuance of the wet runway environment is that typically the rear brakes on a multi-wheel aircraft such as a larger cargo aircraft will get hotter than the front brakes. This is opposite of what is expected during dry runway taxi tests. During a wet runway taxi test, the leading tire of a multi-wheel aircraft tends to clear the water out of the way for the following tires. The drier runway surface experienced by the following tires provides a higher RCR and thus allows a higher brake pressure to be provided by the anti-skid system before a skid occurs. This results in more kinetic energy being absorbed by the rear brakes and thus hotter rear brakes.

During a dry runway taxi test, the aircraft tends to pitch nose down while brakes are applied. This increases the normal load on the leading tires of a multi-wheel aircraft and results in more kinetic energy being absorbed by the front brakes and thus higher front brake temperatures.

During a wet runway taxi test, the nose does not pitch down as much because of the lower aircraft deceleration. The reduced pitch down moment may result in lower front brake temperatures during wet runway taxi tests compared to those experienced during dry runway taxi tests.

4.1 Test Hazard Analysis and Risk Minimizing Procedures

Typical test hazard analysis forms for wet runway taxi tests are provided in Annex E. Typical general minimizing procedures are provided below:

a) All testing will be completed in daytime visual meteorological conditions.
b) Ground personnel will be briefed on emergency ground procedures and all non-test essential personnel will be 200 feet from the edge of the runway during testing.
c) When external fuel tanks are used, they will be filled with water and blocked in such a manner as to provide isolation from the aircraft fuel system.
d) There will be no natural wetting (rain) for any test point.
e) Tests will not be conducted at air temperatures below 37 degrees Fahrenheit (F) (3 degrees Celsius) to prevent runway icing.
f) Wind limits are 5-knot crosswind, 10-knot tailwind and a 10-knot headwind.
g) Tire pressure and wear will be measured at the beginning of each test day to verify compliance with technical order limits.

5.0 WET RUNWAY TEST SECTION DESCRIPTION

Wet runway taxi testing requires that the water be sprayed in a controlled manner to produce a valid, repeatable and safe wet runway condition similar to that which could be expected during fleet operations. The wet runway test section should be the minimum width and length required to support test execution. A narrow, shorter wet runway test section provides a more stable and longer-lasting test section than a wider, longer wet runway test section and provides the maximum size dry runway safety recovery zones.

The wet runway test section is typically on the runway centerline but may be offset as required to satisfy the test requirements, for example to accommodate expected aircraft lateral drift during wet runway one engine off takeoff or wet runway minimum control speed on the ground (Vmcg) testing.

Because of water runoff and water spray effects, the actual wetted runway area will be approximately 5 to 10 feet wider than the planned test section width. For example, a 50 feet wide wet runway test section will actually be approximately 55 to 60 feet wide. The 50 feet wide test section will be thoroughly wetted and have an RCR ≤ 17. Narrow runway areas on both sides of the 50 feet wide test section will be partially wetted and have an RCR ≥ 18.

Wet runway test section preparation can be challenging due to the normally dry and windy Mojave Desert environment and the associated fast water absorption and evaporation rates; therefore, these tests are normally executed in the morning when winds are low and the runway is cool. Testing normally begins at dawn and continues until approximately 10:00 a.m. during the hotter months, but can be performed all day during the cooler months. Normally two to three wet runway taxi test points can be executed before 10:00 a.m. Recent test efforts during cooler months have executed from up to 7 wet runway taxi test points per test day.

The test team has approximately 5 to 7 minutes to prepare the runway and get the aircraft into the wet runway test section. The limited amount of time available to establish a wet runway test section and execute a wet runway taxi test is due to the increase in RCR with time after the runway wetting is complete.

Successful execution of a wet runway taxi test requires close coordination between the CFME operator, the fire department tender drivers, the test conductor and the test pilot to ensure a wet runway test section is properly established and the aircraft enters the wet runway test section as soon as possible. The CFME operator is a critical member of the test team and is responsible for ensuring an adequate wet runway test section is properly prepared and documented.

The maximum allowable wind limit for wet runway test section preparation is 10 knots in any direction due to the adverse effects of winds on the water spray pattern and water retention on the runway. On days with very a high ambient air temperature and high runway temperature, winds above 7 knots may result in an unsatisfactory wet runway test section.

The minimum allowable air temperature for wet runway test section preparation is 37 degrees F. Lower temperatures may result in water freezing which could adversely affect test results and test safety.

6.0 RUNWAY FRICTION MEASUREMENT AND WATER DEPTH CONTROL

The CFME used at Edwards AFB to measure RCR is a Douglas Equipment brand MK6 Mu-Meter pulled by a 4-door pickup truck equipped with a UHF/VHF radio for communication with the test team and control tower. Figure 3 shows a Mu-Meter and the tow vehicle in a wet runway test section. Additional CFME approved for runway friction measurement can be found in Ref. [3] and HQ AFCESA/CESC, Engineering Technical Letter (ETL) 04-10 (Change 1): Determining the Need for Runway Rubber Removal [4].

Figure 3: Mu-Meter and Tow Vehicle.

For consistency in wet runway test point execution and test result reporting, Edwards AFB has used a Mu-Meter since 1970. This consistency is considered important for USAF purposes because there is no defined runway friction standard and the other commercially available CFMEs measure and report runway friction in different ways and provide different Mu and RCR results.

The original CFME was an Mk1 Mu-Meter which has been incrementally replaced by two Mk6 systems. Two Mu-Meters allow for rapid replacement during test execution if required for tire wear or unexpected system failures and allows for simultaneous testing at Edwards AFB and a deployed location.

The Mu-Meter has two friction measuring wheels that are mounted on separate trailer arms as shown in Figure 4. The friction measuring wheels are angled 7.5 degrees out from the longitudinal axis and the left trailer arm is free to pivot on its leading edge. The trailer arms spread out when the Mu-Meter is in motion and the load cell between the trailer arms measured the resulting side load. The side load is used by the on-board computer to determine the Mu and RCR. The higher the runway friction, the more the trailer arms spread out and the higher the resulting side load. More information on the Mu-Meter is available on the manufacturer's website.

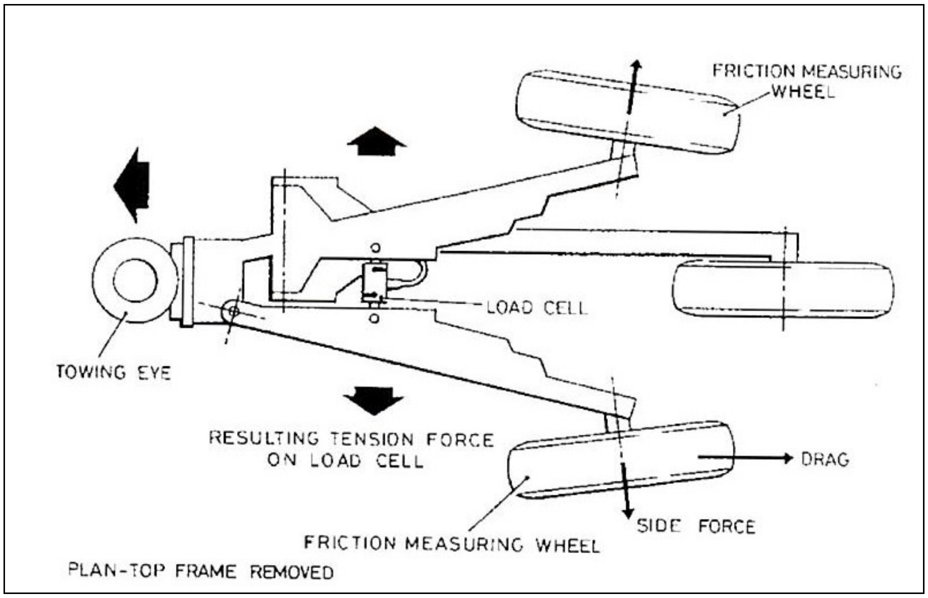


Figure 4: Mu-Meter Overview.

The target RCR for wet runway taxi tests is RCR 15 with a maximum of RCR 17. Empirical data from 1970 to the present shows that an RCR < 17 should result in an anti-skid system response indicative of wet runway operations. An RCR > 18 would require post-test data analysis to verify that the anti-skid system response was indicative of the response expected on a wet runway surface and if the test results satisfy the test success criteria.

A water depth at time of aircraft entry into the test zone of approximately < 1 mm (0.039 inch) is used because this is the standard depth used for friction surveys of runway rubber build-up in accordance with Ref. [3] and Ref. [4]. The water depth was confirmed during development of the runway wetting procedures and is indirectly verified during execution of each wet runway taxi test point.

The Mu-Meter indirectly verifies the water depth is < 1 mm (0.039 inch) due to the effect that water deeper than 1 mm has on this type of CFME. The Mu-Meter was designed to operate with a maximum water depth of 1 mm. Water depths greater than 1 mm imparts a contaminant drag on the friction measuring wheels which prevents the trailing arms from properly spreading out and thus a lower than actual Mu and RCR is measured. It is unknown if any of the other commercially available CFMEs exhibit this phenomenon.

Because runway 04R/22L is relatively new (built in 2006) and is well maintained, it is not possible to get a true RCR < 13 in areas of the runway that do not have a significant amount of rubber build-up. Since most taxi tests are done outside of the rubber build-up areas, an RCR < 13 is a clear indication that the water depth is greater than 1 mm.

