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First Air B727 Aircraft Landing Performance On Contaminated Arctic Runway Surfaces During the Winters of 1998/1999 and 1999/2000

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16. Abstract

The landing performance of a First Air B727 aircraft was recorded on contaminated runway surfaces at the Resolute Bay and Nanisivik airports during the winters of 1998-1999 and 1999-2000. Using data from the aircraft Flight Data Recorder and Global Positioning System, the actual aircraft landing distances during normal operations were determined in comparison with the CRFI (Canadian Runway Friction Index) table of recommended landing distances contained in the Transport Canada Aeronautical Information Publication. Out of a total of 26 B727 landings recorded, only one landing resulted in an actual landing distance in excess of the landing distance recommended by the CRFI table, indicating that the CRFI table was accurate in predicting the landing distance of the B727 to a confidence level of at least 95%. The safety factors included in the CRFI tables of recommended landing distance accounted for minor deviations in optimal short field landing techniques, such as a slightly extended flare, late application of reverse thrust or less than full anti-skid wheel braking. Good winter maintenance of the runway surfaces, which included a scarification process at Resolute Bay, was responsible for the relatively high runway friction index during both winter periods.

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16. Résumé

Les performances à l'atterrissage d'un avion B727 de First Air ont été mesurées sur des pistes contaminées aux aéroports de Resolute Bay et de Nanisivik au cours des hivers 1998-1999 et 1999-2000. À partir des données de l'enregistreur de données de vol et du système de positionnement global (GPS), les distances d'atterrissage réelles de l'avion pendant des vols normaux ont été déterminées par rapport au tableau CRFI (Indice canadien de la glissance des pistes) des distances d'atterrissage recommandées figurant dans la Publication d'information aéronautique de Transports Canada. Des 26 atterrissages de B727 mesurés, un seul atterrissage s'est traduit par une distance d'atterrissage réelle supérieure à la distance d'atterrissage recommandée dans le tableau CFRI, ce qui indique que ce tableau était précis dans la prédiction de la distance d'atterrissage du B727 selon un niveau de confiance d'au moins 95 p. cent. Les facteurs de sécurité intégrés aux tableaux CFRI des distances d'atterrissage recommandées tenaient compte de légers écarts par rapport aux techniques d'atterrissage optimales sur terrain court, comme un arrondi légèrement allongé, un retard dans l'inversion de poussée ou un freinage des roues sans que l'antidérapage soit complet. Un bon entretien des pistes l'hiver, qui comprenait un procédé de scarification à Resolute Bay, explique l'indice de la glissance relativement élevé obtenu au cours des deux hivers.

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GLOSSARY OF TERMS

AFM	Aircraft Flight Manual
AIP	Aeronautical Information Publication
ATIS	Automatic Terminal Information System
B727	Boeing 727 aircraft
CRFI	Canadian Runway Friction Index
DAS	Data Acquisition System
DGPS	Differential Global Positioning System
EPR	Engine Pressure Ratio
EQAR	Extended Storage Quick Access Recorder
ERD	Electronic Recording Decelerometer
EW	East - West
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
ft	Feet
g	Gravitational Constant
GPS	Global Positioning System
GS	Groundspeed
IAR	Institute for Aerospace Research
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IRFI	International Runway Friction Index
JWRFP	Joint Winter Runway Friction Program
LD	Landing Distance
NASA	National Aeronautics and Space Administration
NOTAM	Notice to Airmen
NRC	National Research Council
NS	North - South
QAR	Quick Access Recorder
RTO	Rejected Takeoff
SPS	Standard Positioning Service
TC	Transport Canada
TCH	Threshold Crossing Height
V_{REF}	Aircraft Approach Speed
W	Aircraft Weight
YRB	Resolute Bay Airport
YSR	Nanisivik Airport

Malak Photographs

First Air B727 Aircraft

FIRST AIR B727 AIRCRAFT LANDING PERFORMANCE ON CONTAMINATED ARCTIC RUNWAY SURFACES DURING THE WINTERS OF 1998/1999 AND 1999/2000

1.0 INTRODUCTION

1.1 Background

The Joint Winter Runway Friction Program (JWRFP) is a five year initiative among several countries to study winter runway friction, with the goals of both standardizing its measurement and determining its effect on aircraft performance. As part of the JWRFP, aircraft landing performance tests were conducted each winter at the North Bay airport starting in the winter of 1995/1996. Test aircraft included an NRC Falcon 20, a NASA B737, an FAA B727 and a deHavilland Dash 8. These tests, documented in References 1 through 9, were successful in relating aircraft stopping performance to the measured Canadian Runway Friction Index (CRFI). Based on the test results, the CRFI tables of recommended landing distance were published in the TC AIP to provide guidance to pilots during winter operations.

The First Air B727 program came about primarily because of pilot subjective observations that the CRFI reports for runways in the Canadian Arctic did not accurately reflect the braking performance of the B727. It was generally felt that the braking performance was better than the reported CRFI would indicate, and that the current AIP CRFI tables of recommended landing distance was overly restrictive. To investigate this problem, and to obtain additional data to validate the CRFI tables, the landing performance of a First Air B727-100 was recorded on contaminated Arctic runway surfaces over the period of two winters at the Resolute Bay and Nanisivik airports.

First Air B727 operational landing performance was recorded during normal revenue operations with a minimum of disruption to normal operating procedures.

1.2 Objectives and Scope

The objectives of the First Air B727 project, as agreed to among TC, NRC and First Air, were as follows:

a) Record B727 landing performance and compare to data in the CRFI tables of recommended landing distance contained in the AIP; and

b) Establish the aircraft braking coefficient on typical winter contaminated Canadian Arctic runway surfaces and determine if a correlation exists between the braking coefficient and the CRFI and/or the proposed International Runway Friction Index (IRFI).

Over a two year test period, it was intended that objective a) be achieved during the first year with the installation of a Quick Access Recorder (QAR), and that objective b) be achieved during the second year with the installation of a more complex NRC designed instrumentation package. Since only limited data was recorded during the first year, the use of the QAR was extended into the second year, and the NRC instrumentation package was never installed. Thus, objective b) was not achieved.

This report will cover the results of the First Air B727 landing performance during the winters of 1998/1999 and 1999/2000, and will compare actual landing distances with values predicted from the CRFI tables.

2.0 EQUIPMENT DESCRIPTION

2.1 B727 Aircraft and Instrumentation

The aircraft used for all the recorded landings was First Air B727-100 registration number C-GFRB. The instrumentation available was the basic Flight Data Recorder (FDR), a Plessy PV 1584A, as well as a Dassault Extended Storage Quick Access Recorder (EQAR), part number 1374-102-000, specially installed for this project. The EQAR was used to record the existing FDR parameters as well as selected parameters from the Trimble 8100 GPS. The following lists contain the main parameters recorded from each source:

a) Flight Data Recorder parameters:

- Indicated airspeed
- Longitudinal and vertical acceleration
- Magnetic heading
- Pressure altitude
- Radar Altitude
- Weight on wheels
- #2 Engine Pressure Ratio (EPR)

b) Trimble 8100 GPS parameters

- Latitude, longitude and height
- GPS Time and date
- NS and EW velocities
- Aircraft groundspeed
- Wind speed and direction
- Aircraft ground track

The EQAR input data were accepted in conformance with ARINC 429, 573 and 717-7 formats. The recording medium was a standard 3 1/2 inch removable and rewritable optical disk with a storage capacity of 128 or 230 Mbytes.

Several factors delayed the start of operational data collection, the first being a change in the designated aircraft from C-FRST to C-GFRB, and the second being an intermittent data recording problem that required the EQAR to be sent back to Dassault for repair in December 1998. The EQAR recorded its first set of landing performance data at Resolute Bay on 25 February 1999, well into the first winter season.

The First Air B727 anti-skid braking system is a Hydro-Aire Mark II part number 42-527D. This is an analogue system which uses electrical signals generated as a function of wheel speed to detect an impending skid or rapid wheel deceleration above a preset rate. Upon detection of a skid, the system immediately reduces brake pressure to allow the wheel to recover, and then reapplies brake pressure at a level slightly below the pressure which caused the previous wheel deceleration. Nose wheel braking, also under anti-skid control, is available as a function of nose wheel spin-up and oleo extension. Nose wheel braking is only active when both brake pedals are depressed past 50% full travel, or one brake pedal is depressed past 75%. None of the brake pressures delivered to the wheel brake units were instrumented or recorded.

2.2 Ground Friction Measuring Devices and CRFI

An Electronic Recording Decelerometer (ERD) was used at both the Resolute Bay and Nanisivik airports to measure runway friction, or CRFI. The ERD is rigidly mounted in the cab of an airport vehicle, and friction readings are taken by accelerating the vehicle to 50 km/hr and then applying the brakes to the point of lockup. A number of readings are taken at various intervals along the length of the runway surface, and averaged to produce the CRFI for a particular runway at a particular time of day.

The CRFI itself is a number from 0.0 to 1.0, with the upper value being equivalent to the theoretical maximum deceleration on a dry surface, although in practice it is rarely above 0.8, and with the lower value being representative of zero braking. The CRFI, along with the runway surface condition and other pertinent NOTAM information, is relayed to incoming aircraft by the control tower or Flight Service Station. Typically, CRFI values for hard packed snow conditions expected at Arctic airports are between 0.25 and 0.35, with slightly higher values expected during extreme cold conditions. At Resolute Bay, the airport operator "scarified" the runway longitudinally by dragging a serrated blade fixture back and forth along the snow/ice packed gravel runway to produce small grooves a few inches apart. The presence of the grooves, along with the bits of ice and gravel forming the debris from the scarification process, increased the runway surface friction, resulting in higher ERD readings.

A TC inspector visited the airport operator at Resolute Bay to obtain some first hand information on the effects of the scarification process. He determined that the B727 aircraft, weighing several orders of magnitude more than the ERD vehicle, would be relatively unaffected by the debris on the runway, whereas the ERD vehicle would tend to slide over the debris. This would result in better aircraft braking performance than the reported CRFI would indicate, substantiating the observation made by the First Air pilots. The ERD readings were higher when a wind that blew the debris off the surface was present, or when measured with the airport vehicle perpendicular to the grooves (across the runway). Scarification across the runway would not be practical in terms of time, and even though a higher ERD reading would result, the additional benefits to the aircraft braking performance would be questionable.

In order to determine the First Air B727 landing distance from a 50 foot screen height to taxi speed, and compare it to the recommended landing distance from the CRFI tables, three sources of data were used: 1) the EQAR data, 2) the airport operator CRFI report and runway condition report, and 3) the First Air pilot report on landing parameters and technique. This latter report was a single page questionnaire filled out by the pilot after landing, and included the following information:

Time and Date
Airport and runway
Landing configuration, weight, and V_{REF}
Surface air temperature
Wind speed and direction
Runway condition report and CRFI
Qualitative description of braking and use of reverse thrust

3.0 TEST PROCEDURES

3.1 Tests Conducted

All flight operations were conducted by First Air pilots. For the purpose of obtaining landing distances for comparison with CRFI table data (primary objective of section 1.2), it was sufficient to follow normal procedures for landing at Arctic airports; that is, normal landing configuration and approach speeds, spoiler deployment on touchdown, application of reverse thrust on the #2 engine (1.8 max EPR), and full wheel braking with nose wheel brakes armed.

