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Falcon 20 Aircraft Braking Performance on Wet Concrete Runway Surfaces

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16. Abstract

The braking performance of the NRC Falcon 20 research aircraft was evaluated on wet concrete runways at Montreal Mirabel airport in November 2002 and October 2003. Tests were conducted with full anti-skid braking on runway surfaces in conditions of natural precipitation as well as on wet surfaces laid artificially by water tankers. Saab Surface Friction Tester (SFT) vehicles were used to measure baseline runway friction profiles as well as friction on the wet runway surfaces before and after each aircraft run.

Limited SFT data showed that baseline friction values measured in self-wetting mode closely approximated the friction measured on the actual rain wet runway surfaces. With full anti-skid braking, the aircraft braking coefficients on wet runway surfaces were found to vary in a predictable way with aircraft groundspeed, runway surface texture and degree of wetness.

On a smooth, wet concrete runway surface close to the minimum maintenance standard, the Falcon 20 tire-to-ground effective braking coefficient was found to be less than the aircraft certification requirement for a fully modulating anti-skid system. Based on this finding, the current operational dispatch factor of 1.92 for turbojet aircraft landing on wet runways at destination or alternate airports would have to be increased to a value of 2.2 to 2.4 in order to achieve the same level of safety as that which is currently accepted for dry runway operations.

Additional tests would be required to obtain data for asphalt runways or for surfaces with heavy rubber contamination.

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16. Résumé

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Les données limitées recueillies ont révélé que les valeurs de glissance de référence obtenues en mode d'arrosage automatique se rapprochent beaucoup des valeurs mesurées sous la pluie naturelle. Les essais de freinage avec antidérapage sur pistes mouillées ont donné des coefficients de freinage qui variaient, comme on pouvait s'y attendre, selon la vitesse sol et la texture et le degré de mouillage de la piste.

Sur une piste en béton lisse et mouillée se rapprochant de la norme d'entretien minimale, le coefficient de freinage efficace pneu-sol du Falcon 20 s'est avéré inférieur à l'exigence de certification de l'aéronef, pour un système antidérapage avec mécanisme de modulation. Selon ces résultats, le facteur opérationnel actuel de 1,92 nécessaire pour qu'un turboréacteur puisse être autorisé à atterrir sur une chaussée mouillée à son aéroport de destination ou de dégagement devrait être porté à une valeur de 2,2 à 2,4, pour que le niveau de sécurité soit comparable à ce qui est présentement accepté pour un atterrissage sur chaussée sèche.

D'autres essais devraient être réalisés pour obtenir des données concernant les chaussées en asphalte ou fortement contaminées par des dépôts de caoutchouc.

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Additional tests would be required to obtain data for asphalt runways or for surfaces with heavy rubber contamination.

RÉSUMÉ

La performance en freinage de l'avion de recherche Falcon 20 du CNRC sur des pistes en béton mouillées a été étudiée à l'Aéroport de Montréal-Mirabel en novembre 2002, puis en octobre 2003. Des essais de freinage avec antidérapage ont été réalisés sur les deux pistes, mouillées naturellement par la pluie ou artificiellement, à l'aide de camions-citernes à eau. Des glissancemètres (SFT) de SAAB ont été utilisés pour déterminer les valeurs de glissance de référence des pistes, de même que la glissance des pistes mouillées avant et après chaque essai de freinage.

Les données limitées recueillies ont révélé que les valeurs de glissance de référence obtenues en mode d'arrosage automatique se rapprochent beaucoup des valeurs mesurées sous la pluie naturelle. Les essais de freinage avec antidérapage sur pistes mouillées ont donné des coefficients de freinage qui variaient, comme on pouvait s'y attendre, selon la vitesse sol et la texture et le degré de mouillage de la piste.

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D'autres essais devraient être réalisés pour obtenir des données concernant les chaussées en asphalte ou fortement contaminées par des dépôts de caoutchouc.

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GLOSSARY OF TERMS

AFM	Aircraft Flight Manual
AFMLD	Aircraft Flight Manual Landing Distance
AIP	Aeronautical Information Publication
ASTM	American Society for Testing and Materials
ATIS	Automatic Terminal Information System
CAR	Canadian Aviation Regulations
C_D	Aircraft Coefficient of Drag
C_L	Aircraft Coefficient of Lift
CRFI	Canadian Runway Friction Index
CYMX	Montreal Mirabel airport designator
CYOW	Ottawa airport designator
D	Aerodynamic Drag
DA20	Dassault 20 (Falcon)
DAS	Data Acquisition System
D_{CONTAM}	Contamination Drag
D_F	Friction Drag
DGPS	Differential Global Positioning System
D1	Air Distance (from 50 feet to touchdown)
D2	Delay or Transition Distance (from touchdown to brake application)
D3	Braking Distance (from brake application to a complete stop)
ERD	Electronic Recording Decelerometer
ESDU	Engineering Sciences Data Unit
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
ft	Feet
g	Gravitational Constant
GPS	Global Positioning System
HW	Headwind
Hz	Hertz
IAR	Institute for Aerospace Research
IMU	Inertial Measurement Unit
IRFI	International Runway Friction Index
JAR	Joint Aviation Requirements
JWRFMP	Joint Winter Runway Friction Measurement Program
KEAS	Knots Equivalent Airspeed
kn	knots
KTGS	Knots True Groundspeed
L	Aerodynamic Lift
LDA	Landing Distance Available
LFL	Landing Field Length
lbf	Pounds of force
LD	Landing Distance
m	Meters
MOU	Memorandum of Understanding
Mu	Coefficient of friction
MuB	Aircraft Braking Coefficient
NASA	National Aeronautics and Space Administration
PA	Pressure Altitude

psi	pounds per square inch
R^2	Statistical Coefficient of Determination
RFI	Runway Friction Index
RMS	Root Mean Square
RTO	Rejected Takeoff
S	Wing reference area (ft^2)
SD	Standard Deviation
SFT	Surface Friction Tester
SG	Specific Gravity
t	Time
T	Aircraft Thrust
TC	Transport Canada
TS	Test Section
TW	Tradewind
V	Aircraft velocity along the runway
V_{EAS}	Equivalent Airspeed
V_{EFB}	Equivalent Airspeed at Application of Full Brakes
V_{E50}	Equivalent Airspeed at 50 feet Above the Runway Surface
V_G	Groundspeed
V_{GFB}	Groundspeed at Application of Full Brakes
V_{G50}	Groundspeed at 50 feet Above the Runway Surface
V_{REF}	Aircraft Approach Speed
V_{T50}	True Airspeed at 50 feet Above the Runway Surface
W	Aircraft Weight
ε	Runway Slope (positive uphill)
μ_B	Aircraft Braking Coefficient (= Braking Force/(W-L))
μ_{BM}	Mainwheel Braking Coefficient
μ_R	Rolling Friction Coefficient (= Rolling Resistance/(W-L))
μ_{RN}	Nosewheel Rolling Friction Coefficient
$\mu_{t/g\ MAX}$	Maximum Tire-to-ground Braking Coefficient
$\mu_{t/g\ EFF}$	Effective Tire-to-ground Braking Coefficient

FALCON 20 AIRCRAFT BRAKING PERFORMANCE ON WET CONCRETE RUNWAY SURFACES

1.0 INTRODUCTION

1.1 Background

Canadian aviation regulations for commercial air services state that no turbojet aircraft may be dispatched or conduct a take-off unless a full stop landing can be accomplished within 60% of the landing distance available (LDA) at the destination or alternate airports (CAR 705.60). Dispatch limitations for turbojet landings on wet runways further require the LDA at the destination airport to be 115% of the dry runway landing distance requirement. These operational safety factors have existed for quite some time, and are deemed acceptable even though the accident record shows a higher proportion of aircraft overruns on wet runways. Of 111 landing overrun accidents worldwide between 1970 and 1998, involving "western built jet airliners," 78 overruns were on water-affected runways (*Air Safety Week, May 7, 2001*).

Transport Canada has recently raised some concerns that the current operational dispatch factors for turbojet-powered aircraft may not be appropriate for Land and Hold Short Operations (LAHSO) on wet runways. A statistical study done by the Transport Canada Aircraft Certification Flight Test Division (*Discussion Paper No. 22, December 2001,* Reference 1) concludes that the operational factor of 1.92 for the destination airport is marginal for aircraft with thrust reverser systems, and not adequate for aircraft without thrust reversers, based on a 99% probability of being able to stop within the factored distance.

The NRC Falcon 20 research aircraft was used to conduct braking performance tests on wet runways to provide additional data for a review of applicable regulations and standards. These tests were conducted at the Montreal Mirabel airport in November 2002 and October 2003. Mirabel airport was chosen because its concrete runways were close to a friction level requiring maintenance action to be taken. Due to time constraints, the first series of tests was conducted only on runway 11/29, and in the absence of natural precipitation, was done on wet surfaces laid artificially by water tankers. The results of these tests are reported in *NRC Flight Test Report FR-FTR-25*, Reference 2. The second series of tests in October 2003 was conducted on runways 06/24 and 11/29 in conditions of natural precipitation as well as on wet surfaces laid artificially by water tankers.

1.2 Objectives and Scope

This report covers the results of both Falcon 20 test periods at the Mirabel airport. With the exception of one landing on a rain wet asphalt runway surface at the Ottawa airport, all braking tests were done on the two concrete runways at Mirabel. The results and analyses are therefore mainly applicable to the Falcon 20 aircraft performance on concrete runways. The specific objectives of the tests were as follows:

a) To determine the aircraft braking coefficients during full anti-skid braking as a function of groundspeed on wet runway surfaces;

b) To evaluate the current operational dispatch factors for turbojet-powered aircraft landing on wet runway surfaces at both destination and alternate airports;

c) To determine the effects of different degrees of surface "wetness," different runway surface textures, and natural (rain wet) versus artificial (tanker wet) conditions on aircraft braking coefficients; and

d) To obtain additional data toward the establishment of more accurate models for the effect of wet runway surface conditions on aircraft rejected takeoff and landing performance.

2.0 EQUIPMENT UNDER TEST

The equipment under test included the Falcon 20 research aircraft and the ground friction measurement vehicles, notably the Saab Surface Friction Tester (SFT). In addition, the basic friction profiles of the runways at Mirabel, measured by the SFT in natural rain conditions, and runway 07/25 at Ottawa, measured by the SFT in the self-wetting mode, are shown in this section.

2.1 NRC Falcon 20 Research Aircraft

The NRC-operated Falcon 20, C-FIGD (Figure 1), is a fully instrumented research aircraft well suited for this research program, having participated for a five year period in the Joint Winter Runway Friction Measurement Program (JWRFMP). The aircraft was built by Dassault Aviation and is typical of a small business jet. It has two General Electric CF700-2D-2 engines, a maximum takeoff weight of about 27,300 lbs and conventional hydraulically actuated flight controls. Leading and trailing edge wing flaps are used for lift augmentation, and wing-mounted airbrake panels are hydraulically actuated to dump lift after aircraft touchdown. The aircraft does not have reverse thrust capability, but a drag chute is available for emergency stopping assistance.

Figure 1 – NRC Falcon 20 on Rain Wet Runway 11 at Mirabel

The Falcon 20 landing gear is conventional with a steerable nose gear fitted with dual 14.5 x 5.5 14 P.R. aircraft tires that have side-mounted chines to deflect spray. Each main gear is fitted with dual 26 x 6.6 14 P.R. aircraft tires with ribbed grooves around the circumference of the tire to channel out water on wet surfaces. Prior to testing, tires were replaced to ensure a minimum of 5 mm groove depth (new tires have 7 mm groove depth). Tire pressure for all tires was 136 psi.

A three disc brake unit is flange mounted to each of the four main wheels, and receives pressure from two independent hydraulic systems. The anti-skid system on the Falcon 20 is a fully adaptive modulating system that automatically controls applied brake pressure to achieve maximum braking effectiveness and safety under all runway conditions. Wheel speed sensors mounted in each wheel axle send signals to the anti-skid control box, which controls anti-skid valves to modulate the brake pressure. Full brake pressure, prior to anti-skid modulation, is 1200 psi. The anti-skid system is inoperative at aircraft groundspeeds below about 17 knots. The Falcon 20 anti-skid system is analogue and was developed in the 1960s. It is considered a "Mark II" system, although it has many of the features associated with "Mark III" systems.

The Falcon 20 has an onboard data acquisition system (DAS) that includes all interfaces for the acquisition and recording of typical flight mechanics parameters, including accelerations, angles and rates in three axes, static and dynamic pressures, brake pressures, main wheel speeds, flight control, trim and throttle positions, and pilot event discrete. All parameters were recorded on a portable hard disk at an update rate of 32 Hz. This was supplemented by manual recording of some parameters such as type of test, configuration, fuel, reported wind direction/speed, and pilot qualitative comment.

A NovAtel RT-20 differential global positioning system (DGPS) integrated with a Honeywell HG1700 Inertial Measurement Unit (IMU) was installed in the aircraft as the principal source of aircraft position, velocity and acceleration measurement. For both test periods at Mirabel, the real-time DGPS mode was used, with the ground station receiver and antenna set up to ensure a continuous recording of processed differential GPS data.

2.2 Ground Friction Measurement Vehicles

The Saab Surface Friction Tester (SFT), Figure 2, is a continuous friction measurement device that uses a fifth wheel at a constant slip ratio to measure the surface coefficient of friction. A water tank in the SFT can be used to spray a water film, equivalent to a depth of about 0.5 mm, on the runway surface in front of the fifth wheel. This procedure is used to measure the runway friction in what is called the self-wetting mode. The SFT is used primarily to check the runway surface condition during the summer months to identify the point at which runway maintenance (rubber deposit removal and/or re-surfacing) needs to take place. Corrective maintenance action is required when the average friction index for the entire runway is below 0.50, in accordance with *Aerodrome Standards and Recommended Practices, TP 312E*, Reference 3.

Figure 2 – Saab Surface Friction Tester

Two Saab SFTs were used for the tests at Mirabel, one belonging to Transport Canada and one belonging to Tradewind Scientific Inc. SFT friction indices were recorded on the dry runways (in the self-wetting mode) to characterize their surface texture, and on the wet runway surfaces before and after the aircraft runs. All SFT runs were conducted at test speeds of 65 km/h using an ASTM (American Society for Testing and Materials) E1551 test tire.

The Electronic Recording Decelerometer (ERD) is a spot measurement device that measures deceleration. The device is rigidly mounted in the cab of an airport vehicle, and readings are taken by accelerating the vehicle to 50 km/h and then applying the brakes to the point of wheel lockup. A number of measurements are taken at various intervals on each side of the runway centreline, and averaged to provide a single friction value for the entire runway surface. An ERD was used during the first period of testing at Mirabel in November 2002, but did not provide consistent or complete data. Since there is no intention to use the ERD to measure runway friction on wet surfaces, either as a maintenance tool or as a prediction of aircraft performance (due to the variation of aircraft braking coefficient with speed on wet surfaces), ERDs were not used during the second period of testing at Mirabel in October 2003.

2.3 Runway Friction Profiles

The friction profile of each concrete runway at Mirabel was obtained in conditions of natural rain at the beginning of the October 2003 test period. The Tradewind SFT was run down the entire length of the runway at 65 km/h (200 m short of each threshold to allow for vehicle acceleration), and friction values were recorded at each 100 m interval. Four runs were made on each runway, two on each side of the centreline, and were averaged to provide the data in Figure 3. The data are shown as coefficients from 0 to 1, and are plotted against runway length starting with the threshold of runway 06 or 11 on the left side of the chart and proceeding to the threshold of runway 24 or 29 on the right side of the chart.

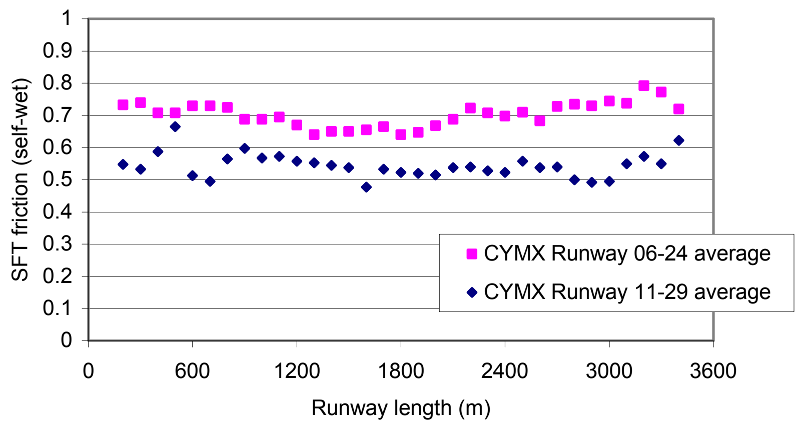

Figure 3 – Runway Friction Profiles at Mirabel (CYMX)

The data in Figure 3 indicate that runway 11/29 is close to the minimum maintenance standard at just over 0.50, and that runway 06/24 is considerably better at an average of about 0.70. There are no large dips in the data at the approach ends of the runways due to the presence of rubber deposits. However, each end of runway 11/29 has some low points close to 0.50: between 500 and 800 m from the threshold for runway 11, and between 500 and 900 m from the threshold for runway 29 (shown between 2700 and 3100 m in Figure 3).

Figure 4 shows the runway friction data for the asphalt runway 07/25 at Ottawa, obtained by the same Tradewind SFT, in the self-wetting mode, just after the October 2003 test period at Mirabel. The data were obtained using the same procedure, and are plotted against runway length starting with the threshold of runway 07 on the left side of the chart and proceeding to the threshold of runway 25 on the right side of the chart. In contrast to Mirabel, the data for Ottawa show significant dips in the surface friction at the normal aircraft touchdown points on both runway 07 and runway 25, presumably due to rubber deposits from the higher volume of airport traffic. Note that the minimum SFT friction value at the touchdown end of runway 25 is still above 0.50, increasing to over 0.80 in the middle of the asphalt runway. These data are shown here to substantiate the Falcon 20 braking performance recorded during the single landing on rain wet runway 25 at Ottawa, discussed in Section 5.2.3.

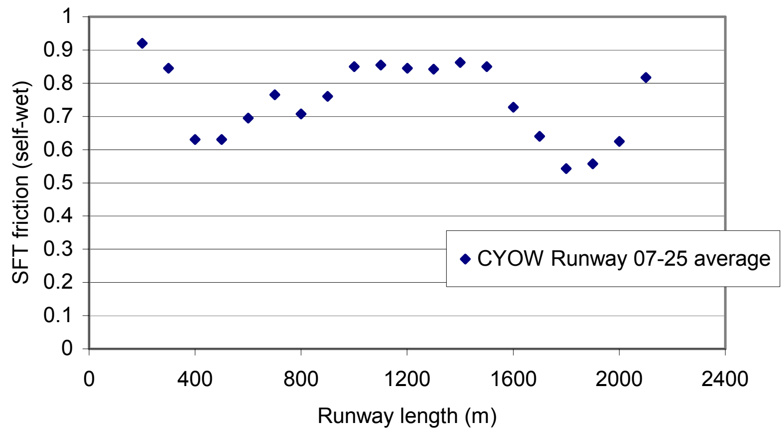

Figure 4 – Runway Friction Profile for Runway 07/25 at Ottawa (CYOW)

3.0 TEST PROCEDURES

The November 2002 tests were limited to artificially wet surfaces laid by water tankers on Mirabel runway 11/29. Test sections were set up on either end of the runway, depending on the prevailing wind, starting about 500 m from the threshold and ending at about 1000 m from the threshold. Start and end points of the test sections were marked by cone markers placed at each side of the runway. The widths of the test sections were about 60 feet centered on the 200 foot wide runway.

Prior to wetting the runway, aircraft taxi tests were conducted along the full length of runway 11/29 in both directions to provide rolling friction data, idle thrust calibrations and runway slope data for use in the data analysis program. A full anti-skid braking run was then conducted in each of the two test sections with the runway surface bare and dry. The two SFTs also conducted runs in each of the two test sections to measure the runway friction index (RFI) in the bare and dry condition and in the self-wetting mode.

Two tanker trucks, each containing about 1800 gallons of water, were used to wet the test sections prior to the aircraft runs, Figure 5. The SFTs measured the RFI immediately after the application of the water. The aircraft then conducted an acceleration-stop (rejected takeoff, or RTO) in the test section, followed by a takeoff on the dry portion of the runway. The aircraft flew an 8 to 10 minute circuit with the landing gear extended for brake cooling, and then conducted a full stop landing in the test section. Full anti-skid braking was initiated upon each entry into the test section and was released just prior to exit from the test section. Following the aircraft runs, the SFTs measured the RFI on the water remaining on the surface of the test section.

The October 2003 tests were expanded to include surfaces that were naturally wet from rainfall as well as artificially wet surfaces laid by the water tankers. Tests were conducted on either end of both runways 11/29 and 06/24, and the test sections were lengthened to end at about 1200 m from the threshold. For the tanker wet surfaces, this allowed for a maximum braking distance of 700 m (2300 feet), almost enough for a complete landing from 100 knots down to about 30 knots. Thus, most test points were conducted from full stop landings during this phase of testing, rather than having to combine the high speed portion of a landing (on a shorter test section) with a low speed acceleration-stop. For the rain wet surfaces, the aircraft and SFTs still operated within the designated test section as much as possible, in order to use the same underlying surface texture.

Figure 5 – Water Tankers Ready to Wet Runway 29 Test Section at Mirabel

SFT readings were again recorded following preparation of the test section, and between each aircraft landing while the aircraft was in the circuit. Test sections were also inspected by ground personnel between aircraft runs to ensure that no unusual conditions had developed as a result of the aircraft run, such as skid marks or foreign objects, and that no significant areas of standing water had formed.

Throughout the tests, safety procedures were followed in accordance with a test plan. For the October 2003 tests, this test plan was entitled *NRC Falcon 20 Aircraft Performance Tests on Wet Runway Surfaces During the Fall of 2003,* Reference 4, updated from the 2002 version. A ground test coordinator maintained radio contact with the airport ground control, test aircraft and ground vehicles, and ensured coordination of all vehicle movements and observation of the aircraft test runs. Photographic records of the various surface conditions were collected.

4.0 DATA ANALYSIS METHODS

The aircraft braking coefficient is defined as the total horizontal force due to wheel braking friction divided by the vertical component of the aircraft weight on all wheels (including those without brakes). With a fully active anti-skid system, it is understood that the term "aircraft braking coefficient" refers to the "effective" aircraft braking coefficient of friction, which includes any inefficiencies of the anti-skid system.

For the continuous full anti-skid braking runs conducted on wet runway surfaces during this test program, the aircraft braking coefficients (Mu braking or μ_B) were determined from an equation for aircraft deceleration along the runway and plotted against the aircraft groundspeed. Detailed analysis methods are contained in the report, *Braking Friction Coefficient and Contamination Drag Obtained for a Falcon 20 Aircraft on Winter Contaminated Runway Surfaces, LTR-FR-132*, Reference 5. The equations are summarized as follows:

$$\mu_B = \left(\frac{T}{W} - \frac{D}{W} - \frac{D_{CONTAM}}{W} - \varepsilon - \frac{1}{g}\frac{dV}{dt}\right) \Big/ \left(1 - \frac{L}{W}\right) \qquad (1)$$

where μ_B = aircraft braking coefficient
T = engine thrust

W = aircraft weight
D = aerodynamic drag
D_{CONTAM} = contamination drag
ε = runway slope (+ve uphill)
V = velocity along the runway
dV/dt = acceleration along the runway
g = gravitational constant
L = aerodynamic lift

The parameter D_{CONTAM}/W in equation (1) can be set to zero for wet runways with less than 3 mm depth of water where displacement drag and impingement drag are both considered to be insignificant. Without braking, equation (1) reduces to the rolling friction coefficient, μ_R, as follows:

$$\mu_R = \left(\frac{T}{W} - \frac{D}{W} - \varepsilon - \frac{1}{g}\frac{dV}{dt}\right) \Big/ \left(1 - \frac{L}{W}\right) \qquad (2)$$

Equations for the aerodynamic lift and drag are as follows:

$$L = \frac{1}{2}\rho_o V_{EAS}^2 S C_L$$
$$D = \frac{1}{2}\rho_o V_{EAS}^2 S C_D \qquad (3)$$

where ρ_o = $0.002377\, slug/ft^3$
V_{EAS} = equivalent airspeed (ft/sec) = $1.688 \times V_{EAS}$ ($knots$)
C_L = lift coefficient in ground effect, ground attitude
C_D = drag coefficient in ground effect, ground attitude, and
S = wing reference area (ft^2)

For the NRC Falcon 20, $S = 441.1\ ft^2$, and C_L and C_D are 0.30 and 0.132, respectively, in the landing configuration (flaps 40°, airbrakes out) and 0.10 and 0.076, respectively, in the rejected takeoff (RTO) configuration (flaps 15°, airbrakes out).

Engine thrust at idle power for the Falcon 20 was modelled as a linear function of V_{EAS} (knots):

$$T = 600 - 4.62\, V_{EAS} \quad (lbf) \qquad (4)$$

The aircraft braking coefficient μ_B can be converted to an equivalent mainwheel braking coefficient μ_{BM} for the Falcon 20 using the following equation from Reference 5:

$$\mu_{BM} = (\mu_B \times d - \mu_{RN} \times (c - CG) - \mu_B \times \mu_{RN} \times h)/(d - (c - CG) - \mu_B \times h) \qquad (5)$$

where μ_{RN} = nosewheel rolling friction coefficient
d,c,h = aircraft dimensional constants in inches (d = 227.39, c = 46.74, h = 56.0), and
CG = aircraft centre of gravity arm, in inches, referenced to the leading edge of the mean aerodynamic chord

The mainwheel braking coefficient μ_{BM} is the effective horizontal decelerating force due to friction at each mainwheel (with full anti-skid braking) divided by the vertical component of the weight on each mainwheel. This parameter can be compared to the maximum tire-to-ground wet runway braking coefficient of friction, corrected for anti-skid system efficiency, defined in the *Federal Aviation Regulations (FAR), subpart 25.109*, Reference 6. For the Falcon 20 with 136 psi tires, on a smooth wet ungrooved runway with moderate texture, the equation for maximum tire-to-ground braking coefficient, $\mu_{t/gMAX}$, as a function of aircraft groundspeed V_G in knots, is:

$$\mu_{t/gMAX} = 0.7637 - 0.7521 \times (\frac{V_G}{100}) + 0.2955 \times (\frac{V_G}{100})^2 - 0.0399 \times (\frac{V_G}{100})^3 \quad (6)$$

The parameter $\mu_{t/gMAX}$ must be reduced by the estimated anti-skid system efficiency value before a comparison can be made with the mainwheel braking coefficient μ_{BM}. In Reference 6, the efficiency value is stated to be 0.50 for a "quasi-modulating" anti-skid system and 0.80 for a "fully modulating" system. The application of these values to the Falcon 20 anti-skid system is discussed in Section 5.2.3.

5.0 RESULTS AND DISCUSSION

During the first test period at the Mirabel airport (November 2002), a total of eight full anti-skid braking runs were accomplished, two on bare and dry surfaces and six on surfaces that were wet by the water tankers. During the second test period in October 2003, a total of 24 full anti-skid braking runs were accomplished, 23 on both rain wet and tanker wet runways at Mirabel and one as a target of opportunity on rain wet runway 25 at Ottawa. Except for the landing at Ottawa, Saab SFT readings were taken for every aircraft braking run. SFT readings were also recorded in the self-wetting mode for each of the four test sections at Mirabel and runway 07/25 at Ottawa.

5.1 Ground Friction Measurements

Figures 6 and 7 show the results of the SFT self-wetting tests conducted on the runway 11 test section and the runway 29 test section, respectively. The friction readings, expressed as a coefficient between 0 and 1, are plotted for each 100 m interval over the length of each test section (700 m in 2003; 500 m in 2002) for both Tradewind (TW) and Transport Canada (TC) SFTs.

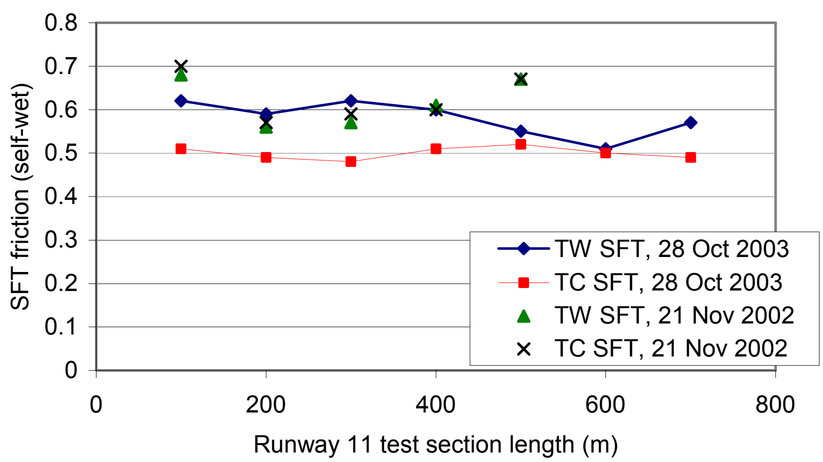

Figure 6 – Mirabel Runway 11 Test Section Friction Profile

The data in Figure 6 show good agreement in the friction readings between the TW and TC SFTs for the 2002 tests but significant differences for the 2003 tests. The differences are thought to be due to a problem with the test tires, which was discovered on the first day of testing. On a rain wet surface, the TW SFT recorded an average friction value of 0.68 while the TC SFT recorded a value of 0.48 on the same surface. Swapping the test tires resulted in the TW SFT recording a value of 0.48 and the TC SFT recording a value of 0.66. The problem was likely due to one of the tires being close to the minimum tread depth, since friction readings tend to become higher as the minimum tread depth is reached. The test tires were replaced on both TW and TC SFTs prior to continuing the tests. This reduced the output differences, but discrepancies of up to 20 percent remained, as shown in Figure 6. Issues relating to test tire quality control and calibration should be addressed.

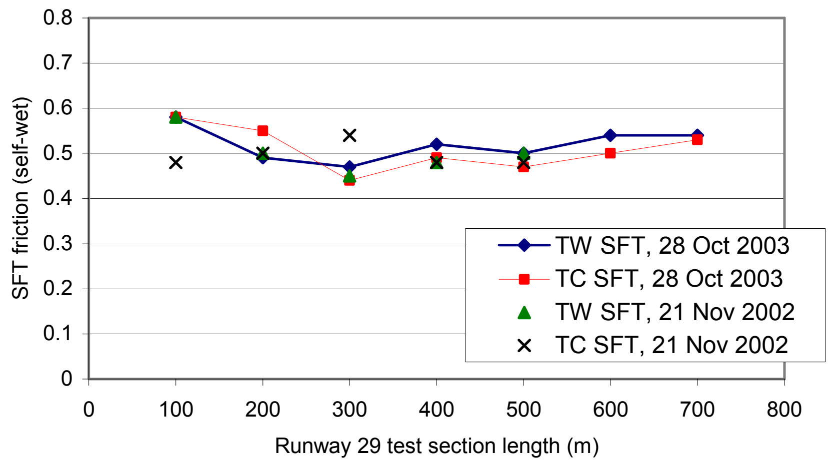

Figure 7 – Mirabel Runway 29 Test Section Friction Profile

The data in Figure 7 show agreement in the friction readings within about 5 percent, except for the TC SFT 2002 tests. The friction values for both the TC SFT 2003 tests and the TW SFT 2003 tests were recorded after the test tires had been replaced, as noted in the previous paragraph. The SFT friction values for the runway 29 test section ranged from a low of 0.44 to a high of 0.58, with a mean value of 0.51. This was below the mean value of 0.54 for the runway 11 test section, which ranged from a low of 0.48 to a high of 0.62. Visually, there appeared to be more rubber deposits on the runway 29 test section than on the runway 11 test section (see Figure 5).

The SFT friction measurements made on the actual wet surfaces in the test sections (in the non-self-wetting mode) are listed in the first three pages of tabular data in Appendix A, along with the data for all the aircraft test runs. The average friction values for each of the TW and TC SFT runs are shown, as well as a TW/TC average. All SFT friction values in Appendix A are interpolated to coincide with the aircraft run time, so that the ground friction measurements and aircraft braking performance could be compared directly. This was not done in the *NRC Flight Test Report FR-FTR-25*, Reference 2, so the SFT values listed in that report may differ slightly from those in this report.

After the test tires on the SFT vehicles were replaced, the measured friction values between the TW and TC SFTs on tanker wet or rain wet surfaces were reasonably consistent, differing by no more than about 0.05 for all surfaces tested. Exceptions were noted for some of the higher friction values (above 0.70) and for a couple of runs during the 2002 test period. The TW SFT measured friction values were usually lower than those for the TC SFT.

Table 1 summarizes the range of average SFT friction values measured on the four runway test sections for self wet and rain wet conditions. Natural rain wet conditions were only obtained for two sessions on runway 11 and one session on runway 06. On runway 11, both sessions were conducted in moderate continuous rain, and the measured friction values were very consistent, varying between 0.54 and 0.57 for all six aircraft runs. On runway 06, the test session was conducted in conditions varying between light rain and drizzle, and the measured friction was higher, between 0.72 and 0.80. The difference in the friction values between the two runways may be partially attributed to the different rates of precipitation, but runway texture also plays a big part. The mean SFT friction values in the self-wetting mode shown in Table 1, 0.54 for runway 11 and 0.71 for runway 06, are very close to the actual rain wet friction for these two cases. These limited data support the fact that runway texture plays a dominant role and that a properly calibrated SFT may be used to predict rain wet runway friction and perhaps aircraft braking performance.

Table 1 – SFT Measured Friction Values for Self Wet and Rain Wet Conditions

	Runway 11	Runway 29	Runway 06	Runway 24
Self wet	0.50 – 0.58	0.50 – 0.52	0.70 – 0.72	0.70 – 0.74
Rain wet	1. 0.56 – 0.57 [1] 2. 0.54 – 0.56 [1]		1. 0.72 – 0.80 [2]	

[1] Moderate continuous rain [2] Light rain / drizzle

Tanker wet test sessions are shown in Table 2 for three of the four runways. The SFT values shown in Table 2 represent start-to-finish variations, unlike the range of average values in Table 1. In Table 2, the lower number for each session is the SFT friction value at which the first aircraft run was made on a fresh tanker wet surface, and the higher number is the SFT friction value at which the last aircraft run was made prior to re-wetting the surface. In all cases, the SFT-measured friction consistently increased as the degree of “wetness” decreased over time as a result of gradual water evaporation and runway drainage.