If an RCR < 13 is measured, then the Mu-Meter operator immediately executes another friction measuring run of at least half of the wet runway test section to ensure the RCR is > 14 prior to test execution. The RCR will increase between the Mu-Meter measurements as the excess water dissipates and will continue to increase as the aircraft executes the test point. An RCR > 14 prior to test execution is adequate to ensure an RCR > 15 is achieved at the time the test aircraft enters the wetted runway test section.

7.0 WATER SPRAY VEHICLES

Two modified Fire Department water tenders with a capacity of 4,800 gallons are used for runway wetting. The water pumps are driven by a power takeoff shaft on the engine and thus the water spray is influenced by engine rotations per minute (rpm) and vehicle speed. All wet runway test section wetting is done at approximately 1,800 rpm and 16 Miles Per Hour (MPH).

One tender is referred to as the "water-only tender" as it is used without a water additive. The other tender is referred to as the "foam-tender" as it is typically used with water and a diluted firefighter training foam agent. Both tenders have a spray bar with four spray heads each as shown Figure 5. The two inner spray heads have staggered heights to eliminate water spray interference due to spray overlap.

Figure 5: Spray Bar with Spray Heads Circled.

The spray bars were specifically designed to provide the flow rate and spray widths required for the preparation of a wet runway test surface. MEGA Corp, 3-inch spray heads, part number 300198 are used due to their high pressure rating and ability to adjust the spray width and thickness. Because the tenders were designed to support firefighting efforts, the water pumps have a much higher flow rate and pressure than those mounted on water trucks typically used for dust control in construction zones. The spray bars were thus designed to accommodate very high water pressures with a primary consideration being a high back pressure due to all spray heads being inadvertently in the closed position when the pump was operating.

The spray heads are marked to allow for quick adjustment of the spray angle centerline which is measured from the spray bar lateral axis, i.e., perpendicular to the length of the spray bar. Figure 6 shows an example of a 30-foot wide spray pattern with the outer spray heads set at 45 degrees and the inner spray heads are set at 90 degrees.

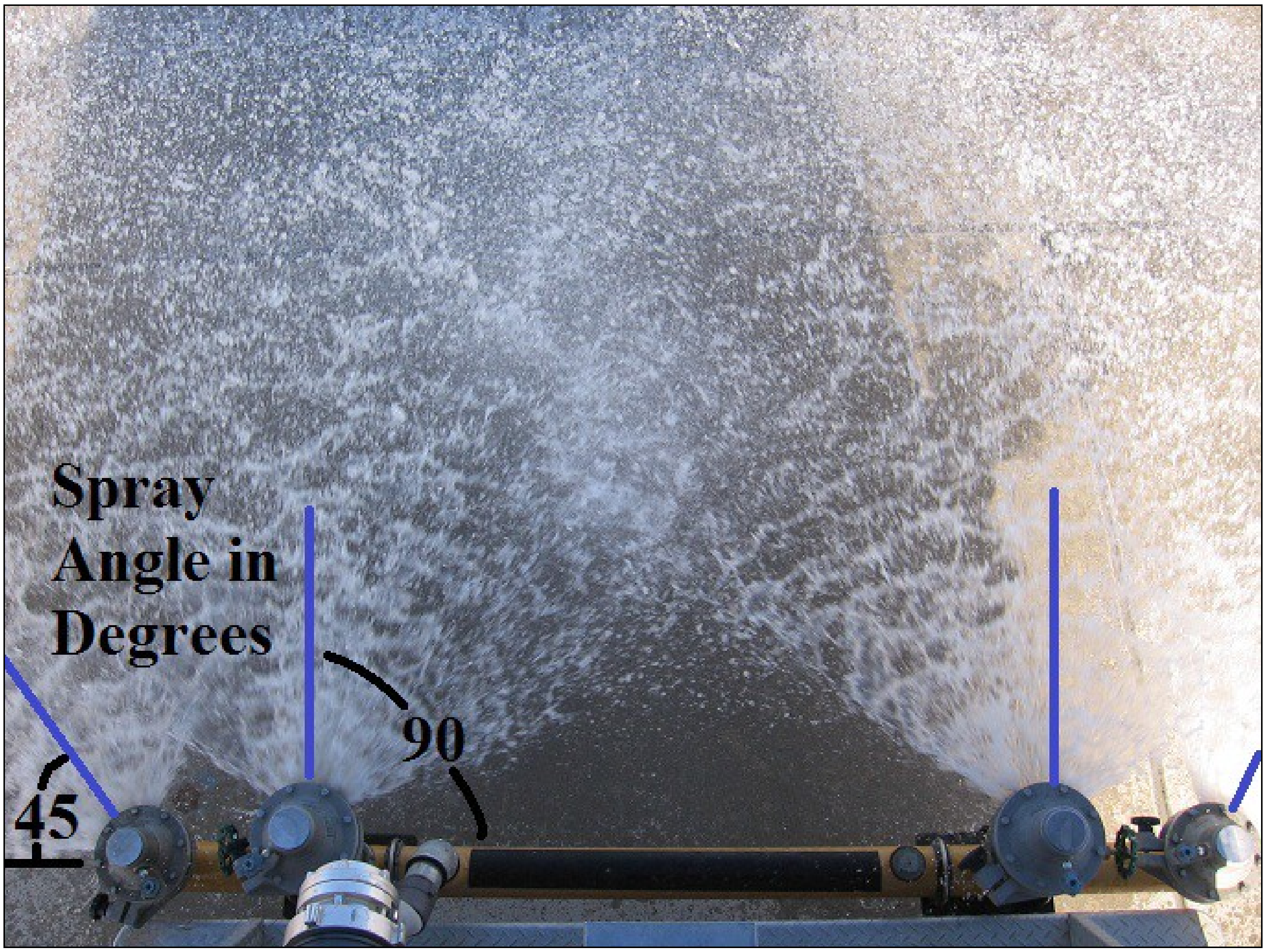


Figure 6: Spray Nozzle Settings for 30-Foot Wide Spray Pattern.

The outer spray heads use a 30 degree tilt fitting as shown in Figure 7 to achieve the maximum spray width of 50 to 60 feet.

Figure 7: Outer Spray Head 30-Degree Tilt Fitting.

The spray heads are adjustable for spray width. The spray heads are aligned in accordance with the settings in Table 3 to achieve the noted test section width. The test section width may not be achieved during the first wetting pass of the water-only tender but will be achieved after all wetting passes are complete. The Mu-Meter operator ensures the spray heads are properly aligned at the beginning of each test day and for each test point.

Table 3: Spray Head Alignment.

Test Section Width (feet)	Outer Spray Head Adjustment Angle (degrees)	Outer Spray Head 30 Degree Tilt Fitting	Inner Spray Head Adjustment Angle (degrees)	Inner Spray Head Width
25	90	Not Installed	90	Full Open
30	45			
35	30			
50	30	Installed		
60	30			Choked 3/4 inch for Pre-Wetting. Full Open for Final Wetting

8.0 FIREFIGHTING TRAINING FOAM

Firefighter training foam significantly improves the quality of the wet runway test section by reducing water evaporation and runoff. The low concentration of training foam used does not reduce the runway Mu and RCR, it only reduces the rate of change of RCR with time which increases the time available for test point execution.

Firefighting protein foam was used for wet runway taxi tests at Edwards AFB from 1970 until 2010. Since 2010 training foam has been used for wet runway taxi tests because protein foam is no longer in regular production and is difficult and expensive to procure.

The training foam is usually used to train firefighters on the use of foaming nozzles and the associated mixing equipment. For normal firefighter training, concentrated training foam is injected into a foaming nozzle which generates a thick blanket of foam. The training foam does not contain persistence agents and thus disperses much quicker than normal firefighting foam and allows for multiple firefighter training events. The training foam is non-toxic, environmentally friendly, leaves no residue and does not require a post-test runway rinse.

Because the runway wetting procedure uses a very diluted training foam to water mixture of approximately 0.006 gallons of training foam per gallon of water [27.5 gallons of training foam (1/2 of one 55-gallon drum) for every 4,800 gallons of water] and does not use foaming nozzles or mixing equipment, the amount of foam produced is negligible as seen in Figure 8.

Figure 8: Water and Training Foam on Runway.

The training foam is not used on runway areas with rubber build-up covering 75 percent or more of the wet runway test section. The rubber build-up usually provides an adequate wet runway RCR and water retention properties without the use of training foam. Under heavy rubber build up conditions it is possible that the RCR could be unacceptably lowered due to the use of training foam. This is a minor concern at Edwards AFB as most wet runway taxi tests are not conducted in the heavy rubber build-up areas. Those areas (the normal aircraft touchdown area of the runway) are normally part of the Accelerating and Coasting zones previously noted in Table 2 and Figure 1.

The training foam is sensitive to agitation (just like bubble bath) so vehicle transits in the wet runway test section are minimized. Because a pile of foam may be created if the training foam is discharged while the tender is not moving, the driver is advised to keep the tender in motion during post-test emptying of the tank. This post-test tank emptying is not done near the runway as any inadvertently produced blowing foam may present a pilot distraction.

9.0 RUNWAY WETTING PROCEDURES

At the beginning of each test day, the Mu-Meter operator ensures the Mu-Meter laptop time is synchronized with local or mission time and obtains a fire department handheld radio to communicate with the water tender operators. The Mu-Meter operator and water tender operators meet to discuss the wetting procedures and agree on which side of the tenders the Mu-Meter vehicle will pass after completing a Mu-Meter run to minimize the risk of vehicle collision.

Runway wetting involves a possible pre-wetting by the water-only tender, a final wetting by both the water-only and foam-tenders, and a Mu-Meter data run to measure RCR. After the completion of the taxi test another Mu-Meter data run is performed to determine the RCR at time of aircraft enters the wet runway test section.