The original test plan initially called for different landing procedures to be used for specific test purposes, including the use of either idle reverse, no reverse or no braking for a portion of the landing roll. These "abnormal" procedures were not implemented for two main reasons: 1) the secondary objective of determining the aircraft braking coefficient was dropped from the test plan for the reasons stated in section 1.2, and 2) a considerable lead time would have been required for the First Air crews to set up training procedures to fly the actual test points.

3.2 Analysis Methods

To determine the actual aircraft landing distance, the Trimble 8100 GPS latitude and longitude data was used in the non-differential mode. The data was transformed, using an NRC developed software program, into distance (in feet) from the runway threshold along the extended runway centreline (positive distance on the approach side). The difference between the position of the aircraft at a screen height of 50 feet above the runway threshold and the completion of the landing roll represented the total actual landing distance of the aircraft. The screen height itself was determined from the radar altimeter, the non-differential GPS height being inadequate to determine this value. Since the aircraft rarely came to a complete stop, the termination of the landing roll was considered to be a deceleration to taxi speed or the commencement of a 180 degree turn to taxi back to the ramp. The accuracy of comparing one position relative to another using the GPS in the Standard Positioning Mode (SPS), was considered to be less than about 100 feet.

From the information provided by the pilots (aircraft configuration, gross weight and surface wind), the aircraft flight manual landing distance (AFM LD) was determined. Using the AFM LD and the value of the CRFI reported by the airport operator, two landing distance predictions were determined from the CRFI tables, both taking into account the use of reverse thrust. The first was from a CRFI table giving "predicted" landing distance without safety factors included, unpublished by NRC or TC, but described in Reference 7. Because the landing distances in this table are determined from a linear fit of the aircraft braking coefficients plotted against CRFI, they are called 50% LD's, and represent a 50% confidence level of being above or below the line. The second landing distance prediction includes safety factors, and comes from the CRFI Table 2 of recommended LD (reverse thrust) published in the AIP. These are called 95% LD's because they include a 95% level of confidence that a properly executed landing will terminate within the stated distance.

The actual landing distance of the First Air B727 was compared to the 50% and 95% LD's to check the validity of the CRFI Tables. Proof of validity would be consistent actual LD's lying between the two predicted LD's. Actual LD's above the values of the 95% LD would indicate that the CRFI tables are not conservative enough. Actual LD's below the values of the 50% LD would indicate landing performance better than the minimum distance possible with no safety factors included, meaning that the model on which the CRFI tables are based is too conservative.

4.0 TEST RESULTS AND DISCUSSION

4.1 Summary of Test Runs

A total of 26 landings were recorded at the Resolute Bay and Nanisivik airports during the winters of 1998/1999 and 1999/2000. This is not a large data set considering that two flights a week were scheduled over the two winters. As mentioned in section 2.1, the first winters activities got off to a late start due to a change in the designated aircraft and some EQAR problems. The second winters activities were suspended during the months of January and February when First Air substituted a different aircraft for the northern route for operational purposes. These priorities, along with the need for minimal disruption to normal revenue operations, significantly limited the number of landings which could be recorded, and limited the breadth of CRFI values for the runways on which data was obtained.

Plots of selected data for each recorded landing are shown in Appendix A for data acquired during the winter of 1998/1999 and in Appendix B for data acquired during the winter of 1999/2000. Plotted for each landing are groundspeed in knots, longitudinal acceleration in "g" units, radar altimeter height in feet, and position "x" in feet from the runway threshold along the runway centreline. The timeline is in seconds and spans the period between the commencement of the landing (at 50 feet on the radar altimeter) to the completion of the landing roll. Statistics are shown in small print above each plot, labeled mean, median, rms, minimum and maximum.

Summarized on the left side of each set of plots in Appendices A and B are the data pertaining to the airport and the runway surface, along with the calculated aircraft landing distances. For each data set, the actual landing distance is averaged between a calculation based on GPS position and a calculation based on the integral of GPS groundspeed. Taking into account the uncertainties in defining both the start and end of the actual landing distance, and the known errors in the GPS SPS mode, the accuracy's of the actual LD's are considered to lie within a maximum deviation of ±300 feet. The AFM landing distance and CRFI chart distances (50% and 95%) are also shown to the left of the plots.

In some cases the FDR data had to be re-synchronized in time with the Trimble GPS data, even though this was usually accomplished during data processing. The first landing data set at the top of page A1 shows an example of this requirement. The plots show that the aircraft groundspeed, which is based on GPS data, begins to decrease about 5 seconds prior to the corresponding decrease in longitudinal acceleration, which is based on the FDR. Since the two parameters are clearly related to each other, the groundspeed plot must be delayed (moved to the right) by 5 seconds to match the longitudinal acceleration. The position "x" plot must also be moved 5 seconds to the right, since it is based on GPS data. The new "x" position at the beginning of the landing would be close to zero, instead of the value shown (maximum) of –1146 feet. The corrected landing distance would be 0 - (-4590) = 4590 feet as opposed to the distance calculated from the uncorrected plot of -1146 - (-4590) = 3444 feet.

The above correction makes sense from an aircraft flight path perspective, where the runway threshold at a position of x = 0 would normally be crossed at a threshold crossing height (TCH) of 50 feet. In the above example, the plots show the aircraft at the 50 foot height at a distance of 1146 feet down the runway, a situation which would rarely occur in practice.

Landing data set 04 on page A2 is an example of a requirement to advance the GPS data by about 5 seconds to match the FDR data. This provides a corrected actual landing distance of about 5030 feet instead of 6250 feet derived from the uncorrected plot. In addition, the 50 foot screen height would occur close to the runway threshold, as opposed to the position shown in the plot of 1217 feet prior to the runway, a situation where the aircraft would be dangerously low and which would very rarely occur in practice.

The landing distance information in Appendices A and B is summarized in Table 1, which shows the CRFI value, the 50% LD, the actual LD and the 95% LD for each of the 26 recorded landings. From the data in Table 1 it can be seen that of the 26 recorded landings, only one landing resulted in an actual landing distance in excess of the 95% LD (shown in bold print for run no. 24), and no landings were accomplished within a distance less than the 50% LD. According to the definitions of the 50% and 95% LD's in section 3.2, this means that the safety factors incorporated into the CRFI tables were appropriate, and that the CRFI tables were accurate in predicting the landing distance to a confidence level of at least 95% (25 out of 26 landings). A discussion of these results follows.

Run No.	Date	Airport	Runway	CRFI	50% LD (feet)	Actual LD (feet)	95% LD (feet)
1	25/02/99	YSR	29	0.38	4500	4600	5850
2	25/02/99	YRB	35	0.46	3870	4540	5060
3	26/02/99	YRB	35	0.50	4140	5020	5430
4	26/02/99	YSR	29	0.41	4110	5150	5360
5	01/03/99	YSR	11	0.42	4320	5310	5670
6	04/03/99	YSR	29	0.46	4870	6210	6350
7	04/03/99	YRB	35	0.47	3950	4730	5290
8	05/03/99	YRB	35	0.43	4240	5040	5540
9	08/03/99	YRB	17	0.45	4280	4450	5590
10	08/03/99	YSR	11	0.43	4810	6230	6260
11	29/03/99	YRB	35	0.57	3990	5130	5230
12	29/03/99	YSR	11	0.31	4770	5430	6180
13	05/04/99	YSR	29	0.34	4640	5800	6030
14	12/04/99	YSR	11	0.33	4680	4960	6080
15	17/11/99	YRB	35	0.45	4100	4910	5350
16	20/11/99	YRB	35	0.45	4100	4240	5350
17	20/11/99	YSR	29	0.39	4570	4680	5950
18	11/12/99	YRB	35	0.49	4170	5220	5460
19	11/12/99	YSR	11	0.41	4200	4310	5480
20	15/12/99	YSR	11	0.34	4700	5940	6100
21	15/12/99	YRB	35	0.49	4170	5330	5460
22	18/12/99	YRB	35	0.51	3940	4840	5170
23	18/12/99	YSR	29	0.35	4820	5580	6260
24	25/02/00	YRB	35	0.45	4280	**6320**	5590
25	25/02/00	YSR	11	0.34	4440	4810	5760
26	18/03/00	YSR	11	0.42	4370	5160	5700

Table 1
First Air B727 Landing Data Summary, February 1999 to March 2000

4.2 Discussion of Results

Pilot subjective comments for most landings indicated the use of “moderate” braking, consistent with passenger comfort level. Since the CRFI tables were developed with the use of maximum anti-skid braking on all the test aircraft, it is not surprising that no landings were accomplished within a distance less than the 50% LD. Some landings came close, however, and it is interesting to note the pilot techniques which resulted in the shortest landing rolls. Since the actual brake pressures were not recorded, the only parameter available to back up the pilot comments was the longitudinal deceleration, which showed the combined effects of wheel braking, reverse thrust and runway friction (CRFI). An inspection of the longitudinal deceleration parameter provided information on the landing technique, and usually verified whether the actual landing distance was closer to the 50% LD or the 95% LD.

An example of a landing with moderate to heavy braking is data set 1, page A1. The initial longitudinal deceleration is about 0.4 g, resulting from a moderate to heavy braking effort along with the application of reverse thrust on the #2 engine. Reverse thrust is phased out below 60 knots, but longitudinal deceleration is maintained around the 0.3 g level with continued brake application down to an aircraft taxi speed. The constant deceleration can also be seen as a fairly constant slope of the groundspeed versus time plot. This technique resulted in the shortest landing distance, which in this case was only 100 feet longer than the 50% LD. Another important factor in the short landing distance is the minimal flare; in this case the point of maximum deceleration on the runway was achieved no more than 10 seconds after passing the 50 foot screen height.

A second example of a good short field landing technique is data set 19, page B3. In this case, the initial longitudinal deceleration is only about 0.3 g, but this level of deceleration is maintained for the duration of the landing run, again resulting in an actual LD of about 100 feet longer than the 50% LD. The point of maximum deceleration on the runway is also achieved a scant 8 seconds after passing the 50 foot screen height.

It is impossible to determine what percentage of maximum anti-skid braking was used in these two examples, but if the pilot was using maximum braking consistent with passenger comfort, then for all practical purposes the 50% LD accurately predicts the shortest landing distance achievable under operational conditions.

The 95% LD includes safety factors to account for small deviations in pilot technique, aircraft braking performance and runway friction index which would increase the landing distance beyond the 50% LD up to a distance, determined statistically, to represent a 95% confidence level. Some of the landings which resulted in actual LD’s close to, and one beyond, the 95% LD will be discussed in the following paragraphs.