Table 2 – SFT Measured Friction Values for Tanker Wet Conditions

	Runway 11	Runway 29	Runway 06	Runway 24
Tanker wet	1. 0.57 – 0.62 [3] 2. 0.61 – 0.65 [3]	1. 0.57 – 0.63 [3] 2. 0.52 – 0.59 3. 0.53 – 0.63 4. 0.53 – 0.58 5. 0.51 – 0.55		1. 0.76 – 0.80 [4]

[3] Year 2002 test period [4] Rapid drying due to high winds

The initial SFT friction measurements on the tanker wet surfaces were slightly higher than the SFT self-wetting friction for that surface. On runway 11 the initial friction was 0.57 – 0.61 compared to 0.50 – 0.58 for self-wetting; on runway 29 the initial friction was 0.51 – 0.57 compared to 0.50 - 0.52 for self-wetting; and on runway 24 the initial friction value was 0.76 compared to 0.70 – 0.74 for self-wetting. In view of the consistency between rain wet friction and self-wetting friction discussed above, the tanker wet friction is likely to be slightly higher than the equivalent rain wet friction, and this can be confirmed by a direct comparison between Table 1 and Table 2 for runway 11.

Physically, it makes sense that the friction measured on a tanker wet surface would be slightly higher than the friction measured on the same rain wet surface, because the tanker wet surface is non self-generating and begins to evaporate and drain even before the aircraft is ready to make its first run. The use of tanker wet surfaces for aircraft testing is still valid, but care must be taken to re-wet the surface often. For this project, no more than three aircraft runs (usually within about 20 minutes) were done prior to re-wetting the test section.

5.2 Aircraft Braking Coefficients

Appendix A is a summary of all the aircraft test runs, including the taxi tests and non-braking (coasting) runs. Pages A1 through A4 tabulate the test conditions for each run, and pages A5 through A23 show time histories of the left and right brake pressures (psi), aircraft groundspeed (knots) and aircraft braking coefficient (MuB, or μ_B) for each run. The time histories include the raw unfiltered data collected at 32 samples per second, with the parameter μ_B calculated from equation (1) in section 4.0 of this report. For the taxi runs and coasting runs, the brake pressures are zero, and μ_B reduces to the aircraft rolling friction coefficient.

Appendix B is a summary of the braking test runs used to determine the aircraft braking coefficient. Pages B1 and B2 tabulate the test conditions for each braking run, including the mean SFT friction value, and also include the mean aircraft groundspeed, the mean aircraft μ_B, and the coefficients for a linear regression between a smoothed aircraft μ_B parameter and the aircraft groundspeed. Pages B3 to B18 show the variation of the smoothed μ_B parameter with aircraft groundspeed for each braking run. The smoothed μ_B parameter is calculated by taking a one second average (16 samples on either side) of each recorded μ_B sample. This procedure filters out the variations of μ_B resulting from anti-skid action, but retains the variations of μ_B resulting from changes in surface wetness or texture.

In the following sections, the variation of aircraft braking coefficients on wet runway surfaces will be examined as a function of mean aircraft brake pressures, SFT measured friction (dependent on runway texture and degree of wetness) and aircraft groundspeed.

5.2.1 Aircraft Braking Coefficients versus Mean Brake Pressure

Two full anti-skid braking runs were conducted on bare and dry runway surfaces as baseline tests. One run was done on runway 29 (flight 2002/1, run 3, page A6) and one run was done on runway 11 (flight 2002/3, run 1, page A8). On runway 29 the brake pressures were constant at about 1100 psi (except for one impending skid on the left wheel), indicating that the brakes had reached their applied torque limit without cycling of the anti-skid system. The mean aircraft μ_B for this run, taken from the row of statistics just above the time history on page A6, was 0.432.

On the runway 11 bare and dry test section, the right brake pressure was constant at about 1100 psi, but the left brake pressure was variable, only occasionally reaching the torque limit, with a mean of only 680 psi. The mean aircraft μ_B for this run was 0.352, considerably less than the value for runway 29. This difference should not be construed as being due to any differences in surface texture between the two runways; rather, it was likely due to impending skids caused by running the left wheel along the painted centerline of the runway or other painted runway markings.

For all the runs on wet runway surfaces shown in Appendix A, the brake pressures modulate with the anti-skid system at about 4 to 5 Hz, and average from about 250 psi to over 600 psi, still well below the torque limit. The brake pressures vary from run to run as a function of surface texture, surface wetness and aircraft groundspeed, as do the aircraft braking coefficients μ_B. Figure 8 is a plot of the mean aircraft braking coefficients μ_B against the mean brake pressures for all the runs in Appendix A. The plot includes a total of 32 braking runs with two on dry surfaces and the remainder on wet surfaces. An excellent linear correlation is shown, with a coefficient of determination R^2 of over 0.97.

The implication of the relationship shown in Figure 8 is that mean anti-skid modulated brake pressure, recorded by a Flight Data Recorder (FDR) and transmitted via data link, could be used to predict aircraft braking performance based on μ_B. Brake pressures would be specific to aircraft type but could be normalized to provide a comparison between aircraft types.

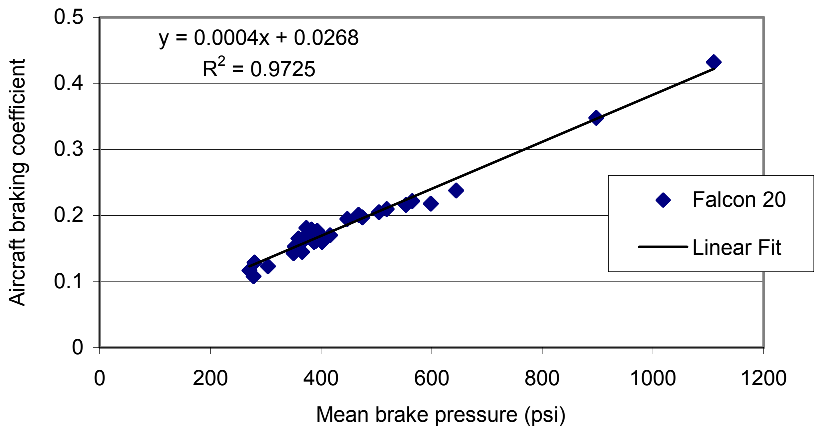

Figure 8 – Aircraft Braking Coefficient versus Mean Brake Pressure

Some of the time histories of brake pressure shown in Appendix A have slight inconsistencies that occur at the same location on the runway. An example is shown on flight 2003/3, runs 1 to 5, pages A14 to A16. These runs were done on tanker wet runway 29, and an examination of the right brake pressure traces shows a drop, or "bucket," of about a two second duration during each run. A comparison between these buckets and the GPS location on the runway shows that each of the buckets occurs at the same location on the runway, between 1060 and 1150 m from the threshold, and on the right side of the centerline since only the right brake seems to be affected. These brake pressure changes are therefore assumed to be due to local variations in runway texture (rubber deposits) and/or wetness, as opposed to brake malfunction or other aircraft characteristics.

The brake pressure buckets on flight 2003/3 result in a corresponding drop in the aircraft μ_B, which can be seen in the time histories of Appendix A and in the regressions of Appendix B. On run 1 (page B10), for example, the μ_B bucket centered at about 50 knots is due to a change in runway texture and/or wetness. It affects the linear regression, which would have a slightly more negative slope were it not for the bucket. Runs 2 and 3 on page B11 would also have more negative slopes without the buckets, and runs 4 and 5 on page B12 would have slopes close to zero without the buckets instead of the positive slopes they show now. The point of this discussion is that the relationship between aircraft μ_B and groundspeed derived from single braking runs can be significantly affected by local variations in runway texture and/or wetness. Combining runs for each test section will be necessary to determine the overall relationship between μ_B and groundspeed.

5.2.2 Aircraft Braking Coefficients versus SFT Measured Friction

Figure 9 shows the mean aircraft braking coefficients μ_B plotted against the SFT friction indices for the wet runway runs listed in Appendix B. Because the values of μ_B also vary with groundspeed, as will be discussed in detail in section 5.2.3, the values of μ_B in Figure 9 have been normalized to a common groundspeed of 66 knots, which is the average for all the runs. The values of μ_B (66 knots) were determined by adjusting the mean aircraft braking coefficients up or down along the gradient of μ_B versus groundspeed for each particular run, shown in Appendix B.

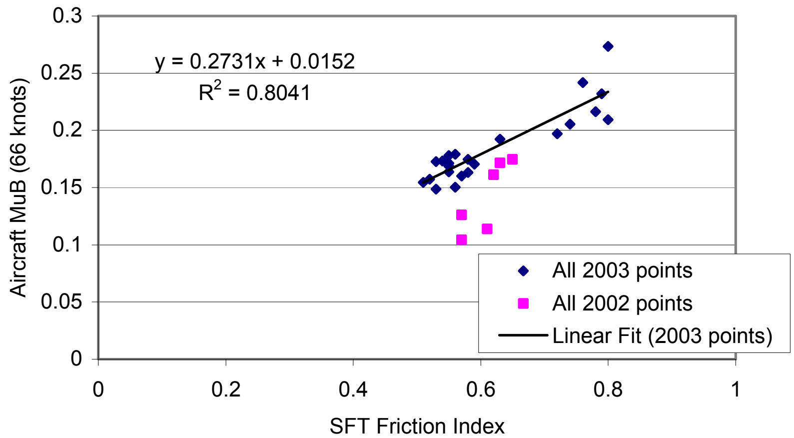

Figure 9 – Aircraft Braking Coefficient versus SFT Friction Index

The plot in Figure 9 shows the variation of mean aircraft μ_B due to the combined effects of runway texture and degree of wetness. There are two clusters of data for the 2003 test points: a left-hand one between SFT friction values of 0.51 and 0.63, and a right-hand one between SFT friction values of 0.72 and 0.80. In fact, the left-hand cluster represents all test points on Mirabel runway 11/29, and the right-hand cluster represents all test points on Mirabel runway 06/24. Within each cluster, there are variations in SFT measured friction and μ_B that are due to degree of wetness and/or data scatter. The linear fit line shows a good correlation, with a coefficient of determination $R^2 = 0.80$. These data suggest that aircraft braking performance is significantly affected by runway texture and degree of wetness, both of which can be quantified by SFT friction measurements on the wet surfaces or in the self-wetting mode.

The mean μ_B data plotted in Figure 9 for the 2002 tests are below the linear fit for the 2003 data, with three points significantly lower. Two of these points were first runs on a tanker wet surface, which was laid following a prolonged dry period, compared to the 2003 tests which were conducted following a 24 hour period of moderate rainfall. Aircraft braking performance is known to improve on a well washed runway surface compared to a surface initially wet but still containing particles of dust, dirt or grease. The data in Table 2 also confirm this effect, with a marked increase in SFT measured friction after the second tanker application of water on runway 11 in 2002, compared to similar SFT friction values for repeated tanker applications on runway 29 in 2003. It is not known why the initial SFT friction values on the newly laid tanker wet surface were not lower than the recorded value of 0.57, consistent with the lower aircraft μ_B data.

Previous comparisons were made between the Falcon 20 mean braking coefficients and SFT measured friction on contaminated runway surfaces, reported in *Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the CRFI, LTR-FR-183,* Reference 7. With SFT friction values below 0.40 on contaminated surfaces, or above 0.80 on mostly bare and dry surfaces, the aircraft μ_B did not correlate well with SFT friction ($R^2 = 0.71$). Although the data points shown in Figure 9 fill the gap between SFT friction values of 0.50 and 0.80, they do not improve the overall correlation, and the SFT is still not considered a suitable device for the prediction of aircraft stopping distance.

5.2.3 Aircraft Braking Coefficients versus Groundspeed

On wet runway surfaces, trapped water enters the leading edge of the aircraft tire-to-ground contact area and gives rise to a lift force acting to separate the tire from the base surface (see *Friction Fundamentals, Concepts and Methodology*, Reference 8). As groundspeed increases, the tire-to-ground contact area and coefficient of friction decrease, becoming approximately zero at the critical hydroplaning speed. Aircraft braking coefficients tend to decrease with increasing groundspeed on wet surfaces, compared to being relatively constant with changing groundspeed on dry surfaces. Plots of aircraft μ_B versus groundspeed have a negative slope that tends to become more negative with increasing water depth, as described in *Behaviour of Aircraft Anti-skid Braking Systems on Dry and Wet Runway Surfaces,* Reference 9.

Plots of smoothed μ_B versus aircraft groundspeed for each run are shown in Appendix B, pages B3 through B18. The regression coefficients for the runs on wet surfaces are listed in the table on pages B1 and B2. Most of these coefficients indicate a negative slope, but there are some exceptions. Runs 4 and 5 on flight 2003/3 (page B12) have slight positive slopes, thought to be a function of the local variations in surface texture and/or wetness described in section 5.2.1, and of the fact that both of these runs were done in a higher speed band than the other runs on flight 2003/3. Positive slopes are also shown for all runs on flight 2003/5 (except the target of opportunity at Ottawa) and flight 2003/7.

All four runs at Mirabel on flight 2003/5 (pages B15 and B16) show a slight positive slope. The runs are all done in the same speed band in the same configuration, and there are no significant local variations due to runway texture or wetness shown in the data. Factors contributing to the positive slope (in addition to data scatter) could be a minimal water depth since this flight was conducted in light rainfall/drizzle, and the fact that the friction profile for runway 06 (Figure 3) is highest at the point of touchdown and decreases as the aircraft slows down. All three runs on flight 2003/7 (pages B17 and B18) show a steep positive slope which is considered unrealistic. Due to the presence of high gusty winds for this flight, and the fact that the water laid by the tanker evaporated quickly to a condition no more than damp, these runs were discounted from further analysis.

The single landing of opportunity on rain wet runway 25 at Ottawa on flight 2003/5, run 5, demonstrated the effect of runway rubber contamination on aircraft braking performance. Reduced runway friction at the point of aircraft touchdown and initial braking, shown in Figure 4, caused a significant reduction in brake pressures and aircraft μ_B, shown in Appendix A, page A20. On the other hand, the increased runway friction in the center of the asphalt runway (about 0.85 from Figure 4) resulted in μ_B values well above 0.2 during the last two thirds of the run. As a result of these variations in surface friction and μ_B along the length of the landing run, the linear relationship between aircraft μ_B and groundspeed, shown in Appendix B on page B17, has a very steep negative slope. Further tests would be required to document the Falcon 20 braking performance on asphalt runways with or without heavy rubber contamination.

As noted in section 5.2.1, single braking runs can be affected by local variations in runway texture and/or wetness, and a combination of runs for each test section would be the best way to determine the overall relationship between μ_B and groundspeed. Plots of raw aircraft μ_B versus groundspeed are shown on the following pages for combined runs on both rain wet and tanker wet test sections. The apparent wide scatter of the data points in Figures 10, 11 and 12 is mostly due to the effect of the anti-skid system cycling on the raw values of μ_B, with only a small portion being actual data scatter. The relationship between μ_B and groundspeed for the rain wet surfaces will then be compared to the FAR requirement, Reference 6 (see equation (6) of section 4.0).

Figure 10 shows the raw values of aircraft μ_B versus groundspeed for all six runs conducted in rain wet conditions on the runway 11 test section. The runs included runs 1 and 2 on flight 2003/1 and runs 1 to 4 on flight 2003/4. The linear relationship between aircraft μ_B and groundspeed is:

$$\mu_B(\textit{rain wet}) = 0.237 - 0.00103 \times V_G \qquad \text{(Runway 11, } V_G \text{ in knots)} \qquad (7)$$

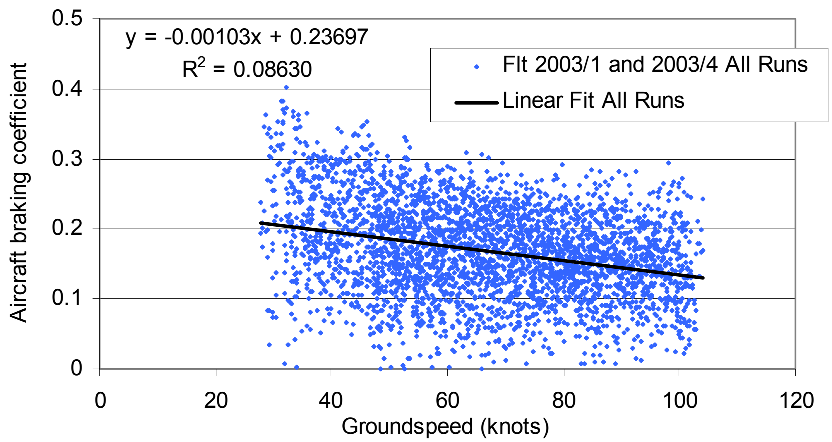

Figure 10 – Aircraft Braking Coefficient versus Groundspeed – Rain Wet Runway 11

A comparison between the coefficients in equation (7) and the coefficients of the smoothed μ_B data for the individual runs shown in Appendix B (pages B1 and B2) indicates a good consistency between the individual runs and the overall plot. Equation (7) can also be compared to the equation shown in the *NRC Flight Test Report FR-FTR-25*, Reference 2, for the tanker wet runway 11 test section, which is:

$$\mu_B(\textit{truck wet}) = 0.250 - 0.00167 \times V_G \qquad \text{(Runway 11, } V_G \text{ in knots)} \qquad (8)$$

Equation (7) for rain wet conditions would result in a lower stopping distance than equation (8) for typical aircraft brake application speeds, due to the higher μ_B available at the higher speeds ($\mu_B = 0.134$ compared to $\mu_B = 0.083$ at 100 knots, for example). The wet runway stopping distances calculated in Reference 2 are therefore conservative (too long), and will be re-calculated in this report.

Figure 11 shows the raw values of aircraft μ_B versus groundspeed for all four runs conducted on flight 2003/5 in rain wet conditions on the Mirabel runway 06 test section. The linear relationship between aircraft μ_B and groundspeed shows a slight positive slope as opposed to the negative slope shown in Figure 10. This slight positive slope was consistent with the coefficients of the smoothed μ_B data recorded for each of the four individual runs on flight 2003/5, shown in Appendix B, page B2.

The reasons for the differences in the relationship between aircraft μ_B and groundspeed in Figures 10 and 11 are runway surface texture and degree of wetness. The Figure 10 runs were done in continuous moderate to heavy rain conditions on the runway 11 test section, which had an average friction profile of about 0.54 (see Table 1). The Figure 11 runs were done in continuous light drizzle conditions (sufficient to keep the runway wet) on the runway 06 test section, which had an average friction profile of about 0.71 (see Table 1). The SFT friction measurements on the actual rain wet surfaces averaged about 0.55 for the runway 11 test section, almost identical to its friction profile, and 0.76 for the runway 06 test section, slightly above its friction profile, probably due to the low degree of wetness.

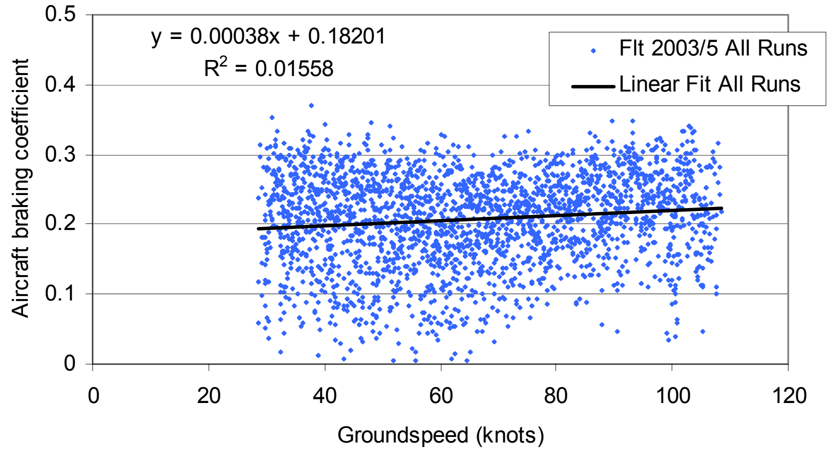

Figure 11 – Aircraft Braking Coefficient versus Groundspeed – Rain Wet Runway 06

Figure 12 shows the raw values of aircraft μ_B versus groundspeed for all five runs conducted on flight 2003/2 on tanker wet runway 29 test section. The linear relationship between aircraft μ_B and groundspeed shows a slight negative slope, about half that shown in Figure 10 for rain wet conditions. This result is consistent with the coefficients of the smoothed μ_B data recorded for each of the five individual runs on flight 2003/2, shown in Appendix B, pages B1 and B2. With the reduced negative slope, the aircraft braking performance and resulting stopping distance would be better than on an equivalent rain wet surface. This is consistent with the comment made in section 5.1 that the friction measured on a tanker wet surface would be slightly higher than the friction measured on the same rain wet surface.

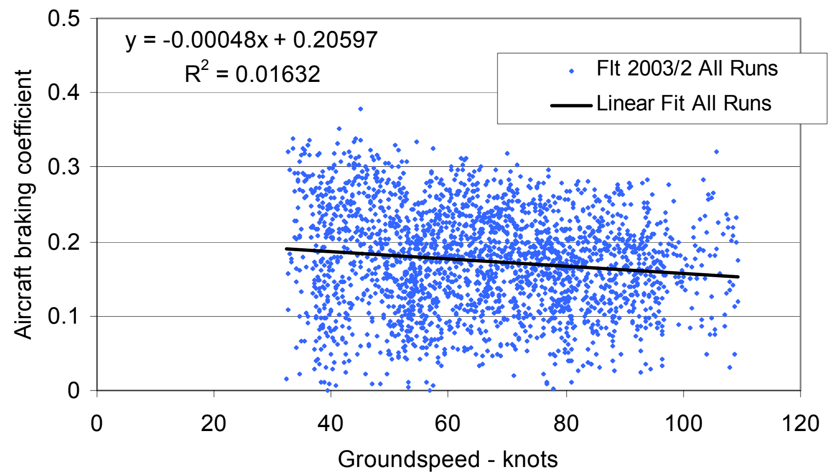

Figure 12 – Aircraft Braking Coefficient versus Groundspeed – Tanker Wet Runway 29

Data from Figure 10 will now be compared to the FAR requirement, reference 6. These data are chosen for this comparison because they represent aircraft braking performance on a smooth wet concrete runway surface, with no standing water, during a period of continuous moderate to heavy rain. The data are more conservative (lower μ_B) than the data for light rainfall on a slightly rougher texture concrete surface (Figure 11), and more realistic and slightly more conservative than the tanker wet data (Figure 12).

Since the FAR requirement is expressed as tire-to-ground braking coefficient, the aircraft μ_B data in Figure 10 must be converted from an aircraft braking coefficient to the Falcon mainwheel effective braking coefficient using equation (5) in section 4.0. The resulting data for a first order fit are shown as equation (9) for the Falcon (DA20) $\mu_{t/g\ EFF}$ as a function of groundspeed V_G. This equation represents the rain wet data for all six runs on flights 2003/1 and 2003/4.

$$DA20\ \mu_{t/g\ EFF} = 0.282 - 0.129 \times (\frac{V_G}{100}) \qquad V_G \text{ in knots} \qquad (9)$$

Equation (9) is plotted against the FAR requirement in Figure 13. This requirement is based on the ESDU (Engineering Sciences Data Unit) International definition of maximum tire-to-ground braking coefficient, multiplied by an efficiency factor applicable to the anti-skid system in use. An efficiency factor of 50% is applied to a "quasi-modulating" anti-skid system, whereas an efficiency factor of 80% is applied to a "fully-modulating" anti-skid system. Even though the Falcon 20 anti-skid system was designed and built in the 1960s, when the Mark II modulating rate type system was being produced, the Falcon 20 system has many of the features of the more advanced Mark III closed-loop feedback control system developed in the early 1970s. The efficiency rating of the Falcon 20 anti-skid system is therefore estimated to be between 50% and 80%, probably closer to 80% considering the modulation characteristics shown consistently in the brake pressure time histories of Appendix A.

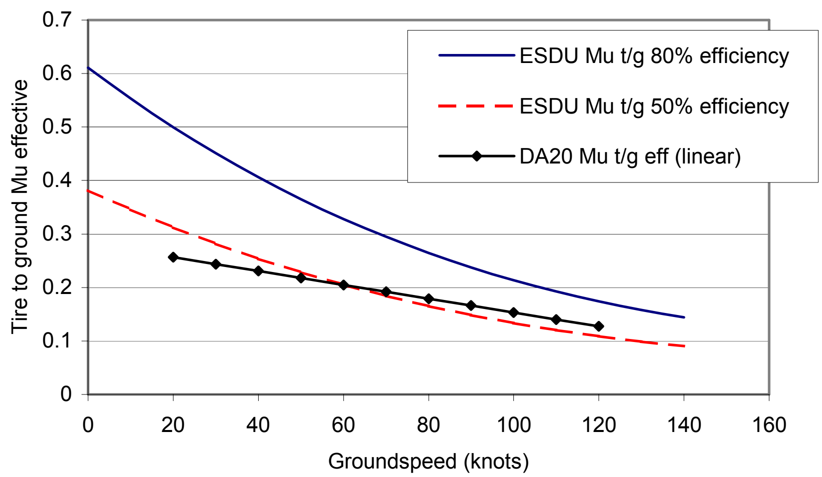

Figure 13 – Falcon 20 Tire-to-Ground Effective Braking Coefficient versus Groundspeed

The first order plot of the Falcon $\mu_{t/g\ EFF}$ on wet runway surfaces is shown in Figure 13 compared to the ESDU 50% and 80% efficiency levels. This plot essentially overlays the ESDU 50% efficiency level for values of $\mu_{t/g\ EFF}$ between about 30 knots and 120 knots, and is well below the certification requirement of 80% efficiency for a fully modulating anti-skid braking system.

The reduced Falcon $\mu_{t/g\ EFF}$ data shown in Figure 13 could be due to an anti-skid braking system efficiency below 80% (either by design or a faulty system), or a runway surface that is considerably smoother than the moderate texture assumed by ESDU, or a combination of both. Considering the fact that no braking system anomalies were evident during the tests, it is reasonable to assume that the smooth concrete surface of runway 11 at Mirabel is part of the problem. Given this assumption, the minimum average SFT friction profile of 0.50 for maintenance action may need to be adjusted upwards, at least for concrete runways, since the reduced braking performance occurred on a runway with an average friction profile of 0.54. Additional aircraft tests at Mirabel and/or Falcon tests on asphalt runways would be beneficial in confirming these data.

5.3 Aircraft Stopping Distance and Landing Field Length

The suitability of current operational dispatch factors for landing on wet runways at destination and alternate airports can be assessed by calculating the aircraft stopping distances D3 for various aircraft weights, and comparing these to landing field lengths (LFL) determined from Aircraft Flight Manual Landing Distances (AFMLD). The relationship in equation (1) is used to determine the aircraft deceleration profile at various weights and values of μ_B for both wet and dry runway surfaces. The deceleration profile is then used to determine aircraft stopping distance.

Rearranging equation (1) with the runway slope (ε) and contamination drag (D_{CONTAM}) equal to zero, and with values of lift (L), drag (D) and thrust (T) inserted for the Falcon 20 in the landing configuration, the equation for aircraft acceleration in "g" units becomes:

$$\frac{1}{g}\frac{dV}{dt} = \frac{600}{W} - \mu_B - \frac{4.62}{W} \times V_{EAS} + \left(\frac{-0.1976}{W} + \frac{0.4492}{W} \times \mu_B\right) \times V_{EAS}^2 \qquad (10)$$

where V_{EAS} is the aircraft equivalent airspeed in knots and W is the aircraft weight in lbf. For wet surface conditions, the braking coefficient (μ_B) itself is a function of aircraft groundspeed as shown in equation (7), so equation (10) becomes a third order function of aircraft velocity. In this case, stopping distance is more accurately computed using a numerical integration technique, as opposed to using the average acceleration method. For dry runways, with μ_B independent of groundspeed, the average acceleration method provides sufficient accuracy.

Table 3 contains a comparison of Falcon 20 stopping distances (D3) on wet and dry runways calculated for typical values of AFMLD. See NRC Report, *Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the CRFI, LTR-FR-183,* Reference 7, for details on stopping distance calculation. A value of μ_B = 0.43 is used for the dry runway calculations, and the value of μ_B given by equation (7) is used for the wet runway calculations. All distances are expressed in feet.

Table 3 – Comparison of Falcon 20 Stopping Distances on Wet and Dry Runways

W (lbs)	PA (ft)	HW (kn)	V_{REF} (kn)	AFMLD	V_{GFB} (kn)	D3 (dry)	D1+ D2	D3 (wet)	LD (wet)
18,000	0	5	109.2	2000	91.1	884	1116	1917	3033
20,700	0	0	117.1	2400	104.0	1144	1256	2570	3826
25,400	0	0	129.7	2800	116.6	1425	1375	3279	4654
25,200	6000	0	129.2	3200	128.2	1723	1477	4196	5673

The following terms are used in Table 3:

W	=	aircraft weight
PA	=	pressure altitude
HW	=	headwind
V_{REF}	=	reference airspeed on approach
V_{GFB}	=	groundspeed at the start of full wheel braking
D3	=	stopping distance from start of wheel braking to a complete stop
D1+D2	=	sum of air distance and transition distance
LD (wet)	=	total landing distance on a wet runway = D1+ D2+ D3 (wet)

The dry landing distances (AFMLD) and wet landing distances shown in Table 3 contain no safety factors. The value for (D1+D2) is determined by simply subtracting D3 (dry) from the AFMLD. This value of (D1+D2) is then added to D3 (wet) to obtain the wet landing distance. The value of D3 (wet) is based on the actual aircraft μ_B obtained during the Falcon full anti-skid braking runs on the rain wet concrete runway 11 at Mirabel.

The wet and dry landing distances in Table 3 are compared to the appropriate landing field lengths (LFL) in Table 4. These LFLs are calculated using the current dispatch factors. The LFL (dry) is calculated by dividing the AFMLD by 0.6 (multiplying by 1.67) and the LFL (wet) is calculated by multiplying the LFL (dry) by 1.15, or multiplying the AFMLD by 1.92. All distances are shown in feet. The difference between the landing distance and the LFL for each case is shown as an “excess,” (wet or dry). In the dry runway case, the excess distance increases with increasing AFMLD, and represents a constant 40% of the LFL (dry). In the wet runway case, the excess distance decreases with increasing AFMLD, dropping from 21% to 8% of the LFL (wet), considerably below the dry runway safety factor.

Table 4 – Comparison of Landing Distance and Landing Field Length on Wet and Dry Runways

AFMLD	LFL (dry) =AFMLD ×1.67	Excess (dry)	LD (wet)	LFL (wet) =AFMLD × 1.92	Excess (wet)
2000	3333	1333 (40%)	3033	3833	800 (21%)
2400	4000	1600 (40%)	3826	4600	774 (17%)
2800	4667	1866 (40%)	4654	5367	713 (13%)
3200	5333	2133 (40%)	5673	6133	460 (8%)

There are many potential ways of applying safety factors for the computation of LFL on wet runways, three of which are offered here for comparison. The three methods are: (1) the current method of multiplying the AFMLD by 1.92; (2) adding the excess distance currently accepted for landings on a dry runway to the wet landing distance; and (3) multiplying the wet landing distance by 1.67. These three methods are summarized in Table 5.

The least conservative method is the current method (1), shown in columns 2 and 3 of Table 5. Column 2 shows the computed LFL (wet) and appropriate factor in brackets for each value of AFMLD. Column 3 shows the excess (wet) distance and its percentage of LFL (wet) in brackets. As noted previously, method (1) results in safety percentages dropping from 21% down to 8% as the AFMLD increases.

Table 5 – Comparison of Three Methods of Computing LFL for Wet Runways

AFMLD	(1) LFL (wet) = AFMLD × 1.92	(1) Excess (wet)	(2) LFL (wet) = LD (wet) + Excess (dry)	(2) Excess (wet)	(3) LFL (wet) = LD (wet) × 1.67	(3) Excess (wet)
2000	3833 (1.92)	800 (21%)	4366 (2.18)	1333 (31%)	5055 (2.53)	2022 (40%)
2400	4600 (1.92)	774 (17%)	5426 (2.26)	1600 (29%)	6377 (2.66)	2551 (40%)
2800	5367 (1.92)	713 (13%)	6520 (2.33)	1866 (29%)	7757 (2.77)	3103 (40%)
3200	6133 (1.92)	460 (8%)	7806 (2.44)	2133 (27%)	9455 (2.95)	3782 (40%)

Columns 4 and 5 of Table 5 show the data resulting from method (2), which calculates LFL (wet) by adding the excess distance currently accepted for a dry runway to the wet landing distance. The resulting factors, between about 2.2 and 2.4, are determined by dividing the LFL (wet) by the AFMLD. These factors are significantly higher than the currently used factor of 1.92, but are consistent with the findings of Reference 1 for turbojet aircraft without thrust reverser systems. Method (2) results in higher safety percentages of 31% to 27%, dropping slightly with increasing AFMLD.

Method (3), shown in the last two columns of Table 5, applies the same factor of 1.67 to the wet landing distance to obtain LFL (wet) as is applied in the dry runway case. This method results in the most conservative factors, ranging from 2.5 to almost 3.0. The safety percentages are constant at 40%, as expected after dividing the wet landing distance by 0.6.

The results discussed above, namely the reduced aircraft tire-to-ground braking coefficient, the increased stopping distance (wet) and the reduced safety margin for LFL (wet) based on current calculation methods, are all applicable to the specific case of the Falcon 20 landing on runway 11 at Mirabel in conditions of moderate rainfall. Runway 11 had a smooth concrete surface, with an average SFT self-wetting friction of 0.54, just above the minimum standard for maintenance action. Falcon 20 landings on a rougher runway texture in equivalent conditions of moderate rainfall would likely have resulted in higher braking coefficients and a better safety margin. Since only light rainfall/drizzle occurred during testing on runway 06 at Mirabel, a direct comparison could not be made. The improved braking coefficients noted during the tests on runway 06 were due to a combination of a rougher surface texture and less wetness; the extent of improvement caused by each one could not be determined.

A single dispatch factor may not be appropriate for all runways in Canada, since each runway has its own characteristic average friction value based on composition, texture and maintenance standard. If a runway friction index (wet) were published for each runway, dispatch factors could be tailored to the condition of the runway and perhaps the capabilities of the aircraft. Modern aircraft with digital anti-skid or brake-by-wire systems would not be limited by safety factors applicable to older analogue systems. Conversely, older aircraft would use higher safety factors appropriate to their anti-skid systems. Additionally, runway maintenance performed to improve the published runway friction index would have direct commercial benefit by lowering the dispatch factors and increasing payload capabilities.

6.0 CONCLUSIONS

The NRC Falcon 20 research aircraft was used to obtain stopping distance data with full anti-skid braking without reverse thrust on wet runway surfaces at the Mirabel airport in November 2002 and October 2003. A total of 32 braking runs were recorded, with two on bare and dry surfaces and 30 on bare and wet surfaces. Tests were conducted on four different test sections on each end of the two concrete runways. Saab SFT ground friction vehicles were used to measure the test section friction profiles in the self-wetting mode, and the test section friction before and after each aircraft run.