9.1 Runway Pre-Wetting

Pre-wetting by the water-only tender is recommended when the ambient air temperature is at or above 90 degrees F and required when wetting a 60 feet wide wet runway test section.

A typical setup for runway pre-wetting is shown in Figure 9. The water-only tender and Mu-Meter are positioned at either end of the test section. The test aircraft is usually not on the runway. The pre-wetting is scheduled to begin approximately 30 minutes before test execution to allow time for refilling of the water-only tender. The pre-wetting is intended to saturate and cool the runway surface.

When directed by the test conductor, the water-only tender begins pre-wetting the test section as shown in Figure 10. The Mu-Meter operator records the pre-wetting start time. The Mu-Meter operator follows the water-only tender to ensure the spray heads are working properly, the tender speed is approximately 16 to 18 MPH, the wet runway test section is properly located longitudinally on the runway, and that cross wind effects are accommodated by lateral displacement of the water tender.

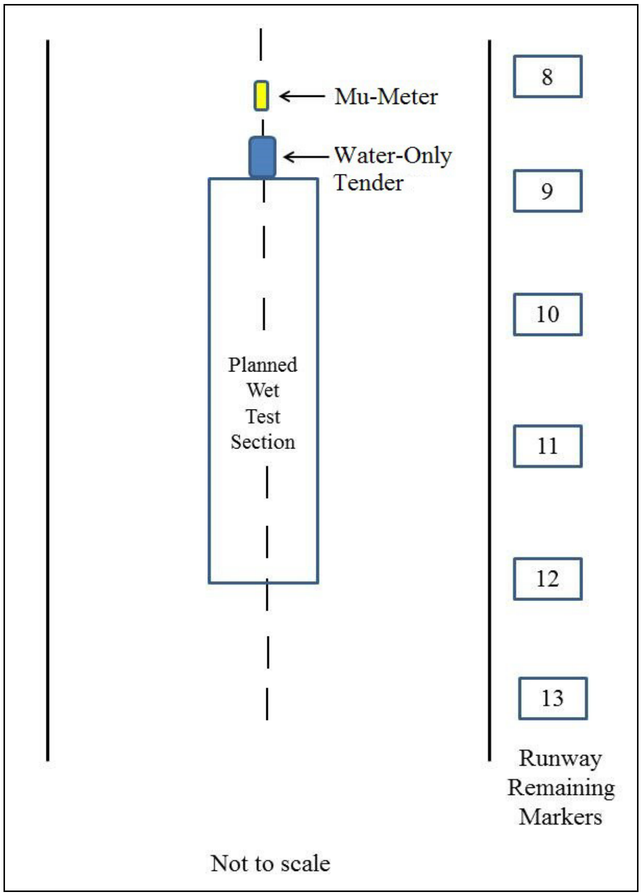


Figure 9: Pre-Wetting Vehicle Positions.

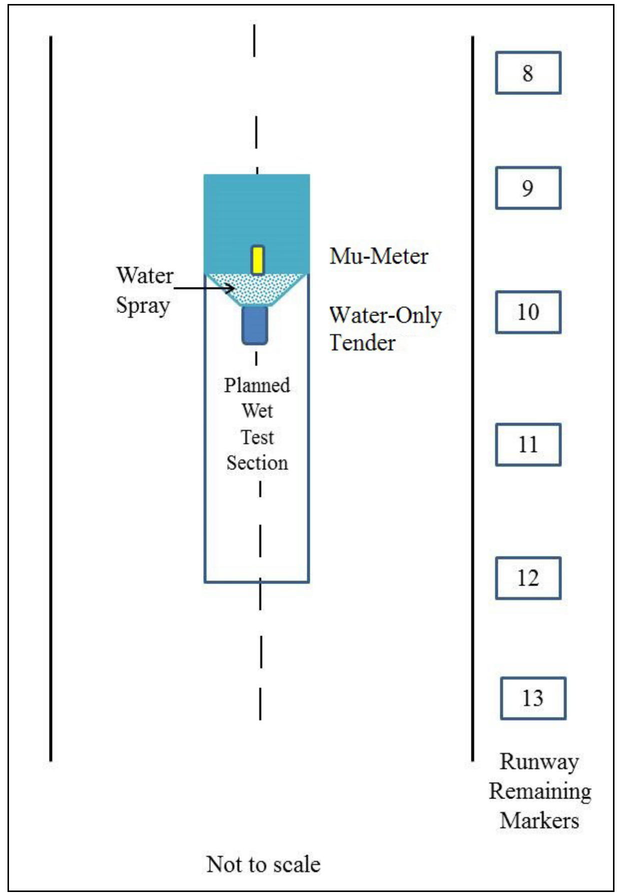


Figure 10: Runway Pre-Wetting.

The Mu-Meter operator provides direction to the water-only tender operator using pre-arranged radio calls to adjust the tender speed and runway lateral placement. Crosswinds may require that the water-only tender be slightly off centerline to compensate for cross wind effects. The Mu-Meter does record RCR data during the pre-wetting.

At the conclusion of the pre-wetting the water-only tender refills as quickly as possible and returns to the designated taxiway staging area.

9.2 Runway Final Wetting

Prior to the final wetting of the test section, the test team must be ready to execute the test. The test aircraft must be on the runway and ready for immediate acceleration into the wet runway test section. All last-minute checks are complete and chocks removed if allowed by the safety plan. The intent is to have the aircraft accelerate into the test section as soon as possible after all ground vehicles are off the runway.

A typical test setup is shown in Figure 11. The water-only tender and Mu-Meter operator are positioned at the far end of the test section facing the test aircraft. The foam-tender is positioned at the beginning of the wet runway test section facing away from the test aircraft. The positions of the tenders and Mu-Meter operator and their direction of travel may be reversed to expedite exiting the runway at a mid-field taxiway if required.

The water-only tender will use all of its water supply when performing the two wetting passes required to establish a 5,000 foot long test section. Accordingly, it is important that water-only tender driver conserves water during preparation, starting and execution of the wetting process.

When directed by the test conductor, the water-only tender begins wetting the test section as shown in Figure 12. The Mu-Meter operator records the runway first wetting start time. The Mu-Meter operator briefly follows the water-only tender to ensure the spray heads are working properly, the tender speed is approximately 16 to 18 MPH, the wet runway test section is properly located longitudinally on the runway, and that cross-wind effects are accommodated by lateral displacement of the water tender. Crosswinds may require that the water-only tender be slightly off centerline to compensate for cross wind effects.

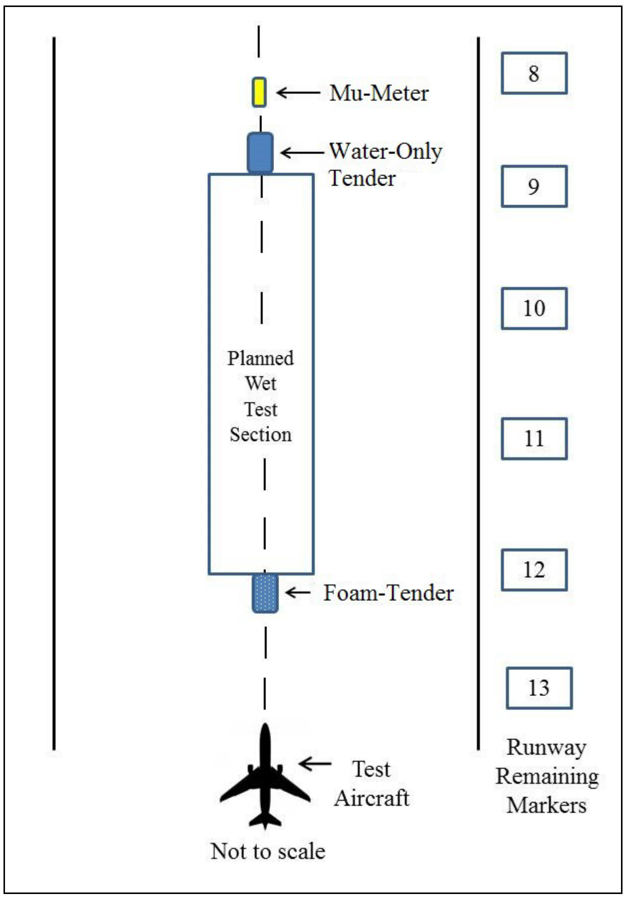


Figure 11: Pre-Test Vehicle Positions.

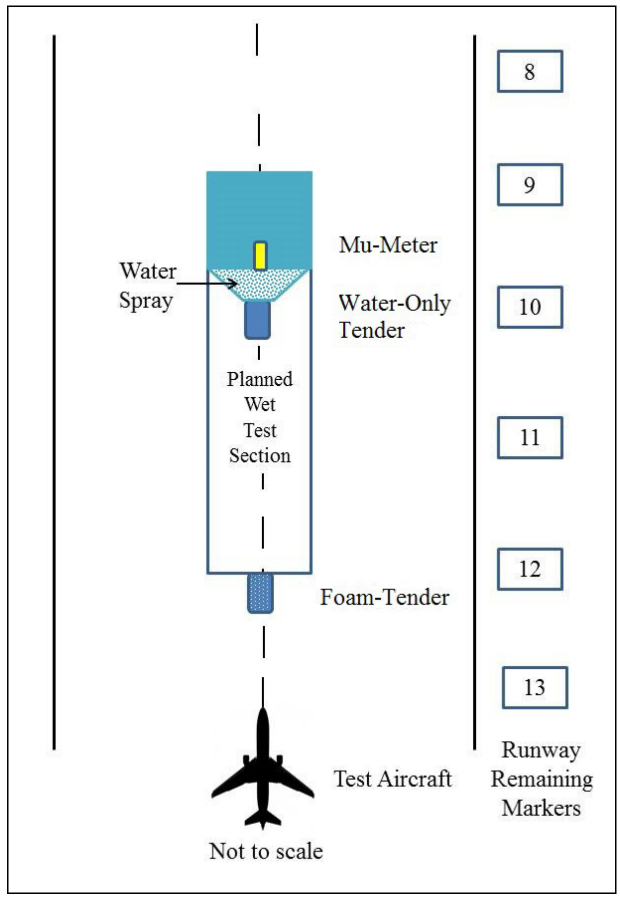


Figure 12: Runway First Wetting – Water-Only.