Three landings resulted in landing distances above 6000 feet. These were data sets 6, 10, and 24, the first two at the Nanisivik airport and the third at Resolute Bay. Data set 6, page A3, shows a slightly extended flare with the point of maximum deceleration on the runway occurring 13 seconds after passing the 50 foot screen height. A good initial deceleration of about 0.4 g is achieved with reverse power and wheel braking, but as reverse thrust is phased out below 60 knots, the braking effort is also reduced and the longitudinal deceleration reduces to only about 0.1 g for the last 17 seconds of the landing roll. This “decreasing” deceleration can be seen as a decreasing slope of the groundspeed versus time plot. The intentional use of light braking during the second half of the landing roll is a normal technique to minimize brake wear, especially on a runway which, in this case, was 70% bare and dry. The actual LD was 140 feet shorter than the 95% LD, meaning that the deviations from optimal techniques were accounted for by the safety factors.

Data set 10, page A5, shows a normal flare and touchdown, but a fairly low initial deceleration of only 0.2 to 0.3 g, due to light application of wheel brakes and/or late application of reverse thrust. The braking effort is further reduced for the latter part of the ground roll, resulting in an actual landing distance just inside the 95% LD. Again, minor deviations to optimal techniques are covered by the safety factors embedded in the CRFI table of recommended LD’s.

It is of interest that the previous two landings, both at Nanisivik, were done with 5 knot tailwind components on a mostly bare and frozen gravel surface with mid level CRFI’s (0.46 and 0.43). The 95% LD’s were just inside the available runway length in both cases, and the actual LD’s were just inside the 95% LD’s. A third landing at Nanisivik, data set 12 on page A6, was done without a tailwind, but on a mostly compact snow surface (CRFI = 0.31). This condition also had a 95% LD just inside the available runway length. Although none of the recorded landings during this project had 95% LD’s beyond the available runway length, the existence of both a tailwind component and a CRFI value below 0.30 (at the same landing weights) would have resulted in a 95% LD greater than the available runway length at either Nanisivik or Resolute Bay.

Data set 24, page B5, shows an extended flare, with the point of maximum deceleration on the runway occurring 17 seconds after passing the 50 foot screen height. This represents a delay of at least 7 seconds beyond what would be considered optimal, and is the primary reason why the actual landing distance is over 700 feet longer than the 95% LD. At an average groundspeed of 125 knots, 7 seconds represents almost 1500 feet of runway. This is a significant deviation from optimal technique, and hence beyond reasonable safety factor considerations.

Based on the above discussion, it is concluded that optimal short field landing techniques, supported by EQAR data, resulted in landing distances that were close to the 50% LD, and that minor deviations to these techniques resulted in landing distances closer to, but not above, the 95% LD. Safety factors included in the CRFI tables of recommended landing distance accounted for minor deviations in pilot technique or aircraft braking performance. In one case, constituting less than 5% of the landings recorded, a major deviation to the optimal aircraft flare technique resulted in a landing distance above the predicted 95% LD.

An inspection of the CRFI values listed in Table 1 shows that the average CRFI for the 26 recorded landings was 0.425, a fairly high value. Divided between Nanisivik and Resolute Bay, there were 14 landings recorded at Nanisivik with an average CRFI of 0.38, and 12 landings at Resolute Bay with an average CRFI of 0.48. The significant difference between the two average CRFI's is most likely due to the scarification process carried out at Resolute Bay, which is said to increase the CRFI by 0.05 to 0.10.

During the first winter, runway conditions were mostly stated as a bare and frozen gravel surface with only patches (up to about 30%) of compact snow. The lack of snow during the winter of 1998/1999 was one of the reasons that the project was extended into the winter of 1999/2000. During the second winter, runway conditions at Resolute Bay were stated as 100% compact snow with exposed gravel (scarified) with CRFI's at 0.45 and above. Some of the lower CRFI's recorded during the dark months of January and February may have been missed due to the substitution of aircraft during that timeframe, but the limited data obtained shows that a high runway friction index was maintained over the course of the two winters. The good braking performance observed by the First Air pilots was due, in general, to this high runway friction, and in particular to the scarification process at Resolute Bay, described in section 2.2.

5.0 CONCLUSIONS

A total of 26 First Air B727 landings were recorded during the winters of 1998/1999 and 1999/2000, on Arctic runway surfaces ranging between 100% compact snow and 100% bare and frozen gravel, with CRFI's ranging between 0.31 and 0.57. Only one landing out of the 26 recorded landings resulted in an actual landing distance in excess of the landing distance recommended by the CRFI Table (with reverse thrust) in the AIP. It is concluded that the CRFI Table was accurate in predicting the landing distance to a confidence level of at least 95% (25 out of 26 landings).

Optimal short field landing techniques, as evidenced by EQAR data for certain landings, resulted in the shortest actual landing distances. Minor deviations in landing techniques, such as a slightly extended flare, late application of reverse thrust or less than full anti-skid wheel braking, resulted in longer actual landing distances, but not in excess of the distance recommended by the CRFI Table. It is concluded that the safety factors included in the CRFI tables of recommended landing distance accounted for minor deviations in pilot techniques and/or aircraft braking performance.

The airport data obtained over the two winters indicate that a relatively high runway friction index was maintained, particularly at Resolute Bay. This was in part due to good weather, but also in part due to good runway maintenance, which included a scarification process at Resolute Bay. The good aircraft braking performance observed by the First Air pilots was due, in general, to this high runway friction, and in particular to the scarification process at Resolute Bay.

6.0 REFERENCES

1. J.C.T. Martin, J.B. Croll, M. Bastian — Braking Friction Coefficient and Contamination Drag Obtained for a Falcon 20 Aircraft On Winter Contaminated Runway Surfaces, National Research Council Canada, LTR-FR-132, September 1996.

2. J.B. Croll, J.C.T. Martin, M. Bastian — Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1996/1997, National Research Council Canada, LTR-FR-137, August 1997.

4. M. Doogan, E. Herrmann, P. Lamont — Braking Friction Coefficient and Contamination Drag for the Dash 8 on Winter Contaminated Runways, de Havilland, Inc, DHC-D4547-97-09, September 1997.

5. M. Doogan, E. Herrmann, P. Lamont — Dash 8 Aircraft Performance Testing on Contaminated Runway Surfaces (Winter 1997/1998), Bombardier Aerospace, DHC-D4547-98-06, June 1998.

6. M. Bastian, P. Lamont — Braking Friction Coefficient and Contaminated Drag of a B727 on Contaminated Runways, National Research Council Canada, LTR-FR-147, TP 13258E, June 1998.

7. J.B. Croll, J.C.T. Martin, M. Bastian — Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1997/1998, National Research Council Canada, LTR-FR-151, December 1998.

8. J.C.T. Martin — Proposed Amendment to the CRFI Recommended Landing Distance Table for Aircraft with Thrust Reverser or Propeller Reversing Systems, Transport Canada Aircraft Certification Flight Test Division, January 1999.

9. J.B. Croll, J.C.T. Martin, M. Bastian — Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1998/1999, National Research Council Canada, LTR-FR-158, December 1999.

First Air B727 landing data set: 01
Date: 25 Feb 99
Airport: Nanisivik
Runway: 29
Runway condition: 70% bare and dry, 30% compact snow, trace of frost, -22º C

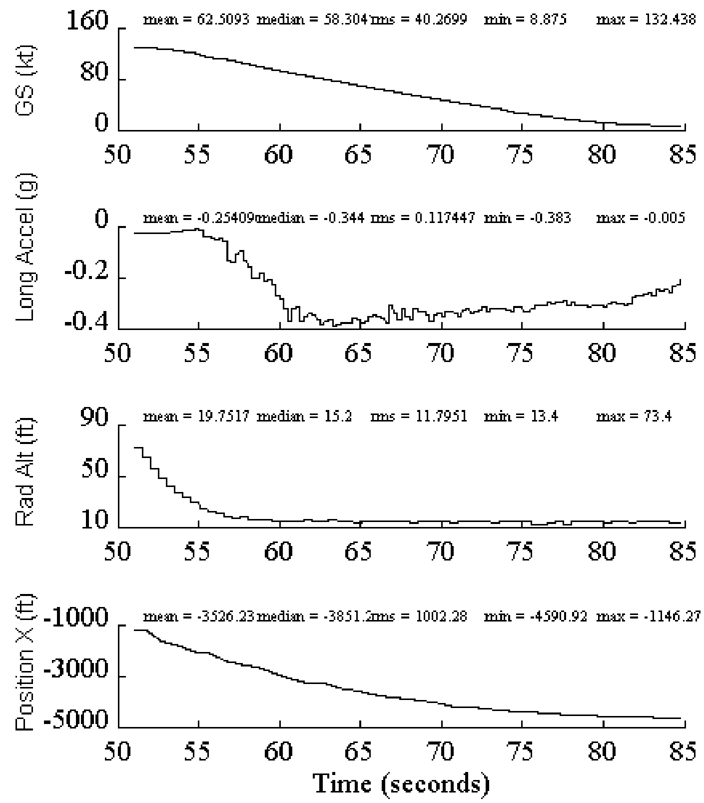
CRFI: 0.38

Actual landing distance:
- based on GPS position: 4590 ft
- based on integral of GS: 4620 ft
- average: 4600 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5850 ft
- 50% chart: 4500 ft

Comments: GPS data delayed 5 seconds to match FDR data.



First Air B727 landing data set: 02
Date: 25 Feb 99
Airport: Resolute Bay
Runway: 35
Runway condition: 140 ft down centre-line bare, frozen gravel surface, -36º C

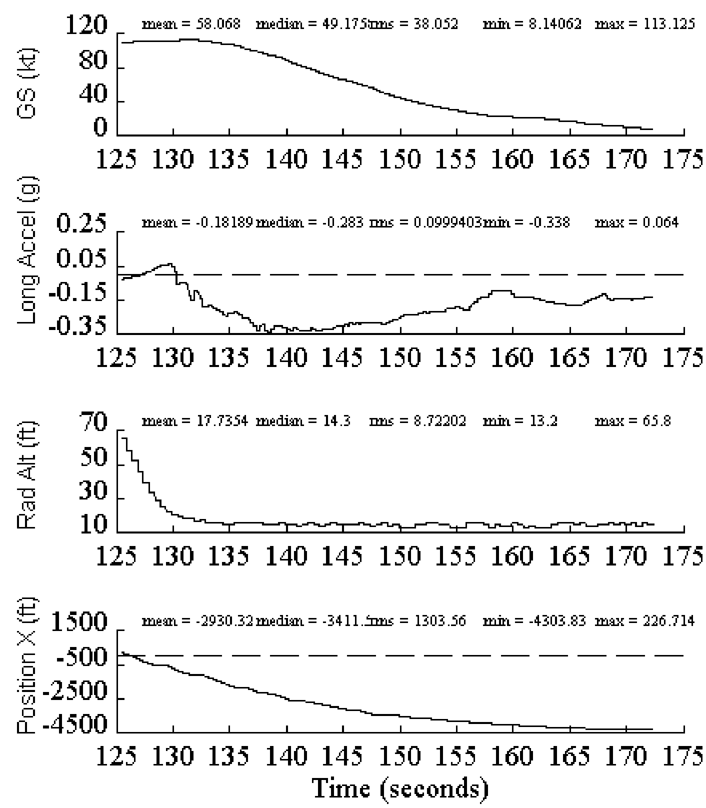
CRFI: 0.46

Actual landing distance:
- based on GPS position: 4530 ft
- based on integral of GS: 4540 ft
- average: 4540 ft