All of the test objectives listed in section 1.2 were met for the Falcon 20 aircraft on smooth concrete runways. With full anti-skid braking, the aircraft braking coefficients on wet runway surfaces were found to vary in a predictable way with aircraft groundspeed, runway surface texture and degree of wetness.

For the Falcon 20, the tire-to-ground effective braking coefficient was found to be less than the certification requirement for a fully modulating anti-skid braking system. Since no braking system anomalies were evident in the data, the certification criteria may not be conservative for concrete runways with a smooth texture close to the minimum standard for maintenance action. Additional tests would be required to obtain data for different aircraft types, or on asphalt runways with or without heavy rubber contamination.

The results of Falcon 20 tests on rain wet concrete runways indicated that the current operational dispatch factor of 1.92 for turbojet aircraft landing on wet runways at destination or alternate airports would have to be increased to a value of at least 2.2 to 2.4 in order to achieve the same level of safety as that which is currently accepted on a dry runway.

The following specific conclusions are made:

a) During the initial part of the October 2003 test period, discrepancies occurred between the Tradewind SFT and the TC SFT friction measurements as a result of test tire configuration. Issues relating to SFT test tire quality control and calibration should be addressed;

b) Limited data on two rain wet test surfaces showed that runway texture plays a dominant role in the SFT-measured friction values, and that SFT self-wetting runs produced friction values close to the SFT-measured friction on the actual rain wet surfaces;

c) SFT-measured friction on tanker wet surfaces consistently increased as the degree of runway “wetness” decreased over time due to water evaporation and runway drainage;

d) SFT-measured friction on tanker wet surfaces was generally slightly higher than values obtained from SFT self-wetting runs or equivalent rain wet friction;

e) Mean aircraft braking coefficients for all test points on both wet and dry surfaces had an excellent linear correlation with mean anti-skid modulated brake pressures;

f) The relationship between aircraft braking coefficient and groundspeed derived from single braking runs can be significantly affected by local variations in runway texture and/or wetness;

g) A single landing of opportunity on rain wet runway 25 at the Ottawa airport resulted in a very low aircraft braking coefficient on the heavy rubber contaminated portion of the runway;

h) SFT-measured friction increased and aircraft braking performance improved on a well washed runway surface, compared to a surface initially wet but still containing particles of dust, dirt or grease;

i) The relationships between aircraft braking coefficients and groundspeed plotted for combined runs on either rain wet or tanker wet test sections were consistent with individual runs on the same test section, with some exceptions noted for local surface variations;

j) The Falcon 20 braking performance significantly improved as friction increased due to rougher surface texture or lower degree of wetness;

k) The Falcon 20 braking performance was generally better on a tanker wet surface than on an equivalent rain wet surface, consistent with higher SFT-measured friction in conclusion (d);

l) The Falcon tire-to-ground effective braking coefficient data were essentially identical to the ESDU 50% efficiency level, well below the certification requirement of 80% efficiency for a fully modulating anti-skid braking system;

m) For landings on wet runways, the excess distance between the landing field length, calculated using the current method, and the actual landing distance was considerably less than the excess distance on dry runways;

n) A wet runway safety factor between 2.2 and 2.4 would have to be used to make the excess distance between the calculated landing field length and the actual landing distance on a wet runway the same as that currently accepted for a dry runway.

7.0 ACKNOWLEDGEMENTS

The majority of the funding for this project was provided by Transport Canada. The aircraft and ground vehicle tests were conducted safely and effectively due to the dedication and expertise of the combined Transport Canada / NRC test team and their subcontractors. The enthusiasm and support of the Mirabel airport personnel was essential to the success of the project, and is gratefully acknowledged.

8.0 REFERENCES

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2. Croll, J.B., *Preliminary Results of Falcon 20 Braking Performance Tests on Wet Runway Surfaces at the Mirabel Airport in November 2002,* National Research Council, Institute for Aerospace Research, Flight Test Report FR-FTR-25, August 2003.

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9. Stubbs, S.M., Tanner, J.A., *Behaviour of Aircraft Anti-skid Braking Systems on Dry and Wet Runway Surfaces – A Velocity-Rate-Controlled, Pressure-Bias-Modulated System,* NASA Technical Note TN D-8332, December 1976.

APPENDIX A - SUMMARY OF TEST RUNS

The following table shows the test conditions for all runs during both test periods in November 2002 and October 2003. The table columns, from the left, include the flight number and date, the run number and local time, the runway used, the aircraft manoeuvre used (taxi, accel/stop or landing), the aircraft configuration, the aircraft weight, the tower reported wind, the runway surface description, the SFT readings and average, and the aircraft CG arm where applicable.

Pages A5 to A23 show the time histories of left and right brake pressures, aircraft ground speed, and aircraft braking coefficient (MuB) for all test runs, with two runs per page. Selected statistics for each parameter are shown in small print above each plot. The aircraft MuB shown is the MuB calculated in equation 1 (section 4.0 of this report) from raw recorded data at a sample rate of 32 samples per second. For the taxi runs and coasting runs (no brakes) the brake pressures are zero, and MuB reduces to the aircraft rolling friction coefficient.

FLT/ DATE	RUN/ Time	RW	TAXI/ RTO/ LAND	CONFIG (see Note 1)	Weight (LB)	TWR Wind (KT)	SURFACE DESCRIPTION And Comments	SFT RFI Average (see Note 2)	CG ARM
2002/01 20/11/02	1 1352	29	TAXI	15/IN/NO	22,860	220/3	Bare and Dry		
	2 1357	11	TAXI	15/IN/NO	22,710	210/3	Bare and Dry		
	3 1408	29	LAND	40/EXT/B	22,460	200/5	Bare and Dry	0.96/1.02 0.99	
	4 1439	29	LAND	15/IN/NO	21,660	220/2	Bare and Dry No data, DAS failure		
	5 1512	29	Accel/ Stop	15/EXT/B	21,060	Calm	Tanker Wet	0.56/0.58 0.57	
	6 1529	29	LAND	40/EXT/B	20,560	Calm	Tanker Wet Remaining	0.60/0.65 0.63	
2002/02 21/11/02	1 1219	11	LAND	40/EXT/NO	23,840	055/4	Bare and Dry		
2002/03 21/11/02	1 1340	11	LAND	40/EXT/B	23,240	060/6	Bare and Dry	0.95/1.02 0.99	
	2 1410	11	Accel/ Stop	40/EXT/B	22,940	060/5	Tanker Wet	0.57/0.58 0.57	
	3 1425	11	LAND	40/EXT/B	22,340	060/5	Tanker Wet Remaining	0.63/0.60 0.62	
	4 1456	11	Accel/ Stop	15/EXT/B	21,790	060/5	Tanker Re-wet	0.57/0.64 0.61	
	5 1508	11	LAND	15/EXT/B	21,340	060/4	Tanker Wet Remaining	0.60/0.70 0.65	
2003/01 27/10/03	1 1438	11	Accel/ Stop	15/EXT/B	22,972	055/4	Rain Wet Aircraft on runway C/L	0.67/0.46 0.56	22.48
	2 1446	11	Accel/ Stop	15/EXT/B	22,812	050/3	Rain Wet Aircraft left of runway C/L	0.67/0.47 0.57	22.46

FLT/ DATE	RUN/ Time	RW	TAXI/ RTO/ LAND	CONFIG (see Note 1)	Weight (LB)	TWR Wind (KT)	SURFACE DESCRIPTION And Comments	SFT RFI Average (see Note 2)	CG ARM
2003/02 28/10/03	1 1111	29	Accel/ Stop	15/EXT/B	23,374	230/6	Tanker Wet	0.52/0.53 0.52	21.84
	2 1124	29	LAND	40/EXT/B	22,894	265/6	Tanker Wet Remaining	0.59/0.58 0.59	21.54
	3 1149	29	LAND	40/EXT/B	22,114	235/8	Tanker Re-wet	0.53/0.54 0.53	21.03
	4 1159	29	LAND	40/EXT/B	21,904	250/5	Tanker Wet Remaining	0.56/0.59 0.58	20.87
	5 1211	29	LAND	40/EXT/B	21,404	250/8	Tanker Wet Remaining	0.60/0.66 0.63	20.72
2003/03 28/10/03	1 1349	29	Accel/ Stop	15/EXT/B	21,104	240/5	Tanker Wet	0.52/0.53 0.53	20.84
	2 1358	29	LAND	40/EXT/B	20,604	250/4	Tanker Wet Remaining	0.55/0.56 0.55	21.05
	3 1407	29	LAND	40/EXT/B	20,354	230/3	Tanker Wet Remaining	0.56/0.60 0.58	21.19
	4 1428	29	Touch & Go	15/EXT/B	19,644	230/4	Tanker Re-wet	0.50/0.53 0.51	21.78
	5 1434	29	LAND	15/EXT/B	19,404	240/4	Tanker Wet Remaining	0.53/0.57 0.55	21.99
2003/04 29/10/03	1 1112	11	LAND	40/EXT/B	22,304	050/9	Rain Wet Aircraft left of rwy C/L	0.54/0.56 0.55	21.20
	2 1127	11	LAND	40/EXT/B	21,754	050/8	Rain Wet Aircraft left of rwy C/L	0.52/0.56 0.54	20.77
	3 1141	11	LAND	40/EXT/B	21,334	055/7	Rain Wet Aircraft left of rwy C/L	0.53/0.57 0.55	20.73
	4 1155	11	LAND	40/EXT/B	20,704	060/6	Rain Wet Aircraft left of rwy C/L	0.53/0.58 0.56	21.01
2003/05 29/10/03	1 1347	06	LAND	40/EXT/B	24,254	035/6	Rain Wet Aircraft on rwy C/L	0.75/0.84 0.80	22.49
	2 1401	06	LAND	40/EXT/B	23,804	025/7	Rain Wet Aircraft on rwy C/L	0.74/0.81 0.78	22.13
	3 1414	06	LAND	40/EXT/B	23,304	005/4	Rain Wet Aircraft on rwy C/L	0.72/0.77 0.74	21.83
	4 1426	06	LAND	40/EXT/B	22,904	020/4	Rain Wet Aircraft on rwy C/L	0.70/0.73 0.72	21.53
	5 1453	25 YOW	LAND	40/EXT/B	21,654	270/5	Rain Wet Target of Opp at Ottawa		20.75
2003/06 30/10/03	1 0931	24	LAND Coast	40/EXT/NO	24,056	265/15	Bare and Dry		21.56

FLT/ DATE	**RUN/ Time**	**RW**	**TAXI/ RTO/ LAND**	**CONFIG (see Note 1)**	**Weight (LB)**	**TWR Wind (KT)**	**SURFACE DESCRIPTION And Comments**	**SFT RFI Average (see Note 2)**	**CG ARM**
2003/07 30/10/03	1 1334	24	Accel/ Stop	15/EXT/B	23,536	260/14	Tanker Wet	0.76/---- 0.76	21.27
	2 1342	24	LAND	40/EXT/B	23,186	270/14	Tanker Wet Remaining	0.80/---- 0.80	21.00
	3 1400	24	LAND	40/EXT/B	22,636	250/15	Tanker Re-wet	0.79/---- 0.79	20.63
	4 1418	24-06	TAXI	15/IN/NO	22,286	255/13	Almost Bare and Dry		

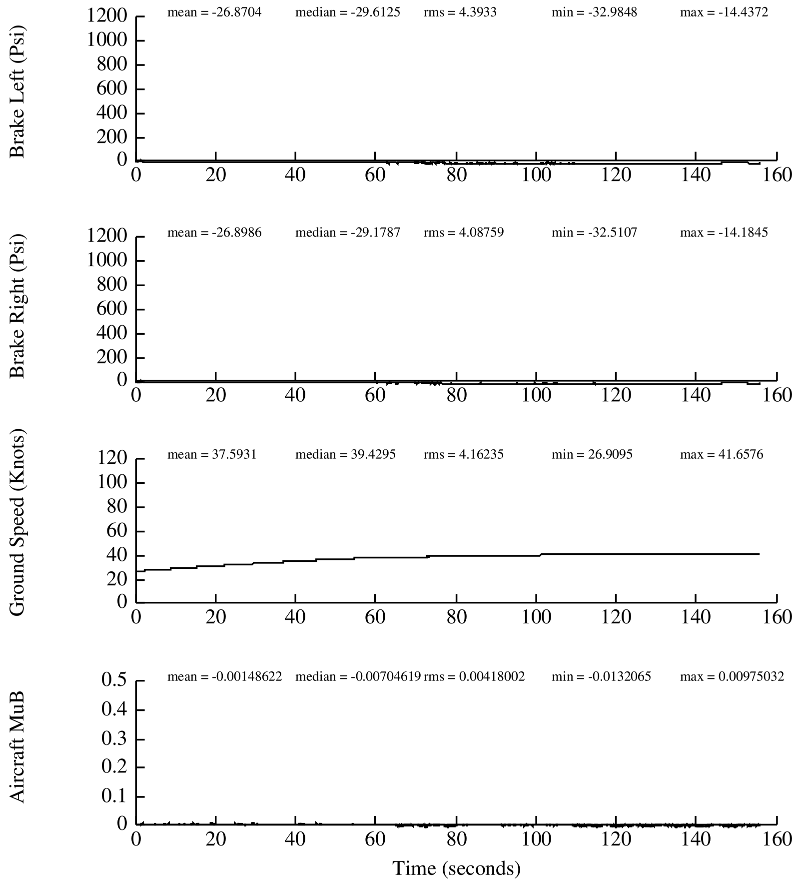
Note 1: Indicates flap setting (15 or 40), airbrake position (IN or EXT) and pilot braking (NO for no braking, B for maximum anti-skid braking)

Note 2: Tradewind SFT / TC SFT Turbo
Average

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/1, Run 1 20-Nov-2002

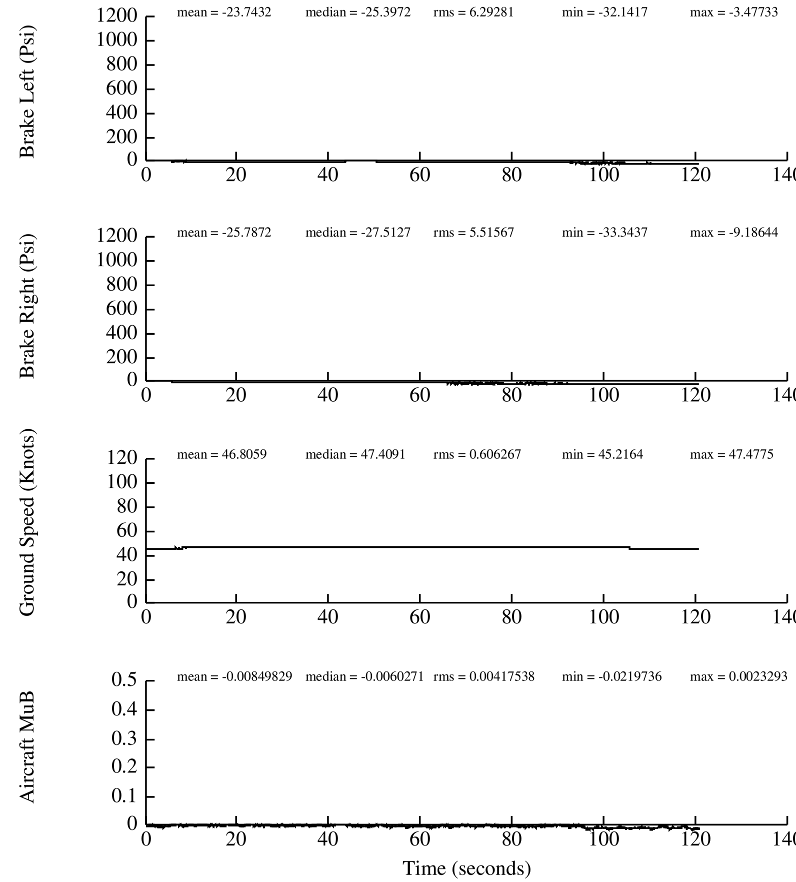
Bare and Dry Runway 29, Wind 220/3



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/1, Run 2 20-Nov-2002

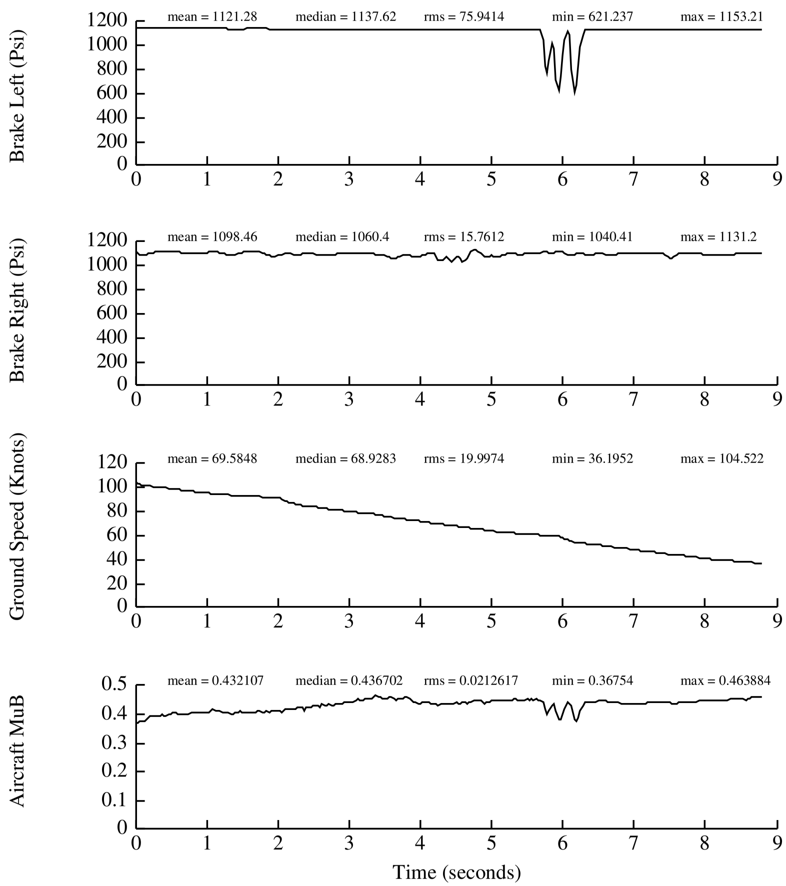
Bare and Dry Runway 11, Wind 210/3



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/1, Run 3 20-Nov-2002

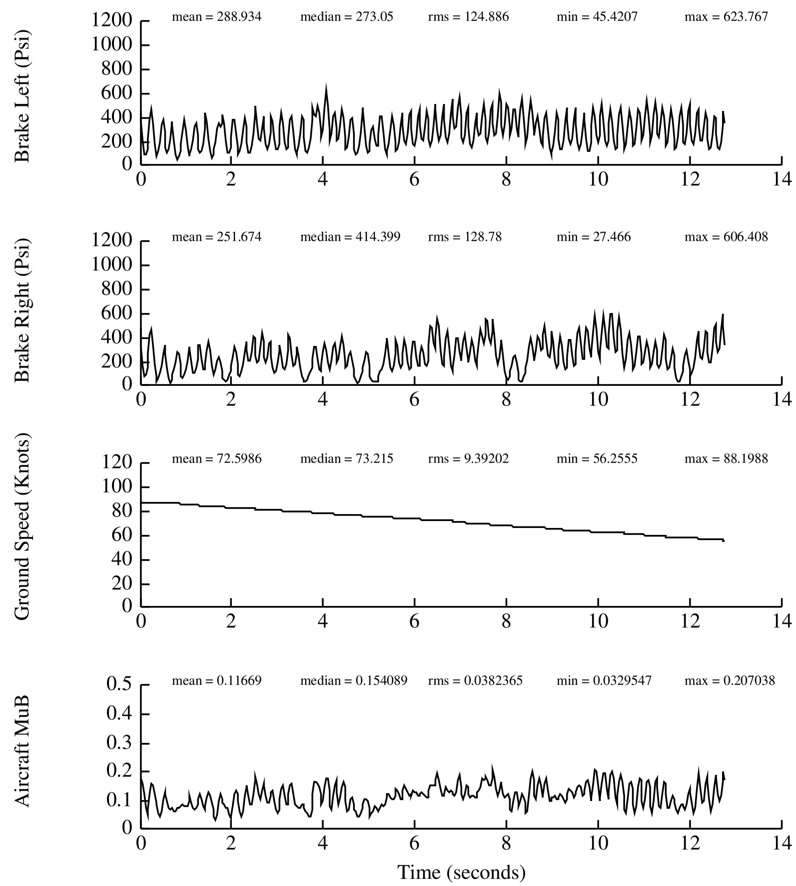
Bare and Dry Runway 29, Wind 200/5



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/1, Run 5 20-Nov-2002

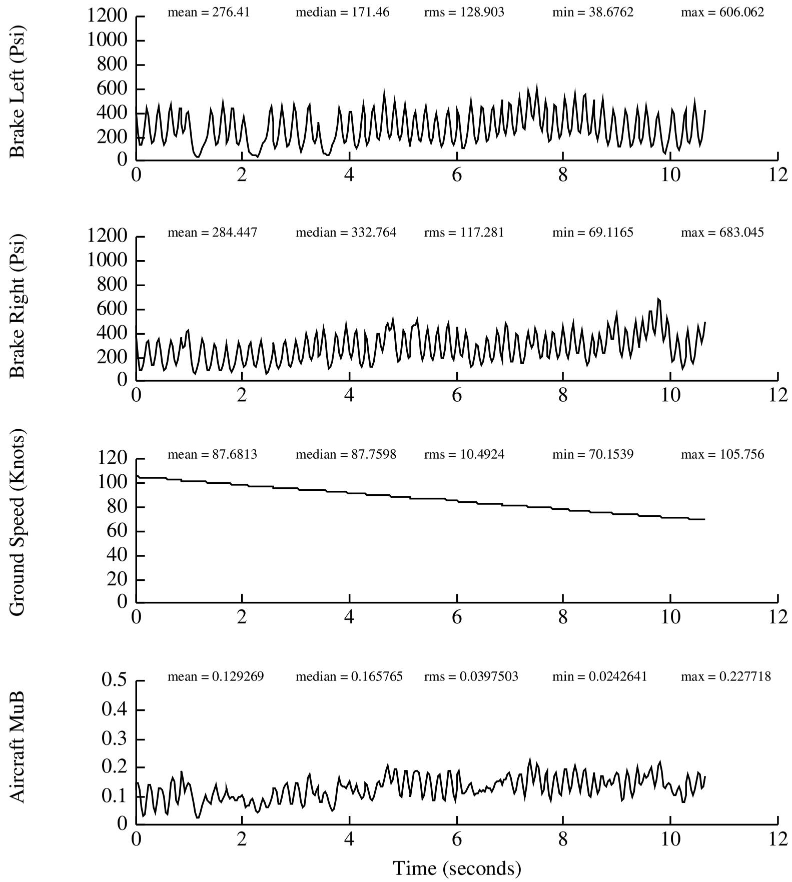
Tanker Wet Runway 29, Wind Calm



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/1, Run 6 20-Nov-2002

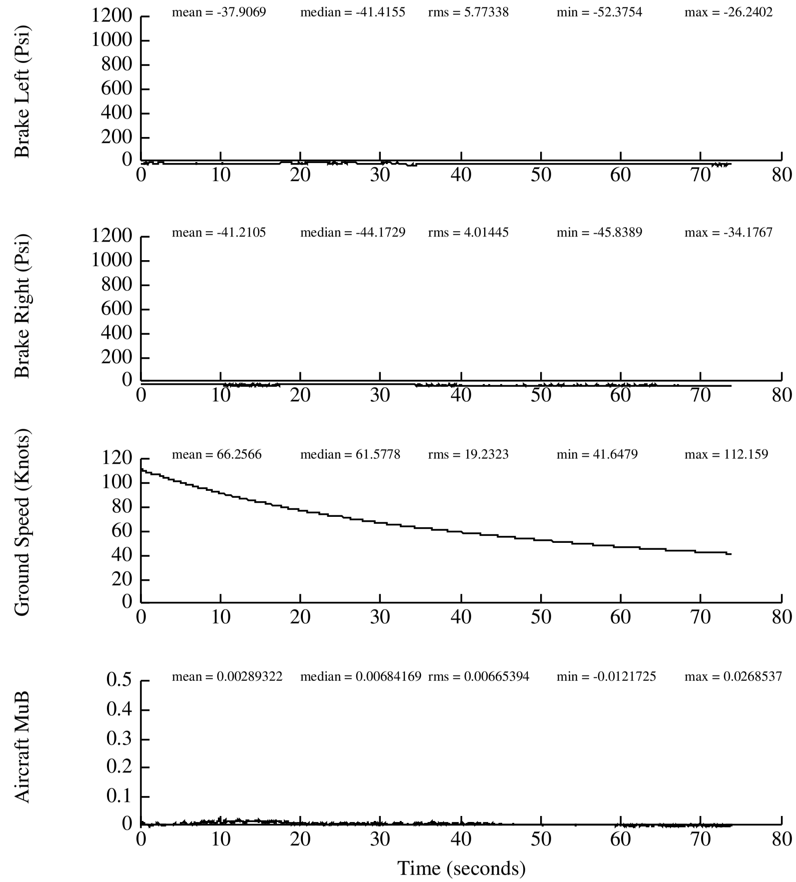
Tanker Wet Remaining Runway 29, Wind Calm

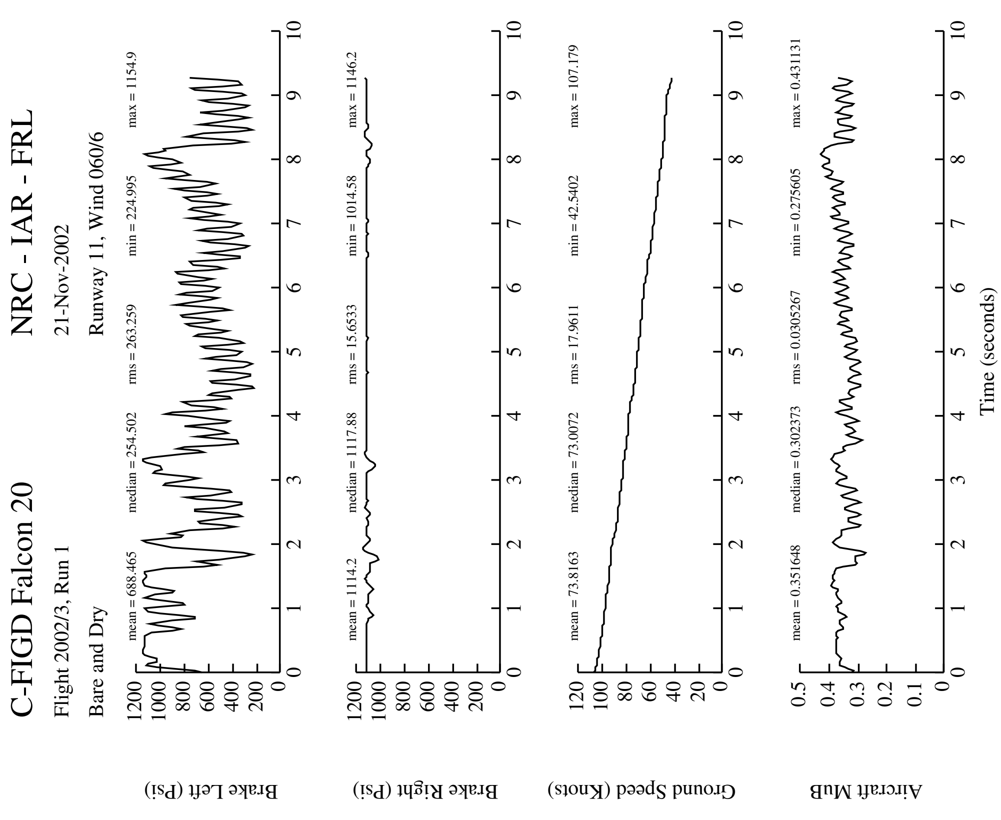


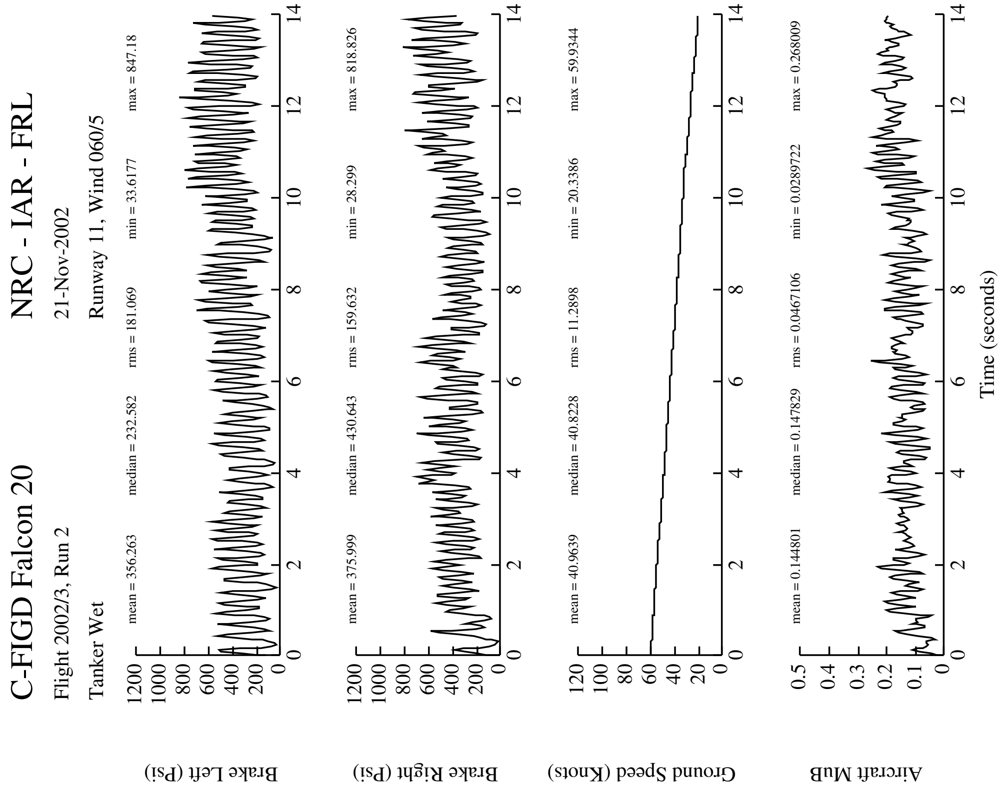
C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/2, Run 1 21-Nov-2002

Bare and Dry Runway 11, Wind 055/4



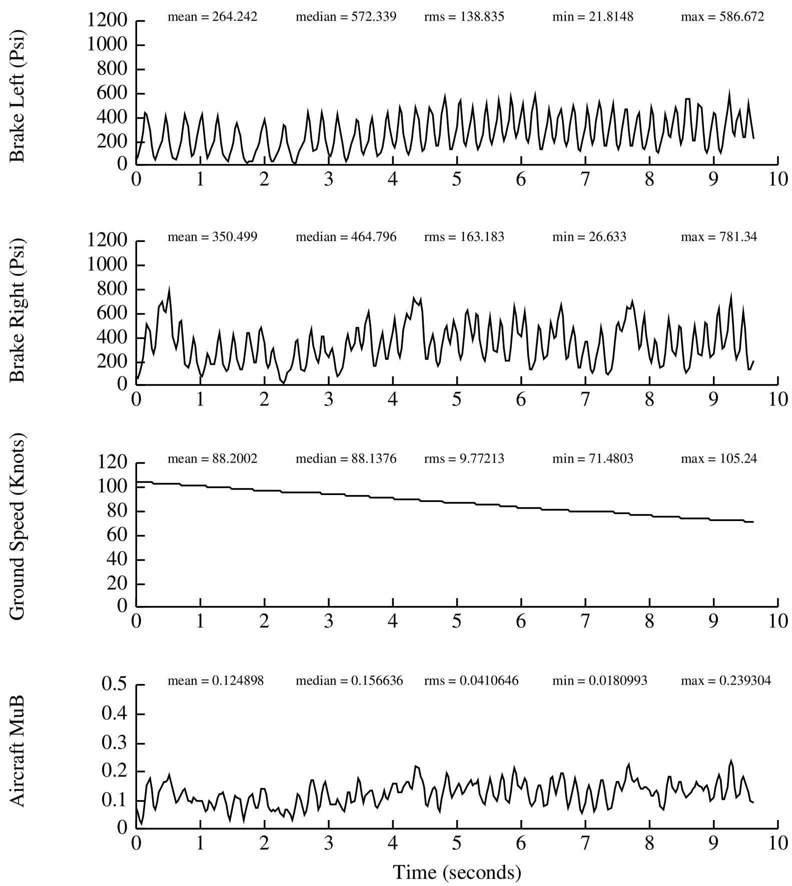

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2002/3, Run 1
21-Nov-2002
Bare and Dry
Runway 11, Wind 060/6
mean = 688.465
median = 254.502
rms = 263.259
min = 224.995
max = 1154.9
mean = 1114.2
median = 1117.88
rms = 15.6533
min = 1014.58
max = 1146.2
mean = 73.8163
median = 73.0072
rms = 17.9611
min = 42.5402
max = 107.179
mean = 0.351648
median = 0.302373
rms = 0.0305267
min = 0.275605
max = 0.431131
Brake Left (Psi)
Brake Right (Psi)
Ground Speed (Knots)
Aircraft MuB
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2002/3, Run 2
21-Nov-2002
Tanker Wet
Runway 11, Wind 060/5
mean = 356.263
median = 232.582
rms = 181.069
min = 33.6177
max = 847.18
mean = 375.999
median = 430.643
rms = 159.632
min = 28.299
max = 818.826
mean = 40.9639
median = 40.8228
rms = 11.2898
min = 20.3386
max = 59.9344
mean = 0.144801
median = 0.147829
rms = 0.0467106
min = 0.0289722
max = 0.268009
Brake Left (Psi)
Brake Right (Psi)
Ground Speed (Knots)
Aircraft MuB
Time (seconds)