The Mu-Meter operator provides direction to the water-only tender operator using pre-arranged radio calls or other means such as hand signals or turn signals to adjust the tender speed and runway lateral placement. The Mu-Meter is not used to record RCR data during the first wetting. For wetted test sections up to 50 feet wide, the water-only tender is located so the water is evenly distributed on both sides of the wet runway test section centerline.

For wetted test sections up to 60 feet wide the water-only tender is located so that it is biased on each of the two wetting runs to accomplish the total wetted test section width plus 5 to 10 feet. The tenders will normally wet a 50 to 54 feet wide test section with shallower water coverage at the extremes of both sides. To accomplish a 60 feet wide wet runway test section the water-only tender is located so that it adequately wets the runway from the wet runway test section centerline to approximately 30 to 35 feet to one side during each of the two wetting passes. It is recommended that the water-only tender wetting runs begin with the left or right side wheels on the runway centerline as appropriate, for low wind conditions this should provide a satisfactory water dispersion pattern and a valid 60 feet wide wet runway test section when wetting is complete.

After the Mu-Meter operator is satisfied that the first wetting is being properly executed, he/she drives around the water-only tender and assumes a position at the beginning of the wet runway test section, behind the foam-tender as shown in Figure 13.

When the water-only tender has completed the first wetting, the driver keeps the pump on, makes a short radius U-turn in front of the foam-tender, and continues wetting the test section back towards the end of the wet runway test section. After the water-only tender completes the U-turn, the foam-tender follows closely behind as shown in Figure 14. The foam-tender oversprays the wetted section previously sprayed by the water-only tender.

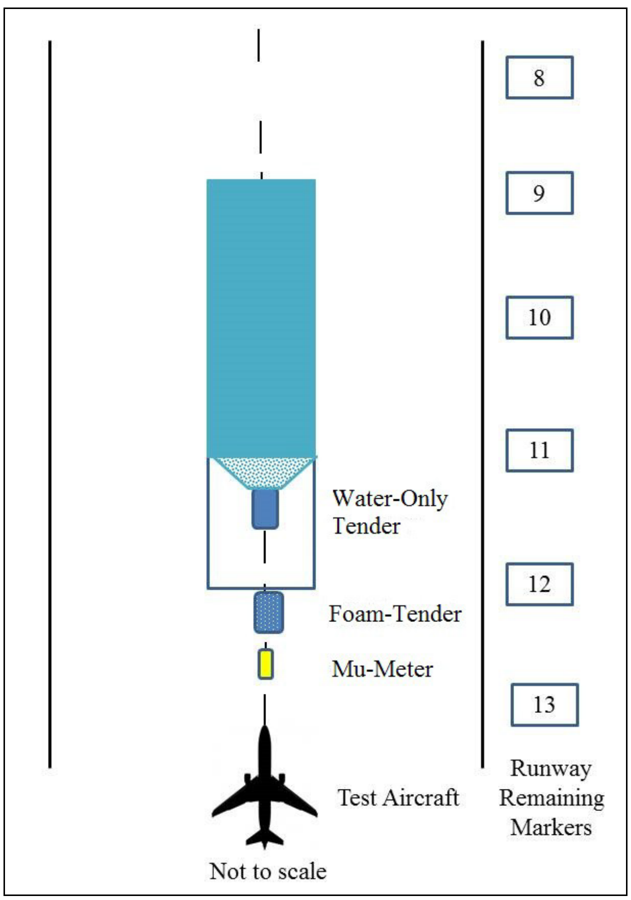


Figure 13: Runway First Wetting – Water-Only (Continued).

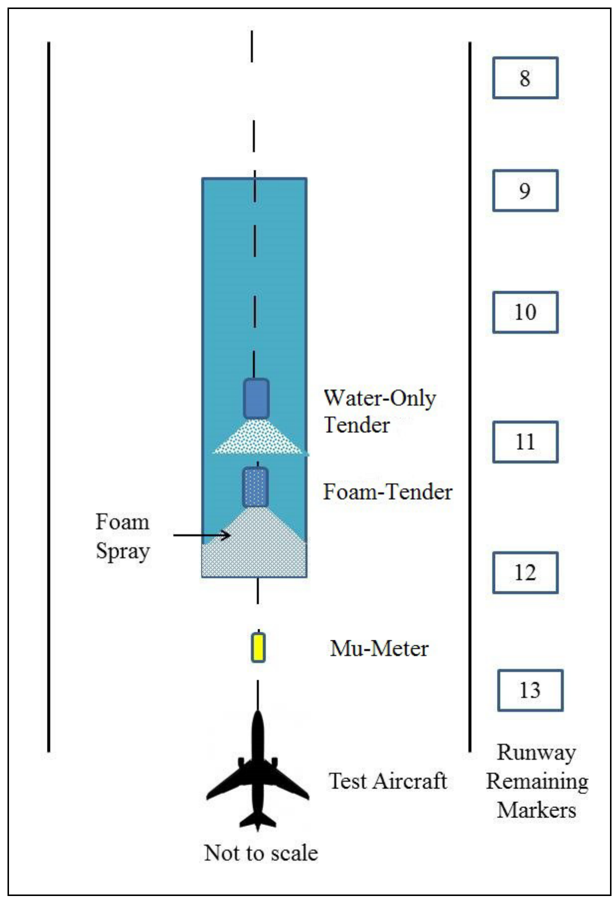


Figure 14: Runway Final Wetting – Water and Training Foam.

For wetted test sections up to 50 feet wide, both tenders are located so the water is evenly distributed on both sides of the wet runway test section centerline. Crosswinds may require that the tenders be slightly off centerline to compensate for cross wind effects.

For wetted test sections 60 feet wide, the water-only tender is located so that it is biased towards the drier side of the wet runway test section during its run back up the wetted test section. The foam-tender is located so the water is evenly distributed on both sides of the wet runway test section centerline.

The Mu-Meter operator records the time final wetting begins and starts a stopwatch. The stopwatch is used to determine when to start the Mu-Meter data run so that the Mu-Meter data is obtained shortly after the foam-tender has finished its spray run.

The Mu-Meter operator briefly follows the tenders to confirm the wetting process is satisfactory. He/she then promptly takes position approximately 500 feet from the beginning of the wet zone in preparation for the Mu-Meter data run.

Table 4 is used to determine the delay time before beginning the Mu-Meter data run. The Mu-Meter begins its data run before the tenders have finished their water spray and will pass the tenders as they are exiting the wet runway test section.

Table 4 includes delay times for two different wind conditions, ≥ 5 and < 5 knots. The intent is to take into account the effect that winds will have on dissipating the water in the wet runway test section. Because it is impossible to have one wetting plan that fits all atmospheric conditions, the Mu-Meter operator may vary the wetting delay times as required to take advantage of lessons learned as the test progresses.

Table 4: Time Delay Before Starting Mu-Meter Data Run.

		Wet Test Section Length (feet)			
		2000	3000	4000	5000
Time Delay (minutes)	For winds ≥ 5 knots	1.0	1.5	2.0	2.5
	For winds < 5 knots	1.5	2.0	2.5	3.0

The Mu-Meter operator accelerates to 40 MPH after the delay noted in Table 4 and gathers RCR data in the wet runway test section as shown in Figure 15 (found at the end of this section). The Mu-Meter operator visually verifies the proper runway section was wet and the surface looks reasonably uniform with good water coverage in the wet runway test section.

The RCR is measured at the approximate location to be transited by the test aircraft main landing gear tires. The RCR is not measured on the runway centerline because the centerline paint stripes provide an unrealistically low friction value.

After the tenders reach the end of the wet runway test section, they quickly turn off the water pumps and exit the runway in accordance with the pre-test briefed procedures.

As the vehicles are exiting the runway the Mu-Meter operator reviews the RCR data and advises the test conductor if a suitable test section is established and the RCR value. Consideration should be given to repeating the wetting if the RCR $\geq$ 18 as this may not be low enough to result in an adequate anti-skid system response.

An RCR $\leq$ 13 indicates an unsuitable test surface. This RCR should be considered invalid and the RCR should be immediately rechecked to verify it is RCR $\geq$ 14 before the aircraft is cleared to execute the test. This restriction ensures that the water depth is not excessive and thus not prone to causing a possible hydroplaning condition.

As discussed earlier, an advantage of using a Mu-Meter for wet runway taxi testing is the effect of water depth on runway friction measurement. A water depth above 1 mm imparts a contaminant drag on the Mu-Meter friction measuring wheels that prevents the trailer arms from properly spreading apart and hence results in an artificially low RCR measurement. Because the runway is relatively new and well maintained, it is not possible to get a true RCR 13 in areas of the runway that do not have rubber build-up.

Since most taxi tests are done outside of the rubber build-up areas, RCR $\leq$ 13 can only be obtained if the water depth is greater than 1 mm. If an RCR $\leq$ 13 is measured then testing is delayed slightly as the RCR is immediately rechecked, this also allows excess water depth to dissipate prior to test execution. The RCR will rise to RCR 14 to 15 by the time the Mu-Meter is off the runway and the aircraft has entered the wet runway test section.

If the RCR is $\leq$ 13, then a repeat Mu-Meter run in the opposite direction is quickly executed. Only the final 1,000 to 2,000 feet of the wetted test section needs to be measured to ensure RCR is $\geq$ 14. This test section will have the deepest water as it was wetted last. The intent of measuring only a limited test section length is to minimize test delay due to low RCR. An RCR 14 will rise to the target RCR 15 by the time the Mu-Meter is off the runway and the aircraft has entered the wet runway test section.

The Mu-Meter operator expedites the exit of all vehicles from the runway in accordance with the pre-test briefed procedures. The Mu-Meter operator reports to the test conductor and control tower when all vehicles are off the runway.

The test conductor quickly directs the pilot to execute the test. A delay of more than 2 minutes between all vehicles being off the runway and beginning the test point may result in RCR $\geq$ 18 at the time the aircraft enters the wet runway test section.

After the aircraft has completed the test point, the test conductor directs the pilot to promptly exit the wet runway test section, and the Mu-Meter operator performs an RCR measurement in either direction in the wet runway test section as shown in Figure 16. The RCR at time of test execution can be determined by assuming a linear change in RCR versus time from the pre-test and post-test RCR measurements.

The water-only tender should be refilled after each test point. Up to 10,000 linear feet of runway wetting can be performed with the foam-tender before a refill is required. Refilling the water-only tender takes approximately 20 minutes from leaving the runway to returning full and repositioned for another wetting. Refilling the foam-tender takes approximately 30 minutes.

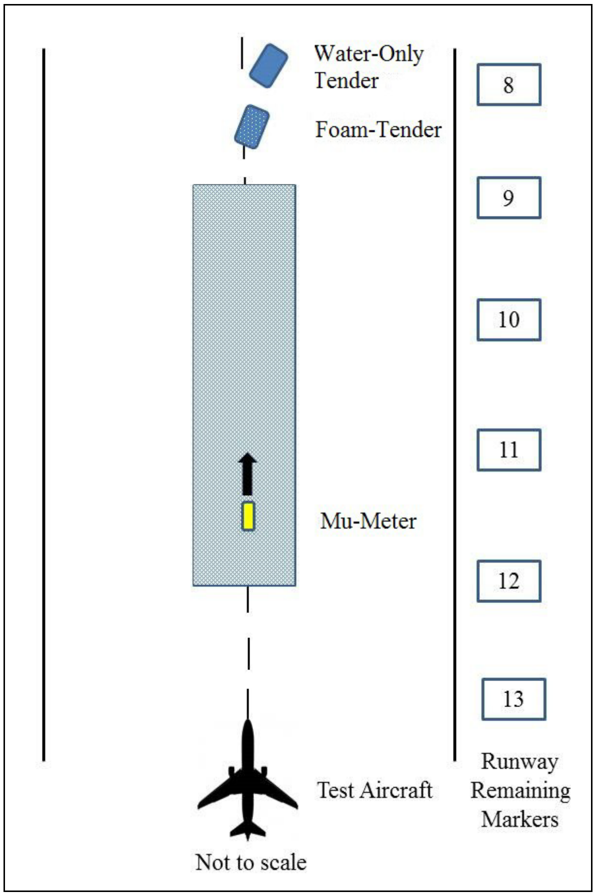


Figure 15: Mu-Meter Pre-Test Data Run.

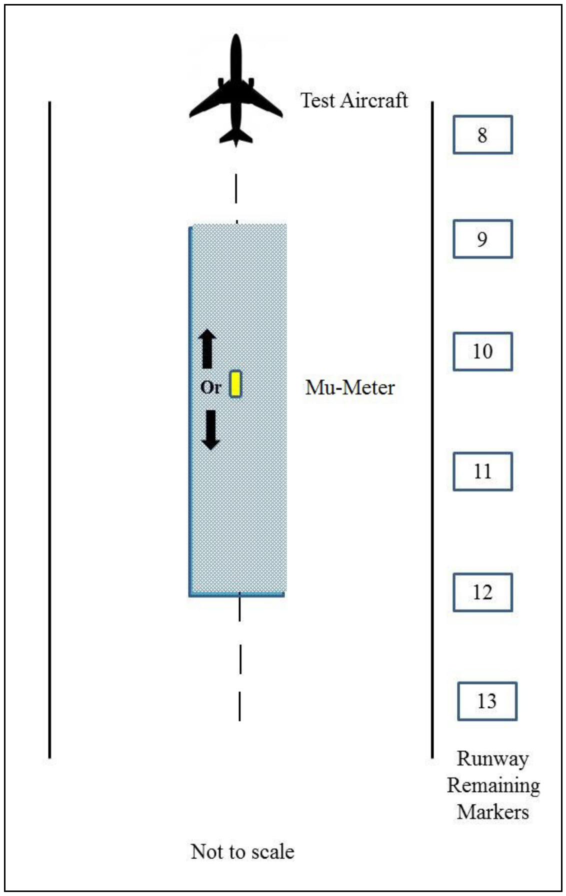


Figure 16: Mu-Meter Post-Test Data Run.

9.3 Multiple Test Points or Runway Re-Wetting

The previously discussed procedures assume a dry runway at the start of the wetting procedures. If multiple test points are executed on the same day, then on-site judgment is used to determine how many additional passes of the tenders are required. Because of the wide variation in temperature conditions possible, it is impossible to pre-determine the optimum re-wetting procedure. The following general guidance is provided:

- Runway pre-wetting is usually not required if water is still present on the runway.
- All tenders should be refilled and repositioned in the pre-test vehicle positions as shown in Figure 11. As the water-only tender is making its way down the runway, the Mu-Meter operator should perform a Mu-Meter data run over approximately half of the test section length. The RCR data are quickly reviewed to determine if a full re-wetting (including training foam) or only one or two passes of the water-only tender are required.
- It is possible that only a single or a double water spray pass would be required to re-establish a valid test surface. In this situation, the use of training foam should be omitted as too much foam build-up may artificially reduce the runway Mu to unacceptably low conditions.

- It is acceptable to use training foam on every third pass of the tenders when re-wetting a test section, but it is not applied at any greater frequency.

10.0 CONCLUDING REMARKS

The procedures described in this AGARDograph are current as of the publication date and are reviewed before and after every new test program is executed to incorporate lessons learned. This document will be updated to incorporate any significant changes made.

11.0 REFERENCES

[1] F.N. Stoliker, AGARDograph 300 Flight Test Techniques Series - Volume 14, Introduction to Flight Test Engineering, September 1995.

[2] L.D. Plews and 1Lt. G.A. Mandt, AFFTC-TIH-81-1, Aircraft Brake Systems Testing Handbook, May 1981.

[3] D.L. Bennett, FAA Advisory Circular 150/5320-12C - Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces, March 18, 1997.

[4] J. Worrell, Engineering Technical Letter (ETL) 04-10 (Change 1): Determining the Need for Runway Rubber Removal, HQ AFCESA/CESC, May 12, 2004.

Annex A – EDWARDS AFB RUNWAY 04L/22R DESCRIPTION

A.1 EDWARDS AFB AIRPORT DIAGRAM

The Edwards AFB airport diagram is shown in Figure A-1. Wet runway taxi tests are executed on the outer runway 04R/22L which is marked in red. Runway 04R/22L was made with Portland cement concrete and is 15,024 feet long and 300 feet wide.

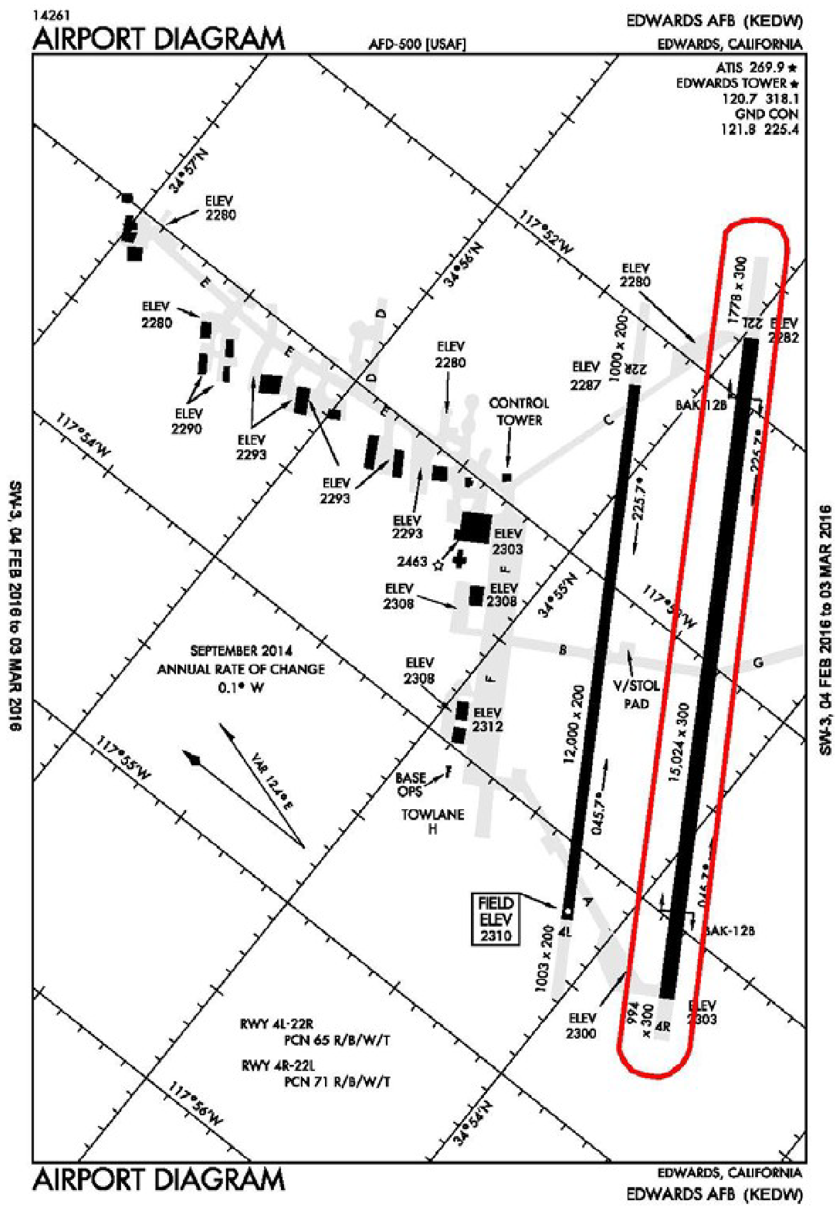


Figure A-1: Edwards AFB Airport Diagram.

Runway 04R/22L is unusually flat with a longitudinal slope of only -0.2 to 0.3 percent every 500 feet and was built in accordance with Unified Facilities Criteria (UFC) 3-260-01, Airfield and Heliport Planning and Design [1] with the following deviations to facilitate wet runway taxi testing:

a) The runway does not have the standard FAA/Air Force/NATO runway grooves that are usually cut into a runway surface to increase the wet runway friction by increasing rain water drainage. The lack of runway grooves improves water retention and replicates ground operations on un-grooved runway surfaces.

b) The runway has a reduced transverse grade of 0.0 to 0.6 percent rather than the reference 5 specified 1.0 to 1.5 percent. This improves water retention and reduces water flow onto the adjacent dry runway safety zones to both sides of the wetted area. The runway 04R/22L transverse and longitudinal slope measurements are shown in Figure A-2.

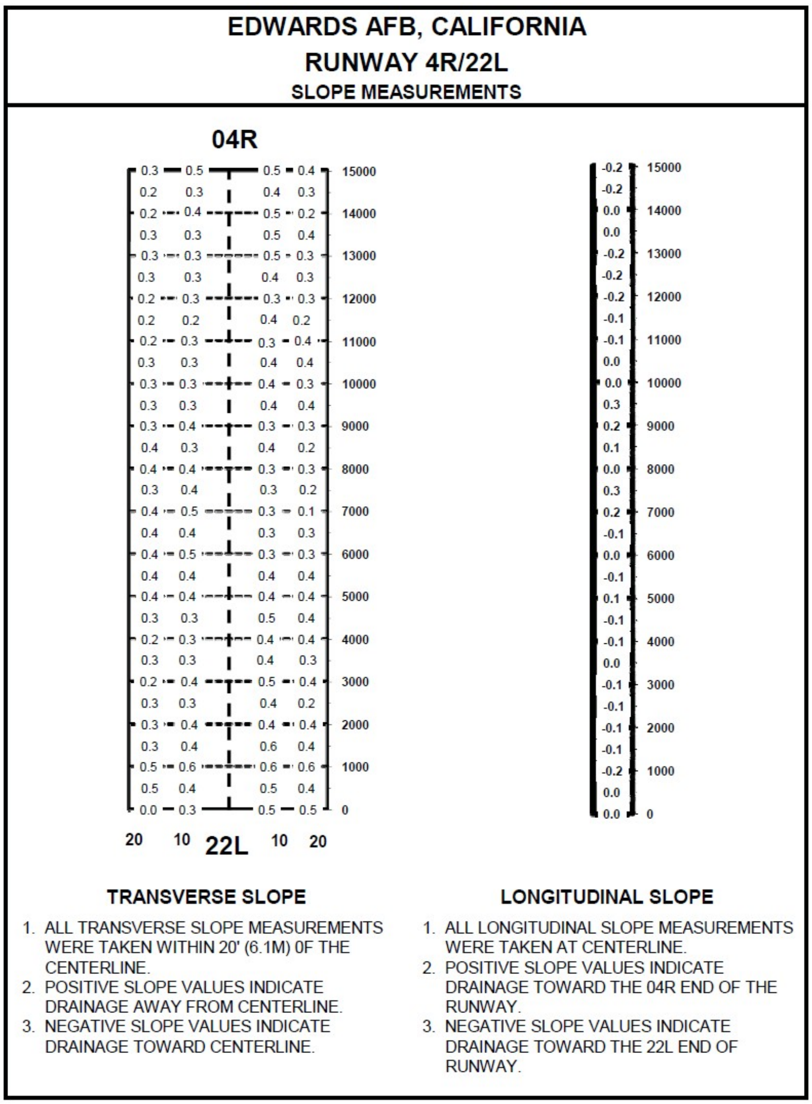


Figure A-2: Runway 04R/22L Slope Measurements.

A.2 REFERENCES

[1] J.C. Dalton, Unified Facilities Criteria (UFC) 3-260-01, Airfield and Heliport Planning and Design, November 17, 2008.

Annex B – TYPICAL TAXI TEST INSTRUMENTATION REQUIREMENTS

Table B-1: Typical Taxi Test Instrumentation.

Description	Units	Sample Rate (Hz)
Ground speed	knots	20
Indicated airspeed	knots	20
Pressure altitude	feet	20
Pitch angle	degrees	20
Roll angle	degrees	20
True heading	degrees	20
Weight on wheels	status	20
Ground speed	feet/second	20
Power level angle	degrees	20
Engine core speed	RPM	20
Latitude	degrees	20
Longitude	degrees	20
Inertial Velocity North	feet/second	20
Inertial Velocity East	feet/second	20
Inertial Velocity Up	feet/second	20
Pitch Command	degrees	20
Roll Command	degrees	20
Yaw Command	degrees	20
Elevator position	degrees	20
Aileron position	degrees	20
Rudder position	degrees	20
Roll rate	degrees/second	20
Pitch rate	degrees/second	20
Yaw rate	degrees/second	20
Brake pedal position – LH	percent	200

Description	Units	Sample Rate (Hz)
Brake pedal position – RH	percent	200
Utility system supply pressure	psi	200
Utility system return pressure	psi	200
Brake inlet pressure – LH	psi	1,000
Brake inlet pressure – RH	psi	1,000
Anti-skid valve current – LH	mA	1,000
Anti-skid valve current – RH	mA	1,000
Wheel speed – LH wheel	Hz	1,000
Wheel speed – RH wheel	Hz	1,000
Strut pressure (high) – LH	psi	200
Strut pressure (low) – LH	psi	200
Strut pressure (high) – RH	psi	200
Strut pressure (low) – RH	psi	200
Strut pressure – NLG	psi	200
Strut displacement – LH MLG	inch	200
Strut displacement – RH MLG	inch	200
Strut displacement – NLG	inch	200
Axle temperature – LH	degrees F	1
Axle temperature – RH	degrees F	1
Brake housing temperature – LH	degrees F	1
Brake housing temperature – RH	degrees F	1
Brake fluid temperature – LH	degrees F	1
Brake fluid temperature – RH	degrees F	1
Brake stator temperature – LH	degrees F	1
Brake stator temperature – RH	degrees F	1
MLG accelerations (X) – LH	feet/second^2	1,000
MLG accelerations (Y) – LH	feet/second^2	1,000
MLG accelerations (Z) – LH	feet/second^2	1,000
MLG accelerations (X) – RH	feet/second^2	1,000
MLG accelerations (Y) – RH	feet/second^2	1,000

Description	**Units**	**Sample Rate (Hz)**
MLG accelerations (Z) – RH	feet/second^2	1,000
MLG Drag Brace Load – LH	pound force	1,000
MLG Drag Brace Load – RH	pound force	1,000
Flap command	degrees	20
Speedbrake command	degrees	20

Annex C – TYPICAL PILOT QUESTIONNAIRE

DATE:	TAXI TEST PILOT QUESTIONNAIRE		
Test Number:	GW: lbs	ENERGY MFP	DRY	WET

Pilot: ____________________

Brake Responsiveness

1. Is the onset of braking predictable and smooth? Yes No

2. Is the brake response to pedal inputs proportional and smooth? Yes No

Noise and Vibration

3. Describe any unusual noise and vibration heard or felt during taxi, braking, or after landing.

____

Environmental Conditions

4. Is there noticeable difference (either in response or pilot feel) between a cold and hot brake taxi? If yes, explain:

____

5. Is there any difference in brake system responsiveness on wet and dry runway? If yes, explain:

____

6. Is wet runway braking performance effective in terms of stopping distance and controllability? Yes No

Speed

7. Is there any difference in brake system responsiveness at high vs. low speed? If yes, explain:

____

Gross Weight

8. Is there any difference in brake system responsiveness at heavy vs. light gross weights? If yes, explain:

____

9. Throughout a heavy/aggressive stop, do brakes provide a firm response? YES NO

Anti-skid Cycling

10. Can anti-skid cycling be felt when it is active? If so, is it felt in the pedals or in the airframe?

____

Overall Pilot Impression

11. Is the new brakes system performance equivalent to or better than the legacy brake system? YES NO

Overall Pilot Impression

____

____

Figure C-1: Typical Pilot Questionnaire.

Annex D – SAMPLE RUNWAY FRICTION MEASUREMENTS

Figure D-1 and Figure D-2 show sample pre- and post-test Mu-Meter runway friction and RCR data. The important data for test execution is circled in blue. The Average Mu table shows the runway measured (04/22), the average Mu and RCR for each 1/3rd of the sampled section, and the average Mu and RCR over the total area. The average RCR is used to determine if the wetted test section is satisfactory for test execution.

The time the two Mu-Meter data runs were started is used to determine the RCR at the time the test aircraft enters the wetted runway test section.

It is interesting to note the different values for Mu and RCR for both data runs. The wetted runway test section was fully wetted with standing water and puddles for both data runs yet the Mu and RCR was significantly different. This reflects the importance in proper test section preparation and prompt test point execution.

MuMeter Run Report

Edwards AFB AIRPORT

RUNWAY 04-22

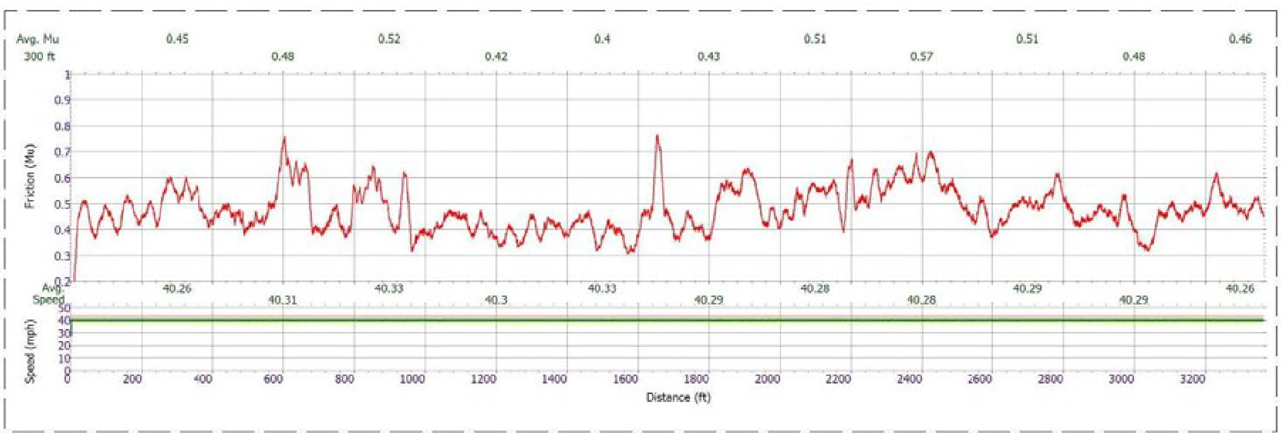
Calibration Results		
Zero Reference	2/23/2010 2:20:05 PM	58
Distance	5/21/2004 10:37:48 AM	406
Board Test	7/29/2010 6:20:49 AM	2816

Average Mu	1/3	2/3	3/3	Total
04-22	0.47 / 15	0.45 / 14	0.5 / 16	0.48 / 15

Run Start:	8/13/2010 6:55:09 AM	
Auto. End Distance	Off	
Distance Travelled	3366	feet
Average Speed	40.3	mph

Weather Condition	Sunny
Air Temperature	64
Operator Notes	Runway 22L right of Centerline. Winds 200@03. Before test point 1234.

Location	Event Note
ft	
ft	
ft	



8/13/2010 8:19:55 AM

Page 1 of 1

Figure D-1: Sample Pre-Test Mu-Meter Data.

MuMeter Run Report

Edwards AFB AIRPORT

RUNWAY 04-22

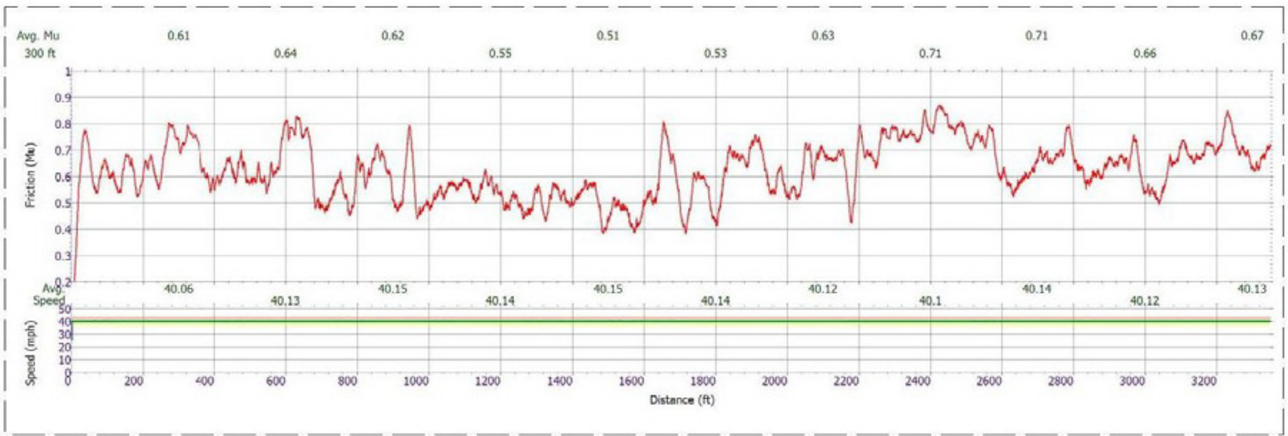
Calibration Results		
Zero Reference	2/23/2010 2:20:05 PM	58
Distance	5/21/2004 10:37:48 AM	406
Board Test	7/29/2010 6:20:49 AM	2816

Average Mu	1/3	2/3	3/3	Total
04-22	0.61 /19	0.57 /18	0.69 /22	0.62 /20

Run Start:	8/13/2010 7:06:08 AM	
Auto. End Distance	Off	
Distance Travelled	3351	feet
Average Speed	40.1	mph

Weather Condition	Sunny
Air Temperature	64
Operator Notes	Runway 22L right of Centerline. Winds 200@03. After test point 1234

Location	Event Note
ft	
ft	
ft	



8/13/2010 8:17:21 AM

Page 1 of 1

Figure D-2: Sample Post-Test Mu-Meter Data.

Annex E – TYPICAL TEST HAZARD ANALYSIS FORMS

TEST HAZARD ANALYSIS (THA)		Page 1/1
TEST SERIES Wet Runway Taxi Tests		MISHAP CATEGORY/PROBABILITY
PREPARED BY (NAME AND TITLE)	SIGNATURE	
UNIT TEST SAFETY OFFICER (NAME AND GRADE)	SIGNATURE	

HAZARD: Landing Gear Structural Failure

CAUSE:
1. Unexpected Anti-Skid Response, Gear Walk
2. Landing Gear Overload
3. Landing Gear, Anti-Skid or Brake Malfunction or Failure

EFFECT: Death/Loss of Aircraft

MINIMIZING PROCEDURES:

1. (1,2) The landing gear performance and structural response will be reviewed between test points to ensure that the dynamic response is not divergent, that load limits were not exceeded and that load limits are not predicted to be exceeded during the next test point.

2. (1,2) Testing will be accomplished in a buildup fashion and will start with the lightweight aircraft configuration before progressing to medium weight and then heavy weight aircraft configurations. For a given aircraft configuration, lower brake energy points will be executed before higher brake energy test points.

3. (1,2) For a given aircraft configuration, a dry runway test point of equivalent brake energy will precede the wet runway test point.

4. (3) Testing will not be executed if an antiskid system fault is indicated in the cockpit or mission control room.

5. (3) The brakes, wheels, tires and landing gear will be visually inspected for damage and wear before and after each test point.

CORRECTIVE ACTIONS:

1. Immediately release brake pressure.
2. Resume gradual braking after gear instability dampens out.
3. Additional deceleration options include the aft stick (below rotation speed), speedbrakes (if not already deployed) and barrier arrestment.

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Figure E-1: Landing Gear Structural Failure Test Hazard Analysis (THA).

TEST HAZARD ANALYSIS (THA)		Page 1/1
TEST SERIES Wet Runway Taxi Tests		MISHAP CATEGORY/PROBABILITY
PREPARED BY (NAME AND TITLE)	SIGNATURE	
UNIT TEST SAFETY OFFICER (NAME AND GRADE)	SIGNATURE	

HAZARD: Loss of Directional Control

CAUSE:
1. Brake System Failure
2. Unexpected Anti-Skid Response
3. Insufficient or Asymmetric Braking Performance
4. Brake/Wheel/Tire Failure
5. Hydroplaning.

EFFECT: Death/Loss of Aircraft

MINIMIZING PROCEDURES:

1. (All) Testing will be terminated upon uncommanded drift.
2. (All) Prior to execution of a high risk test point the pilot will have already completed a low risk or medium risk test point. The program will repeat low/medium risk points as required to qualify new pilots for high risk test points.
3. (All) The pilot will reduce brake pressure and terminate the test point if the aircraft approaches the sides of the wet runway test section.
4. (All) Testing will be accomplished in a buildup fashion and will start with lightweight aircraft configuration before progressing to medium weight and then heavy weight aircraft configurations. For a given aircraft configuration, lower brake energy points will be executed before attempting higher brake energy test points.
5. (1,2,3) For a given aircraft configuration, a dry runway test point of equivalent brake energy will precede the wet runway test point.
6. (1,4) The brakes, wheels, tires and landing gear will be visually inspected for damage and wear before and after each test point.
7. (4,5) Tires will have at least 2/32 inch of tread depth prior to each test point.
8. (5) The wet runway test section will be prepared in accordance with the latest verion of 773TS Flight Systems Integration Squadron Internal Office Memorandum, Runway Wetting Procedures for Taxi Tests at Edwards AFB, CA

CORRECTIVE ACTIONS:

1. Reduce throttles to idle, extend speedbrakes.
2. Use aerodynamic controls, nosewheel steering and/or differential braking to regain control.
3. If the normal brake system is not functioning properly, release brakes and switch to the emergency brake system and re-apply brakes per flight manual direction.
4. If the aircraft appears to be exiting the side of the wet runway test section:
   a. Release brakes and enter dry section.
   b. Reapply brakes after the aircraft has fully entered the dry section.
5. The pilot will consider shutting down motors in case of runway departures
6. If departure from a prepared surface is imminent, steer to avoid obstructions, turn off emergency generator, and shut down engines prior to departing the prepared surface.
7. Eject if necessary.

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Figure E-2: Loss of Directional Control THA.

TEST HAZARD ANALYSIS (THA)		Page 1/1
TEST SERIES Wet Runway Taxi Tests		MISHAP CATEGORY/PROBABILITY
PREPARED BY (NAME AND TITLE)	SIGNATURE	
UNIT TEST SAFETY OFFICER (NAME AND GRADE)	SIGNATURE	

HAZARD: Aircraft Overruns Runway

CAUSE:
1. Brake System Failure
2. Insufficient Braking Performance
3. Hydroplaning
4. Aircrew Fixation or Lack of Aircrew Situational Awareness

EFFECT: Sever Injury/Major Aircraft Damage

MINIMIZING PROCEDURES:

1. (All) Aircrew procedures for a runway overrun/departure will be briefed at the mision brief.
2. (1,2,4) The departure end BAK-12 arresting system cable will be rigged and the approach end cable will be derigged for all tests.
3. (1,2) Testing will not be executed if an antiskid system fault is indicated in the cockpit or mission control room.
4. (1,2) If normal system braking does not respond, release brakes, select emergency brakes (Emergency Brake Switch – EMERG) and re-apply brakes per flight manual direction.
5. (2,3) A safety margin of at least 2,500 feet plus the predicted aircraft stopping distance beyond the wet runway test section will be provided such that the pilot could exit the wetted runway section at the test speed and use normal to light brakes to bring the aircraft to a stop.
6. (3) The wet runway test section will be prepared in accordance with the latest verion of 773TS Flight Systems Integration Squadron Internal Office Memorandum, Runway Wetting Procedures for Taxi Tests at Edwards AFB, CA
7. (4) For all test points the Brake Not-Later-Than (NLT) distance shall be 5,000 feet of runway remaining. In the event braking has not begun by 5,000 feet remaining the test will immediatedly be terminated via an "Abort, Abort, Abort" call. The pilot will use maximum braking as required to stop the aircraft.
8. (4) Minimum Acceleration Check Speed (MACS), and Brake Not-Later-Than (NLT) distances will be briefed at the mission brief and listed on the test cards.

CORRECTIVE ACTIONS:

1. If aircraft speed is not under 70 knots at 3,500 feet runway remaining, deploy hook for arresting gear engagement.
2. If departure from a prepared surface is imminent, steer to avoid obstructions, and shut down engines prior to departing the prepared surface.

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Figure E-3: Aircraft Overruns Runway THA.

TEST HAZARD ANALYSIS (THA)		Page 1/1
TEST SERIES Wet Runway Taxi Test Points		MISHAP CATEGORY/PROBABILITY
PREPARED BY (NAME AND TITLE)	SIGNATURE	
UNIT TEST SAFETY OFFICER (NAME AND GRADE)	SIGNATURE	

HAZARD: Brake/Wheel/Tire Failure and/or Fire

CAUSE:
1. Anti-Skid or Brake Malfunction or Failure
2. Fuse Plug Failure
3. Brake Hydraulic Fluid Leak
4. Excessive/Cumulative Brake Energy/Brake or Tire Heat Buildup
5. Cumulative Tire Wear

EFFECT: Death, Loss of Aircraft

MINIMIZING PROCEDURES:

1. (1,3,5) The brakes, wheels, tires and landing gear will be visually inspected for damage and wear before and after each test point.
2. (1)Testing will not be executed if an antiskid system fault is indicated in the cockpit or mission control room.
3. (4) Before taxiing onto the runway, the tire sidewall temperatures will be checked. Maximum allowable tire sidewall temperature is 150 degrees Fahrenheit. Tire temperatures will be measured at a consistent location halfway up the tire sidewall.
4. (4) Before taxiing onto the runway, the brake temperature will be checked. Maximum allowable brake temperture is 200 degrees Fahrenheit. Brake temperatures will be measured at a consistent location on the upper area of the pressure plate with a handheld temperature device or at a brake stator using pre-installed instrumenation.
5. (4) Brake application speeds will be adjusted based on actual absorbed brake energies of previously executed test points.
6. (5) The pilot will release brake pedal pressure at 20 knots and bring the aircraft to a stop using normal braking techniques to prevent locking the wheels and flat spotting the tires below the anti-skid cutoff speed.
7. (1,2,3,4) For all testing with predicted brake kinetic energies in the upper Caution zone or higher, a representative from the fire department will attend the Mission Readiness Review and the fire/rescue crews and vehicles will be pre-positioned on the airfield to meet the aircraft following the test point.
8. (5) Tires will have at least 2/32 inch of tread depth prior to each test point.

CORRECTIVE ACTIONS:

1. Follow flight manual procedures for *Hot Brakes* and/or *Emergency Ground Egress.*
   a. Maintenance personnel will install nosewheel chocks. Pilotwill set parking brake if nosewheel chocks are not installed.
   b. Safe ejection seats.
   c. Shut down engines.
   e. Turn off battery.
   f. Abandon aircraft and remain at least 300 feet from the aircraft.
2. If hot brakes are suspected then ground crew personnel will not approach the aircraft until at least 45 minuted have passed, the brake stator instrumentation temperatures are below 400 degrees Fahrenheit, or all fuse plugs have released.

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Figure E-4: Brake/Wheel/Tire Failure and/or Fire THA.

Annex F – AGARD, RTO and STO Flight Test Instrumentation and Flight Test Techniques Series

1. Volumes in the AGARD, RTO and STO Flight Test Instrumentation Series, AGARDograph 160

Volume Number	Title	Publication Date
1.	Basic Principles of Flight Test Instrumentation Engineering (Issue 2) Issue 1: Edited by A. Pool and D. Bosman Issue 2: Edited by R. Borek and A. Pool	 1974 1994
2.	In-Flight Temperature Measurements by F. Trenkle and M. Reinhardt	1973
3.	The Measurements of Fuel Flow by J.T. France	1972
4.	The Measurements of Engine Rotation Speed by M. Vedrunes	1973
5.	Magnetic Recording of Flight Test Data by G.E. Bennett	1974
6.	Open and Closed Loop Accelerometers by I. McLaren	1974
7.	Strain Gauge Measurements on Aircraft by E. Kottkamp, H. Wilhelm and D. Kohl	1976
8.	Linear and Angular Position Measurement of Aircraft Components by J.C. van der Linden and H.A. Mensink	1977
9.	Aeroelastic Flight Test Techniques and Instrumentation by J.W.G. van Nunen and G. Piazzoli	1979
10.	Helicopter Flight Test Instrumentation by K.R. Ferrell	1980
11.	Pressure and Flow Measurement by W. Wuest	1980
12.	Aircraft Flight Test Data Processing – A Review of the State of the Art by L.J. Smith and N.O. Matthews	1980
13.	Practical Aspects of Instrumentation System Installation by R.W. Borek	1981
14.	The Analysis of Random Data by D.A. Williams	1981
15.	Gyroscopic Instruments and Their Application to Flight Testing by B. Stieler and H. Winter	1982
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22.	Application of Fiber Optic Instrumentation by L. Richards, A.R. Parker Jr., W.L. Ko, A. Piazza and P. Chan	2012

2. Volumes in the AGARD, RTO and STO Flight Test Techniques Series, AGARDograph 300

Volume Number	Title	Publication Date
AG237	Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK)	1979

The remaining volumes are published as a sequence of Volume Numbers of AGARDograph 300.

1.	Calibration of Air-Data Systems and Flow Direction Sensors by J.A. Lawford and K.R. Nippress	1988
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14.	Introduction to Flight Test Engineering Issue 1: Edited by F. Stoliker Issue 2: Edited by F. Stoliker and G. Bever	 1995 2005
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31.	Reduced Friction Runway Surface Flight Testing – Wet Runway Taxi Test Procedures at Edwards Air Force Base by T.E. Lundberg	2018

[‡] Superseded by Volume 28.

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14. Abstract

This report documents the wet runway taxi test procedures used by the 412th Test Wing at Edwards Air Force Base, California, USA. Wet runway taxi tests warrant special considerations to ensure a valid, repeatable and safe wet runway test surface is prepared and that the test is executed safely and efficiently. The 412th Test Wing uses detailed runway wetting procedures, specially equipped ground vehicles and a runway that was specifically designed for wet runway taxi tests. The wet runway test section is tailored to the aircraft size and expected braking distance and is typically 25 to 50 feet wide and up to 5,000 feet long. There are dry runway safety recovery zones to both sides and beyond the end of the wet runway test section in case the test pilot experiences an unexpected aircraft response.

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