AFM derived landing distance:
- factored: 4550 ft
- unfactored: 2730 ft

CRFI chart landing distance:
- 95% chart: 5060 ft
- 50% chart: 3870 ft

Comments:



First Air B727 landing data set: 03
Date: 26 Feb 99
Airport: Resolute Bay
Runway: 35
Runway condition: 140 ft down centre-line bare, frozen gravel surface, -32º C

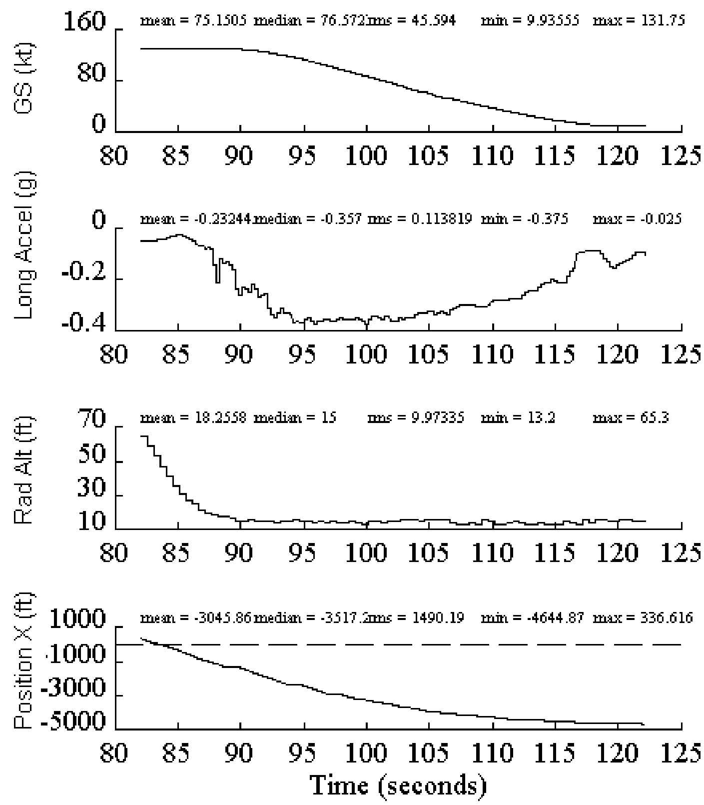
CRFI: 0.50

Actual landing distance:
- based on GPS position: 4980 ft
- based on integral of GS: 5050 ft
- average: 5020 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5430 ft
- 50% chart: 4140 ft

Comments:



First Air B727 landing data set: 04
Date: 26 Feb 99
Airport: Nanisivik
Runway: 29
Runway condition: 70% bare and dry, 30% compacted snow, -22º C

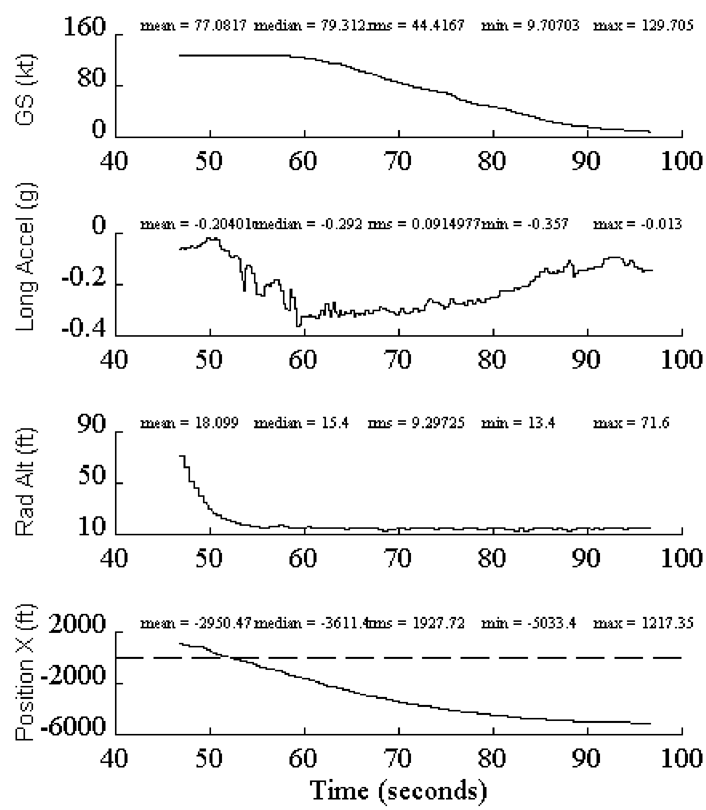
CRFI: 0.41

Actual landing distance:
- based on GPS position: 5030 ft
- based on integral of GS: 5260 ft
- average: 5150 ft

AFM derived landing distance:
- factored: 4700 ft
- unfactored: 2820 ft

CRFI chart landing distance:
- 95% chart: 5360 ft
- 50% chart: 4110 ft

Comments: GPS data advanced 5 seconds to match FDR data.



First Air B727 landing data set: 05
Date: 01 Mar 99
Airport: Nanisivik
Runway: 11
Runway condition: 70% bare and dry, 30% compacted snow, -31º C

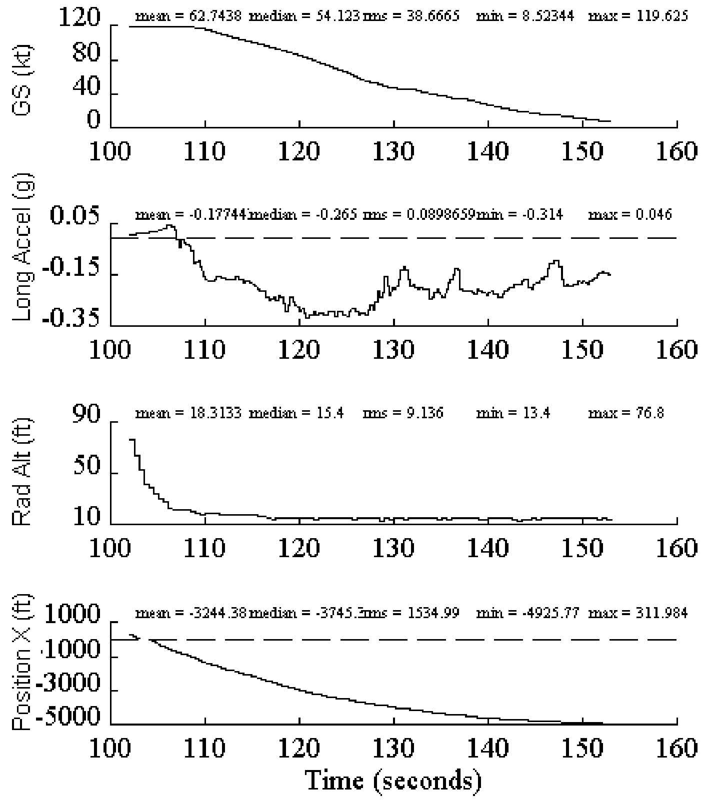
CRFI: 0.42

Actual landing distance:
- based on GPS position: 5240 ft
- based on integral of GS: 5370 ft
- average: 5310 ft

AFM derived landing distance:
- factored: 4950 ft
- unfactored: 2970 ft

CRFI chart landing distance:
- 95% chart: 5670 ft
- 50% chart: 4320 ft

Comments:



First Air B727 landing data set: 06
Date: 04 Mar 99
Airport: Nanisivik
Runway: 29
Runway condition: 70% bare and dry, 30% compacted snow, -32º C

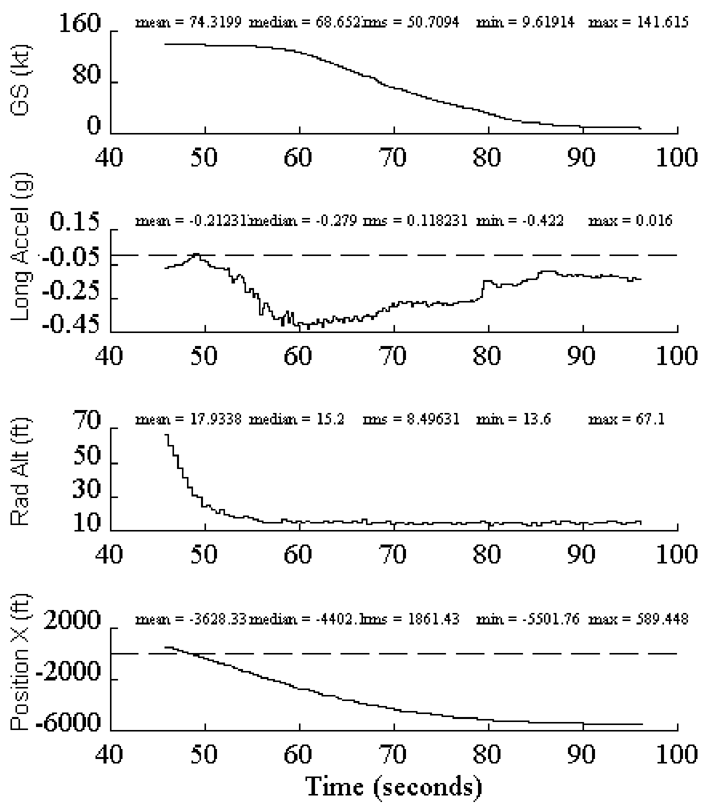
CRFI: 0.46

Actual landing distance:
- based on GPS position: 6090 ft
- based on integral of GS: 6320 ft
- average: 6210 ft

AFM derived landing distance:
- factored: 5700 ft
- unfactored: 3420 ft

CRFI chart landing distance:
- 95% chart: 6350 ft
- 50% chart: 4870 ft

Comments: 5 kt tailwind on landing



First Air B727 landing data set: 07
Date: 04 Mar 99
Airport: Resolute Bay
Runway: 35
Runway condition: 140 ft down centre-line bare, frozen gravel surface, -33º C

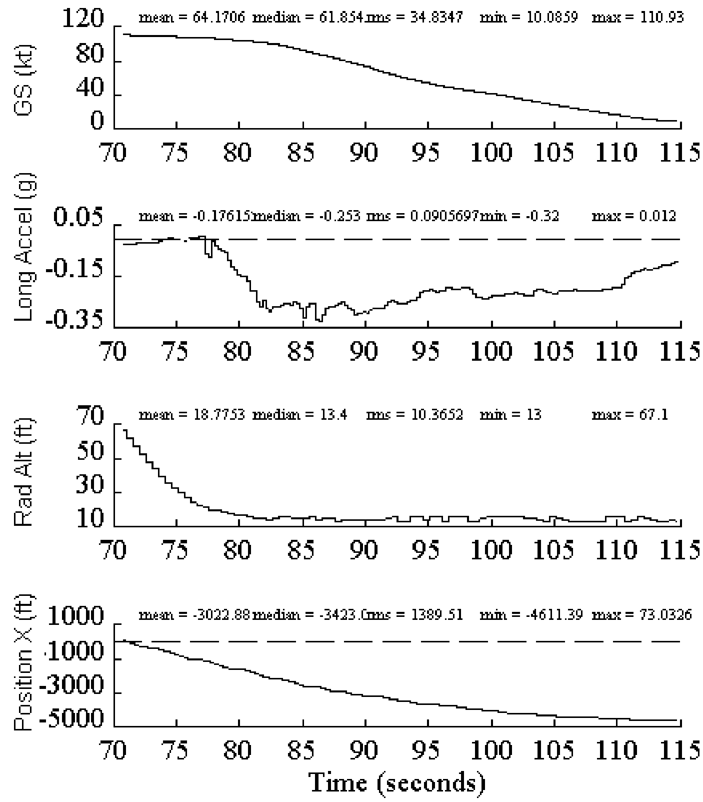
CRFI: 0.47

Actual landing distance:
- based on GPS position: 4680 ft
- based on integral of GS: 4770 ft
- average: 4730 ft