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2002/3, Run 3 21-Nov-2002

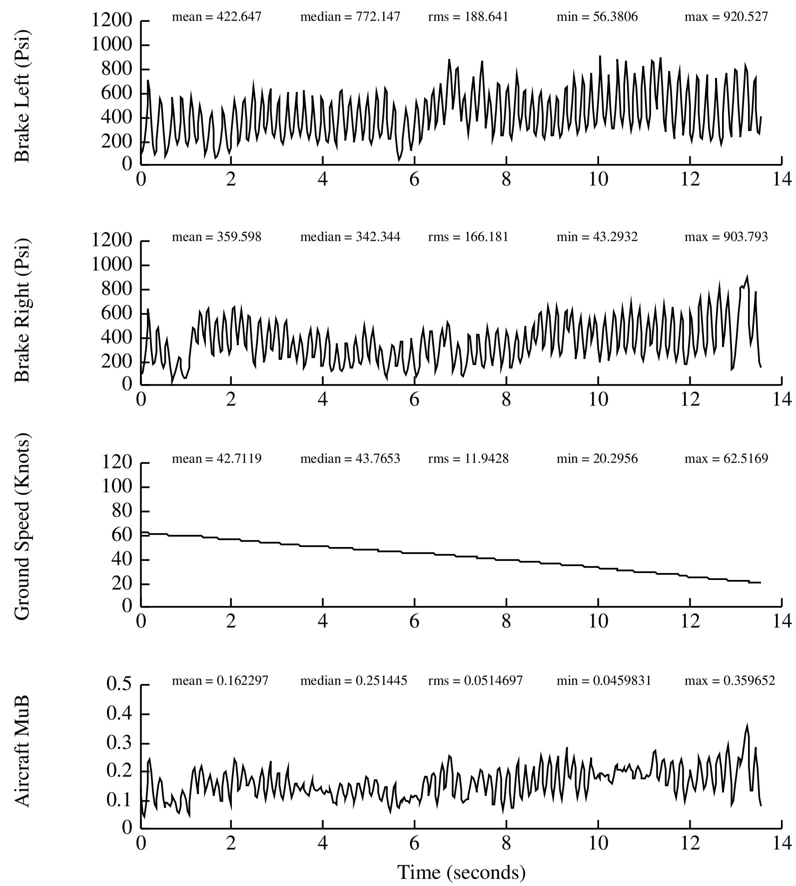
Tanker Wet Remaining Runway 11, Wind 060/5

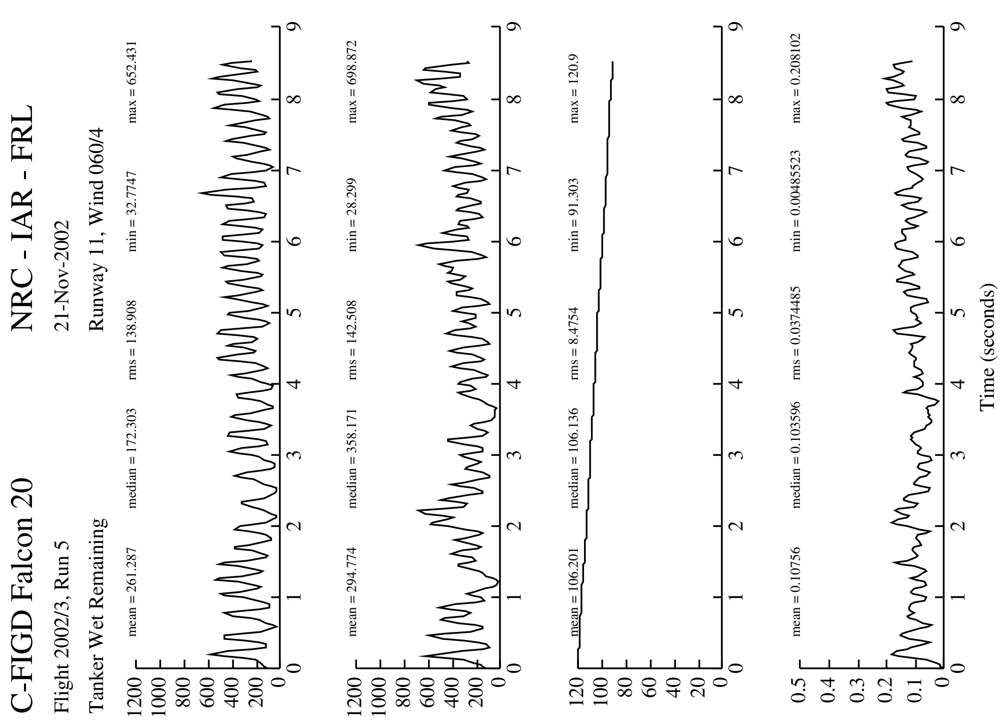


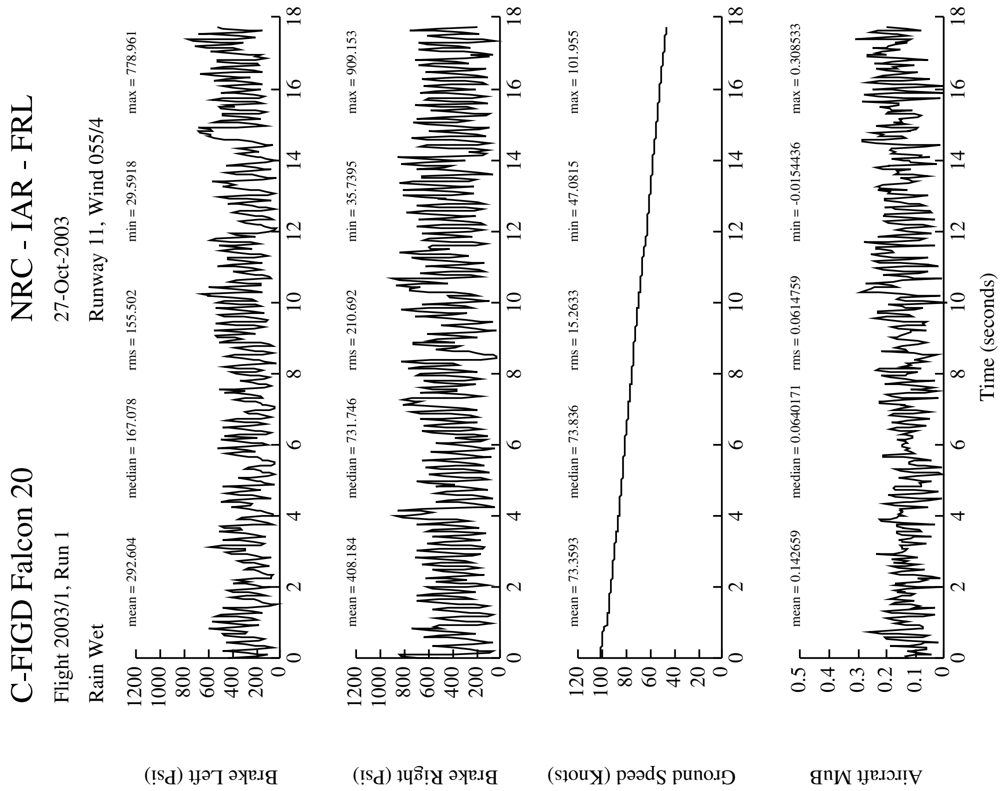
C-FIGD Falcon 20 NRC - IAR - FRL

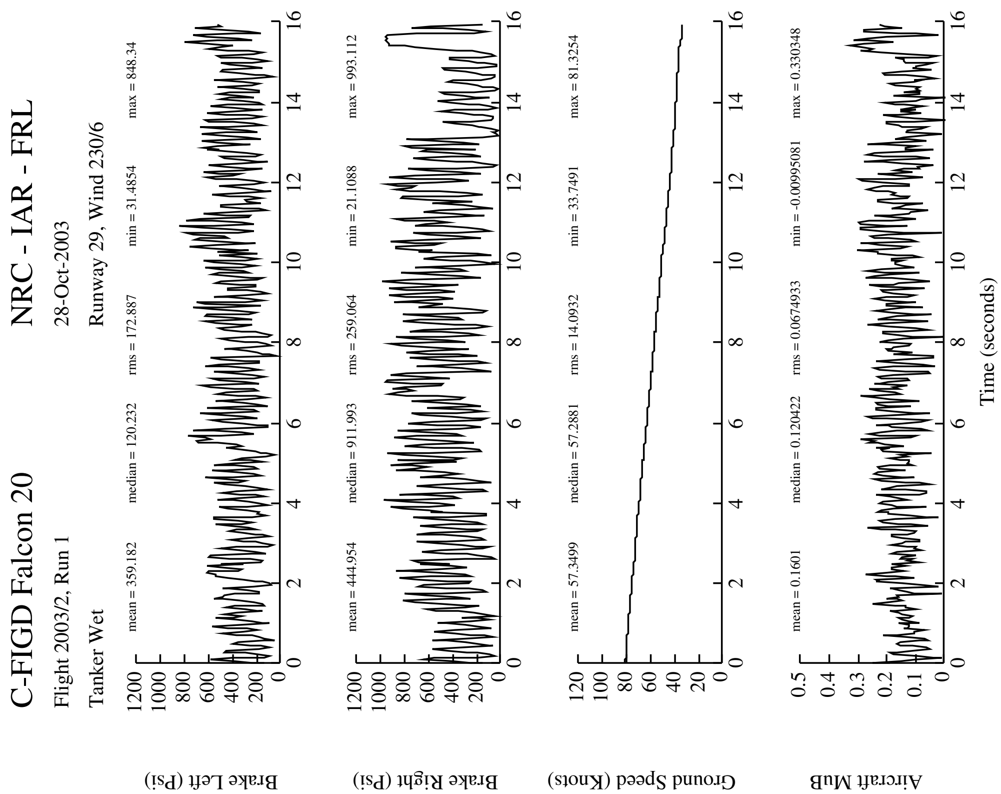
Flight 2002/3, Run 4 21-Nov-2002

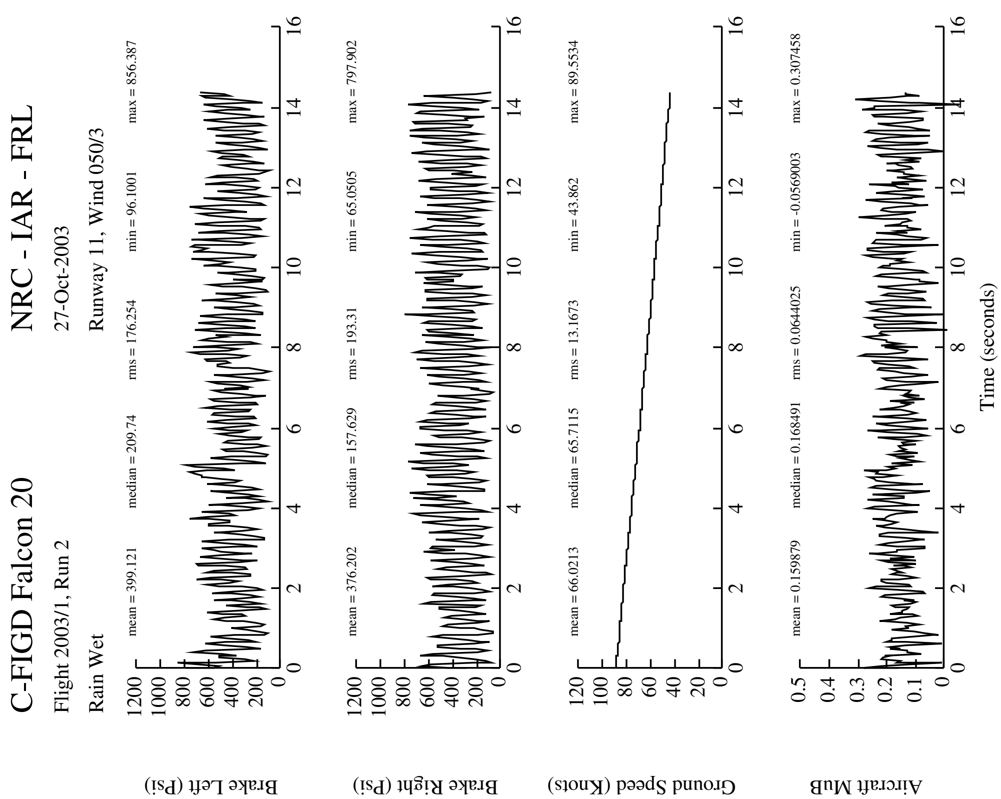
Tanker Re-wet Runway 11, Wind 060/5



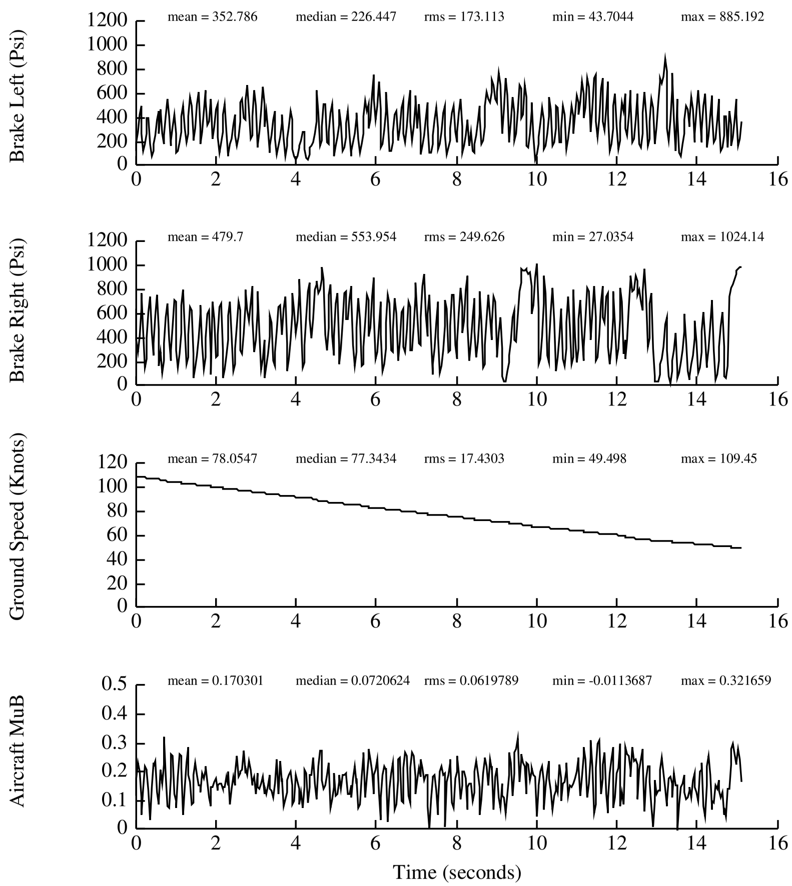

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2002/3, Run 5
21-Nov-2002
Tanker Wet Remaining
Runway 11, Wind 060/4
mean = 261.287 median = 172.303 rms = 138.908 min = 32.7747 max = 652.431
mean = 294.774 median = 358.171 rms = 142.508 min = 28.299 max = 698.872
mean = 106.201 median = 106.136 rms = 8.4754 min = 91.303 max = 120.9
mean = 0.10756 median = 0.103596 rms = 0.0374485 min = 0.00485523 max = 0.208102
Brake Left (Psi)
Brake Right (Psi)
Ground Speed (Knots)
Aircraft MuB
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/1, Run 1
27-Oct-2003
Rain Wet
Runway 11, Wind 055/4
mean = 292.604 median = 167.078 rms = 155.502 min = 29.5918 max = 778.961
mean = 408.184 median = 731.746 rms = 210.692 min = 35.7395 max = 909.153
mean = 73.3593 median = 73.836 rms = 15.2633 min = 47.0815 max = 101.955
mean = 0.142659 median = 0.0640171 rms = 0.0614759 min = -0.0154436 max = 0.308533
Brake Left (Psi)
Brake Right (Psi)
Ground Speed (Knots)
Aircraft MuB
Time (seconds)

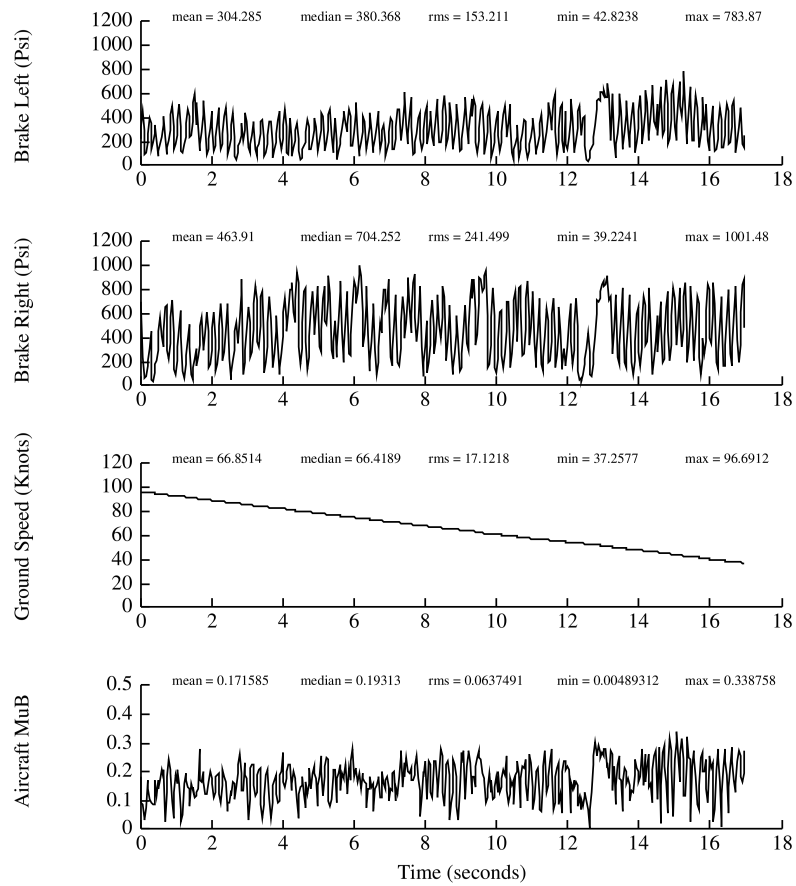

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/2, Run 1
28-Oct-2003
Tanker Wet
Runway 29, Wind 230/6
Brake Left (Psi)
mean = 359.182
median = 120.232
rms = 172.887
min = 31.4854
max = 848.34
Brake Right (Psi)
mean = 444.954
median = 911.993
rms = 259.064
min = 21.1088
max = 993.112
Ground Speed (Knots)
mean = 57.3499
median = 57.2881
rms = 14.0932
min = 33.7491
max = 81.3254
Aircraft MuB
mean = 0.1601
median = 0.120422
rms = 0.0674933
min = -0.00995081
max = 0.330348
Time (seconds)

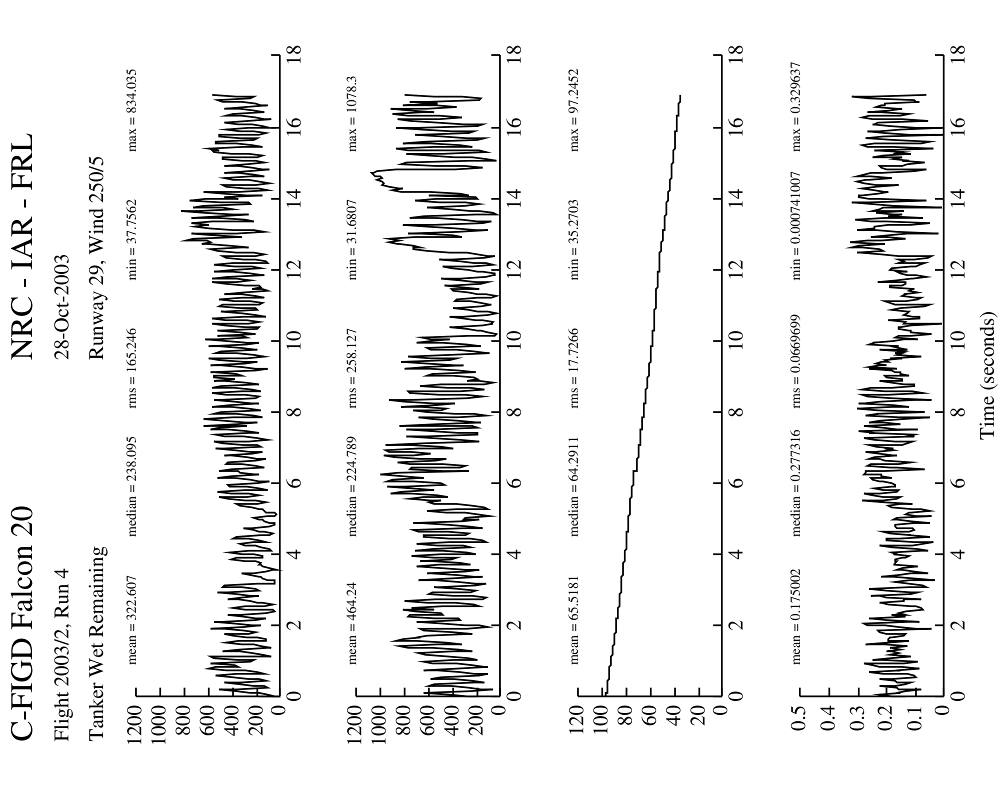

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/1, Run 2
27-Oct-2003
Rain Wet
Runway 11, Wind 050/3
Brake Left (Psi)
mean = 399.121
median = 209.74
rms = 176.254
min = 96.1001
max = 856.387
Brake Right (Psi)
mean = 376.202
median = 157.629
rms = 193.31
min = 65.0505
max = 797.902
Ground Speed (Knots)
mean = 66.0213
median = 65.7115
rms = 13.1673
min = 43.862
max = 89.5534
Aircraft MuB
mean = 0.159879
median = 0.168491
rms = 0.0644025
min = -0.0569003
max = 0.307458
Time (seconds)

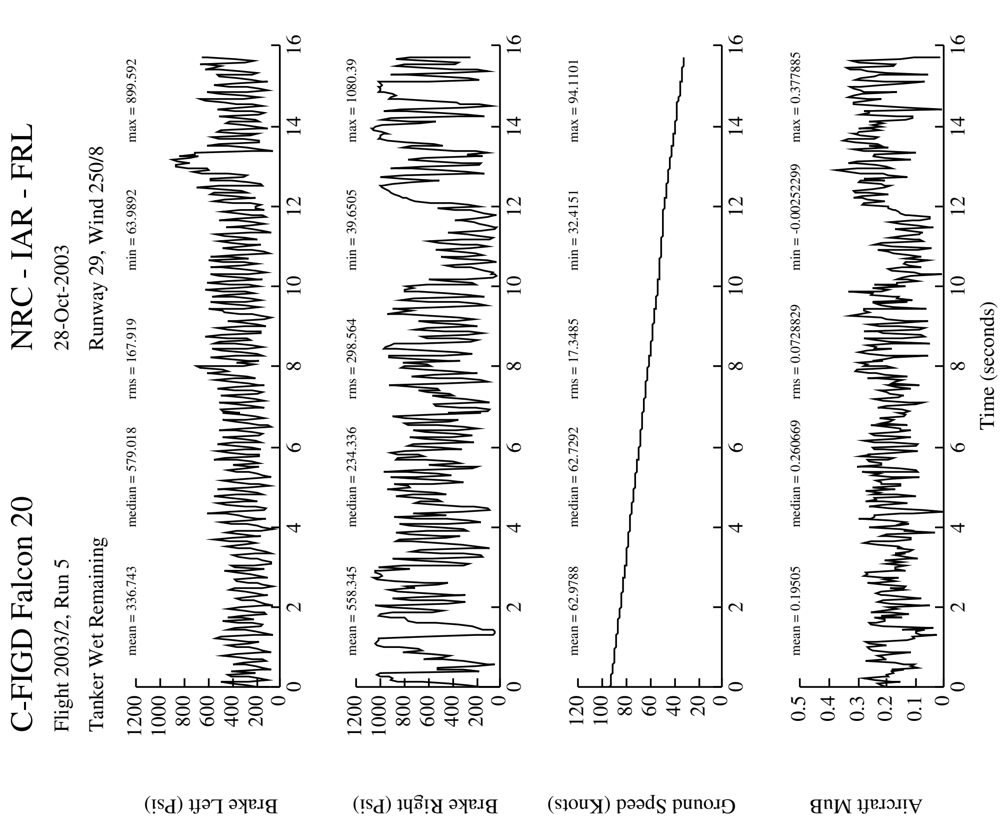
C-FIGD Falcon 20 NRC - IAR - FRL
Flight 2003/2, Run 2 28-Oct-2003
Tanker Wet Remaining Runway 29, Wind 265/6

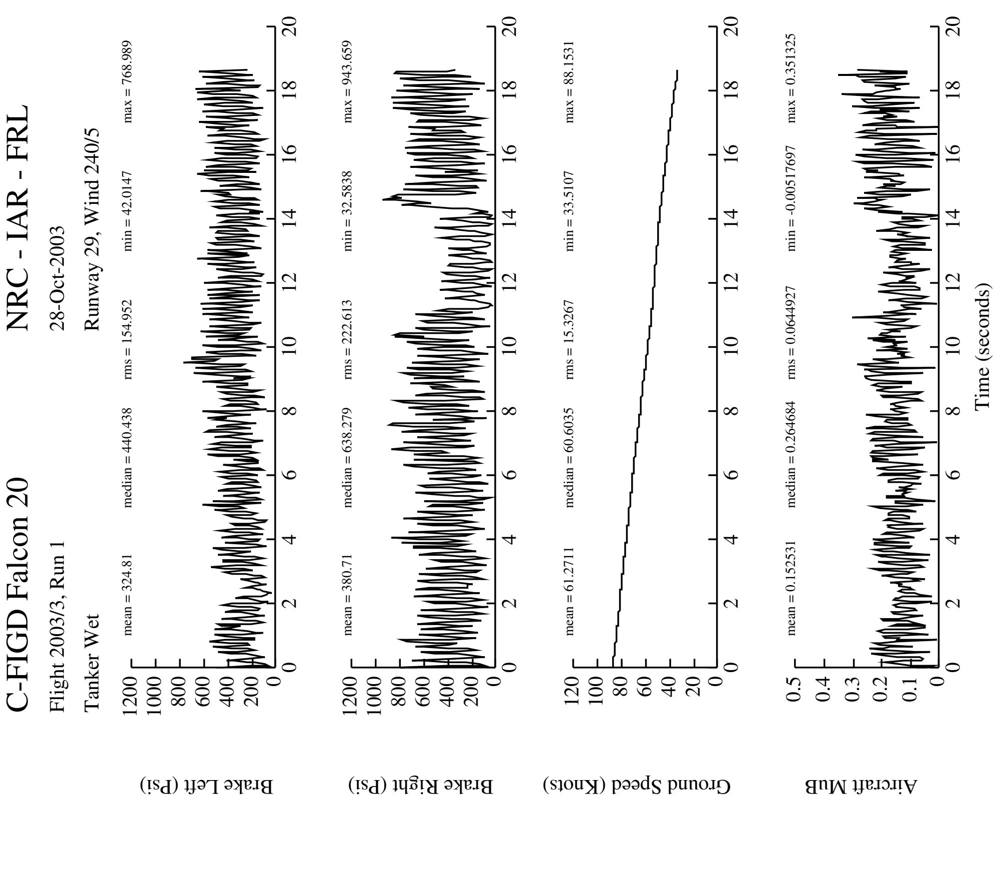


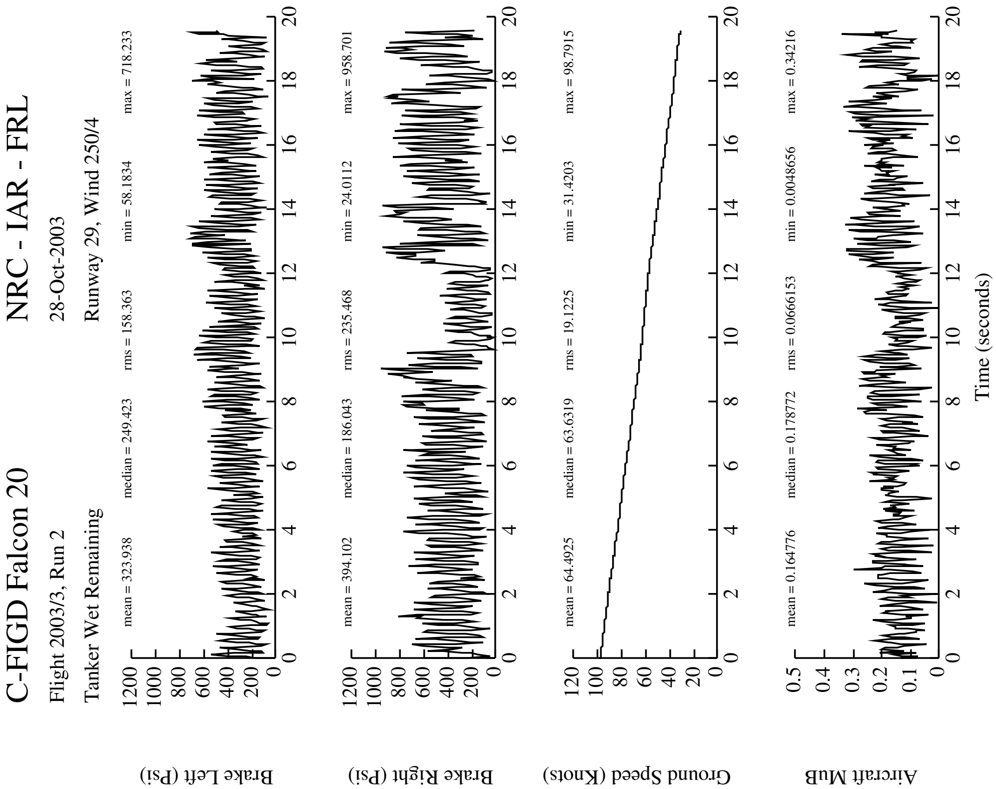
C-FIGD Falcon 20 NRC - IAR - FRL
Flight 2003/2, Run 3 28-Oct-2003
Tanker Re-wet Runway 29, Wind 235/8




C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/2, Run 4
28-Oct-2003
Tanker Wet Remaining
Runway 29, Wind 250/5
mean = 322.607
median = 238.095
rms = 165.246
min = 37.7562
max = 834.035
Brake Left (Psi)
mean = 464.24
median = 224.789
rms = 258.127
min = 31.6807
max = 1078.3
Brake Right (Psi)
mean = 65.5181
median = 64.2911
rms = 17.7266
min = 35.2703
max = 97.2452
Ground Speed (Knots)
mean = 0.175002
median = 0.277316
rms = 0.0669699
min = 0.000741007
max = 0.329637
Aircraft MuB
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/2, Run 5
28-Oct-2003
Tanker Wet Remaining
Runway 29, Wind 250/8
mean = 336.743
median = 579.018
rms = 167.919
min = 63.9892
max = 899.592
Brake Left (Psi)
mean = 558.345
median = 234.336
rms = 298.564
min = 39.6505
max = 1080.39
Brake Right (Psi)
mean = 62.9788
median = 62.7292
rms = 17.3485
min = 32.4151
max = 94.1101
Ground Speed (Knots)
mean = 0.19505
median = 0.260669
rms = 0.0728829
min = -0.00252299
max = 0.377885
Aircraft MuB
Time (seconds)

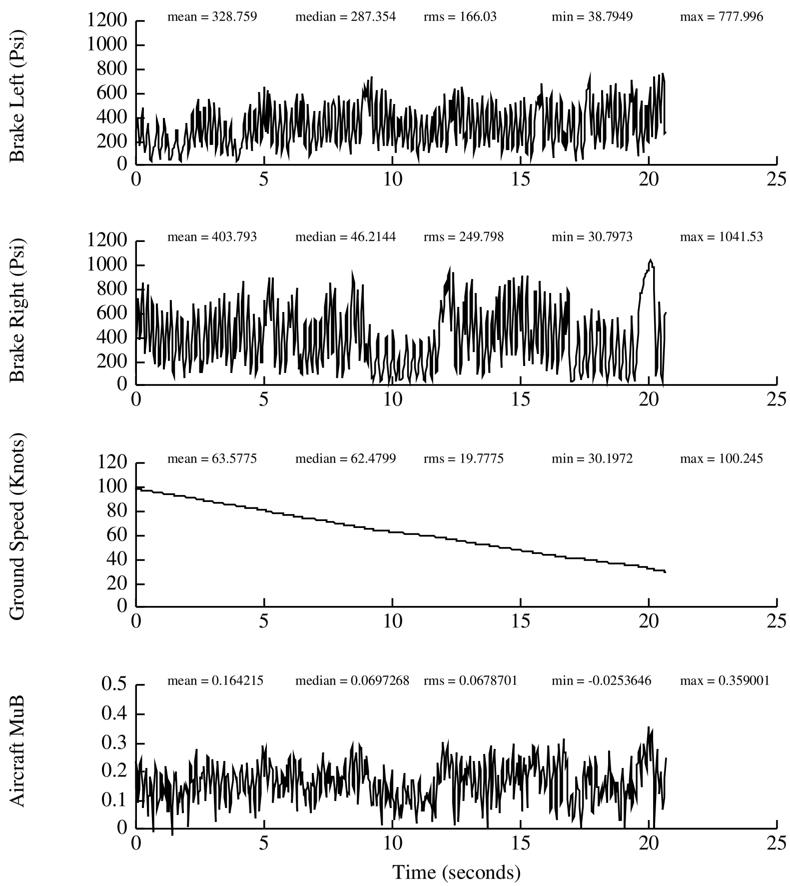

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/3, Run 1
28-Oct-2003
Tanker Wet
Runway 29, Wind 240/5
Brake Left (Psi)
mean = 324.81
median = 440.438
rms = 154.952
min = 42.0147
max = 768.989
Brake Right (Psi)
mean = 380.71
median = 638.279
rms = 222.613
min = 32.5838
max = 943.659
Ground Speed (Knots)
mean = 61.2711
median = 60.6035
rms = 15.3267
min = 33.5107
max = 88.1531
Aircraft MuB
mean = 0.152531
median = 0.264684
rms = 0.0644927
min = -0.00517697
max = 0.351325
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/3, Run 2
28-Oct-2003
Tanker Wet Remaining
Runway 29, Wind 250/4
Brake Left (Psi)
mean = 323.938
median = 249.423
rms = 158.363
min = 58.1834
max = 718.233
Brake Right (Psi)
mean = 394.102
median = 186.043
rms = 235.468
min = 24.0112
max = 958.701
Ground Speed (Knots)
mean = 64.4925
median = 63.6319
rms = 19.1225
min = 31.4203
max = 98.7915
Aircraft MuB
mean = 0.164776
median = 0.178772
rms = 0.0666153
min = 0.0048656
max = 0.34216
Time (seconds)