AFM derived landing distance:
- factored: 4700 ft
- unfactored: 2820 ft

CRFI chart landing distance:
- 95% chart: 5290 ft
- 50% chart: 3950 ft

Comments:



First Air B727 landing data set: 08
Date: 05 Mar 99
Airport: Resolute Bay
Runway: 35
Runway condition: 140 ft down centre-line bare, frozen gravel surface, -35º C

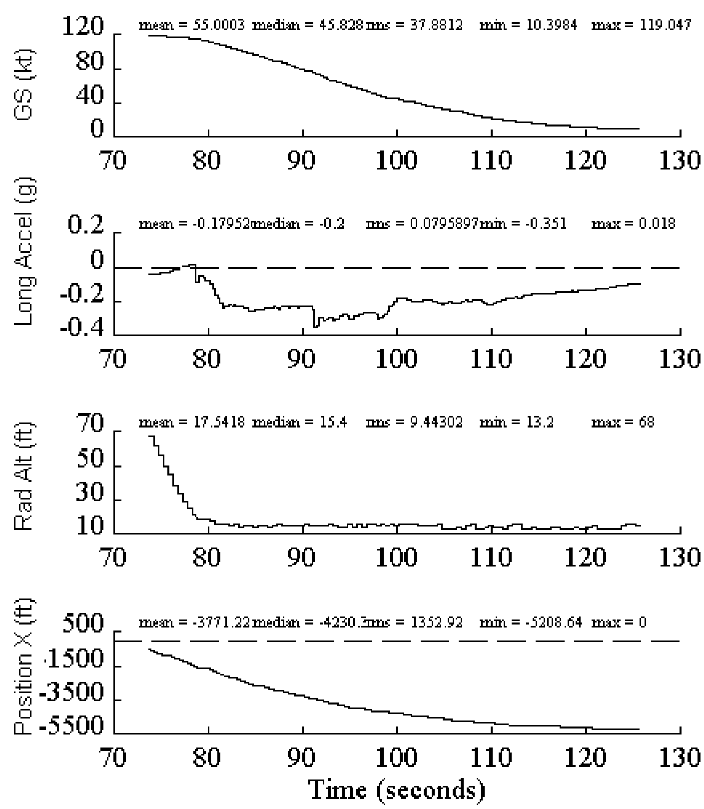
CRFI: 0.43

Actual landing distance:
- based on GPS position: 5210 ft
- based on integral of GS: 4860 ft
- average: 5040 ft

AFM derived landing distance:
- factored: 4900 ft
- unfactored: 2940 ft

CRFI chart landing distance:
- 95% chart: 5540 ft
- 50% chart: 4240 ft

Comments:



First Air B727 landing data set: 09
Date: 08 Mar 99
Airport: Resolute Bay
Runway: 17
Runway condition: 140 ft down centre-line bare, frozen gravel surface, -37º C

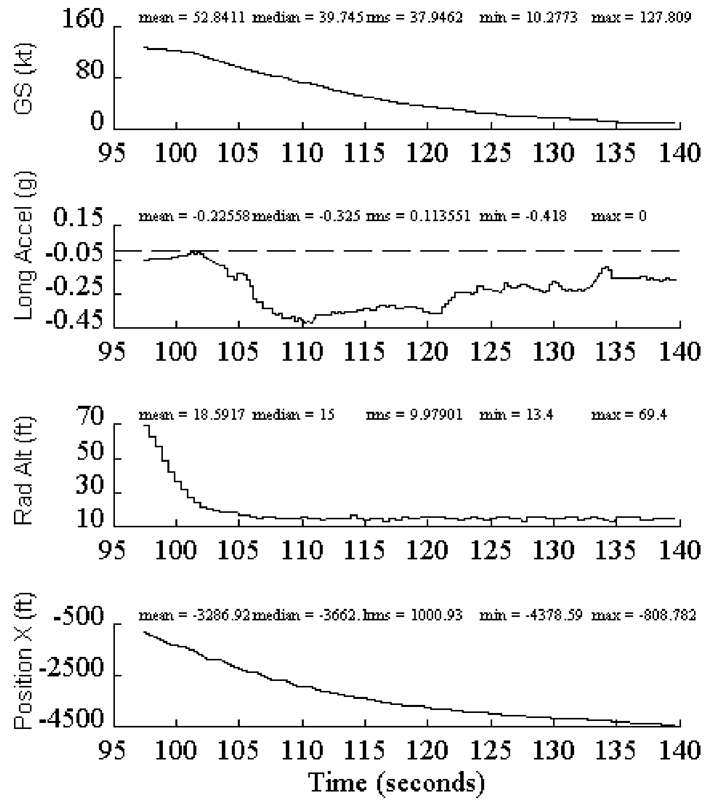
CRFI: 0.45

Actual landing distance:
- based on GPS position: 4380 ft
- based on integral of GS: 4510 ft
- average: 4450 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5590 ft
- 50% chart: 4280 ft

Comments: GPS data delayed 4 seconds to match FDR data.



First Air B727 landing data set: 10
Date: 08 Mar 99
Airport: Nanisivik
Runway: 11
Runway condition: 80% bare and dry, 20% compacted snow, -30º C

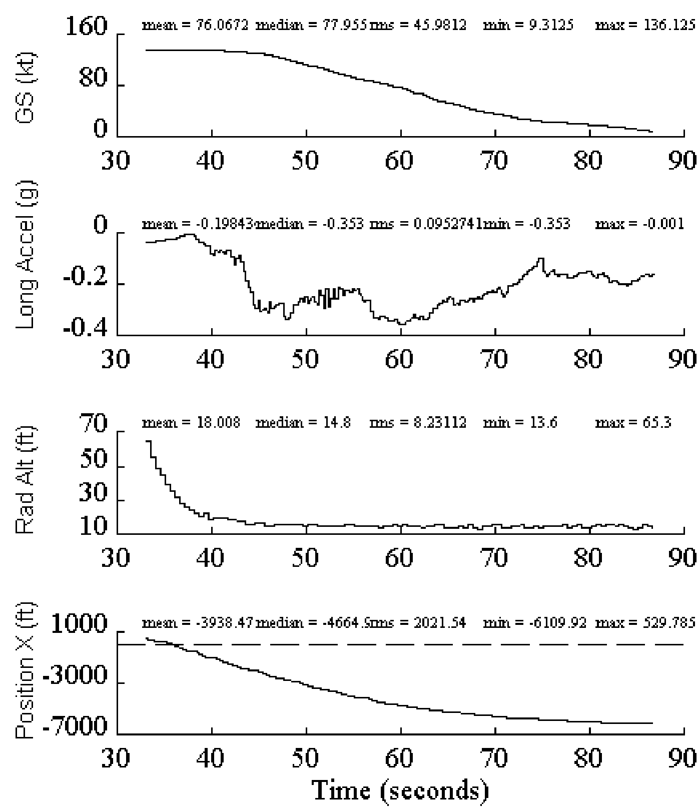
CRFI: 0.43

Actual landing distance:
- based on GPS position: 6110 ft
- based on integral of GS: 6340 ft
- average: 6230 ft

AFM derived landing distance:
- factored: 5500 ft
- unfactored: 3300 ft

CRFI chart landing distance:
- 95% chart: 6260 ft
- 50% chart: 4810 ft

Comments: GPS data advanced 2 seconds to match FDR data. 5 kt tail-wind on landing.



First Air B727 landing data set: 11
Date: 29 Mar 99
Airport: Resolute Bay
Runway: 35
Runway condition: 140 ft down centre-line bare, frozen gravel surface, -33º C

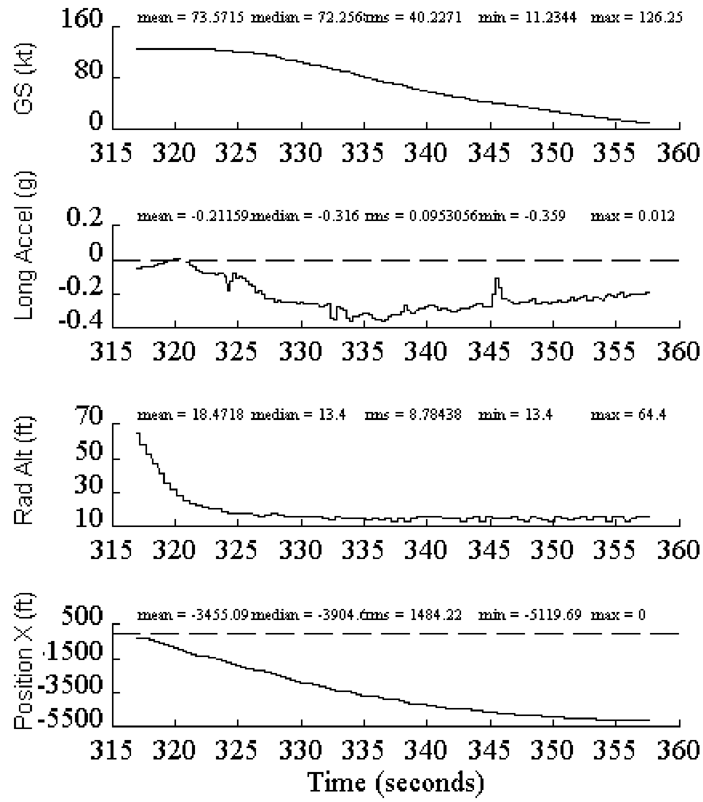
CRFI: 0.57

Actual landing distance:
- based on GPS position: 5120 ft
- based on integral of GS: 5135 ft
- average: 5130 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5230 ft
- 50% chart: 3990 ft

Comments:



First Air B727 landing data set: 12
Date: 29 Mar 99
Airport: Nanisivik
Runway: 11 (no pilot report)
Runway condition: 30% bare, 70% compact snow, scattered icy patches

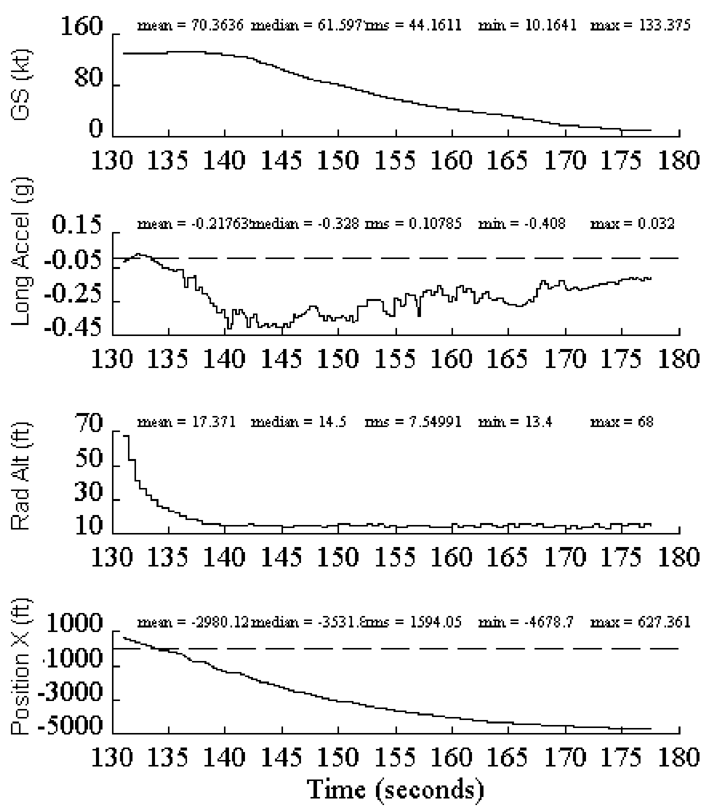
CRFI: 0.31

Actual landing distance:
- based on GPS position: 5310 ft
- based on integral of GS: 5540 ft
- average: 5430 ft

AFM derived landing distance:
- factored: 5000 ft (nominal)
- unfactored: 3000 ft (nominal)

CRFI chart landing distance:
- 95% chart: 6180 ft
- 50% chart: 4770 ft

Comments:



First Air B727 landing data set: 13
Date: 05 April 99
Airport: Nanisivik
Runway: 29 (no pilot report)
Runway condition: 40% compact snow, 60% bare, scattered ice patches, -20º C

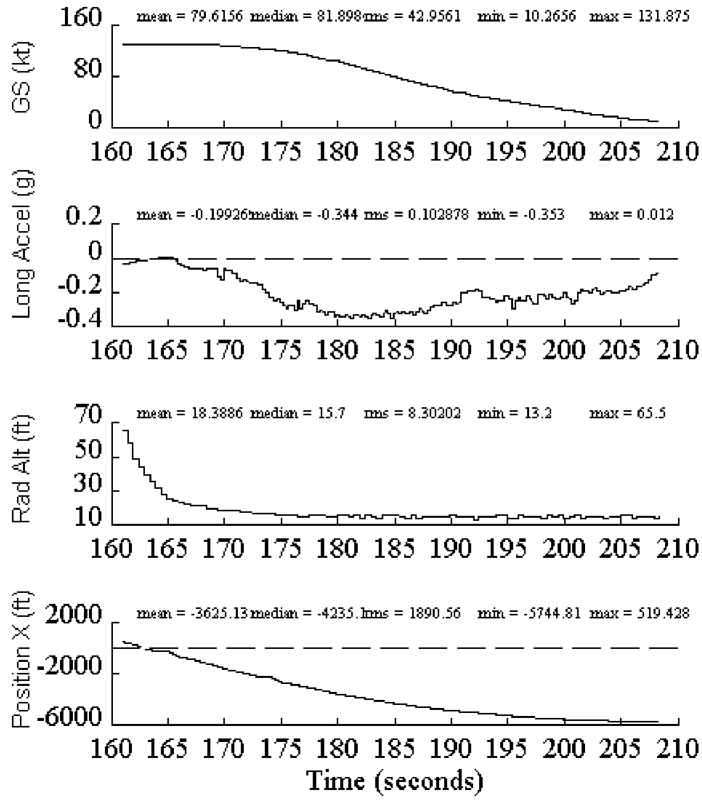
CRFI: 0.34

Actual landing distance:
- based on GPS position: 5740 ft
- based on integral of GS: 5850 ft
- average: 5800 ft

AFM derived landing distance:
- factored: 5000 ft (nominal)
- unfactored: 3000 ft (nominal)

CRFI chart landing distance:
- 95% chart: 6030 ft
- 50% chart: 4640 ft

Comments: GPS data advanced 2.5 seconds to match FDR data.



First Air B727 landing data set: 14
Date: 12 Apr 99
Airport: Nanisivik
Runway: 11 (no pilot report)
Runway condition: 50% compact snow, 50% bare, scattered ice patches, -17º C

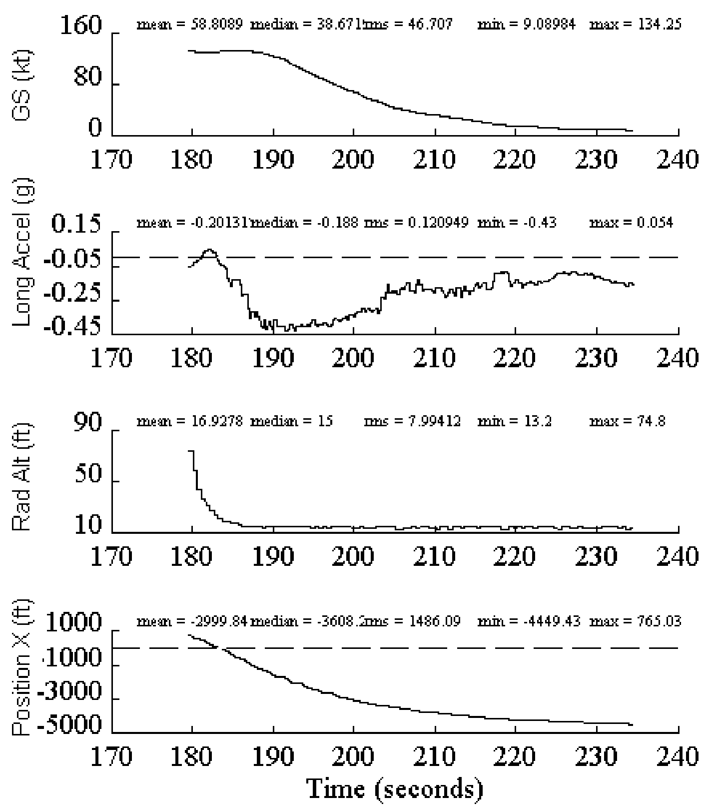
CRFI: 0.33

Actual landing distance:
- based on GPS position: 4900 ft
- based on integral of GS: 5010 ft
- average: 4960 ft

AFM derived landing distance:
- factored: 5000 ft (nominal)
- unfactored: 3000 ft (nominal)

CRFI chart landing distance:
- 95% chart: 6080 ft
- 50% chart: 4680 ft

Comments: GPS data advanced 2 seconds to match FDR data.



First Air B727 landing data set: 15
Date: 17 Nov 99
Airport: Resolute Bay
Runway: 35
Runway condition: 100% compacted snow, gravel showing, -23º C

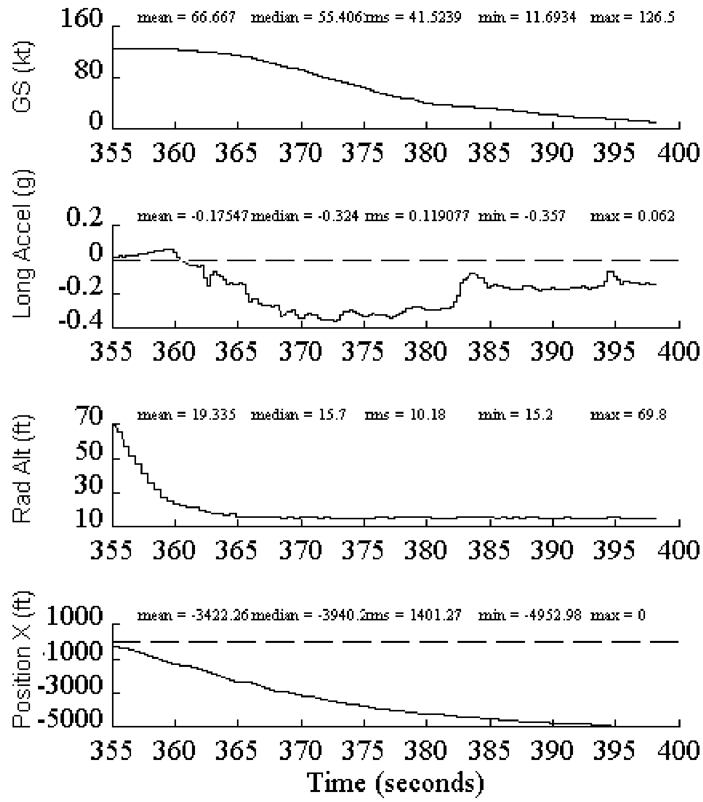
CRFI: 0.45

Actual landing distance:
- based on GPS position: 4950 ft
- based on integral of GS: 4870 ft
- average: 4910 ft

AFM derived landing distance:
- factored: 4800 ft
- unfactored: 2880 ft

CRFI chart landing distance:
- 95% chart: 5350 ft
- 50% chart: 4100 ft

Comments:



First Air B727 landing data set: 16
Date: 20 Nov 99
Airport: Resolute Bay
Runway: 35
Runway condition: 100% compacted snow, gravel showing, -26º C

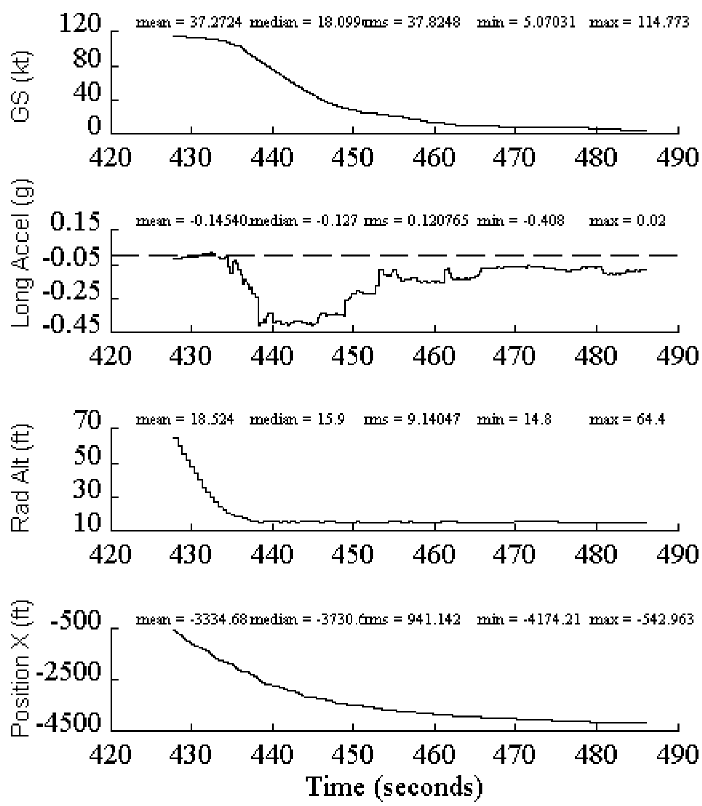
CRFI: 0.45

Actual landing distance:
- based on GPS position: 4210 ft
- based on integral of GS: 4270 ft
- average: 4240 ft

AFM derived landing distance:
- factored: 4800 ft
- unfactored: 2880 ft

CRFI chart landing distance:
- 95% chart: 5350 ft
- 50% chart: 4100 ft

Comments: GPS data delayed 3 seconds to match FDR data.