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2003/3, Run 3 28-Oct-2003

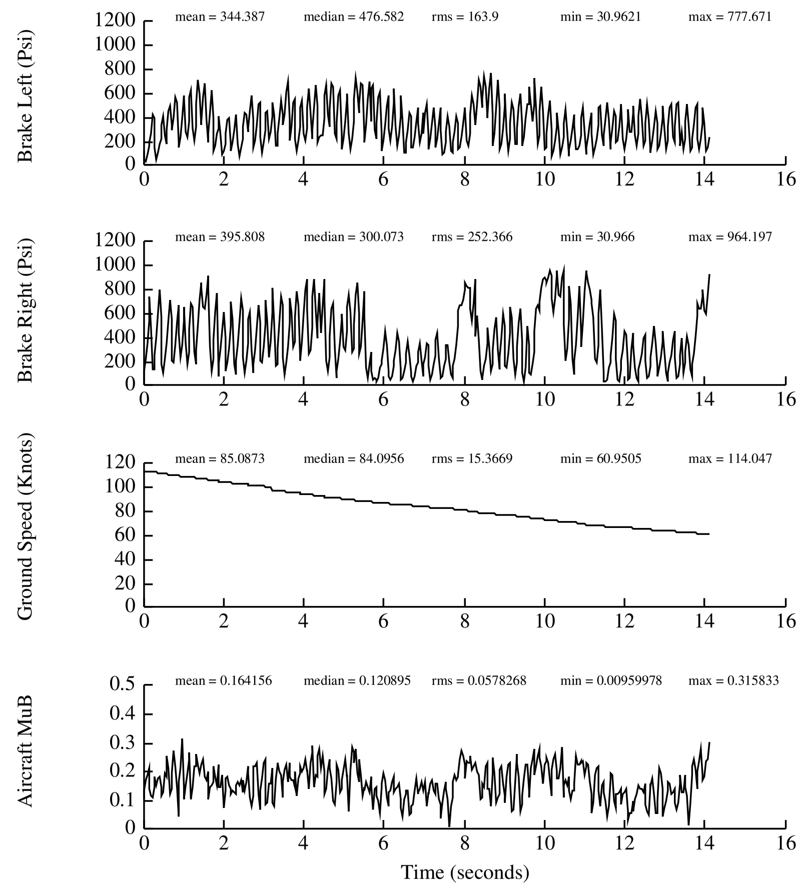
Tanker Wet Remaining Runway 29, Wind 230/3



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2003/3, Run 4 28-Oct-2003

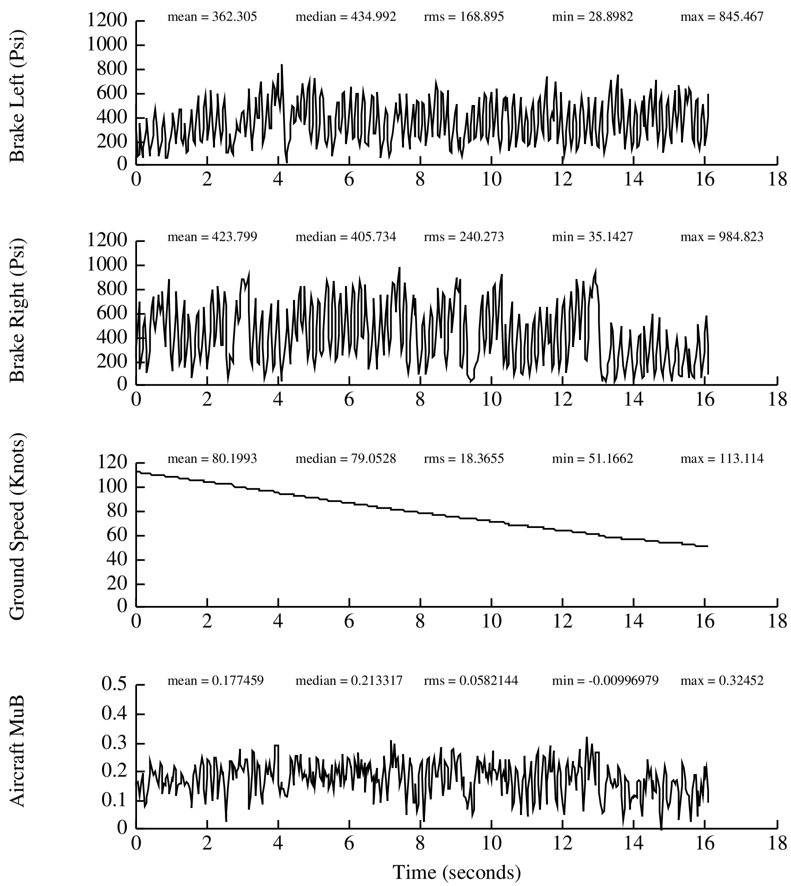
Tanker Re-wet Runway 29, Wind 230/4



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2003/3, Run 5 28-Oct-2003

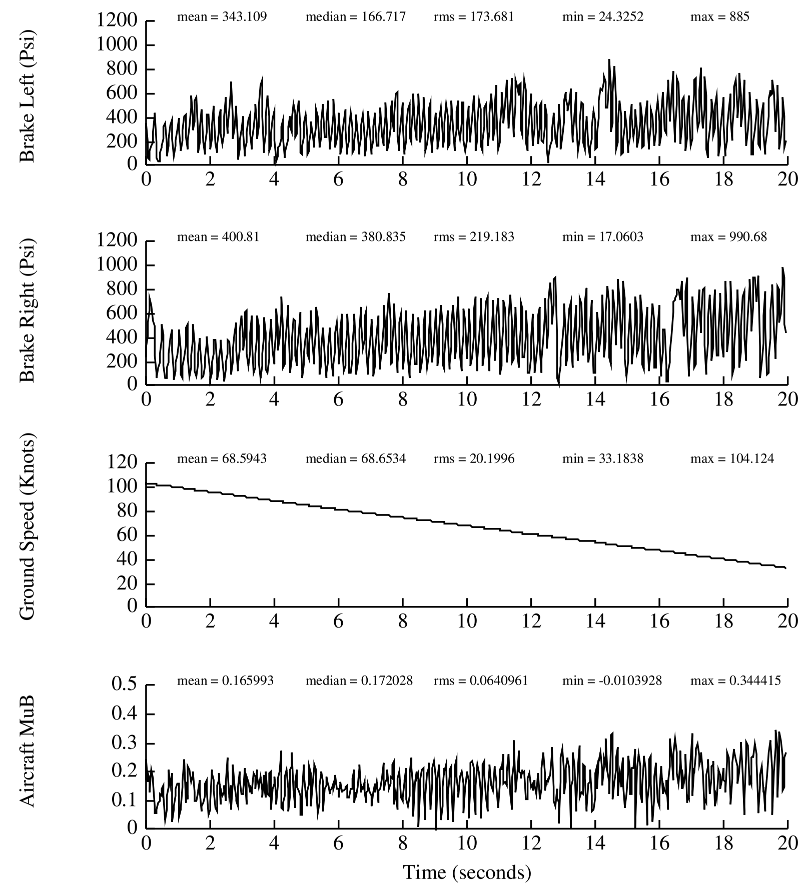
Tanker Wet Remaining Runway 29, Wind 240/4

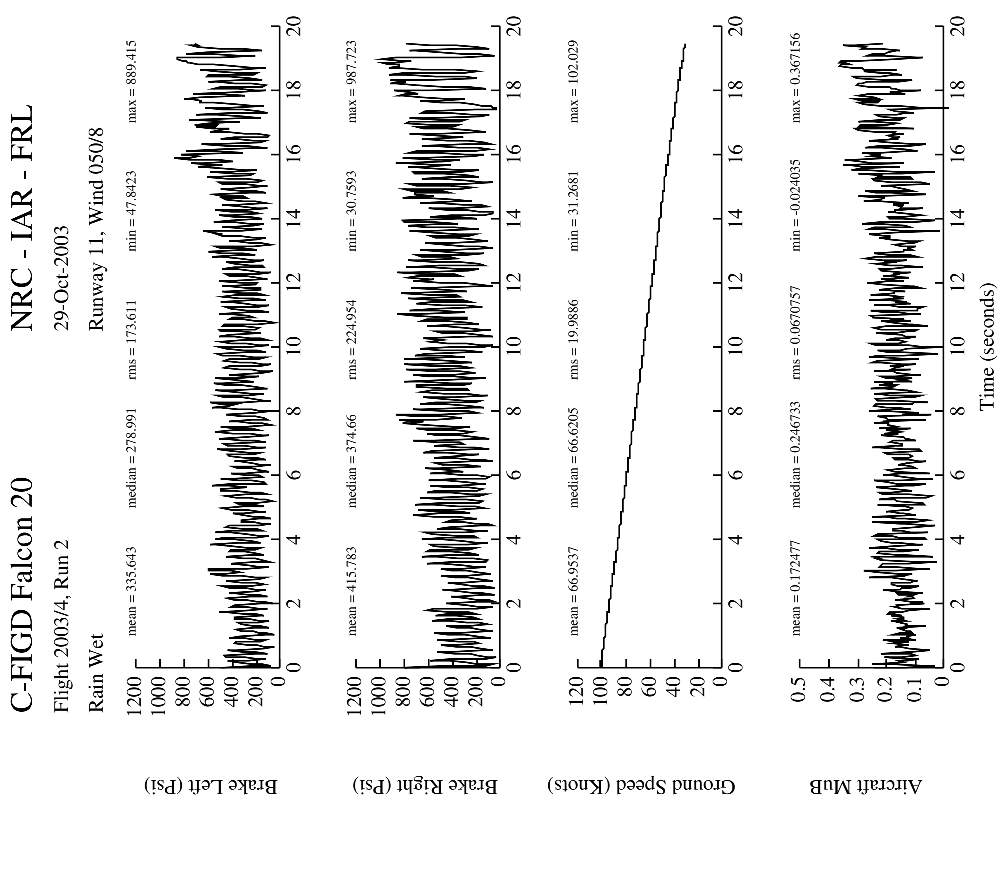


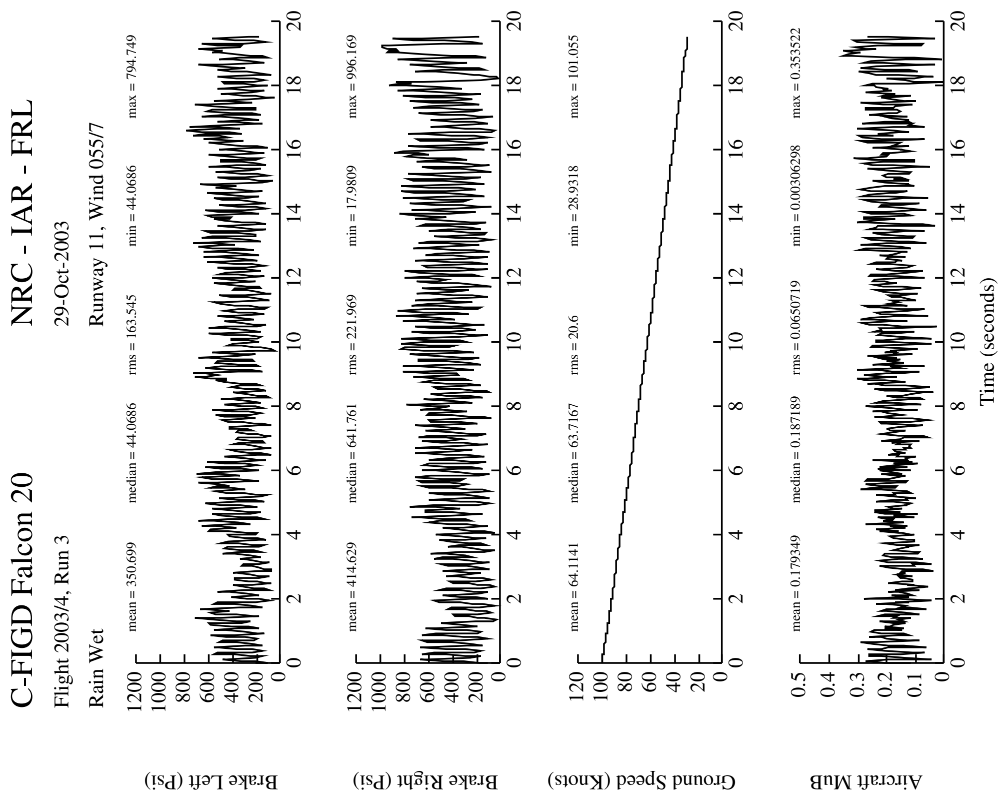
C-FIGD Falcon 20 NRC - IAR - FRL

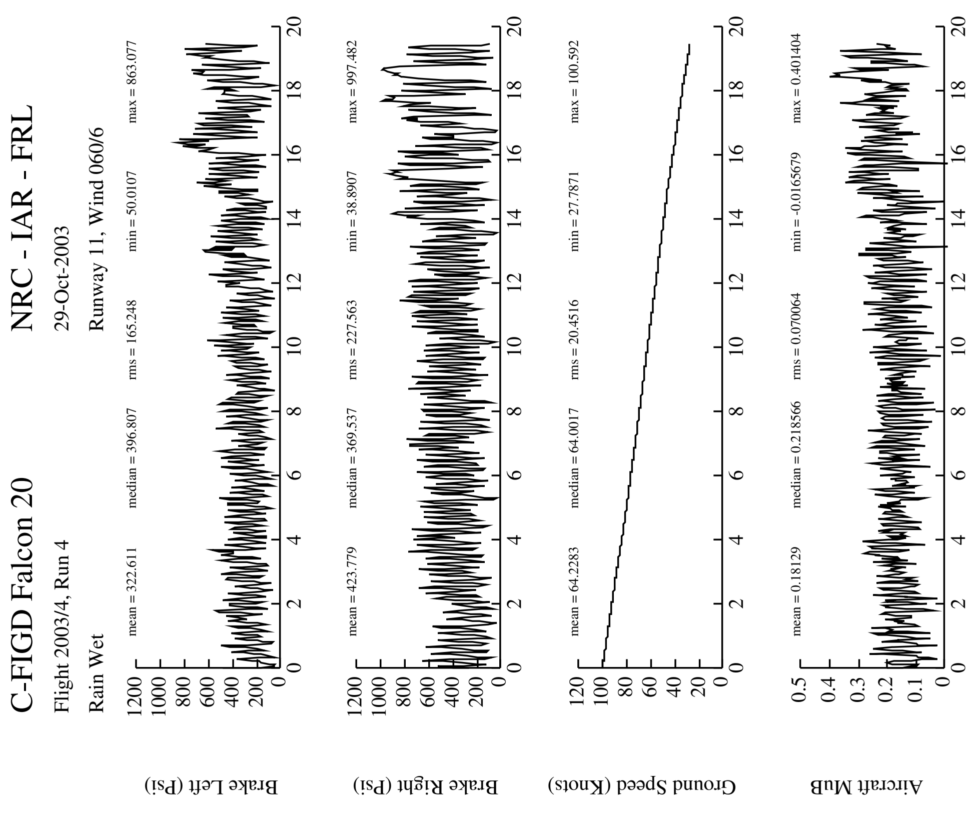
Flight 2003/4, Run 1 29-Oct-2003

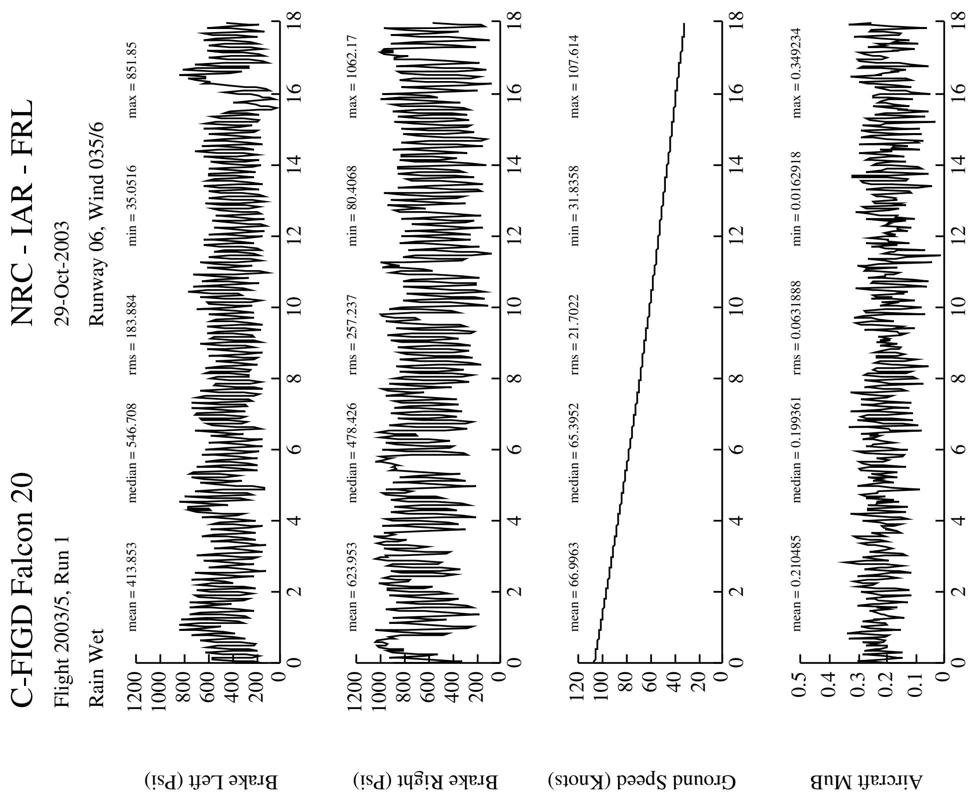
Rain Wet Runway 11, Wind 050/9

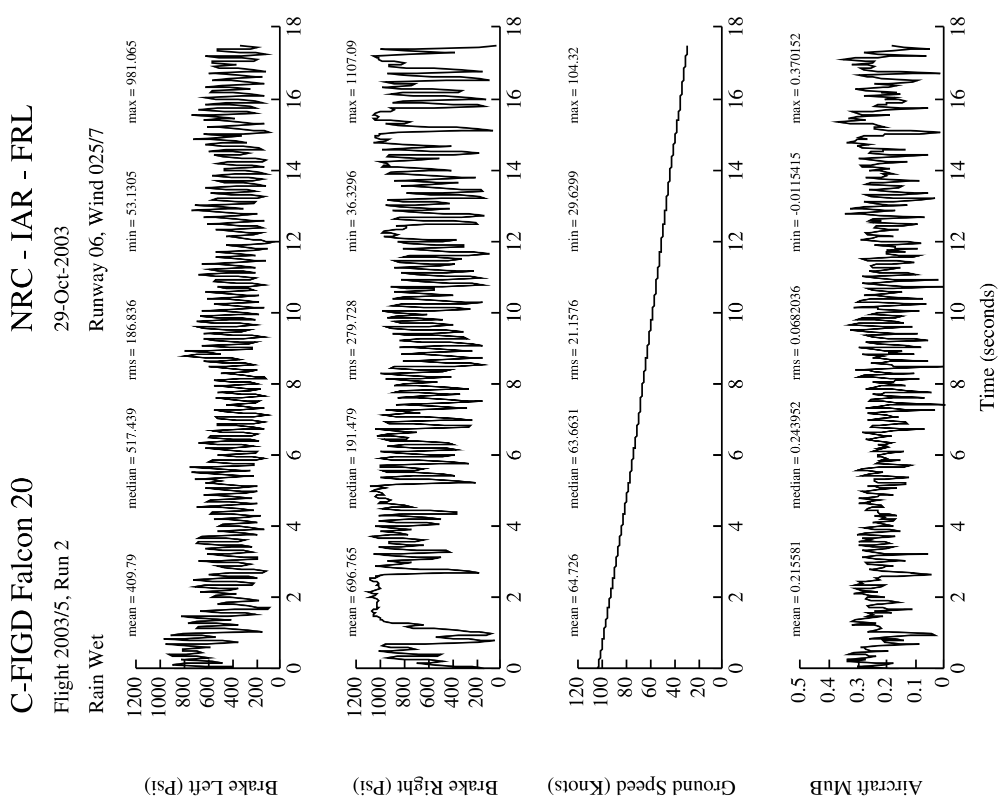


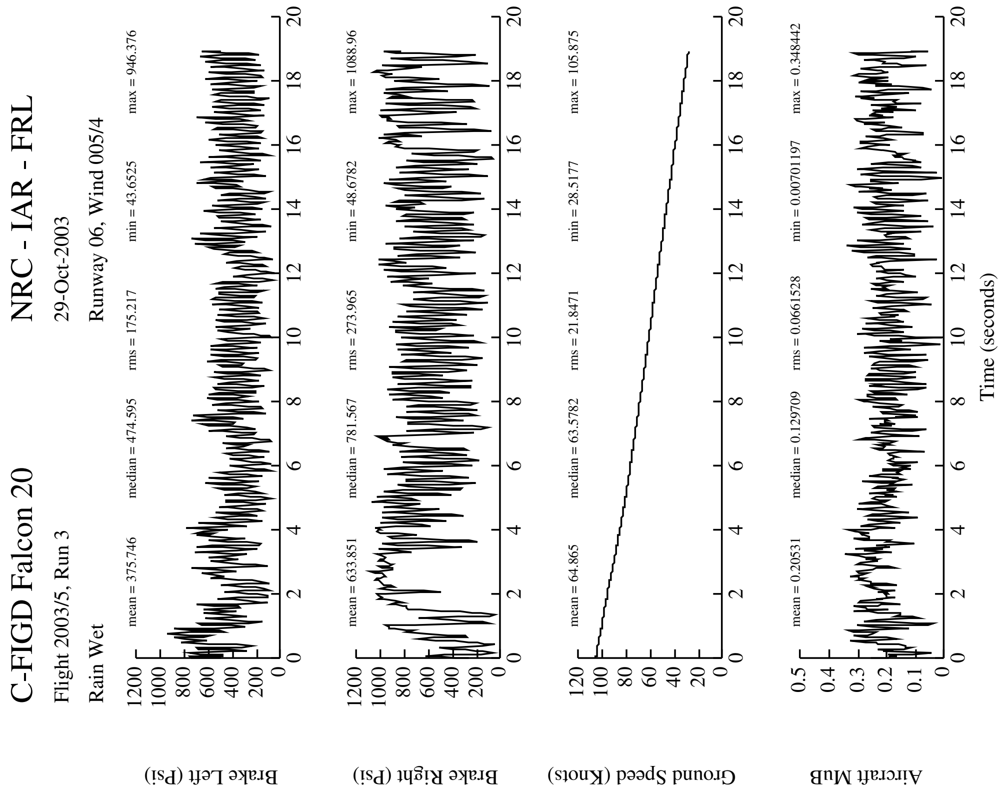

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/4, Run 2
29-Oct-2003
Rain Wet
Runway 11, Wind 050/8
mean = 335.643
median = 278.991
rms = 173.611
min = 47.8423
max = 889.415
Brake Left (Psi)
mean = 415.783
median = 374.66
rms = 224.954
min = 30.7593
max = 987.723
Brake Right (Psi)
mean = 66.9537
median = 66.6205
rms = 19.9886
min = 31.2681
max = 102.029
Ground Speed (Knots)
mean = 0.172477
median = 0.246733
rms = 0.0670757
min = -0.024035
max = 0.367156
Aircraft MuB
Time (seconds)

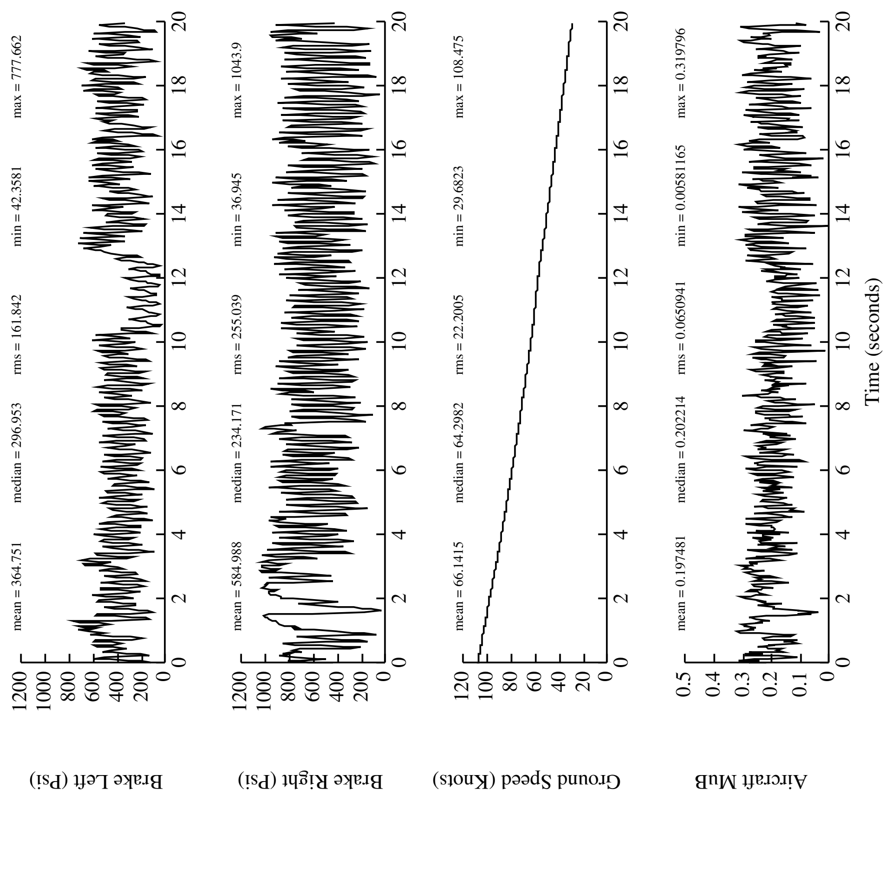

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/4, Run 3
29-Oct-2003
Rain Wet
Runway 11, Wind 055/7
mean = 350.699
median = 44.0686
rms = 163.545
min = 44.0686
max = 794.749
Brake Left (Psi)
mean = 414.629
median = 641.761
rms = 221.969
min = 17.9809
max = 996.169
Brake Right (Psi)
mean = 64.1141
median = 63.7167
rms = 20.6
min = 28.9318
max = 101.055
Ground Speed (Knots)
mean = 0.179349
median = 0.187189
rms = 0.0650719
min = 0.00306298
max = 0.353522
Aircraft MuB
Time (seconds)

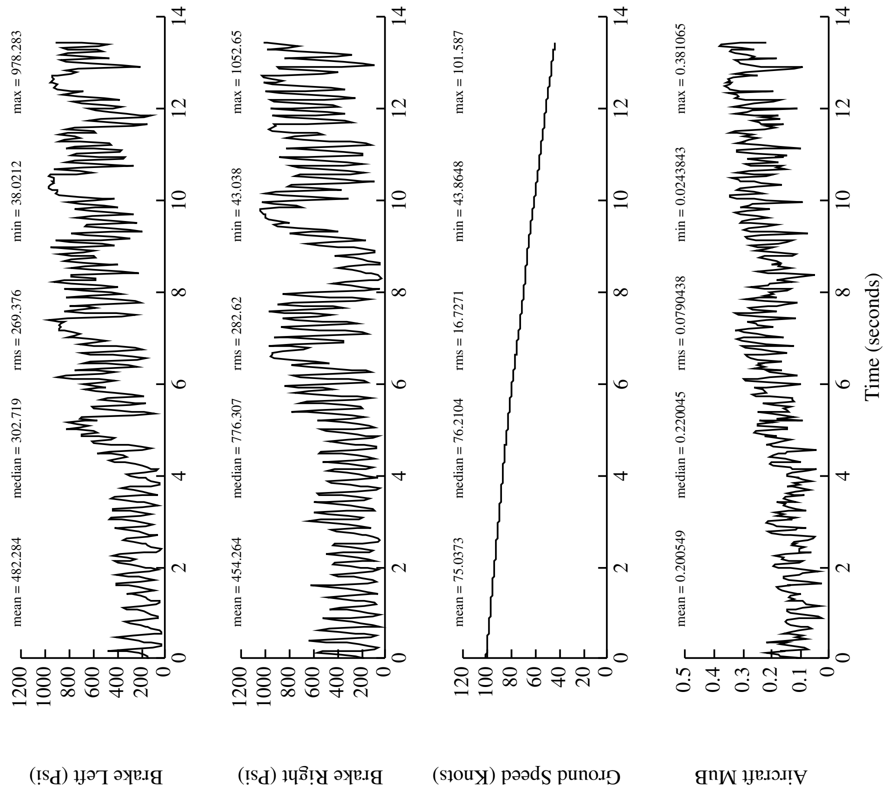

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/4, Run 4
29-Oct-2003
Rain Wet
Runway 11, Wind 060/6
mean = 322.611
median = 396.807
rms = 165.248
min = 50.0107
max = 863.077
Brake Left (Psi)
mean = 423.779
median = 369.537
rms = 227.563
min = 38.8907
max = 997.482
Brake Right (Psi)
mean = 64.2283
median = 64.0017
rms = 20.4516
min = 27.7871
max = 100.592
Ground Speed (Knots)
mean = 0.18129
median = 0.218566
rms = 0.070064
min = -0.0165679
max = 0.401404
Aircraft MuB
Time (seconds)

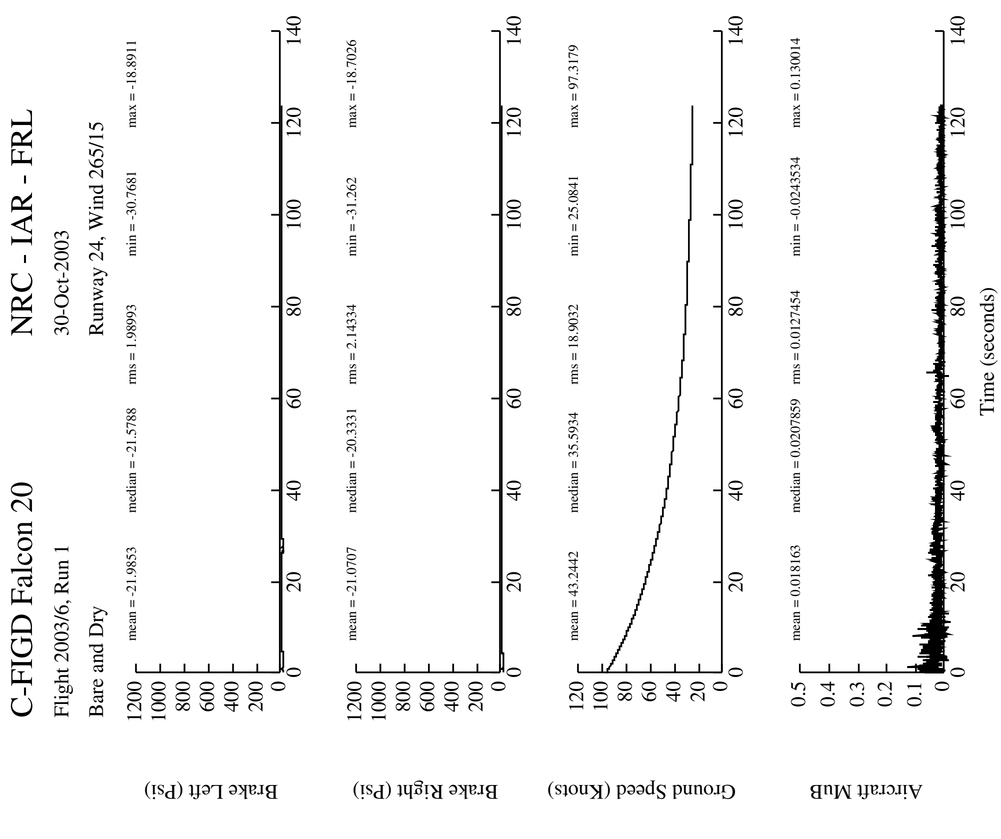

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 1
29-Oct-2003
Rain Wet
Runway 06, Wind 035/6
mean = 413.853
median = 546.708
rms = 183.884
min = 35.0516
max = 851.85
Brake Left (Psi)
mean = 623.953
median = 478.426
rms = 257.237
min = 80.4068
max = 1062.17
Brake Right (Psi)
mean = 66.9963
median = 65.3952
rms = 21.7022
min = 31.8358
max = 107.614
Ground Speed (Knots)
mean = 0.210485
median = 0.199361
rms = 0.0631888
min = 0.0162918
max = 0.349234
Aircraft MuB
Time (seconds)

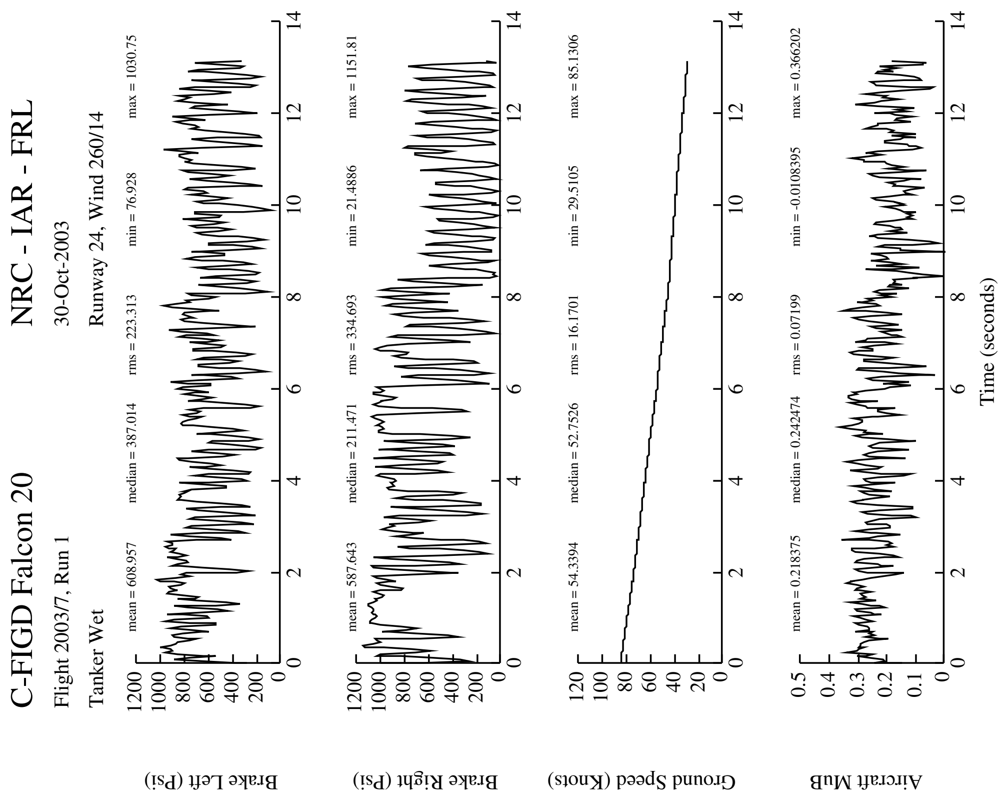

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 2
29-Oct-2003
Rain Wet
Runway 06, Wind 025/7
Brake Left (Psi)
mean = 409.79 median = 517.439 rms = 186.836 min = 53.1305 max = 981.065
Brake Right (Psi)
mean = 696.765 median = 191.479 rms = 279.728 min = 36.3296 max = 1107.09
Ground Speed (Knots)
mean = 64.726 median = 63.6631 rms = 21.1576 min = 29.6299 max = 104.32
Aircraft MuB
mean = 0.215581 median = 0.243952 rms = 0.0682036 min = -0.0115415 max = 0.370152
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 3
29-Oct-2003
Rain Wet
Runway 06, Wind 005/4
Brake Left (Psi)
mean = 375.746 median = 474.595 rms = 175.217 min = 43.6525 max = 946.376
Brake Right (Psi)
mean = 633.851 median = 781.567 rms = 273.965 min = 48.6782 max = 1088.96
Ground Speed (Knots)
mean = 64.865 median = 63.5782 rms = 21.8471 min = 28.5177 max = 105.875
Aircraft MuB
mean = 0.20531 median = 0.129709 rms = 0.0661528 min = 0.00701197 max = 0.348442
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 4
29-Oct-2003
Rain Wet
Runway 06, Wind 020/4
mean = 364.751 median = 296.953 rms = 161.842 min = 42.3581 max = 777.662
mean = 584.988 median = 234.171 rms = 255.039 min = 36.945 max = 1043.9
mean = 66.1415 median = 64.2982 rms = 22.2005 min = 29.6823 max = 108.475
mean = 0.197481 median = 0.202214 rms = 0.0650941 min = 0.00581165 max = 0.319796
Brake Left (Psi)
Brake Right (Psi)
Ground Speed (Knots)
Aircraft MuB
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 5
29-Oct-2003
Rain Wet
Ottawa Runway 25, Wind 270/5
mean = 482.284 median = 302.719 rms = 269.376 min = 38.0212 max = 978.283
mean = 454.264 median = 776.307 rms = 282.62 min = 43.038 max = 1052.65
mean = 75.0373 median = 76.2104 rms = 16.7271 min = 43.8648 max = 101.587
mean = 0.200549 median = 0.220045 rms = 0.0790438 min = 0.0243843 max = 0.381065
Brake Left (Psi)
Brake Right (Psi)
Ground Speed (Knots)
Aircraft MuB
Time (seconds)

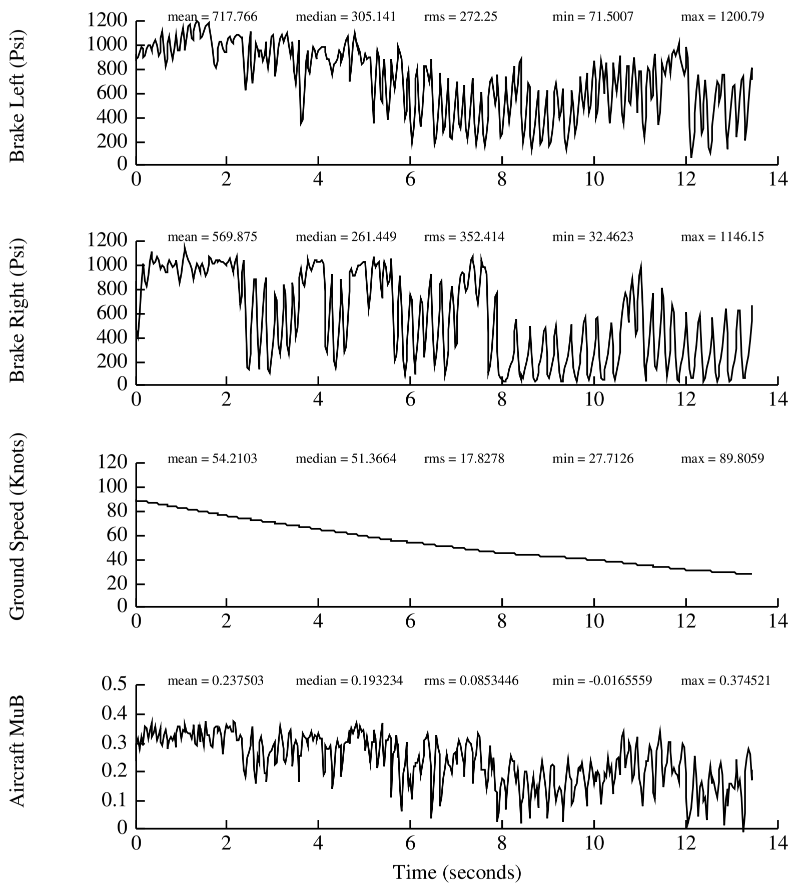

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/6, Run 1
30-Oct-2003
Bare and Dry
Runway 24, Wind 265/15
Brake Left (Psi)
mean = -21.9853
median = -21.5788
rms = 1.98993
min = -30.7681
max = -18.8911
Brake Right (Psi)
mean = -21.0707
median = -20.3331
rms = 2.14334
min = -31.262
max = -18.7026
Ground Speed (Knots)
mean = 43.2442
median = 35.5934
rms = 18.9032
min = 25.0841
max = 97.3179
Aircraft MuB
mean = 0.018163
median = 0.0207859
rms = 0.0127454
min = -0.0243534
max = 0.130014
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/7, Run 1
30-Oct-2003
Tanker Wet
Runway 24, Wind 260/14
Brake Left (Psi)
mean = 608.957
median = 387.014
rms = 223.313
min = 76.928
max = 1030.75
Brake Right (Psi)
mean = 587.643
median = 211.471
rms = 334.693
min = 21.4886
max = 1151.81
Ground Speed (Knots)
mean = 54.3394
median = 52.7526
rms = 16.1701
min = 29.5105
max = 85.1306
Aircraft MuB
mean = 0.218375
median = 0.242474
rms = 0.07199
min = -0.0108395
max = 0.366202
Time (seconds)

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2003/7, Run 2 30-Oct-2003

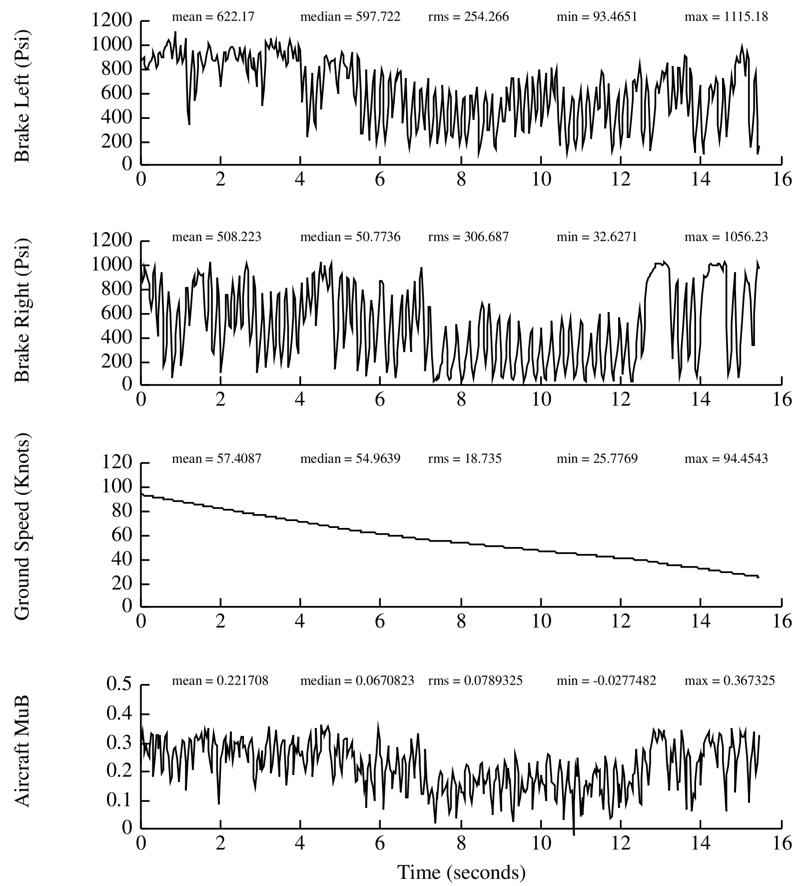
Tanker Wet Remaining Runway 24, Wind 270/14



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2003/7, Run 3 30-Oct-2003

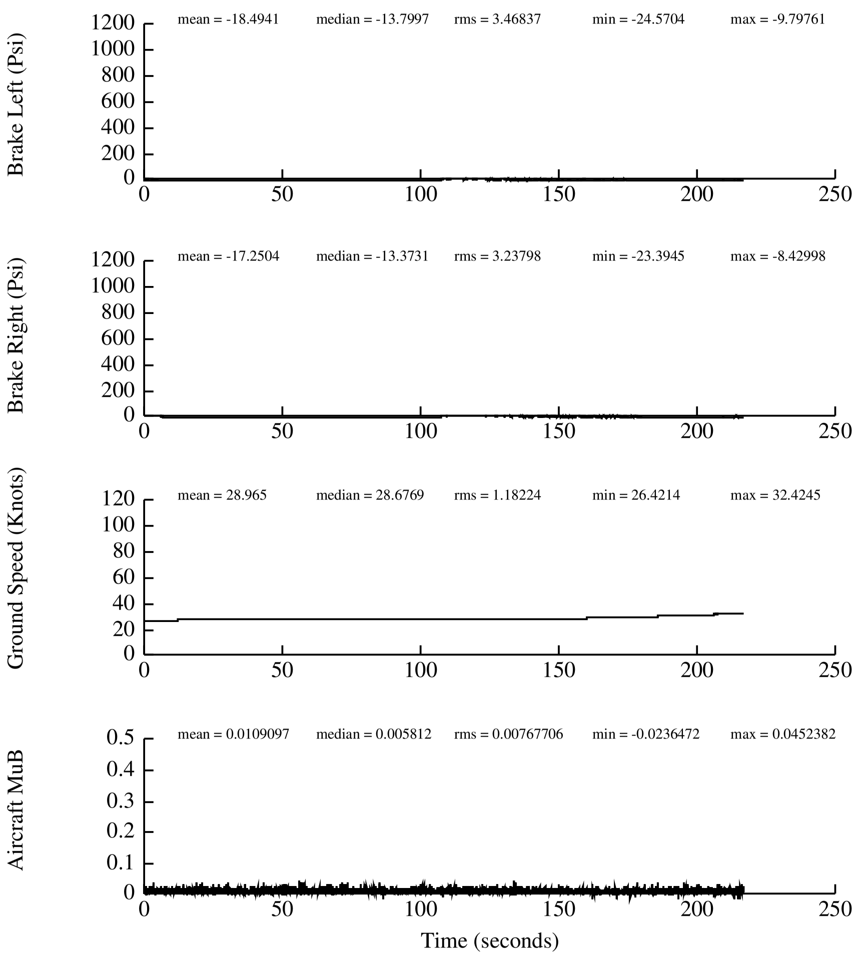
Tanker Re-wet Runway 24, Wind 250/15



C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2003/7, Run 4 30-Oct-2003

Almost Bare and Dry Runway 24-06, Wind 255/13



APPENDIX B - TEST RUNS FOR AIRCRAFT BRAKING COEFFICIENT

The following table shows the test runs used to determine aircraft braking coefficient (MuB, or μ_B) during both test periods in November 2002 and October 2003. The table columns, from the left, include the flight number and date, the run number and local time, the runway used, the aircraft manoeuvre used (taxi, accel/stop or landing), the aircraft configuration, the runway surface description, the mean SFT reading, the mean aircraft groundspeed, the mean aircraft μ_B, and the coefficients of a linear regression between μ_B and groundspeed. Values of mean μ_B and mean groundspeed shown in the table are taken from the charts in Appendix A.

Pages B3 to B18 show the variation of a smoothed aircraft μ_B parameter with aircraft groundspeed for each braking run, two runs per page. The smoothed μ_B parameter is calculated by taking a one second average (16 samples on either side) of each recorded μ_B sample. This procedure filters out the variations of μ_B resulting from anti-skid action, but retains the variations of μ_B resulting from changes in surface wetness or texture. The coefficients C0 and C1 shown in the table are taken from the charts in this Appendix.

FLT/ Date	RUN/ Time	RW	TAXI/ RTO/ LAND	CONFIG see note 1	Surface Description	Mean SFT note 2	MEAN SPEED (KTGS)	MEAN μ_B	Coefficients	
									C0	C1
2002/01 20/11/02	3 1408	29	LAND	40/EXT/B	Bare and Dry	0.99	69.6	0.432		
	5 1512	29	Accel/ Stop	15/EXT/B	Tanker Wet	0.57	72.6	0.117	0.216	-0.00139
	6 1529	29	LAND	40/EXT/B	Tanker Wet Remaining	0.63	87.7	0.129	0.301	-0.00196
2002/03 21/11/02	1 1340	11	LAND	40/EXT/B	Bare and Dry	0.99	75.5	0.348		
	2 1410	11	Accel/ Stop	40/EXT/B	Tanker Wet	0.57	41.0	0.145	0.212	-0.00163
	3 1425	11	LAND	40/EXT/B	Tanker Wet Remaining	0.62	88.0	0.123	0.278	-0.00174
	4 1456	11	Accel/ Stop	15/EXT/B	Tanker Re-wet	0.61	42.7	0.162	0.251	-0.00207
	5 1508	11	LAND	15/EXT/B	Tanker Wet Remaining	0.65	106.2	0.108	0.283	-0.00166
2003/01 27/10/03	1 1438	11	Accel/ Stop	15/EXT/B	Rain Wet	0.56	73.4	0.143	0.215	-0.00098
	2 1446	11	Accel/ Stop	15/EXT/B	Rain Wet	0.57	66.0	0.160	0.171	-0.00017
2003/02 28/10/03	1 1111	29	Accel/ Stop	15/EXT/B	Tanker Wet	0.52	57.3	0.160	0.178	-0.00031
	2 1124	29	LAND	40/EXT/B	Tanker Wet Remaining	0.59	78.1	0.170	0.172	-0.00003
	3 1149	29	LAND	40/EXT/B	Tanker Re-wet	0.53	66.9	0.172	0.231	-0.00088

FLT/ Date	RUN/ Time	RW	TAXI/ RTO/ LAND	CONFIG see note 1	Surface Description	Mean SFT note 2	MEAN SPEED (KTGS)	MEAN μ_B	Coefficients	
									C0	C1
	4 1159	29	LAND	40/EXT/B	Tanker Wet Remaining	0.58	65.5	0.175	0.210	-0.00053
	5 1211	29	LAND	40/EXT/B	Tanker Wet Remaining	0.63	63.0	0.195	0.251	-0.00088
2003/03 28/10/03	1 1349	29	Accel/ Stop	15/EXT/B	Tanker Wet	0.53	61.3	0.153	0.211	-0.00095
	2 1358	29	LAND	40/EXT/B	Tanker Wet Remaining	0.55	64.5	0.165	0.215	-0.00079
	3 1407	29	LAND	40/EXT/B	Tanker Wet Remaining	0.58	63.6	0.164	0.188	-0.00038
	4 1428	29	Touch & Go	15/EXT/B	Tanker Re-wet	0.51	85.1	0.164	0.121	0.00050
	5 1434	29	LAND	15/EXT/B	Tanker Wet Remaining	0.55	80.2	0.177	0.146	0.00040
2003/04 29/10/03	1 1112	11	LAND	40/EXT/B	Rain Wet Aircraft left of rwy C/L	0.55	68.6	0.166	0.240	-0.00110
	2 1127	11	LAND	40/EXT/B	Rain Wet Aircraft left of rwy C/L	0.54	67.0	0.172	0.255	-0.00123
	3 1141	11	LAND	40/EXT/B	Rain Wet Aircraft left of rwy C/L	0.55	64.1	0.179	0.216	-0.00058
	4 1155	11	LAND	40/EXT/B	Rain Wet Aircraft left of rwy C/L	0.56	64.2	0.181	0.253	-0.00111
2003/05 29/10/03	1 1347	06	LAND	40/EXT/B	Rain Wet Aircraft on rwy C/L	0.80	67.0	0.210	0.174	0.00054
	2 1401	06	LAND	40/EXT/B	Rain Wet Aircraft on rwy C/L	0.78	64.7	0.216	0.202	0.00022
	3 1414	06	LAND	40/EXT/B	Rain Wet Aircraft on rwy C/L	0.74	64.9	0.205	0.188	0.00028
	4 1426	06	LAND	40/EXT/B	Rain Wet Aircraft on rwy C/L	0.72	66.1	0.197	0.172	0.00037
	5 1453	25 YOW	LAND	40/EXT/B	Rain Wet Target of Opp at Ottawa		75.0	0.201	0.447	-0.00330
2003/07 30/10/03	1 1334	24	Accel/ Stop	15/EXT/B	Tanker Wet	0.76	54.3	0.218	0.108	0.00204
	2 1342	24	LAND	40/EXT/B	Tanker Wet Remaining	0.80	54.2	0.238	0.074	0.00301
	3 1400	24	LAND	40/EXT/B	Tanker Re-wet	0.79	57.4	0.222	0.156	0.00117

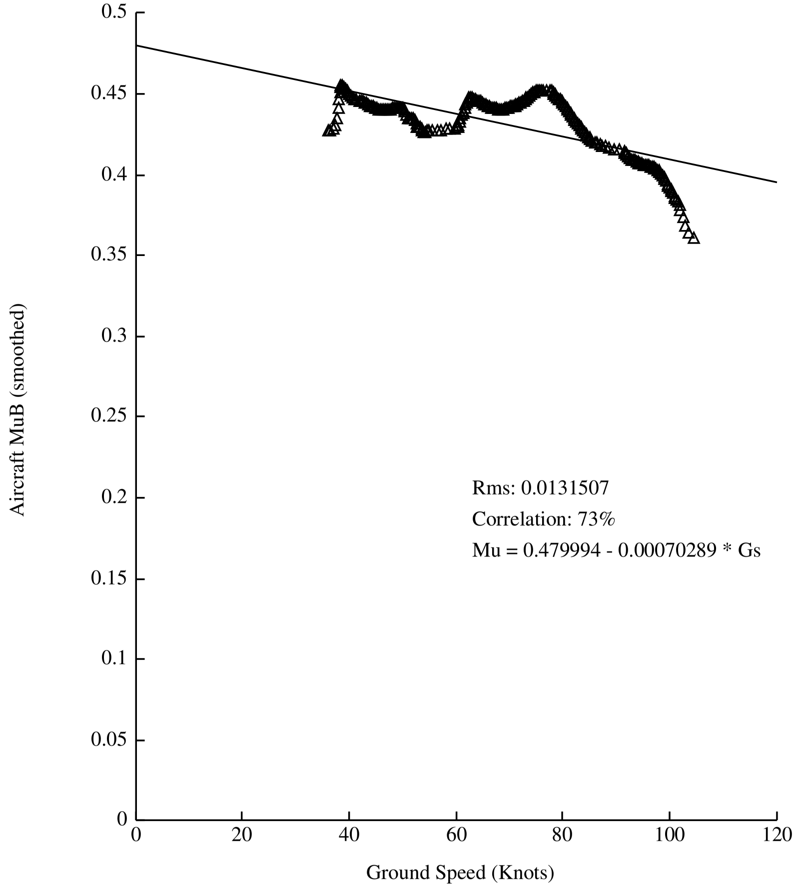
Note 1: Indicates flap setting (15 or 40), airbrake position (IN or EXT) and pilot braking (NO for no braking, B for maximum anti-skid braking)

Note 2: Average of Tradewind SFT and TC SFT Turbo

C-FIGD Falcon 20 — NRC - IAR - FRL

Flight 2002/1, Run 3 — 20-Nov-2002

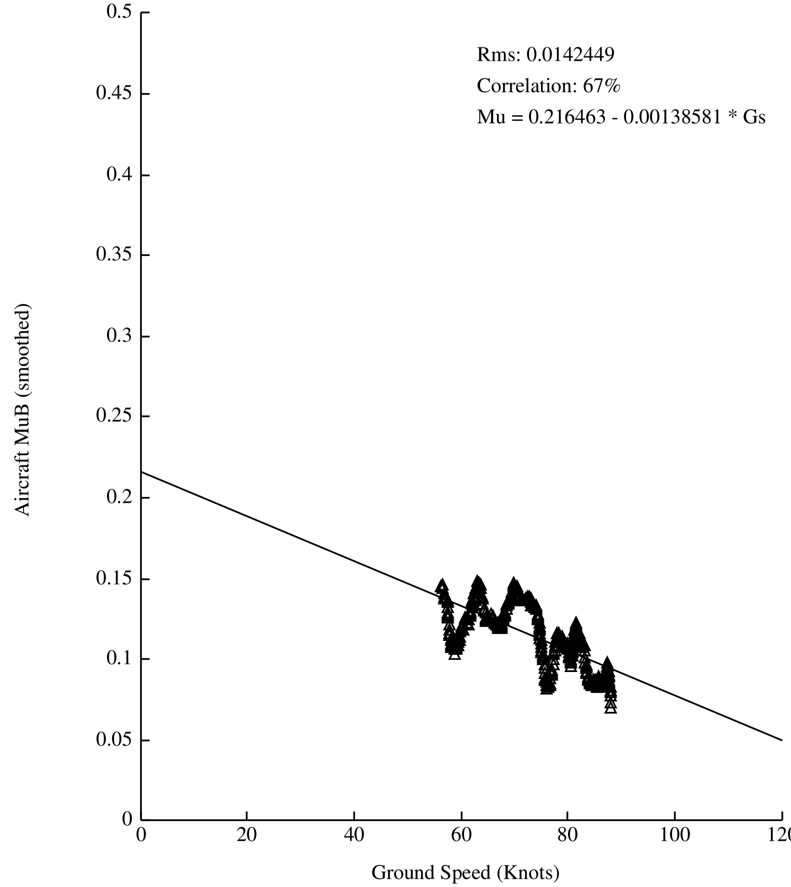
Bare and Dry — Runway 29, Wind 200/5

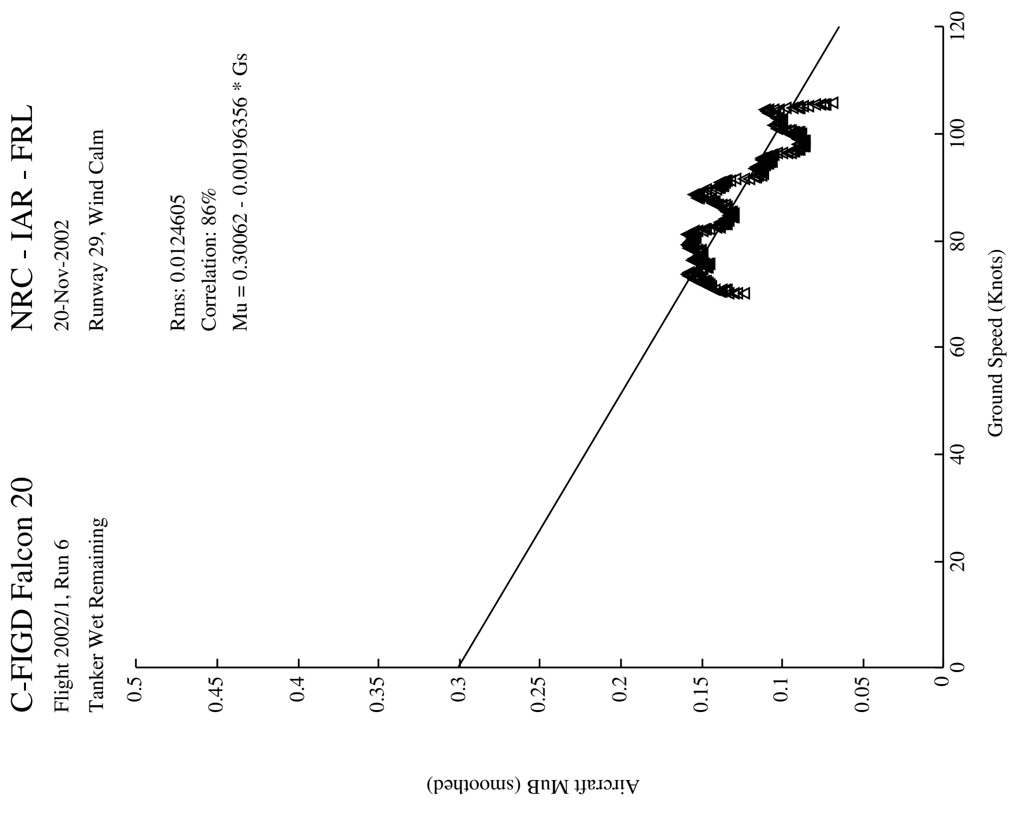


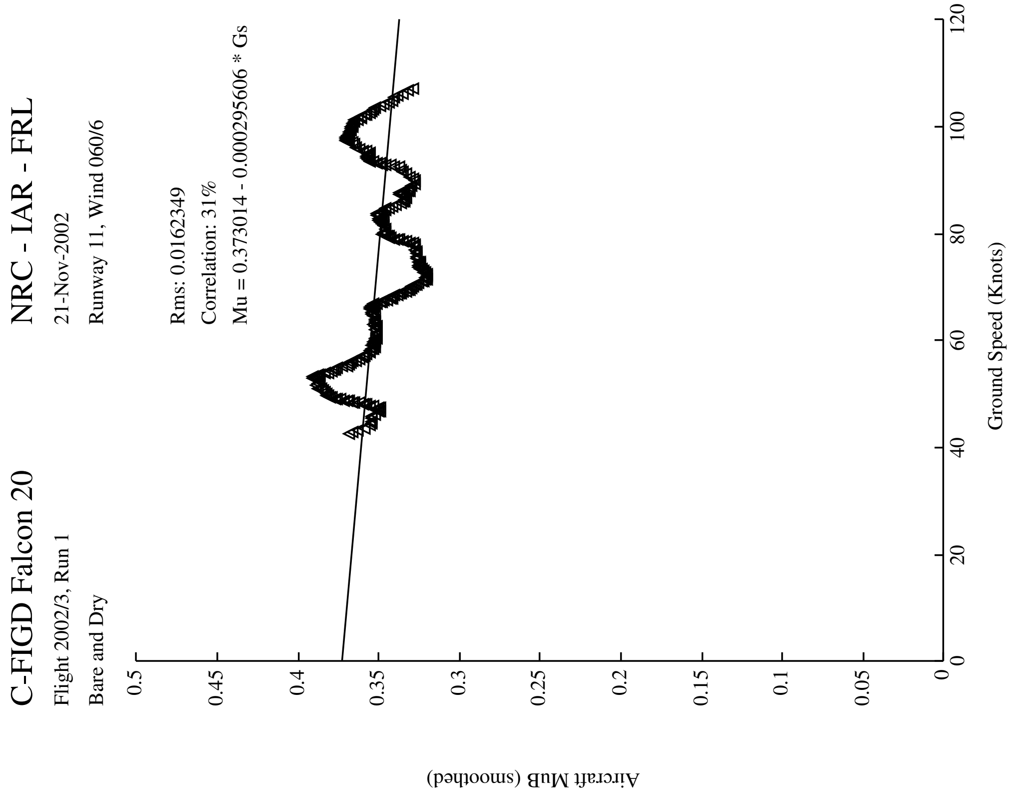
C-FIGD Falcon 20 — NRC - IAR - FRL

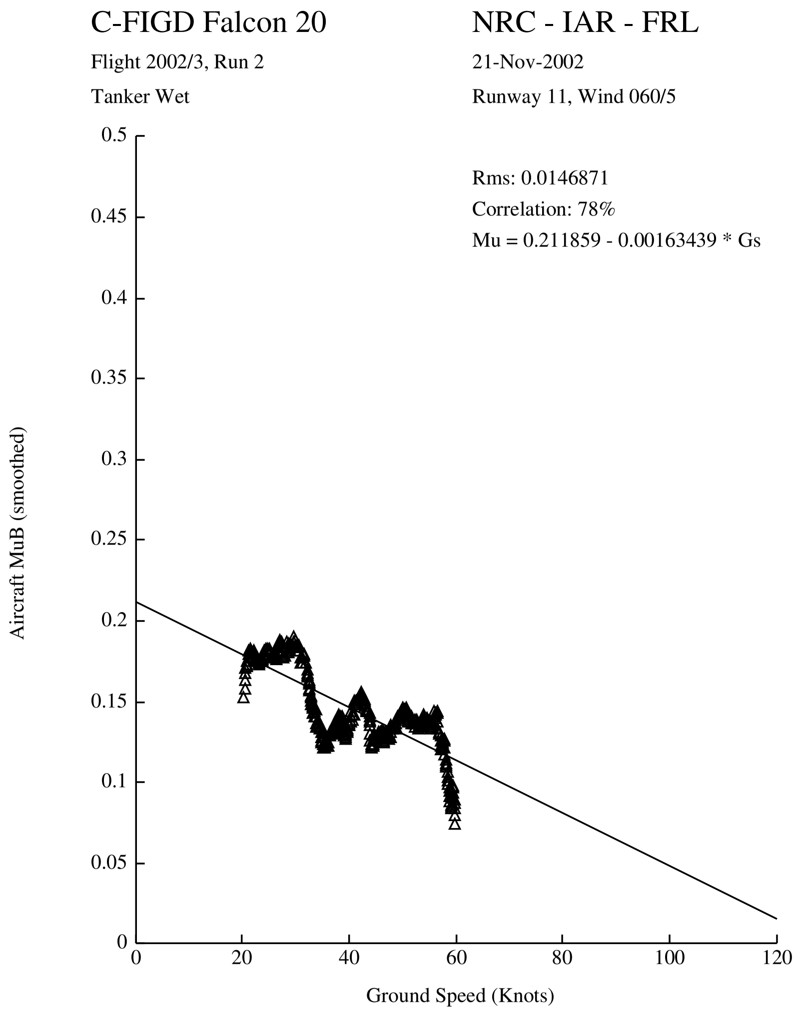
Flight 2002/1, Run 5 — 20-Nov-2002

Tanker Wet — Runway 29, Wind Calm

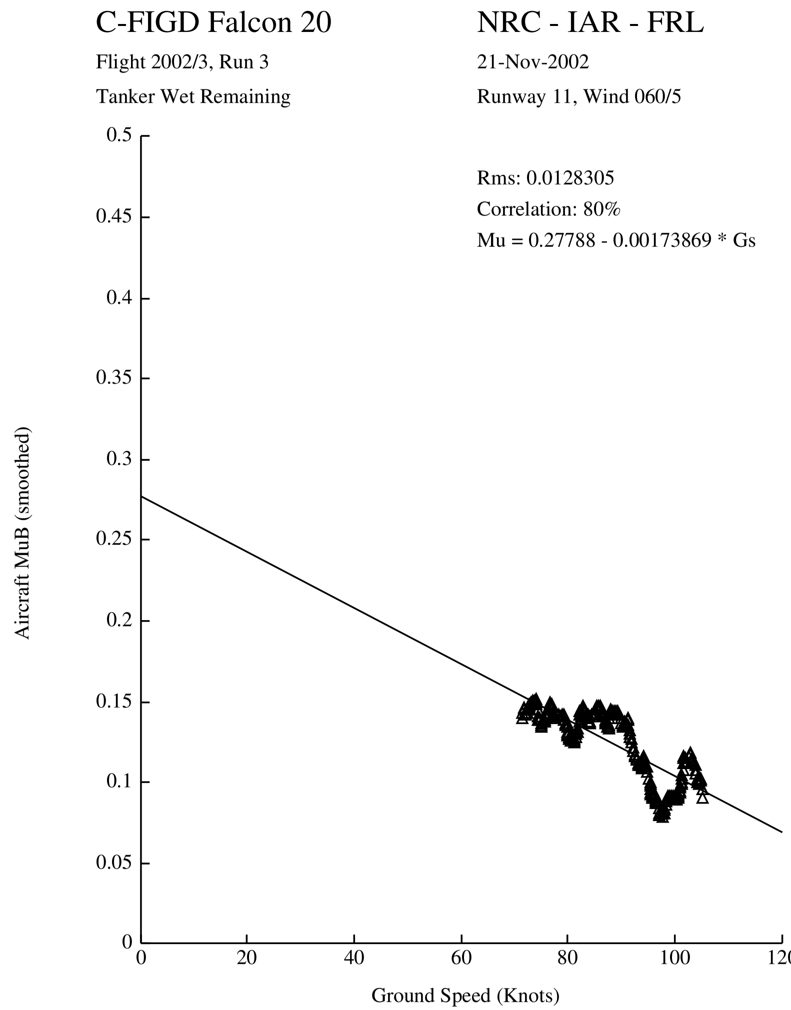



C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2002/1, Run 6
20-Nov-2002
Tanker Wet Remaining
Runway 29, Wind Calm
Rms: 0.0124605
Correlation: 86%
Mu = 0.30062 - 0.00196356 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120

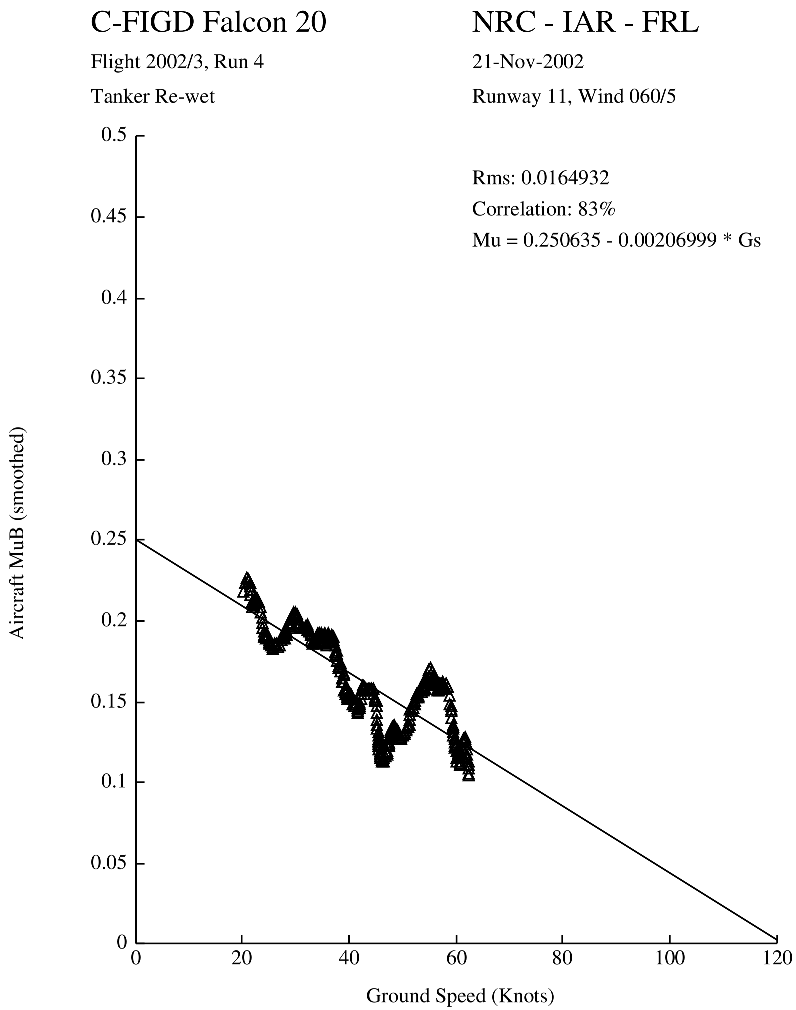

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2002/3, Run 1
21-Nov-2002
Bare and Dry
Runway 11, Wind 060/6
Rms: 0.0162349
Correlation: 31%
Mu = 0.373014 - 0.000295606 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120

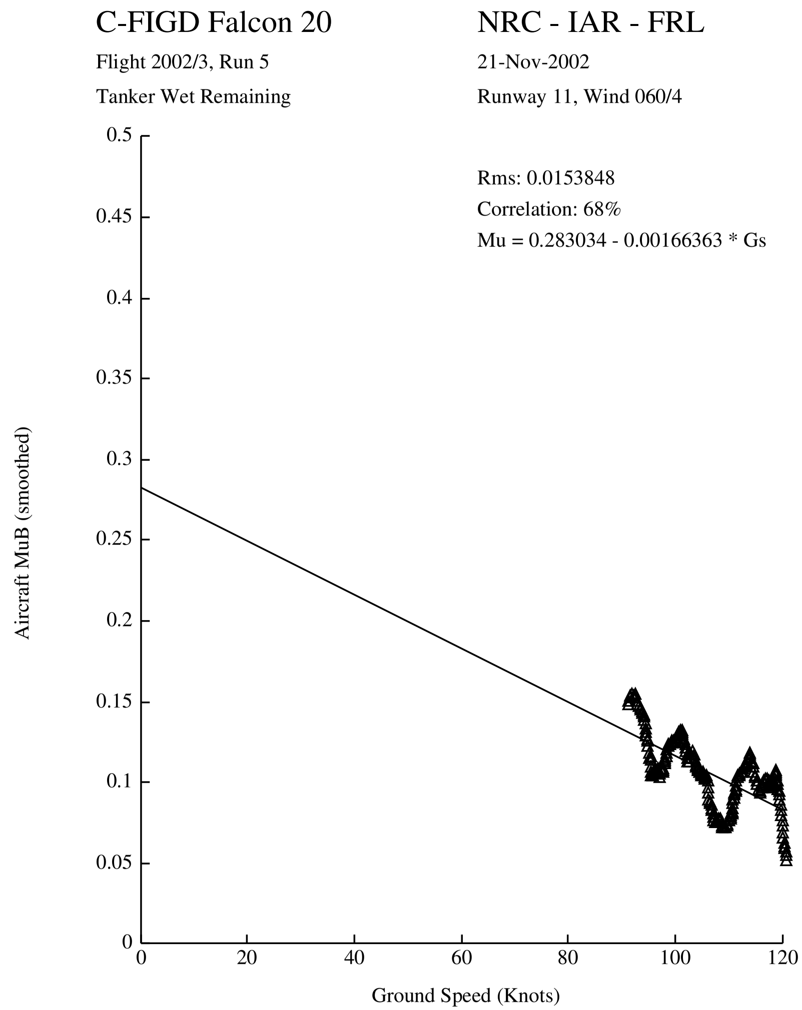


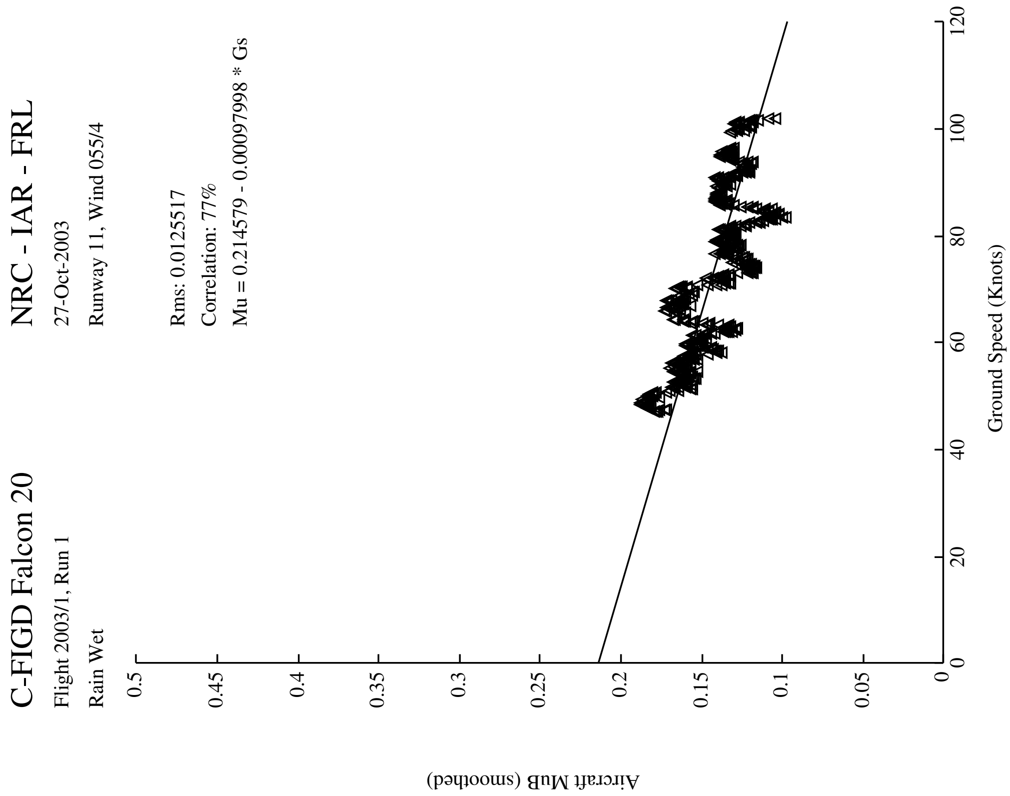
C-FIGD Falcon 20
Flight 2002/3, Run 2
Tanker Wet
NRC - IAR - FRL
21-Nov-2002
Runway 11, Wind 060/5
Rms: 0.0146871
Correlation: 78%
Mu = 0.211859 - 0.00163439 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120

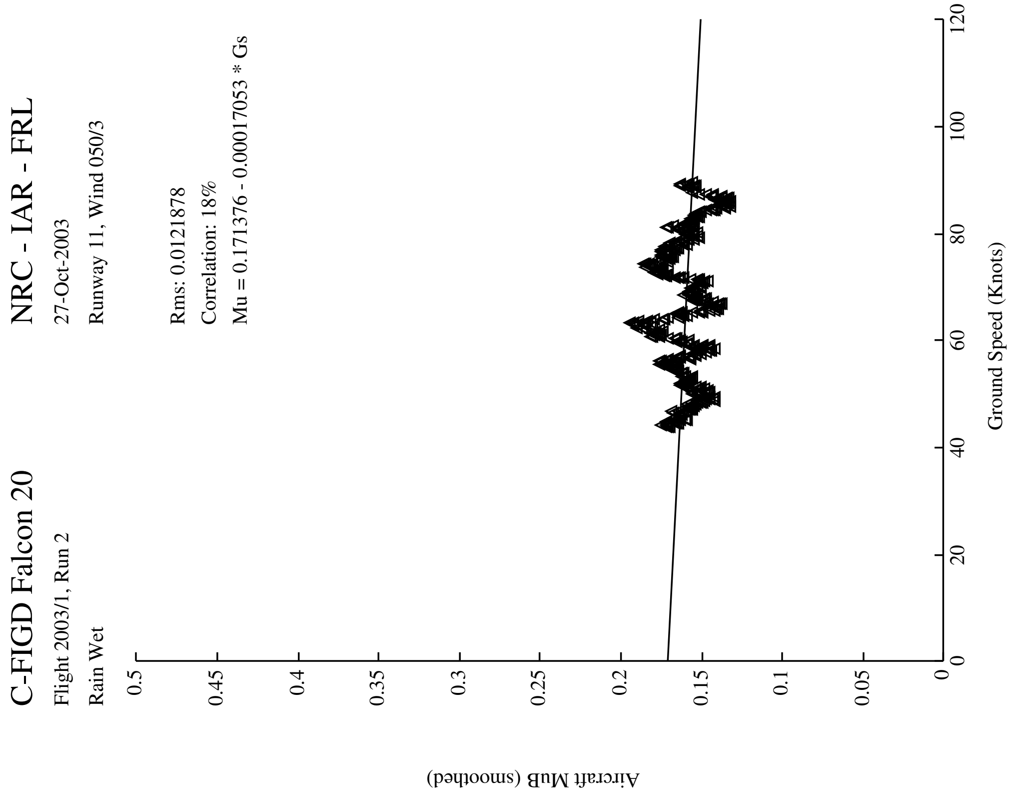


C-FIGD Falcon 20
Flight 2002/3, Run 3
Tanker Wet Remaining
NRC - IAR - FRL
21-Nov-2002
Runway 11, Wind 060/5
Rms: 0.0128305
Correlation: 80%
Mu = 0.27788 - 0.00173869 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2002/3, Run 4
Tanker Re-wet
NRC - IAR - FRL
21-Nov-2002
Runway 11, Wind 060/5
Rms: 0.0164932
Correlation: 83%
Mu = 0.250635 - 0.00206999 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120

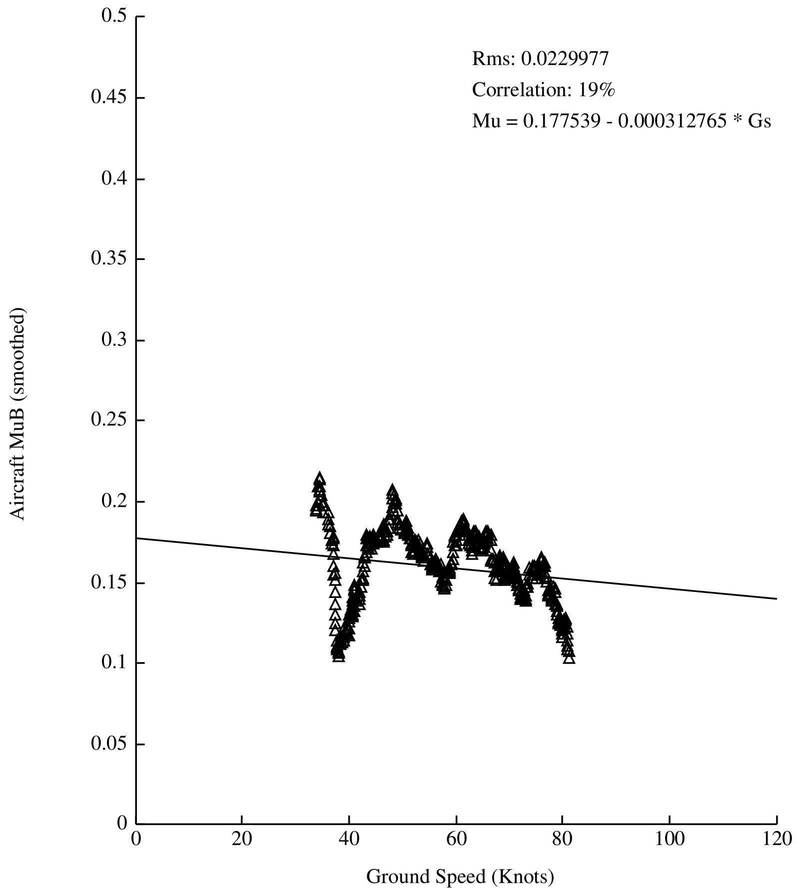

C-FIGD Falcon 20
Flight 2002/3, Run 5
Tanker Wet Remaining
NRC - IAR - FRL
21-Nov-2002
Runway 11, Wind 060/4
Rms: 0.0153848
Correlation: 68%
Mu = 0.283034 - 0.00166363 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2003/1, Run 1
Rain Wet
NRC - IAR - FRL
27-Oct-2003
Runway 11, Wind 055/4
Rms: 0.0125517
Correlation: 77%
Mu = 0.214579 - 0.00097998 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2003/1, Run 2
Rain Wet
NRC - IAR - FRL
27-Oct-2003
Runway 11, Wind 050/3
Rms: 0.0121878
Correlation: 18%
Mu = 0.171376 - 0.00017053 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120

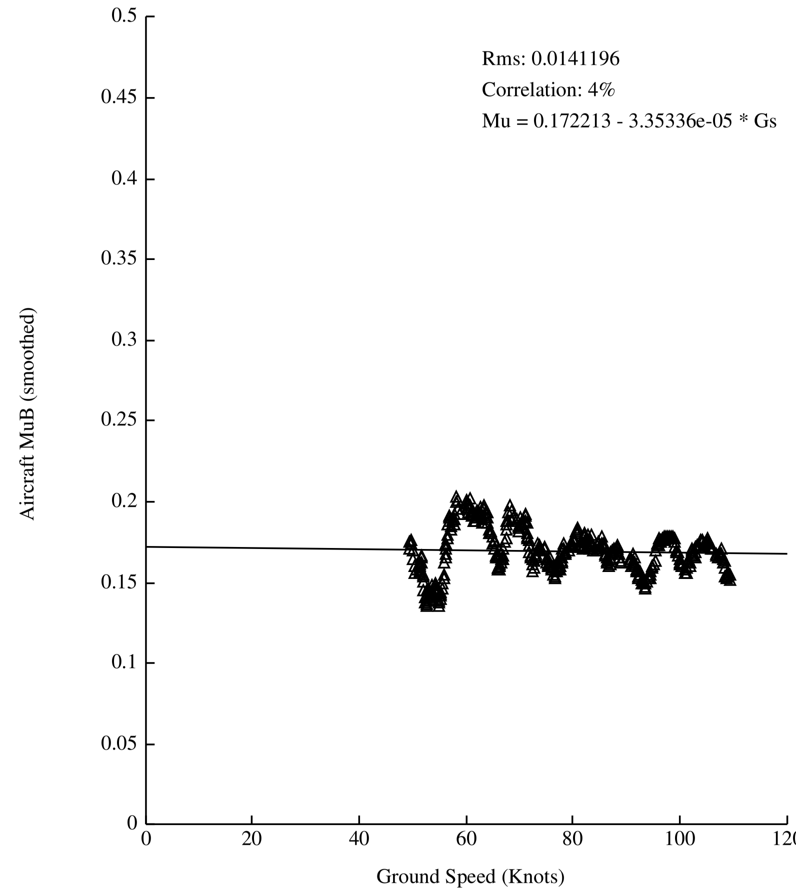
C-FIGD Falcon 20
Flight 2003/2, Run 1
Tanker Wet

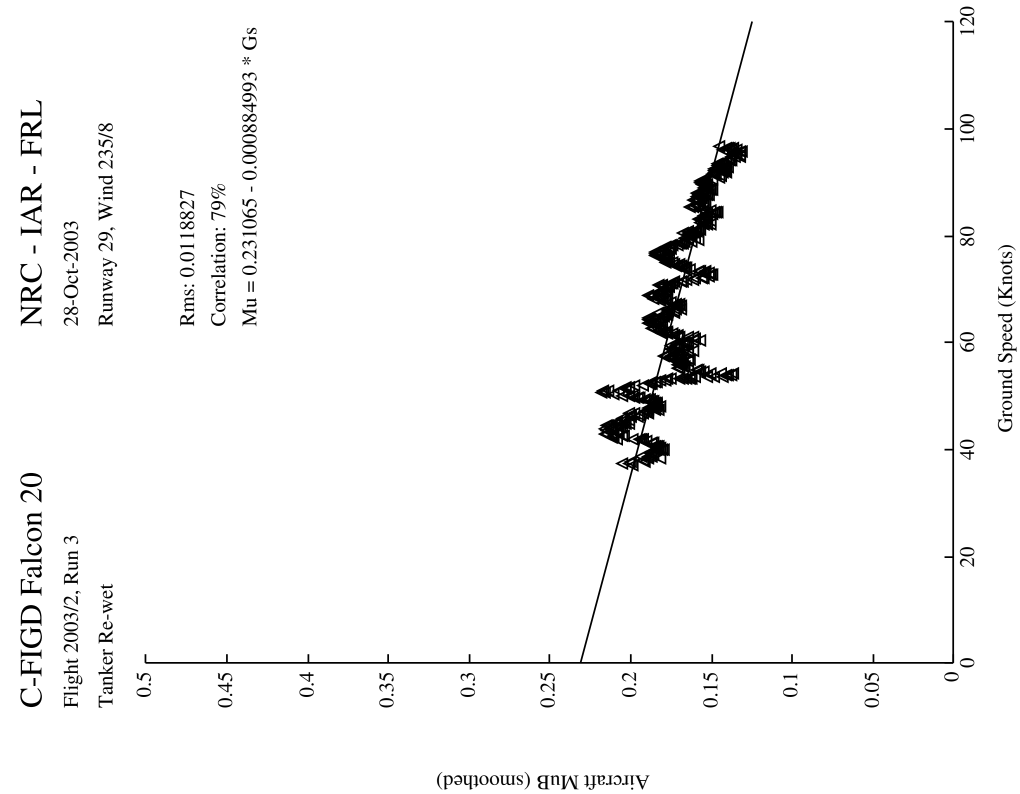
NRC - IAR - FRL
28-Oct-2003
Runway 29, Wind 230/6

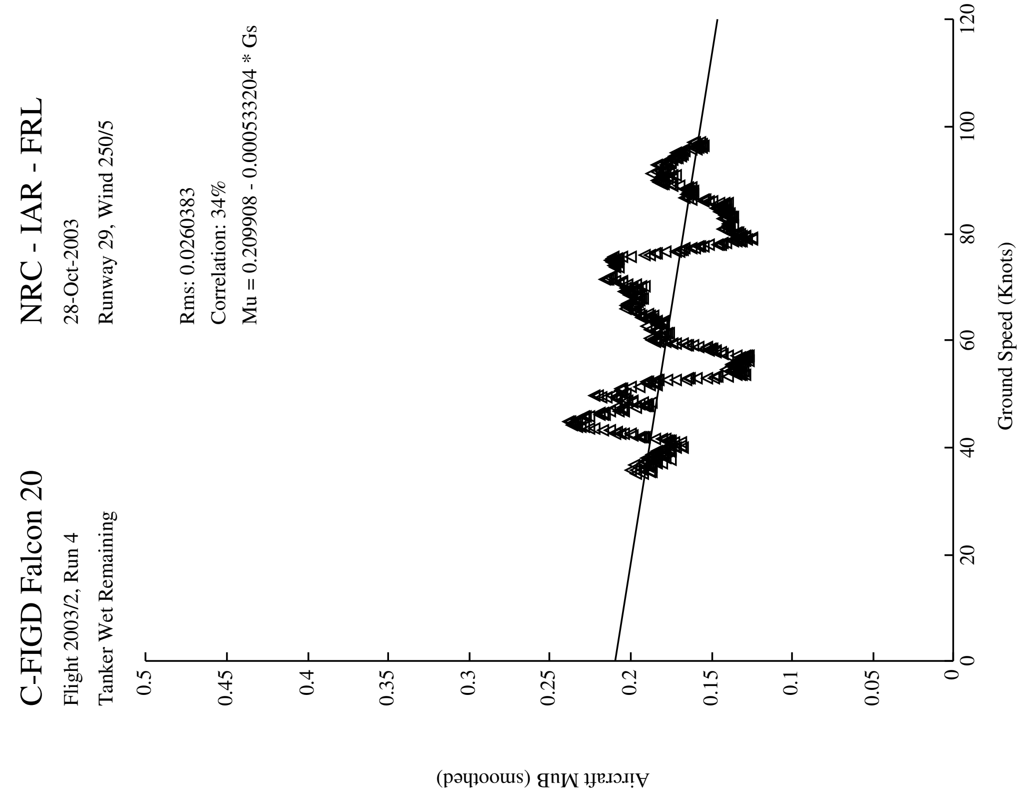


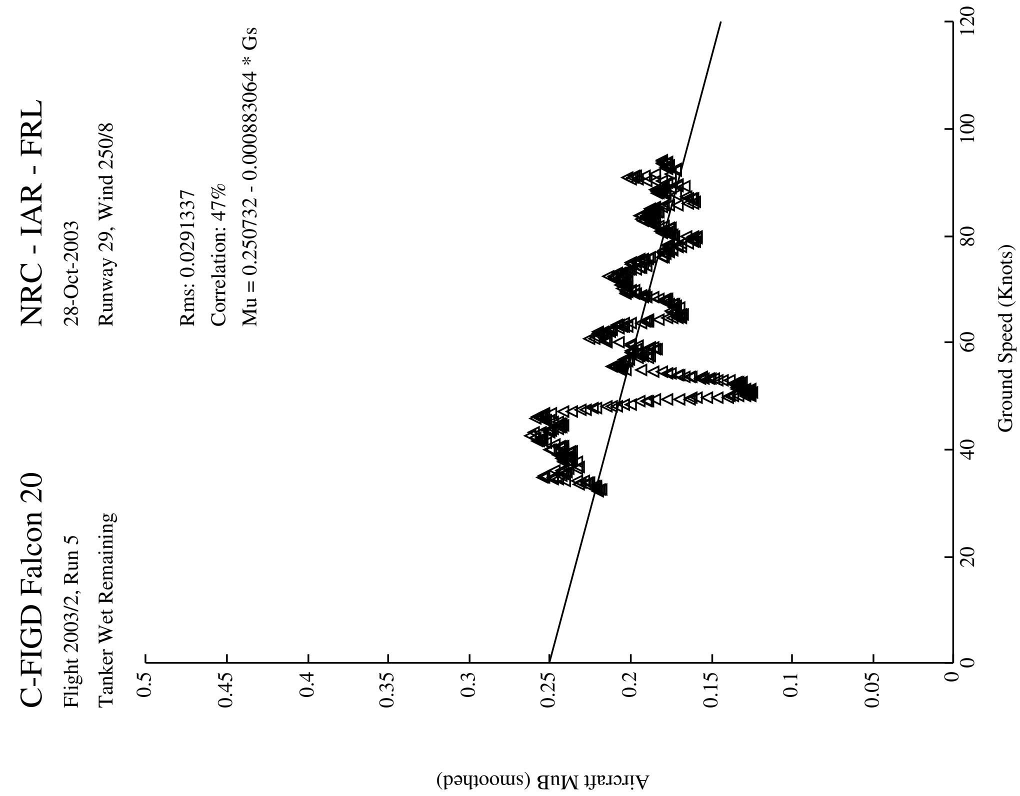
C-FIGD Falcon 20
Flight 2003/2, Run 2
Tanker Wet Remaining

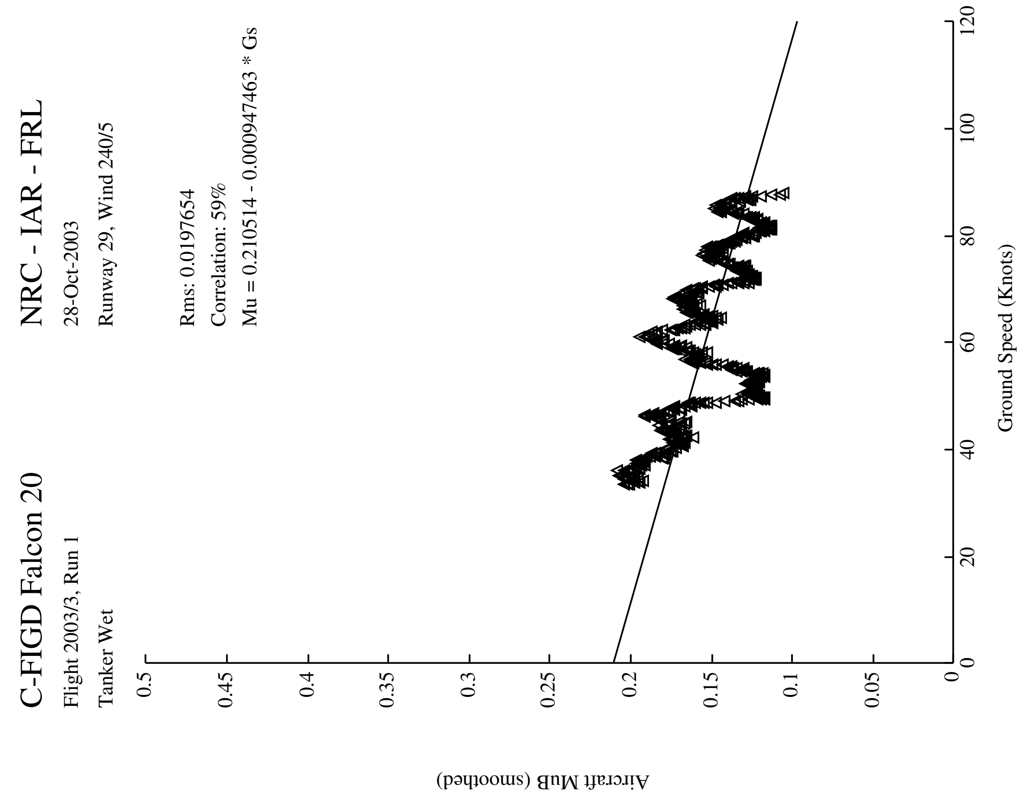
NRC - IAR - FRL
28-Oct-2003
Runway 29, Wind 265/6




C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/2, Run 3
28-Oct-2003
Tanker Re-wet
Runway 29, Wind 235/8
Rms: 0.0118827
Correlation: 79%
Mu = 0.231065 - 0.000884993 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/2, Run 4
28-Oct-2003
Tanker Wet Remaining
Runway 29, Wind 250/5
Rms: 0.0260383
Correlation: 34%
Mu = 0.209908 - 0.000533204 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120

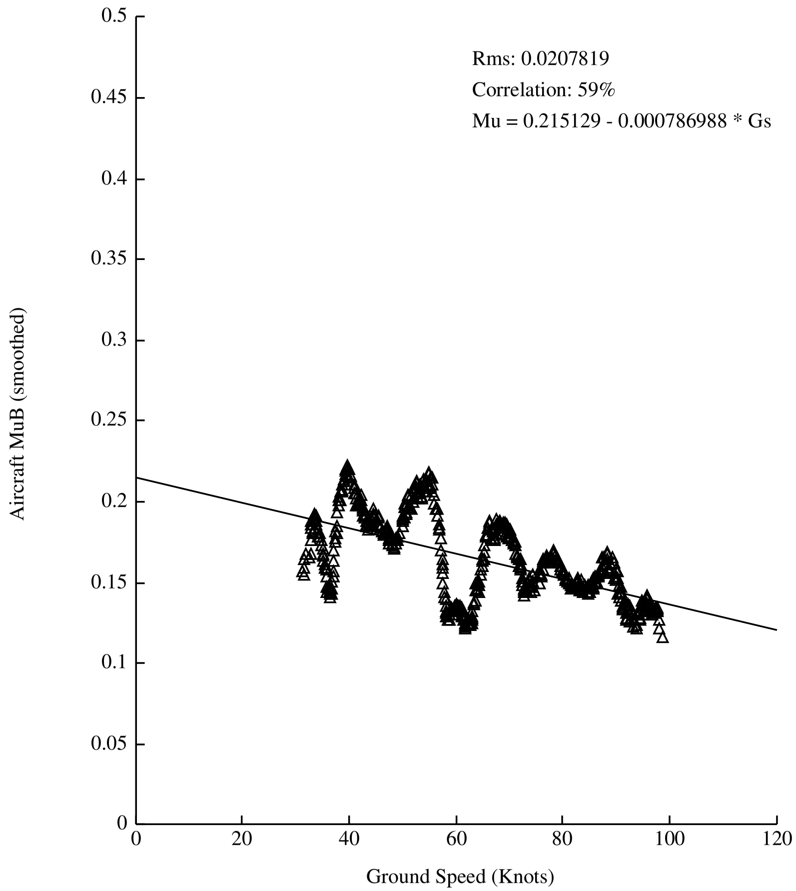

C-FIGD Falcon 20
Flight 2003/2, Run 5
Tanker Wet Remaining
NRC - IAR - FRL
28-Oct-2003
Runway 29, Wind 250/8
Rms: 0.0291337
Correlation: 47%
Mu = 0.250732 - 0.000883064 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2003/3, Run 1
Tanker Wet
NRC - IAR - FRL
28-Oct-2003
Runway 29, Wind 240/5
Rms: 0.0197654
Correlation: 59%
Mu = 0.210514 - 0.000947463 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120

C-FIGD Falcon 20 | NRC - IAR - FRL

Flight 2003/3, Run 2 | 28-Oct-2003

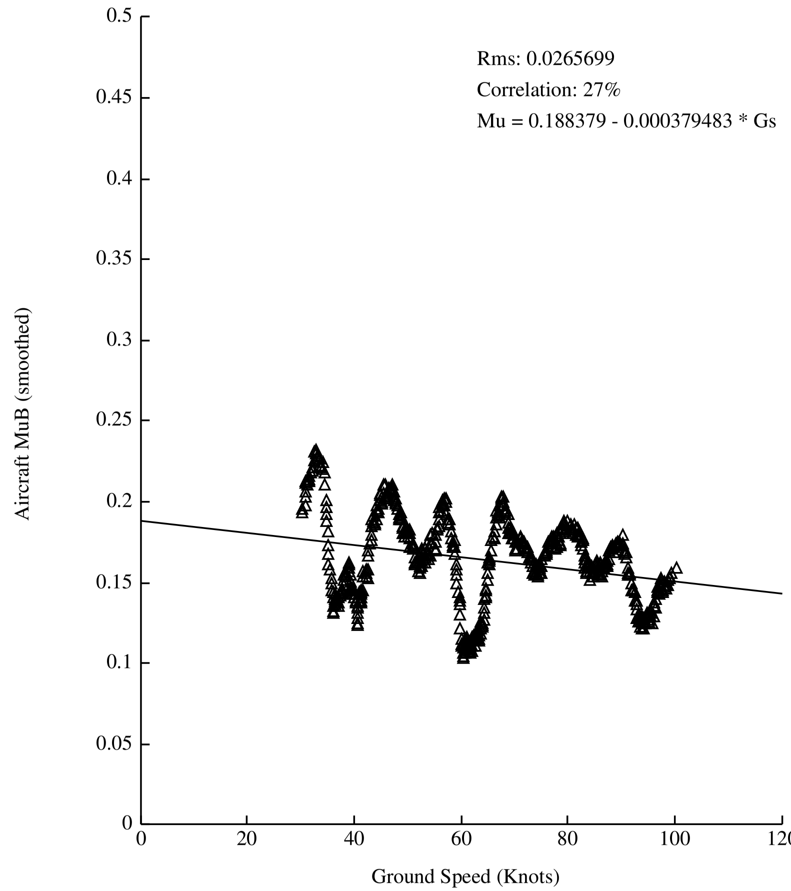
Tanker Wet Remaining | Runway 29, Wind 250/4



C-FIGD Falcon 20 | NRC - IAR - FRL

Flight 2003/3, Run 3 | 28-Oct-2003

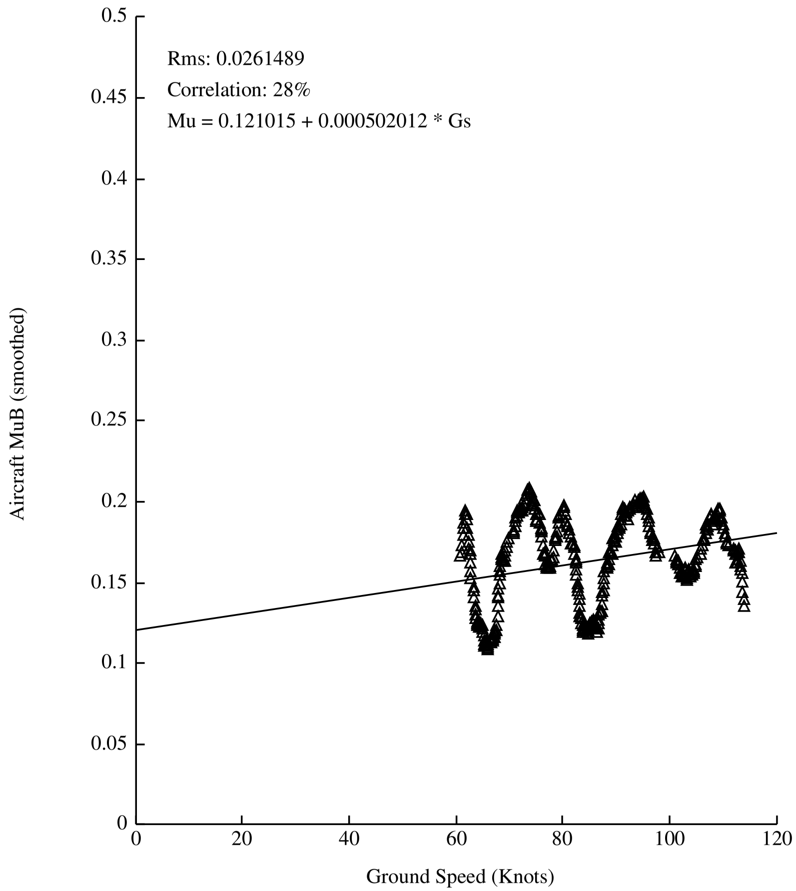
Tanker Wet Remaining | Runway 29, Wind 230/3



C-FIGD Falcon 20 | NRC - IAR - FRL

Flight 2003/3, Run 4 | 28-Oct-2003

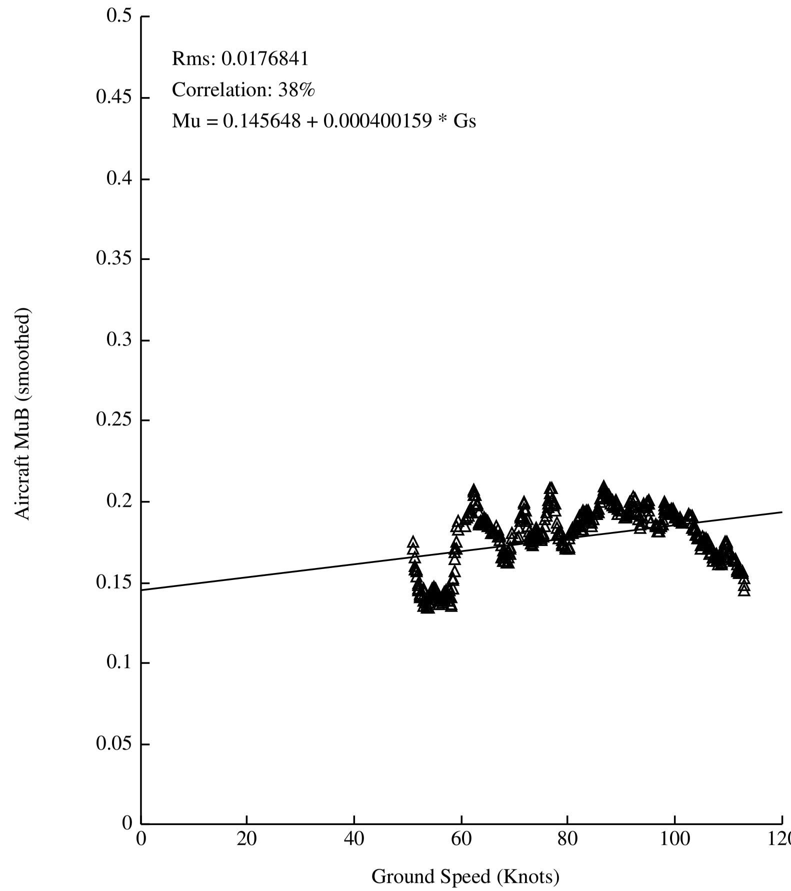
Tanker Re-wet | Runway 29, Wind 230/4

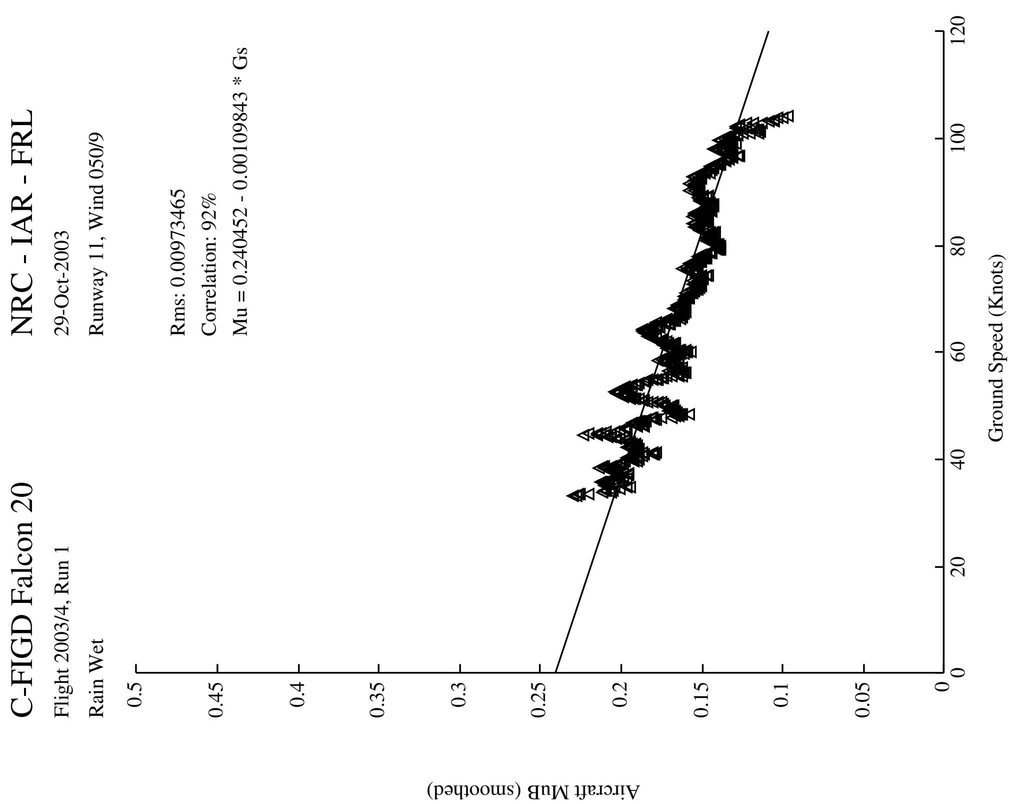


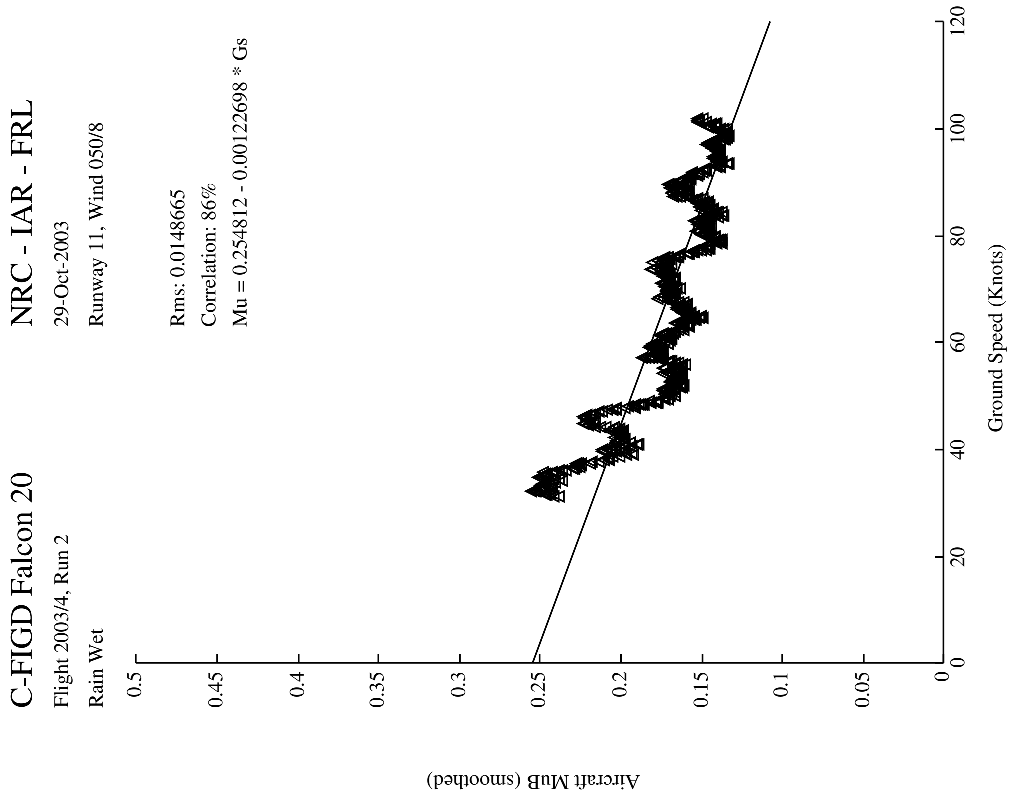
C-FIGD Falcon 20 | NRC - IAR - FRL

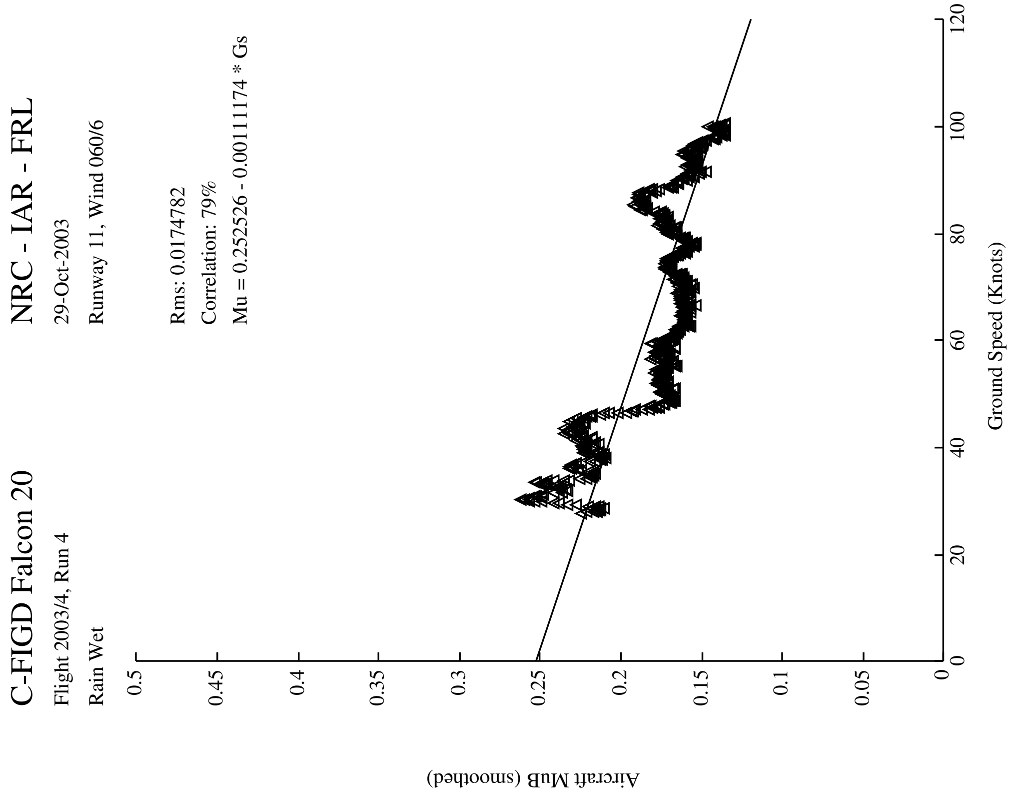
Flight 2003/3, Run 5 | 28-Oct-2003

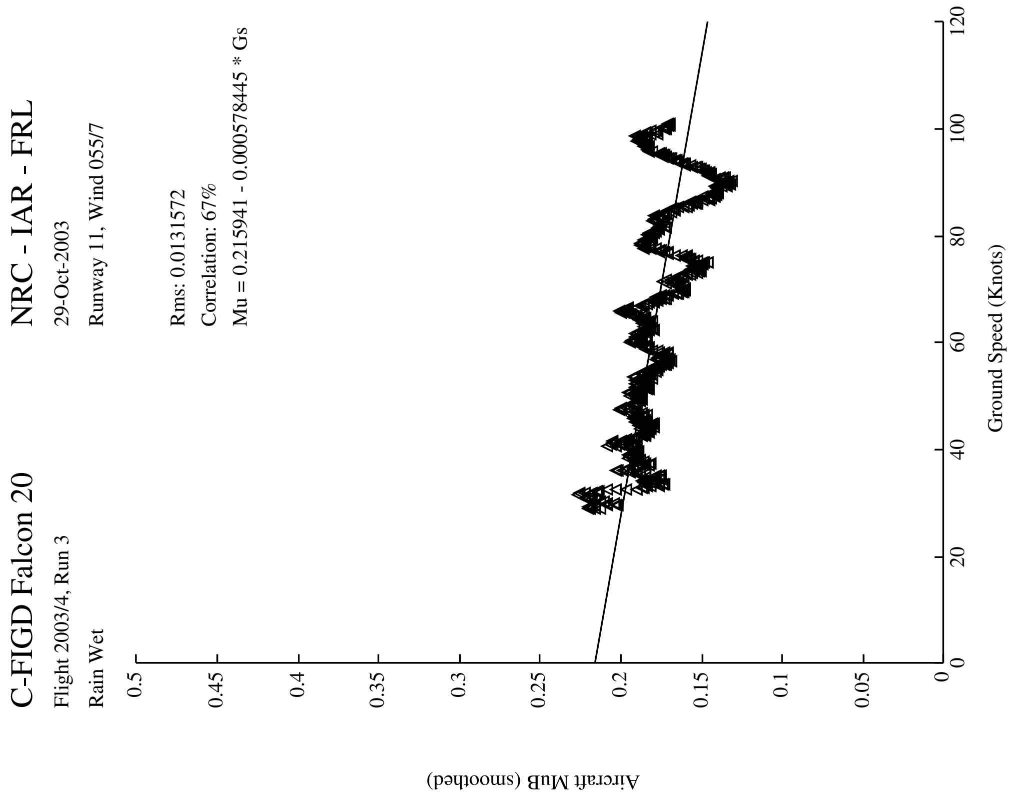
Tanker Wet Remaining | Runway 29, Wind 240/4



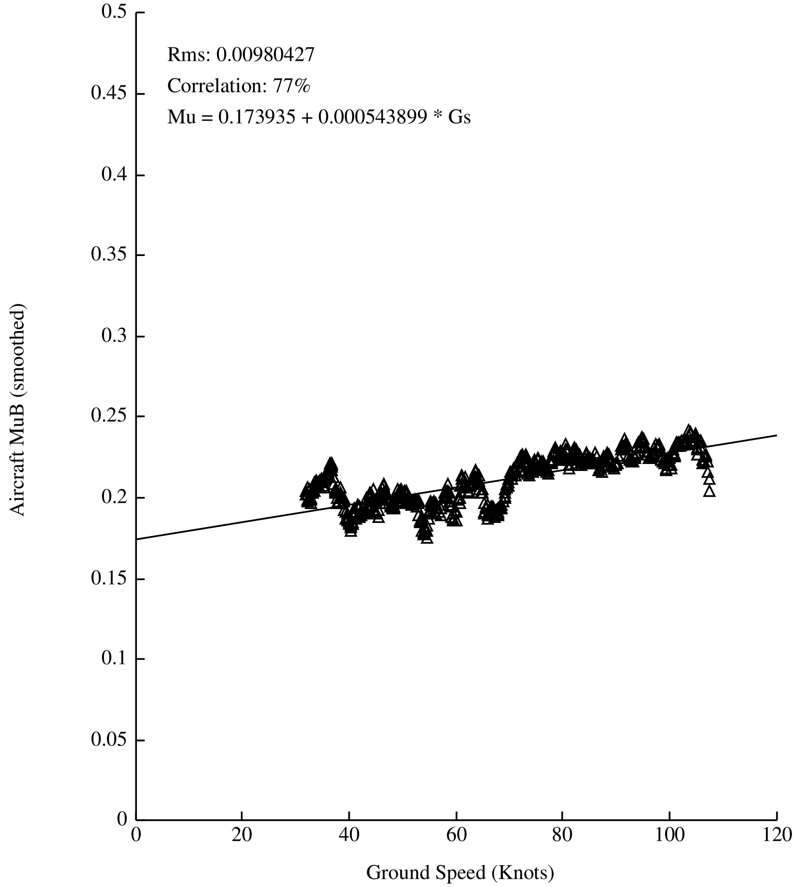

C-FIGD Falcon 20
Flight 2003/4, Run 1
Rain Wet
NRC - IAR - FRL
29-Oct-2003
Runway 11, Wind 050/9
Rms: 0.00973465
Correlation: 92%
Mu = 0.240452 - 0.00109843 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2003/4, Run 2
Rain Wet
NRC - IAR - FRL
29-Oct-2003
Runway 11, Wind 050/8
Rms: 0.0148665
Correlation: 86%
Mu = 0.254812 - 0.00122698 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120

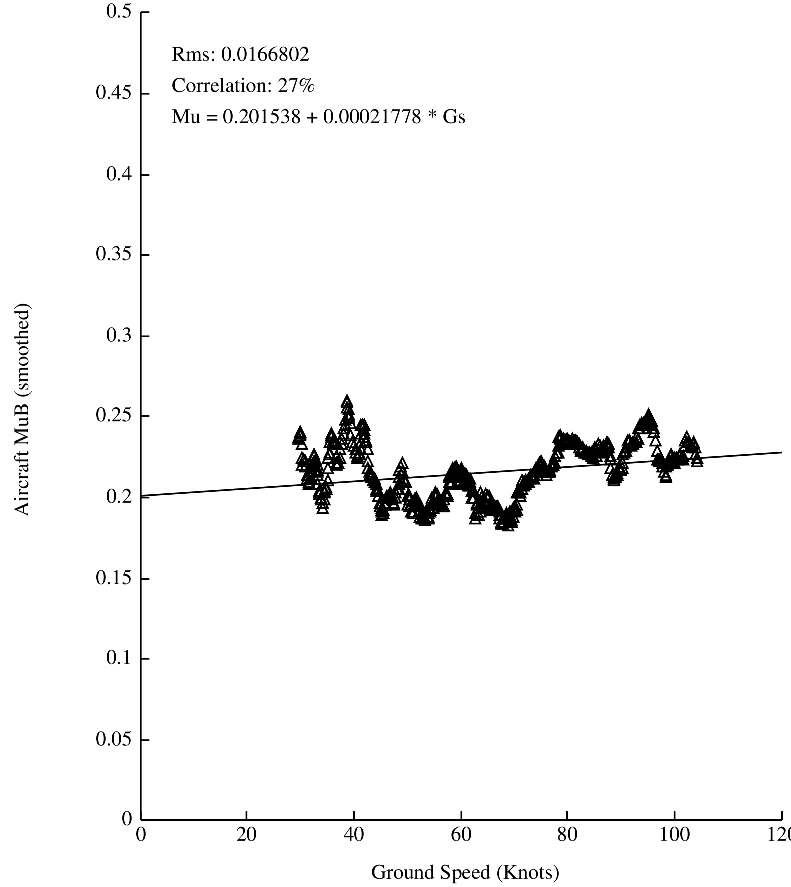

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/4, Run 4
29-Oct-2003
Rain Wet
Runway 11, Wind 060/6
Rms: 0.0174782
Correlation: 79%
Mu = 0.252526 - 0.00111174 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120

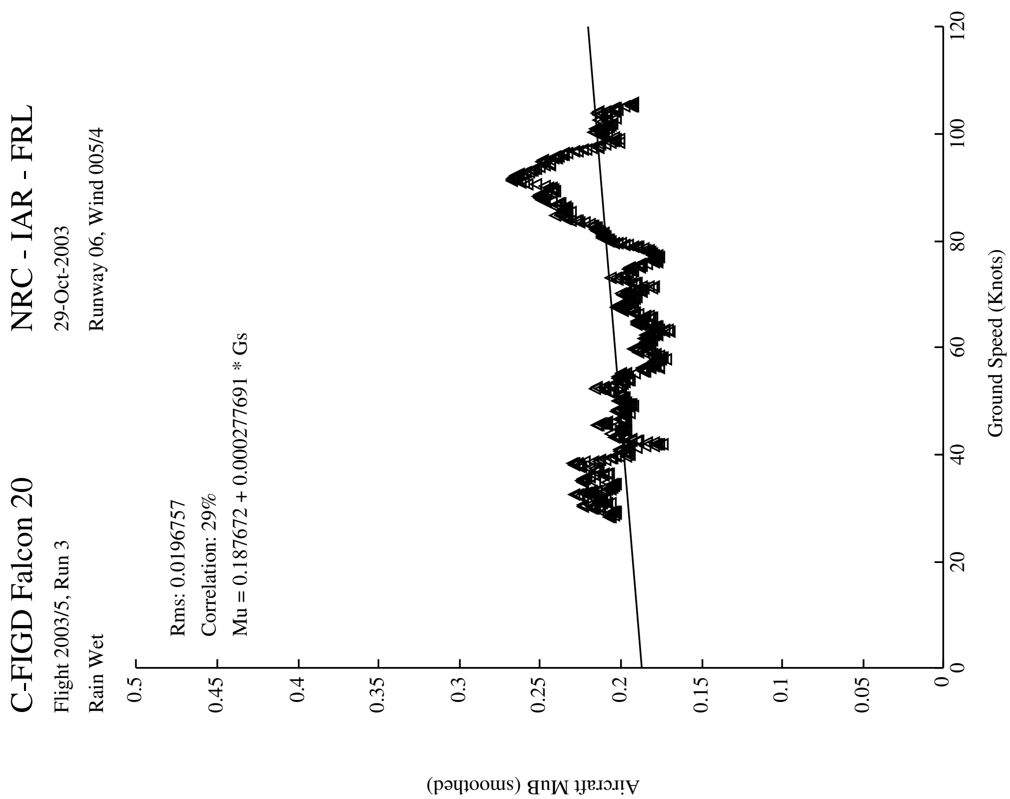

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/4, Run 3
29-Oct-2003
Rain Wet
Runway 11, Wind 055/7
Rms: 0.0131572
Correlation: 67%
Mu = 0.215941 - 0.000578445 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120

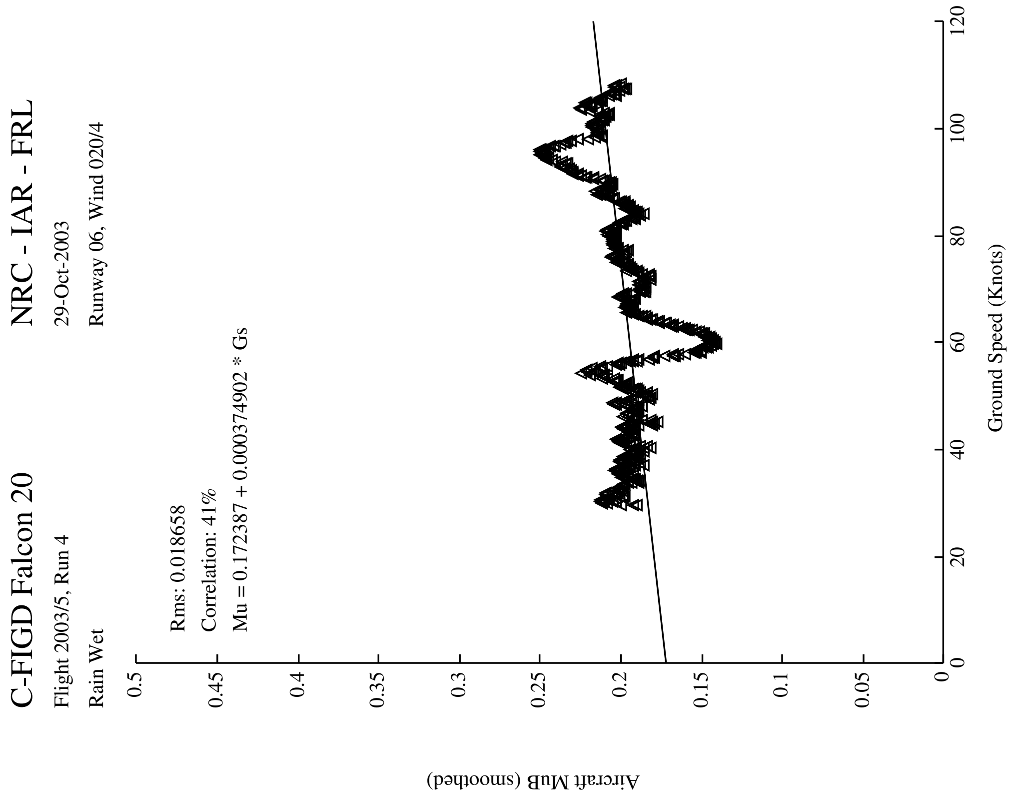
C-FIGD Falcon 20 — NRC - IAR - FRL
Flight 2003/5, Run 1 — 29-Oct-2003
Rain Wet — Runway 06, Wind 035/6

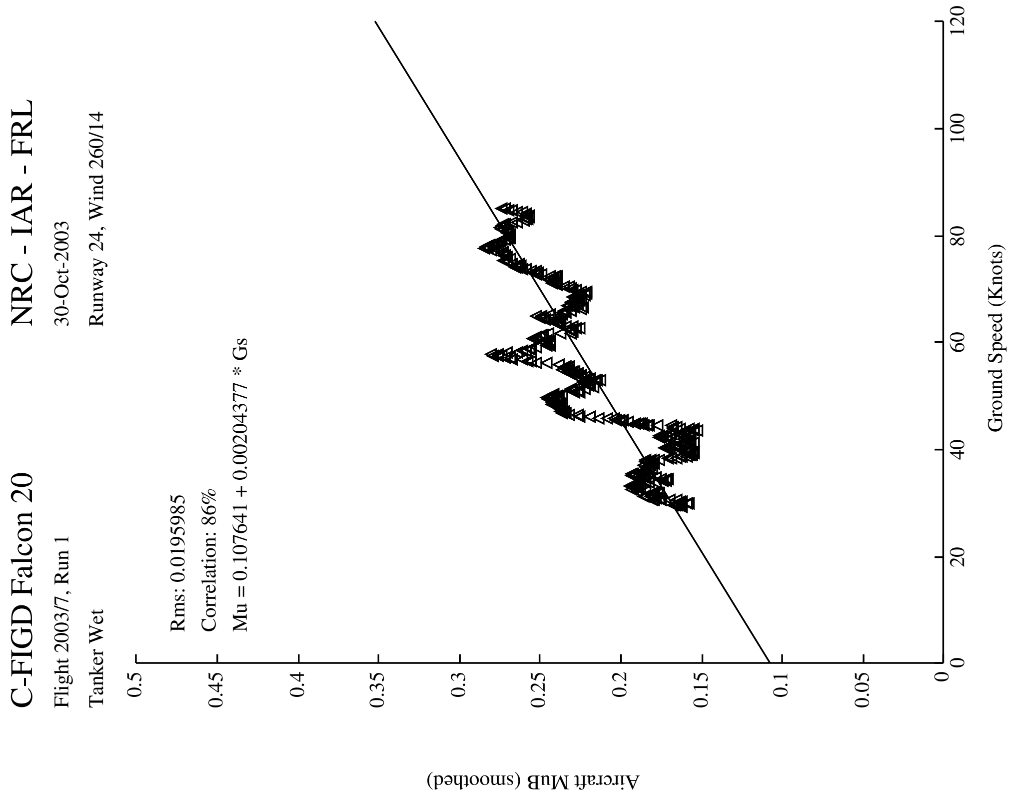


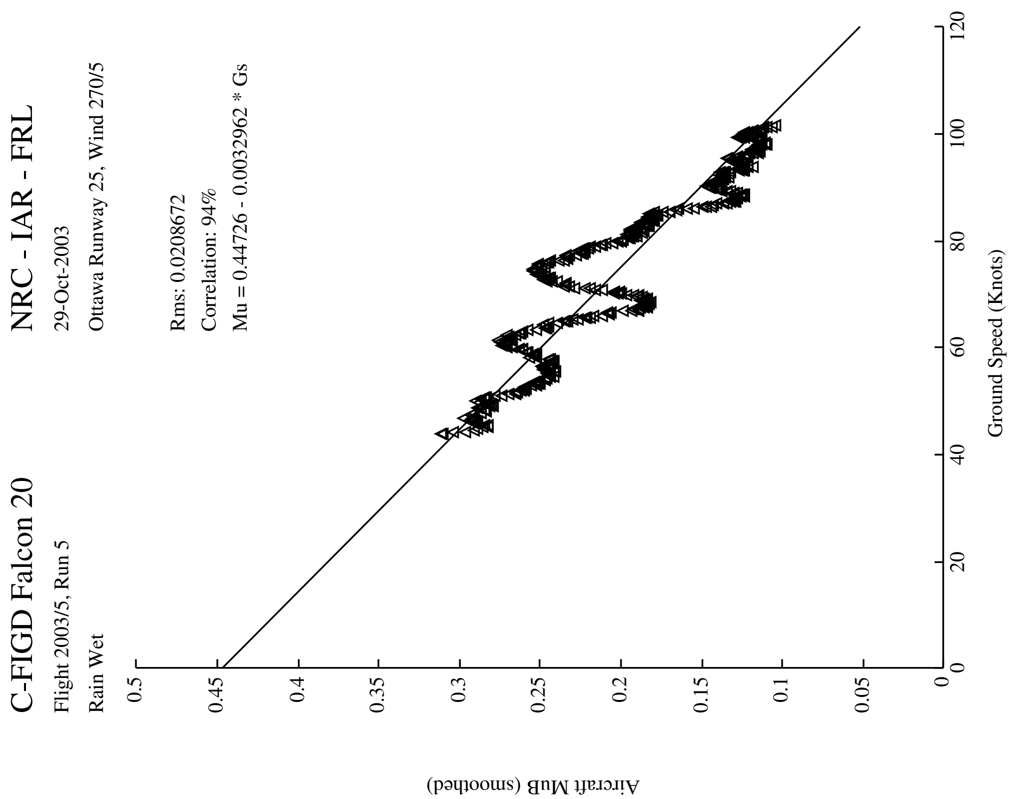
C-FIGD Falcon 20 — NRC - IAR - FRL
Flight 2003/5, Run 2 — 29-Oct-2003
Rain Wet — Runway 06, Wind 025/7

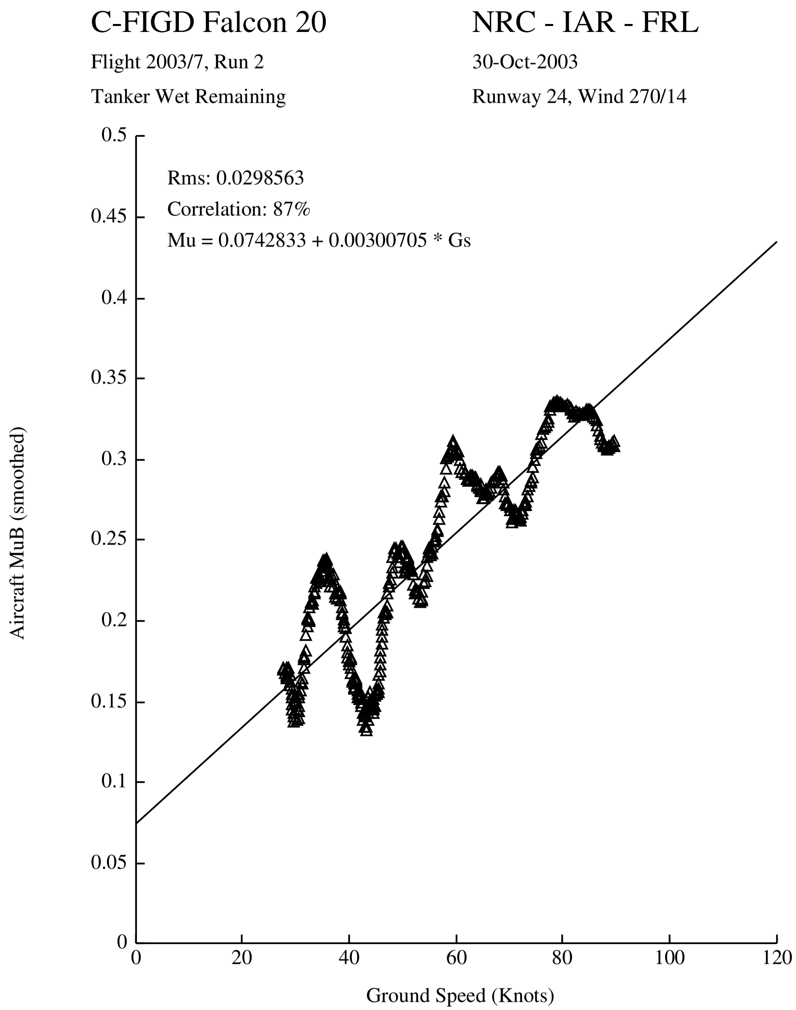


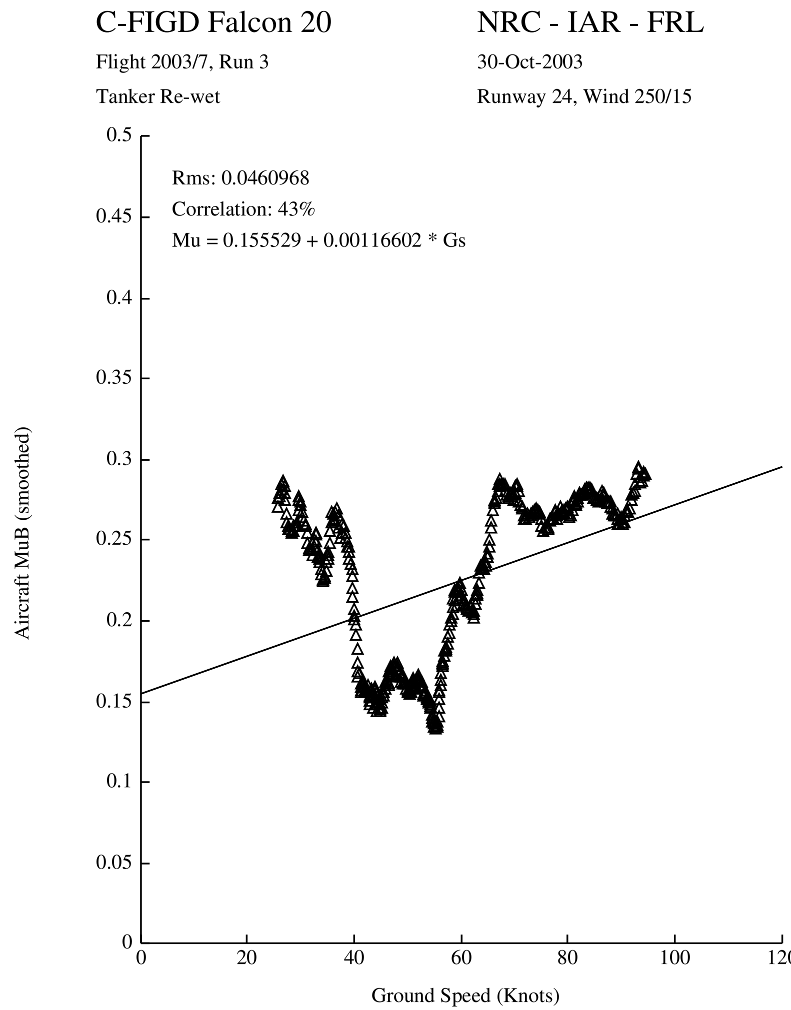

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 3
29-Oct-2003
Rain Wet
Runway 06, Wind 005/4
Rms: 0.0196757
Correlation: 29%
Mu = 0.187672 + 0.000277691 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/5, Run 4
29-Oct-2003
Rain Wet
Runway 06, Wind 020/4
Rms: 0.018658
Correlation: 41%
Mu = 0.172387 + 0.000374902 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2003/7, Run 1
Tanker Wet
NRC - IAR - FRL
30-Oct-2003
Runway 24, Wind 260/14
Rms: 0.0195985
Correlation: 86%
Mu = 0.107641 + 0.00204377 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2003/5, Run 5
Rain Wet
NRC - IAR - FRL
29-Oct-2003
Ottawa Runway 25, Wind 270/5
Rms: 0.0208672
Correlation: 94%
Mu = 0.44726 - 0.0032962 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/7, Run 2
30-Oct-2003
Tanker Wet Remaining
Runway 24, Wind 270/14
Rms: 0.0298563
Correlation: 87%
Mu = 0.0742833 + 0.00300705 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2003/7, Run 3
30-Oct-2003
Tanker Re-wet
Runway 24, Wind 250/15
Rms: 0.0460968
Correlation: 43%
Mu = 0.155529 + 0.00116602 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
20
40
60
80
100
120