First Air B727 landing data set: 17
Date: 20 Nov 99
Airport: Nanisivik
Runway: 29
Runway condition: 50% bare frozen gravel, 50% compact snow, -19º C

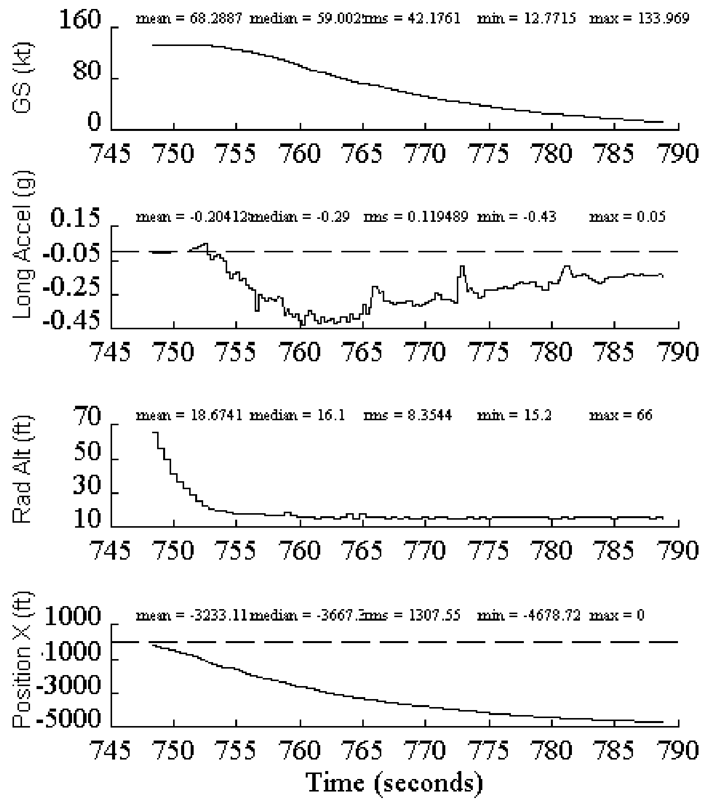
CRFI: 0.39

Actual landing distance:
- based on GPS position: 4680 ft
- based on integral of GS: 4670 ft
- average: 4680 ft

AFM derived landing distance:
- factored: 5100 ft
- unfactored: 3060 ft

CRFI chart landing distance:
- 95% chart: 5950 ft
- 50% chart: 4570 ft

Comments:



First Air B727 landing data set: 18
Date: 11 Dec 99
Airport: Resolute Bay
Runway: 35
Runway condition: 100% compacted snow, gravel showing, -26º C

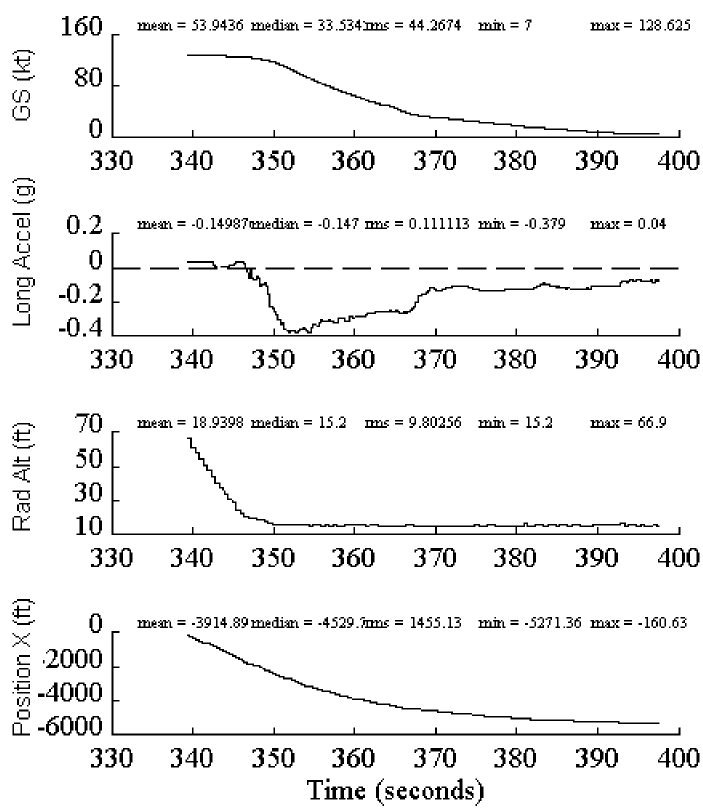
CRFI: 0.49

Actual landing distance:
- based on GPS position: 5110 ft
- based on integral of GS: 5320 ft
- average: 5220 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5460 ft
- 50% chart: 4170 ft

Comments:



First Air B727 landing data set: 19
Date: 11 Dec 99
Airport: Nanisivik
Runway: 11
Runway condition: 50% bare frozen gravel, 50% compact snow, -28º C

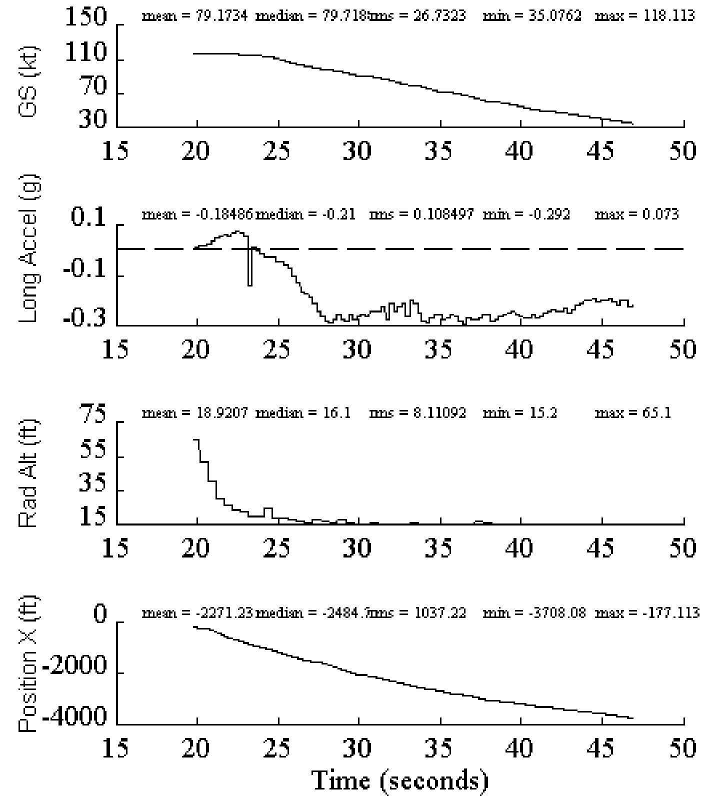
CRFI: 0.41

Actual landing distance:
- based on GPS position: 4260 ft
- based on integral of GS: 4360 ft
- average: 4310 ft

AFM derived landing distance:
- factored: 4800
- unfactored: 2880

CRFI chart landing distance:
- 95% chart: 5480 ft
- 50% chart: 4200 ft

Comments: GPS data delayed 2 seconds to match FDR data, correction made to cropped end of file.



First Air B727 landing data set: 20
Date: 15 Dec 99
Airport: Nanisivik
Runway: 11
Runway condition: 50% bare frozen gravel, 50% compact snow, -21º C

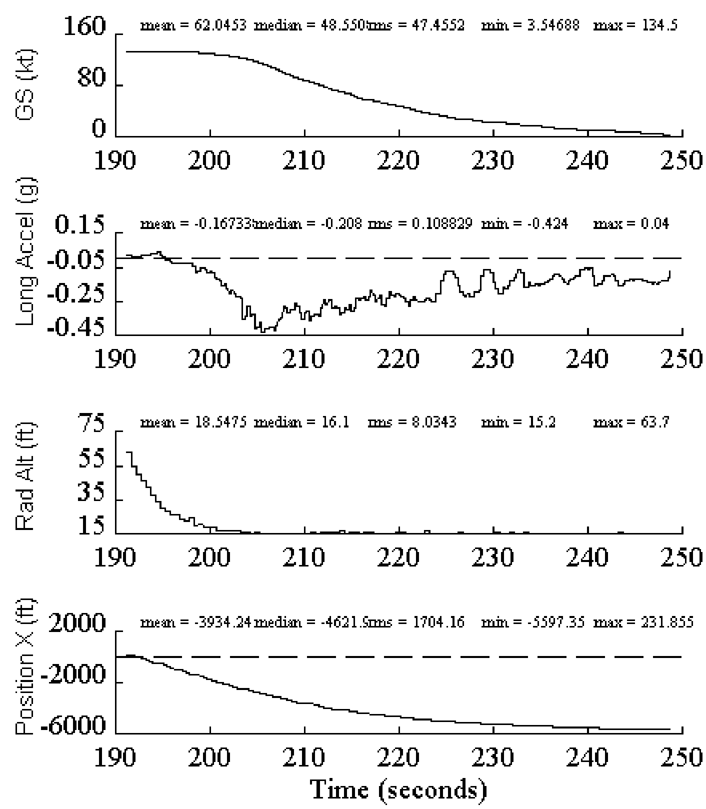
CRFI: 0.34

Actual landing distance:
- based on GPS position: 5830 ft
- based on integral of GS: 6040 ft
- average: 5940 ft

AFM derived landing distance:
- factored: 5050 ft
- unfactored: 3030 ft

CRFI chart landing distance:
- 95% chart: 6100 ft
- 50% chart: 4700 ft

Comments:



First Air B727 landing data set: 21
Date: 15 Dec 99
Airport: Resolute Bay
Runway: 35
Runway condition: 100% compacted snow, gravel showing, -26º C

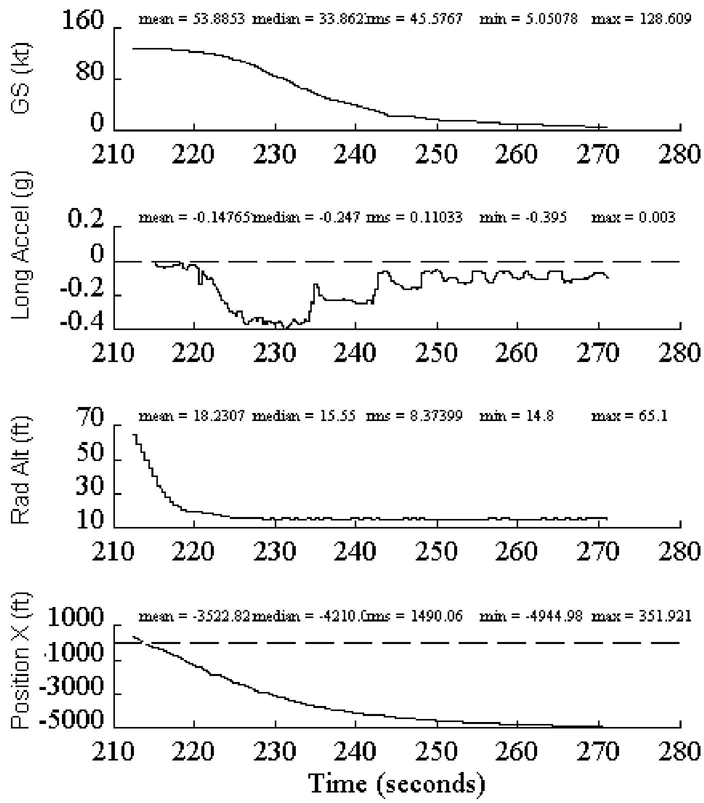
CRFI: 0.49

Actual landing distance:
- based on GPS position: 5300 ft
- based on integral of GS: 5350 ft
- average: 5330 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5460 ft
- 50% chart: 4170 ft

Comments:



First Air B727 landing data set: 22
Date: 18 Dec 99
Airport: Resolute Bay
Runway: 35
Runway condition: 100% compacted snow, gravel showing, -33º C

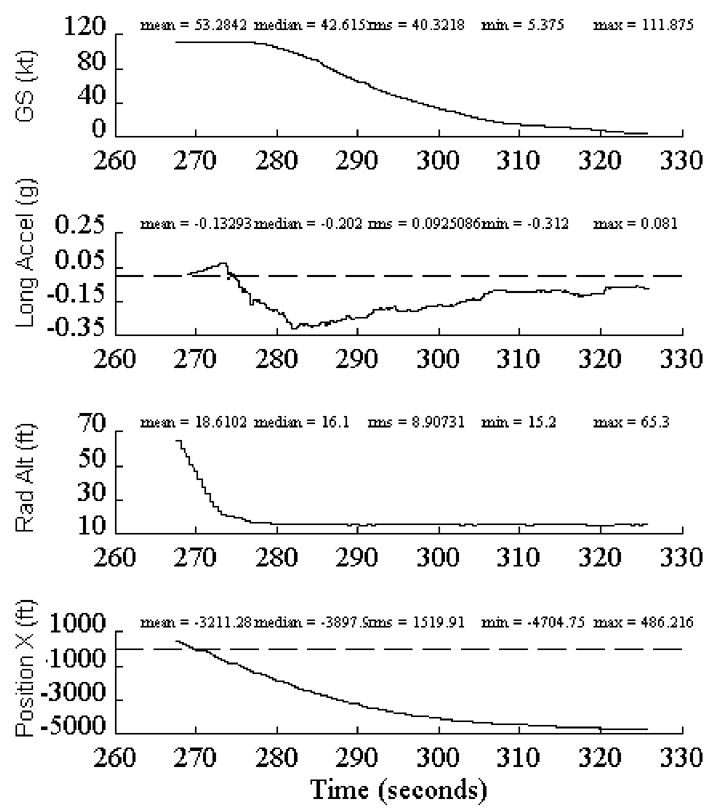
CRFI: 0.51

Actual landing distance:
- based on GPS position: 4810 ft
- based on integral of GS: 4870 ft
- average: 4840 ft

AFM derived landing distance:
- factored: 4800 ft
- unfactored: 2880 ft

CRFI chart landing distance:
- 95% chart: 5170 ft
- 50% chart: 3940 ft

Comments: GPS data advanced 2 seconds to match FDR data.



First Air B727 landing data set: 23
Date: 18 Dec 99
Airport: Nanisivik
Runway: 29
Runway condition: 50% bare frozen gravel, 50% compact snow, -23º C

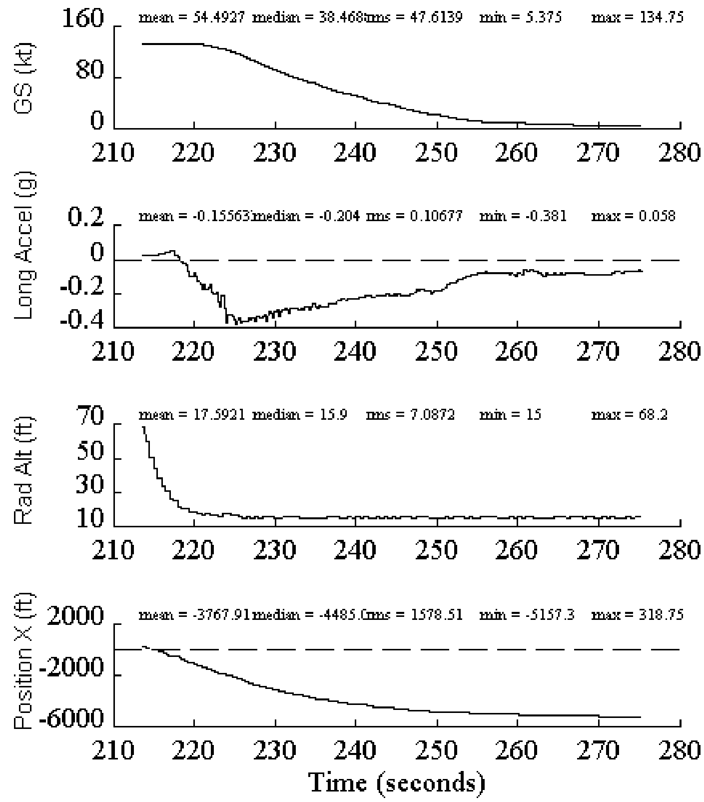
CRFI: 0.35

Actual landing distance:
- based on GPS position: 5480 ft
- based on integral of GS: 5680 ft
- average: 5580 ft

AFM derived landing distance:
- factored: 5200 ft
- unfactored: 3120 ft

CRFI chart landing distance:
- 95% chart: 6260 ft
- 50% chart: 4820 ft

Comments:



First Air B727 landing data set: 24
Date: 25 Feb 00
Airport: Resolute Bay
Runway: 35
Runway condition: 100% compacted snow, gravel showing, -33º C

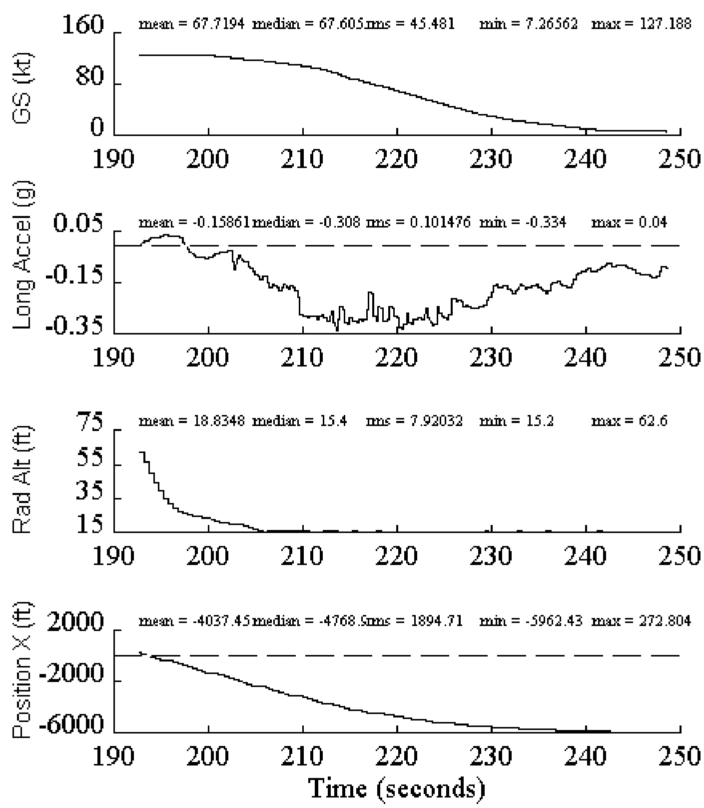
CRFI: 0.45

Actual landing distance:
- based on GPS position: 6240 ft
- based on integral of GS: 6400 ft
- average: 6320 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5590 ft
- 50% chart: 4280 ft

Comments: Actual LD longer than 95% CRFI chart.



First Air B727 landing data set: 25
Date: 25 Feb 00
Airport: Nanisivik
Runway: 11
Runway condition: 50% bare frozen gravel, 50% compact snow, -26º C

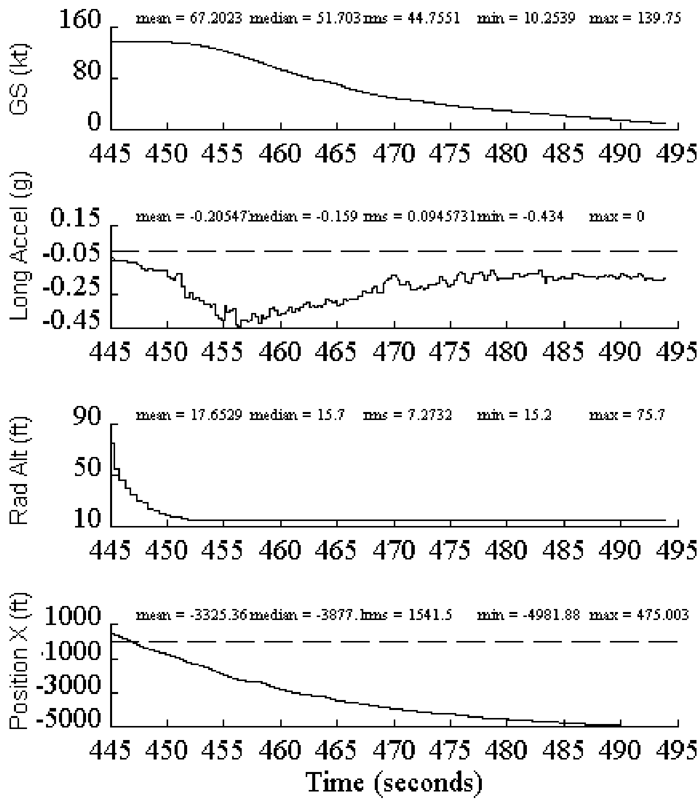
CRFI: 0.34

Actual landing distance:
- based on GPS position: 4750 ft
- based on integral of GS: 4860 ft
- average: 4810 ft

AFM derived landing distance:
- factored: 4800 ft
- unfactored: 2880 ft

CRFI chart landing distance:
- 95% chart: 5760 ft
- 50% chart: 4440 ft

Comments: GPS data advanced 3 seconds to match FDR data.



First Air B727 landing data set: 26
Date: 18 Mar 00
Airport: Nanisivik
Runway: 11
Runway condition: 75% bare frozen gravel, 25% compact snow, -30º C

CRFI: 0.42

Actual landing distance:
- based on GPS position: 5050 ft
- based on integral of GS: 5270 ft
- average: 5160 ft

AFM derived landing distance:
- factored: 5000 ft
- unfactored: 3000 ft

CRFI chart landing distance:
- 95% chart: 5700 ft
- 50% chart: 4370 ft

Comments: