NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

May 26, 2006

Aircraft Performance Group Study

I. ACCIDENT

NTSB Number:	DCA06MA009
Description:	Runway Overrun
Location:	Chicago Midway Airport, Chicago, Illinois
Date:	December 8, 2005
Time:	1914 CST
Aircraft:	Boeing 737-7H4, N471WN
Operator:	Southwest Airlines Co.

II. GROUP

Chairman	Kevin J. Renze, Ph.D. National Transportation Safety Board Vehicle Performance Division, RE-60
Member	Brian Gleason Southwest Airlines Co. Director of Flight Operations Technical
Member	Captain John Gadzinski Southwest Airlines Pilot Association Air Safety Committee
Member	Don Stimson Aerospace Engineer Airplane & Flight Crew Interface Branch, ANM-111 FAA Transport Standards Staff
Member	John D. Anderson Accident/Incident Investigation Aerodynamics Engineering The Boeing Company

1.0 INTRODUCTION

On December 8, 2005, 1914 Central Standard Time, Southwest Airlines (SWA) flight 1248, a Boeing B-737-7H4 registered as N471WN, overran runway 31C at Chicago Midway International Airport (MDW) in Chicago, Illinois, during the landing rollout. The airplane departed the end of the runway, rolled through a blast fence, a perimeter fence, and onto a roadway. The airplane came to a stop after impacting one automobile. Instrument meteorological conditions (IMC) prevailed at the time. The airplane was substantially damaged. The flight was conducted under 14 CFR Part 121 and had departed from the Baltimore/Washington International Thurgood Marshall Airport, Maryland.

The event flight time alignment between the Cockpit Voice Recorder (CVR), Flight Data Recorder (FDR), Air Traffic Control (ATC) radar data, ACARS data, MDW security camera video, and preceding arrival flights was determined. Radar data were processed and overlaid on a Chicago area map and the flight 1248 weight and balance buildup was examined. The FDR data from 5 Southwest Airlines B737-700W flights arriving at MDW were time shifted to a common reference elapsed time touchdown point and plotted. The calculated accident flight ground track was overlaid on the MDW airport layout plan and annotated with significant FDR and CVR events.

Two methods used FDR data and the Boeing PSIM engineering simulator to estimate the airplane braking coefficient for each of the 5 SWA landings. A third method used the flight 1248 FDR ground speed data and the arrival parameters recorded on the SWA Onboard Performance Computer (OPC) to estimate the airplane braking coefficient required to stop. Finally, hypothetical Canadian Runway Friction Index (CRFI) landing performance and SWA dispatch scenarios were analyzed.

2.0 METHOD

The data sources and methods used in the study are outlined in this section.

2.1 Time Alignment

The Cockpit Voice Recorder (CVR), Flight Data Recorder (FDR), radar, Air Traffic Control (ATC) recording, Aircraft Communication Addressing and Reporting System (ACARS), and MDW security camera data are each recorded as a function of time. However, the “timestamp” value associated with these data is not necessarily explicit. Moreover, data from two or more independent sources that record explicit timestamp information are generally not perfectly synchronized to a common or desired reference time basis. In particular, the CVR and the FDR do not explicitly record a time value with each respective event or data sample. In contrast, each record in a radar log, ATC transcript, security video frame, and ACARS entry is associated with an explicit time value, but the time reference used for each may not be synchronized to a common reference time basis.

The time alignment process yields one or more equations that correlate recorded information from independent sources to a reference clock, thereby defining the accident event sequence and elapsed time between events as a function of physical time. The reference clock selected is generally the ATC radar time.

The ability to correlate information between any two independent sources is dependent on the existence of at least one common event between the two sources. In practice, the FDR discrete parameters that indicate the activation of the Captain's or First Officer's VHF radio transmit keys provide common event sources because the begin- and end-keying events are typically recorded on the CVR and the FDR. The communication that occurs between the begin- and end-keying event is typically recorded on both the CVR and the ATC recordings.

2.1.1 Aircraft Recorder Data

The CVR transcript data and the FDR data for the accident flight are documented in the Cockpit Voice Recorder Factual Report and Transcript and the Flight Data Recorder Group Chairman's Factual Report, respectively. Events excerpted from the CVR transcript are overlaid on the MDW airport layout diagram in Section 3.0.

2.1.2 CVR and FDR Alignment

Common events on the CVR and FDR were identified and used to define the CVR/FDR time alignment constraints. Each FDR common event has an associated begin and end time value due to the discrete nature of the FDR data. Corresponding CVR common events are associated with a single CVR time value, which must be precisely measured. The points on a common event plot of FDR time versus CVR time define the constraints. A curve that satisfies all the constraints defines a mapping from CVR time to FDR time.

2.1.3 FDR and ATC Alignment

The existence of one or more common events between the ATC transcript and the CVR and the CVR/FDR time alignment permits the FDR data to be aligned to the ATC transcript. Time alignment between the ATC transcript and the FDR data is accomplished by choosing a specific ATC clock time to equal a specific FDR time.

2.1.4 FDR and Radar Alignment

The FDR and radar data were time aligned using the FDR pressure altitude and the radar reinforced return altitude information. Given local barometric pressure and knowledge of the pressure reference used on the aircraft, the FDR pressure altitude was corrected for atmospheric deviation from standard day conditions. The radar and

FDR time alignment was then accomplished by 1) creating an overlay plot of the pressure altitude versus time from each source, 2) adding a +/-50 foot error band to the radar altitude data, and 3) time shifting the radar data with respect to the corrected FDR altitude data to a point where the FDR altitude curve was bounded by the +/-50 foot radar altitude error band throughout the time period of interest.

2.1.5 FDR and Security Video Alignment

Security camera video recorded at the Midway Communications Center (MCC) was screened to identify aircraft arrival times and footage that might document aircraft touchdown locations. The elapsed times between arriving aircraft viewed from a fixed camera position, orientation, and magnification were used to correlate the aircraft arrival sequence with available radar and FDR data. The touchdown times for two flights that preceded flights documented with archived radar data were calculated based on the security camera time correlation.

2.1.6 FDR and ACARS Data Alignment

Aircraft Communication Addressing and Reporting System (ACARS) data were requested from 6 Southwest Airlines flights and 1 United Airlines flight as an additional independent record of airplane flight position/status. The ACARS data were provided at 1-minute resolution for 5 Southwest Airlines flights and 1 United Airlines flight. The SWA flight 1248 arrival (i.e., ACARS ON message) was not recorded because SWA airplanes are typically connected to the ORD ground station and lose coverage just prior to touchdown at MDW.[1]

2.2 Radar Data

The radar data were converted from range-azimuth format to distance north and distance east of a known reference point. The reference point chosen for the N471WN radar data was the location of the Chicago ASR-9 radar antenna. The radar data and radar antenna coordinates are documented in the Aircraft Performance Group Accident Site Factual.

The radar data were converted to latitude-longitude coordinates and plotted in planform view plots that depict the N471WN ground track relative to the airport environment (see Attachment 1). The measurement tolerance[2] on the ASR radar range data is +/-380 feet (+/-1/16 nautical mile). The ASR radar azimuth data is subject to a measurement tolerance of +/-0.18 degrees (+/-2 azimuth pulse counts).

[1] The airplane Communications Management Unit (CMU) takes several minutes to reconnect with the MDW ground station. Once the CMU reconnects, the ACARS ON message is sent from the aircraft.

[2] The aircraft position derived from radar data may not place the aircraft precisely in an expected location. For example, the aircraft may not appear to be aligned on the runway centerline during landing even though the aircraft ground track may be parallel to the runway.

2.3 FDR Data

Flight Data Recorder (FDR) data from 5 Southwest Airlines B737-700W airplanes and 1 United Airlines A320-200 airplane were obtained and processed by the FDR specialist. Selected longitudinal and lateral-directional axes FDR data from the five Southwest Airlines flights were plotted on pages 2-3, respectively, of Attachments 2 through 6. The accident flight FDR data are presented in Attachment 2. Subsequent attachments provide FDR data in reverse chronological order of flight arrival. Additional FDR data for the United Airlines flight is available in the Flight Data Recorder, Group Chairman's Factual Report.

The longitudinal plot, ordered top to bottom, includes pressure and radio altitude; computed airspeed and ground speed; air/ground discrete; left and right engine N1; left and right throttle resolver angle; left and right thrust reverser in transit discrete; left and right thrust reverser full deploy discrete; left and right brake pressure; longitudinal acceleration; pitch attitude; control column deflection; horizontal stabilizer position; normal load factor; glide slope deviation; speed brake handle position; and left and right trailing edge flap deflection as a function of elapsed time. For reference, touchdown occurs at 6351.5 seconds per the air/ground discrete parameter.

The lateral-directional plot, ordered top to bottom, depicts pressure altitude; computed airspeed and ground speed; left and right engine N1; left and right throttle resolver angle; air/ground discrete; roll attitude; control wheel deflection; left and right aileron deflection; lateral acceleration; magnetic heading and drift angle; rudder pedal deflection; rudder deflection; localizer deviation; wind direction; and wind speed as a function of elapsed time. Once again, touchdown occurs at 6351.5 seconds per the air/ground discrete parameter. Wind speed and direction data from the FDR are not valid on the ground.

The FDR data indicated that flight 1248 was aligned on centerline and positioned slightly above the glide slope at touchdown. Touchdown occurred at about 132 knots ground speed with both speed brake deployment and brake pressure ramping up within about 1 second. Left and right brake pressure ramped up symmetrically to about 2500 psi within about 5 seconds (although the right recorded brake pressure was biased higher than the left recorded value by about 200 psi) and transitioned to about 2900 psi at approximately 6363 seconds.

Left and right throttle resolver angle were symmetric, constant at a pre-touchdown setting of about 36 degrees until 6365.5 seconds, when they transitioned to about 25 degrees in 1 second, held there for about 1 second, and continued to transition to about 6 degrees (maximum reverse) over a period of approximately 1 second. Left and right engine N1 parameters were also symmetric, spooling down to about 30 percent at touchdown, decreasing toward 20 percent about 4 seconds later, and holding at 20 percent until about 6368 seconds when they began to spool up toward 80 percent N1 by about 6377 seconds.

The left and right thrust reverser in transit discrete values depicted transit between 6366.5 and 6369.5 seconds. The left and right thrust reverser full deploy discrete values indicated full deploy at 6369.8 seconds (about 18 seconds after touchdown).

Magnetic heading varied between about 313 and 318 degrees during the landing rollout. Localizer data indicated that the airplane remained on centerline until about 6370 seconds, when it began to deviate to the right. Acceleration data indicated increased normal load factor activity shortly after 6381 seconds, and significant activity in all 3 accelerometer axes beginning at about 6384 seconds.

Pitch attitude during most of the landing rollout was about –1.5 degrees, with a peak attitude of about 2.5 degrees at about 6384.8 seconds. The final pitch attitude was approximately –6 degrees.

2.4 Weight and Balance

The accident aircraft weight was estimated by itemizing the aircraft component weights. Component weights include the aircraft empty weight, the crew weights including nominal crew baggage, passenger weights including carry-on baggage and personal effects, cargo, and fuel. The component weight buildup approach sums the component weights to arrive at a weight estimate for the event condition, accounting for weight changes from a reference condition. The N471WN reference condition is the aircraft weight just prior to flight 1248 engine start. Given the component weights and locations, the aircraft moment balance can be calculated.

2.4.1 Operating Empty Weight

According to the Southwest Airlines Weight and Balance Calculation and Weight Control Record, the N471WN operating empty weight was 85,232 pounds with the center of gravity located at 659.94 inches aft of the reference datum. Southwest Airlines computes fleet average weights in accordance with Operations Specification paragraph E096. The loading schedule reflects a fleet average adjusted operating empty weight of 84,661 pounds.[3] The operating empty weight includes crew weights for two flight crew members and three flight attendants.

2.4.2 Crew and Crew Baggage Weights

Southwest Airlines uses crew weights (including bags) of 240 pounds per flight crewmember and 210 pounds per flight attendant, consistent with the guidance published in AC120-27E.

[3] The fleet average operating empty weight is 84,647 pounds with the center of gravity located at 659.77 inches aft of the reference datum. The fleet average adjusted operating empty weight refers to the fact that center of gravity location data (in index units) is overloaded in the last 2 digits of the fleet average operating empty weight.

2.4.3 Passenger Weights

The Southwest Airlines average weight method accounts for a nominal "winter" weight of 195 pounds per passenger when operating between the months of November and April, inclusive. The flight 1248 loading schedule lists a total of 98 passengers on board, including 3 children. The nominal weight of 195 pounds per passenger includes a 16 pound per passenger allowance for carry-on baggage and personal effects.

At the Captain's discretion, an average weight of 90 pounds may be used for children between 2 years and (less than) 13 years of age. In practice, Southwest Airlines uses 90 pounds per child and then rounds up to the next 100 pound increment. The weight of infants and associated items is incorporated in the adult average weights.

2.4.4 Fuel Weight

According to the dispatch release, the planned fuel for flight 1248 was 23,700 pounds prior to departure. Southwest Airlines assumes a 600 pound nominal taxi fuel burn for aircraft departing Baltimore, yielding 23,100 pounds of fuel at takeoff for nominal conditions.

Flight 1546, N471WN, reportedly arrived in Baltimore, MD from San Diego, CA with 7,300 pounds of fuel remaining. Two fuel receipt records documented in the Aircraft Performance Group Accident Site Factual Report show that a total of 2,431 gallons of fuel were added in Baltimore prior to the flight 1248 departure. Assuming a fuel density of 6.7 pounds per gallon, N471WN would have had 23,588 pounds of fuel available prior to ramp departure and 22,988 pounds of fuel available at takeoff for nominal conditions. The loading schedule listed 17,200 pounds of fuel in the wing tanks and 6,000 pounds of fuel in the center tank, for a total of 23,200 pounds at takeoff.

2.4.5 Cargo Weight

The Southwest Airlines average weight method accounts for a nominal weight of 30 pounds per checked bag and 60 pounds per heavy bag. The flight 1248 loading schedule accounts for 55 standard bags and 1 heavy bag located in the forward cargo compartment and 12 standard bags, 2 heavy bags, and 100 pounds of freight in the aft cargo compartment.

2.5 Estimated Airplane Braking Coefficient

The airplane braking coefficient is defined as the ratio of the retarding force due to braking relative to the normal force (i.e., weight minus lift) acting on the airplane. The FDR data from each of five Southwest Airlines flights that arrived at MDW on the evening of December 8, 2005 were used in conjunction with the Boeing 737-700W engineering simulation[4] to estimate the airplane braking coefficient available on runway 31C. An independent approach used the SWA OPC, the flight 1248 OPC initial conditions, and FDR ground speed data to estimate the airplane braking coefficient required to stop.

The airplane braking coefficient is not equivalent to the tire-to-ground friction coefficient. The estimated airplane braking coefficient is an all inclusive term that incorporates effects due to the runway surface, contaminants, and airplane braking system (e.g., antiskid efficiency, brake wear). The maximum airplane braking coefficient will result if the commanded brake pressure meets or exceeds the brake pressure threshold governed by the antiskid valve. If the commanded brake pressure is less than the brake pressure governed by the antiskid valve, the airplane braking coefficient will be a function of the level of the commanded brake pressure.

Three methods were used to estimate the airplane braking coefficient. Methods A and B both used FDR data and the engineering simulation to estimate aerodynamic, thrust, and gear loads. Method A subsequently used Equation 3 below to calculate a time varying airplane braking coefficient whereas Method B used the engineering simulation to estimate an equivalent constant airplane braking coefficient. Method C used the SWA Onboard Performance Computer (OPC) and the flight 1248 initial condition data to estimate the airplane braking coefficient required to stop on runway 31C and, separately, the airplane braking coefficient required to stop the airplane.

2.5.1 Assumptions

Airplane braking coefficient extraction Methods A and B assumed that 1) the FDR airplane load factor data are valid (or other FDR data can be used to derive load factor data), 2) any simulator aerodynamic, propulsion, flight controls, or gear modeling errors are small, 3) the nominal, integrated, simulation airplane model is representative of the particular airplane being analyzed, and 4) other external forces are negligible. If, for example, additional external forces such as impingement drag played a measurable role in retarding the airplane motion, the true airplane braking coefficient magnitude would be smaller than that calculated using these two methods.

Method C assumed that 1) the initial condition data available to the flight 1248 flight crew for OPC calculations reflected the actual conditions, 2) N471WN was at V_{REF40} at a height of 50 feet over the threshold, and 3) the constant deceleration calculated

[4] The Boeing PSIM tool was used for the engineering simulator calculations documented in this study. All PSIM calculations were performed in the desktop environment.

from the flight 1248 FDR ground speed data during the ground roll on improved surfaces continued until the airplane came to a complete (and unobstructed) stop.

2.5.2 Time Varying Airplane Braking Coefficient Extraction (Method A)

For Method A, a time varying airplane braking coefficient was calculated using the basic physics relationship that the sum of the longitudinal forces (F_x) equals the product of the mass and the acceleration to derive Equation 3 below, as follows:

$$F_x = ma_x \tag{1}$$

where

$$F_x = F_{x,\,gear} + F_{x,\,thrust} + F_{x,\,aerodynamic}\,, \tag{1.1}$$

$$F_{x,\,gear} = \mu_{airplane\ braking} * F_z\,, \tag{1.2}$$

$$F_z = W + F_{z,\,thrust} + F_{z,\,aerodynamic}\,, \tag{1.3}$$

and

m is the airplane mass (from the FDR/load manifest),
a_x is the kinematically corrected FDR acceleration data,
W is the airplane weight.

The thrust and aerodynamic forces (F_{thrust} and $F_{aerodynamic}$) were estimated using the engineering simulator. The unknown gear force ($F_{x,\,gear}$) is defined as the unknown airplane braking coefficient ($\mu_{airplane\ braking}$) times the summation of the normal forces (F_z). The normal forces acting on the airplane are weight and the normal components of the aerodynamic and thrust forces. Substitution of Equations 1.1-1.3 into Equation 1 yields

$$\mu_{airplane\ braking} * (W + F_{z,\,thrust} + F_{z,\,aerodynamic}) + F_{x,\,thrust} + F_{x,\,aerodynamic} = ma_x \tag{2}$$

Solving for the airplane braking coefficient gives

$$\mu_{airplane\ braking} = \frac{ma_x - F_{x,\,thrust} - F_{x,\,aerodynamic}}{(W + F_{z,\,thrust} + F_{z,\,aerodynamic})} \tag{3}$$

The kinematically corrected[5] FDR acceleration (a_x) was determined by passing the FDR data through separate rotational and translational kinematic consistency processes[6] to ensure that required integral/derivative relationships were consistent and that integration of the corrected translational accelerations would recover the FDR altitude, ground speed, and drift angle data. The resulting angular data (i.e.,

[5] Kinematics is the branch of dynamics that is concerned with the motion of objects independent of the forces acting upon or generated by the objects in motion.

[6] The Boeing Kinematic Consistency (KINCON) tool uses an optimal control approach to minimize objective functions and calculate constant accelerometer biases for each axis. The rotational calculation computes consistent angular attitudes, rates, and accelerations. The translational calculation uses the resulting angular data and computes constant accelerometer bias terms, in addition to the inertial speeds, position, angle of attack, sideslip angle, flight path angle, and winds.

attitudes, rates, and accelerations) and calculated winds are available as inputs to the engineering simulation.

For Methods A and B, the simulation airplane was configured based on the FDR flap, gear, spoiler, and horizontal stabilizer positions, initialized to the FDR weight and airspeed values, and trimmed on the ground approximately 1 second after touchdown. Throttle resolver angle was selected to match the FDR engine N1 and center of gravity location was specified.[7] The simulation was backdriven with FDR flap, gear, spoiler, horizontal stabilizer, control column, and control wheel values. The process used to estimate the Method A time varying airplane braking coefficient is outlined below.

2.5.2.1 Brake Math Pilot Simulation (Step 1)

First the engineering simulation was used to calculate aerodynamic, thrust, and distributed gear loads acting on the airplane. The airplane was configured, initialized, and trimmed as previously described and a brake math pilot calculated closed-loop[8] brake inputs (independent of the actual runway surface condition) required to match FDR ground speed during the landing rollout.

2.5.2.2 Airplane Braking Coefficient (Step 2)

The kinematically corrected FDR load factor data were first used to determine the total airplane inertial acceleration components. The aerodynamic and thrust forces from Step 1 were then transformed to earth axes and used to construct the ratio of the retarding forces (X-axis) to the normal forces (Z-axis). The resulting time varying airplane braking coefficient was then calculated using Equation 3.

2.5.2.3 Open Loop Match (Step 3)

Distributed airplane braking coefficients are required to be compatible with the landing gear model in the simulation. The distributed coefficients are the nose and main gear specific ratios of the retarding forces (X-axis) to the normal forces (Z-axis). Using the simulation gear loads from Step 1, the airplane braking coefficient from Step 2 was subsequently distributed among braked (main gear) and free rolling (nose gear) wheels. A rolling friction coefficient value of 0.0165[9] was used for the nose gear wheels.

---

[7] The center of gravity was assumed to be located at 20 percent mean aerodynamic chord (MAC). The airplane braking coefficient sensitivity to center of gravity location will be evaluated in an addendum to the Aircraft Performance Group Study.
[8] A mathematical control strategy that determines the simulator brake inputs required to match target ground speed data as a function of time.
[9] This is the default rolling friction coefficient value in the Boeing PSIM tool for the B737-700.

The simulation was configured, initialized, and trimmed as described in Step 1. The distributed airplane braking coefficient and FDR applied brake pressures were applied during the open-loop simulation as the match to FDR ground speed and longitudinal acceleration was evaluated. The Step 3 goal was to match the FDR data during the landing rollout using the Step 2 calculated (and properly distributed) total airplane braking coefficient.

2.5.2.4 Flight Test Data Validation (Method A)

The time varying airplane braking coefficient extraction method was validated using existing Boeing 737-700 flight test data. Data from 4 dry runway landings and 1 wet, smooth (ungrooved) runway landing were processed to evaluate the time varying airplane braking coefficient extracted for known airplane landing configurations and runway conditions. The runway condition, airplane configuration, and calculated result[10] for each case are summarized in Table 1.

Table 1: B737-700 airplane braking coefficient flight test validation cases

CASE #	RUNWAY CONDITION	BRAKING	SPEEDBRAKES	THRUST REVERSER	CALCULATED AIRPLANE BRAKING COEFFICIENT
1	DRY	MAXIMUM MANUAL	DEPLOYED	stowed	Increased from 0.38 to 0.43
2	DRY	none	DEPLOYED	stowed	Varied between 0.01 and 0.02
3	DRY	none	stowed	stowed	0.01
4	DRY	none	DEPLOYED	DEPLOYED	Varied between 0.01 and 0.02
5	WET SMOOTH	MAXIMUM MANUAL	DEPLOYED	stowed	Increased from 0.05 to 0.30 as ground speed decreased

2.5.3 Constant Equivalent Airplane Braking Coefficient (Method B)

In Method B, the engineering simulation was used to estimate a constant equivalent airplane braking coefficient. First the brake math pilot simulation was run as in Step 1 (see Section 2.5.2.1). Second, the simulation gear loads and a constant airplane braking coefficient in the range of the one determined from Method A were used to calculate a distributed airplane braking coefficient. The simulation was then set up and run as described in Section 2.5.2.3, except that the constant airplane braking friction coefficient was used instead of a time varying one. Manual iteration was used to update the constant airplane braking coefficient value until a match of the FDR ground speed data was achieved.

---

[10] The flight test time history data are Boeing Proprietary information, so the Method A validation results were summarized.

The constant airplane braking coefficient values determined by Method B are provided in Section 3.5.2 for the 5 SWA landings analyzed.

2.5.4 OPC Estimate of Airplane Braking Coefficient (Method C)

The landing performance submodule[11] of the Southwest Airlines B737-700 Onboard Performance Computer (OPC) was used to estimate the flight 1248 airplane braking coefficient available on runway 31C. First, flight 1248 OPC inputs were used to perform OPC landing distance calculations with and without thrust reverser for airplane braking coefficient values of 0.40, 0.20, and 0.15 through 0.05, by 0.01 increments[12] (see Attachment 7). Landing distances with and without thrust reverser were calculated to bracket the actual flight 1248 airplane rollout configuration. Second, the unobstructed flight 1248 landing distance was calculated based on FDR ground speed data, assuming constant deceleration during the final segment of the landing rollout on unimproved surfaces.

The OPC inputs were identical to those entered by the flight crew, with the exception of the winds and the selected runway condition. A 6 knot tailwind was entered to simulate a 9 knot tailwind on arrival,[13] which was slightly conservative compared to the reported winds of 090 at 11 knots. The OPC does not provide a direct approach speed adjustment, so calculations were made at V_{REF40}. A constant air distance of 1,250 feet was added to the OPC ground distance to determine the landing distance.

The estimated unobstructed rollout distance and the runway 31C landing distance available were defined by blue and red horizontal lines, respectively, on a landing distance chart. Each horizontal line was intersected by two operational landing performance curves. Each pair of intersection points defined a range of estimated airplane braking coefficient required to stop.

2.6 Canadian Runway Friction Index

Transport Canada publishes guidance to Canadian pilots on how to estimate aircraft performance under adverse runway conditions based in part on decelerometer measurements collected by ground surface vehicles. Section 1.6 of the Canadian Airman's Information Manual, dated April 13, 2006, is reproduced in Attachment 8.

The Canadian A.I.M. includes two tables of recommended landing distances as a function of Canadian Runway Friction Index (CRFI) measurement and AFM landing distance/landing field length; CRFI-based crosswind landing guidance; and surface

[11] The Southwest Airlines B737-700 OPC landing performance module uses the Boeing Landing Module (BLM) to perform calculations.
[12] This complete range of airplane braking coefficients is not generally available to SWA pilots that use the OPC. The aircraft braking coefficients in the OPC are pre-assigned to specific reported braking action inputs, as shown in Table 10.
[13] The OPC multiplies the input wind value by a factor of 1.5.

conditions when a CRFI will not be provided. In particular, "… runway friction readings will not be taken and a CRFI will not be provided to ATS or pilots when any of the following conditions are present:

a) the runway surface is simply wet with no other type of contamination present;
b) there is a layer of slush on the runway surface with no other type of contamination present; or
c) there is loose snow on the runway surface exceeding 2.5 cm (1 in.) in depth."

If a CRFI is not provided, a runway surface condition report would typically describe the contaminant type, depth, affected runway(s) or portions thereof, age of report, etc.

The CRFI performance tables were published with and without the effects of reverse thrust/discing based on extensive field test performance data of aircraft braking on winter-contaminated surfaces, correlation to ground surface vehicle decelerometer friction measurements, and engineering assumptions. The declared intent was to provide a 95 percent level of confidence that the stated distance would be conservative for properly executed landings with all systems serviceable on runway surfaces with the reported CRFI value.

The Survival Factors Group Chairman's Factual Report of Investigation documented that a Bowmonk AFM2 device was used to perform a friction test on runway 31C at 18:47 after the runway had just been broomed, plowed, and deiced. The test results at that time were .72/.59/.68 for an average reading of .67. Runway 31C was open for arrival aircraft from that time until the accident occurred with no additional snow removal procedures. A friction survey conducted with the identical Bowmonk AFM2 device at 19:22 on runway 31C, following the accident, produced values of .41/.40/.38 for an average of .40.

The CRFI tables were used to calculate the recommended landing distances given hypothetical flight 1248 parameters and MDW runway 31C average decelerometer readings (.67 prior to the accident and .40 following the accident). The Airplane Flight Manual (AFM) indicated an F.A.R. dry field length of approximately 5,050 feet for a 120,000 pound[14] B737-700W at flaps 40 (assuming maximum manual braking, no reverse thrust, V_{REF40}, a pressure altitude of 482 feet, standard day temperature, zero runway slope, and winds from 090 degrees at 11 knots). Multiplying 5,050 feet by a factor of 0.6 yields a flight 1248 bare and dry, unfactored landing distance of 3,030 feet.

The unfactored landing distance and the two MDW decelerometer measurements were used in the CRFI tables on pages A8.7-8 to estimate the hypothetical flight 1248 CRFI-based landing distances, with and without the use of reverse thrust. The interpolated results are provided in Section 3.6.

[14] The flight 1248 OPC reflected a landing weight of 119,700 pounds, which was rounded to the nearest 1,000 pounds for CRFI-based landing performance scenarios.

2.7 Flight 1248 Dispatch Scenarios

The flight 1248 dispatch release revision history is summarized in Table 2. The data columns, ordered left to right, correspond to the dispatch release revision number; wind direction and magnitude in knots; temperature in degrees Celsius; altimeter in inches of mercury; runway condition; engine bleed status; engine and wing anti-ice status; enroute icing status; landing flap position; arrival runway; maximum takeoff weight based on landing performance limitations; and limiting landing weight parameter.

Table 2: Flight 1248 dispatch release revision history. Revision 3 was final.

REV. #	WIND	TEMP	QNH	R/W	BLEEDS	ENG/ WNG A/I	ICE	FP	RWY	WT	LMT
1	CALM	0	30.10	WET-GOOD	ON	ON / OFF	YES	30	04R	136.7	STRUC
2	CALM	0	30.10	WET-GOOD	ON	ON / OFF	YES	30	04R	136.8	STRUC
3	080/11	0	30.10	WET-FAIR	ON	ON / OFF	YES	30	31C	129.0	RUNWY

Four additional hypothetical SWA dispatch scenarios were calculated for wet-fair/wet-poor and planned flaps 30/40 arrivals using initial conditions extracted from the flight 1248 OPC. The results of these hypothetical SWA dispatch release scenarios are presented in Section 3.7.

2.8 Airplane Braking Coefficient Mapping

The relationship between numeric values of airplane braking coefficient used for landing performance calculations and nomenclature specific to Southwest Airlines and Boeing is defined in Table 3. For airplane braking coefficient values less than 0.20, SWA and Boeing use different mappings between numeric airplane braking coefficient values and runway condition or reported braking action nomenclature. For example, Southwest Airlines “wet-poor” equates to an airplane braking coefficient value of 0.10, whereas Boeing “poor” corresponds to a value of 0.05.

Table 3: Airplane braking coefficient mapping to runway condition or reported braking action

<table>
<tr><th>Airplane Braking Coefficient</th><th colspan="2">Southwest Airlines OPC</th><th>Boeing FPPM/ QRH</th></tr>
<tr><td>0.40</td><td colspan="2">DRY</td><td>DRY[15]</td></tr>
<tr><td>0.20</td><td rowspan="3">WET</td><td>GOOD</td><td>GOOD</td></tr>
<tr><td>0.15</td><td>FAIR</td><td>---</td></tr>
<tr><td>0.10</td><td>POOR</td><td>MEDIUM</td></tr>
<tr><td>0.05</td><td colspan="2">NIL</td><td>POOR</td></tr>
</table>

[15] The airplane braking coefficient value of 0.40 for DRY is an approximate value.

Southwest Airlines OPC results for dry, wet-good, wet-fair, and wet-poor conditions based on the flight 1248 input conditions are included in Attachment 9 for reference. Boeing 737-700W flaps 40 Normal Configuration Landing Quick Reference Handbook (QRH) data are documented in Attachment 10 for comparison. Note that the SWA OPC calculations use an air distance of 1,500 feet compared to an assumed value of 1,000 feet in the QRH or Flight Planning and Performance Manual (FPPM) data.

3.0 RESULTS

3.1 Time Alignment

The time alignment between the FDR data and radar data is summarized in Table 4 below. The Local Time value is based on the ATC radar time code generated by a GPS clock.

Table 4: Time alignment mapping

Local Time	UTC Time	FDR Time	Plotted FDR Time
19:13:52.6	01:13:52.6	96396.9	6396.9

The CVR to FDR time alignment solution was found to be linear over the approximately 4 minute length of the CVR recording selected. The linear solution required to satisfy the common event constraints listed in Table 5 is presented in Table 6, where the time relationship is defined as

$$\text{CVR Time} = (\text{slope})(\text{FDR Time}) + \text{intercept}. \qquad (4)$$

In Table 6, *CVR Time* in hh:mm:ss format is converted to total seconds (e.g., 00:30:18.760 = 1818.760 seconds).

Table 5: CVR/FDR common event constraints[16]

CVR Time	FDR Low	FDR High	Source	Event
00:26:19.9	96157.8	96158.8	RDO-2	begin transmission 1
00:26:21.7	96159.8	96160.8	RDO-2	end transmission 1
00:26:32.5	96169.8	96170.8	RDO-2	begin transmission 2
00:26:33.0	96170.8	96171.8	RDO-2	end transmission 2
00:28:52.9	96310.8	96311.8	RDO-2	begin transmission 3
00:28:54.5	96311.8	96312.8	RDO-2	end transmission 3
00:30:17.7	96394.8	96395.8	RDO-2	begin transmission 4
00:30:19.0	96396.8	96397.8	RDO-2	end transmission 4
00:30:20.5	96397.8	96398.8	RDO-2	begin transmission 5
00:30:21.6	96398.8	96399.8	RDO-2	end transmission 5

[16] CVR elapsed time values include a 71 millisecond lead for “begin” transmission events and a 71 millisecond lag for “end” transmission events.

Table 6: Solution to flight 1248 CVR/FDR common event constraints

CVR Time	FDR Time	Slope	Intercept
1818.760	96396.901	1.00	-94578.141

The time alignment between ten aircraft arriving at MDW on runway 31C or diverting to an alternate destination is summarized in Table 7, based on ATC radar, FDR, ACARS, and MCC security camera video. The runway 31C exit column indicates where the airplane transitioned to a taxiway. Calculated aircraft arrival time appears in column 8 as local touchdown time.

Table 7: Calculated aircraft arrival times (local) based on ATC radar, FDR, ACARS, and MCC security camera video data.

Aircraft Number	Operator/ Model	Flight Number	Beacon Code	Landing Weight (LB)	Ground Speed at T.D. (KT)	RWY 31C Exit	Touch-down Time	Time Between Touch-downs	ACARS ON/DIV Time	FDR Time
N479UA	UA A320-200	1446	---	113,830	128.0	end	18:49:31	---	18:49	---
N795SW	SWA B737-700W	2920	---	114,560	139.5	B&N T/W	18:52:41	0:03:10	18:52	18:52:39
N213WN	SWA B737-700W	321	3076	103,320	121.5	end	19:00:39	0:07:58	19:00	19:00:36
N482WN	SWA B737-700W	2947	3202	110,320	132.5	end	19:02:28	0:01:50	19:02	19:02:26
N788SA	SWA B737-700W	1830	6275	105,520	126.5	end	19:04:07	0:01:39	19:04	19:04:05
N430WN	SWA B737-700W	1205	6245	125,200	N/A	N/A	N/A	N/A	19:05	N/A
N565CC	Cessna C500	N/A	4323	---	---	---	19:08:39	0:04:32	---	---
N603KF	Gulfstream IV	N/A	4053	---	---	---	19:10:26	0:01:47	---	---
N471WN	**SWA B737-700W**	**1248**	**0510**	**118,280**	**131.5**	**overran**	**19:13:07**	**0:02:41**	**N/A**	**19:13:05**
N614SW	SWA B737-300	1952	2150	112,500	N/A	N/A	N/A	N/A	---	N/A

Purple – denotes flight that diverted
Green – denotes non-transport category aircraft
Blue – denotes the accident flight

3.2 Radar Data Overlay

The radar data and GPS data were overlaid on a Topo U.S.A. planform view plot of Chicago Midway International Airport (see Figures A1.1 and A1.2 in Attachment 1) to correlate the airplane ground track, witness marks, and airport reference points. The QXM radar data for flight 1248 appeared to be offset to the left of the runway 31C centerline by about 270 feet and did not include the event touchdown or landing rollout.

3.3 FDR Data

3.3.1 Longitudinal and Lateral-Directional FDR data

Longitudinal and lateral-directional axes data from the N471WN FDR are presented in Attachment 2, pages A2.2-3 as a function of elapsed time. Data in Attachments 2 through 6 were also plotted as a function of elapsed time to facilitate comparison between landings. The flight 1248 touchdown time in elapsed seconds (i.e., 6351.5

seconds) was used as a common reference point to calculate the FDR time shift required for each of the 4 additional SWA landings. Refer to Section 2.3 for a discussion of the event FDR data.

3.3.2 Airplane Ground Track

The calculated flight 1248 airplane ground track was overlaid on the MDW airport layout plan and annotated with significant FDR and CVR events in Figure 1. The ground track was computed by integrating the corrected normal, longitudinal, and lateral load factor FDR data and comparing the results to recorded altitude, ground speed, drift angle, localizer, and glide slope data.

Events excerpted from the CVR transcript data documented in the Cockpit Voice Recorder Factual Report and Transcript are presented in Table 8. The time alignment results were used to position events excerpted from the CVR transcript and the FDR.

Table 8: CVR Transcript Event Excerpt

Local Time	FDR Time	Source	Event
19:12:56.5	96340.9	HOT-2	one hundred.
19:13:02.7	96347.1	CAM	[sound similar to click].
19:13:07.2	96351.5	CAM	[sound similar to click and squeak].
19:13:07.9	96352.2	CAM	[sounds similar to aircraft touchdown].
19:13:15.9	96360.3	HOT-2	you jumpin' on the?
19:13:23.2	96367.6	CAM	[sound similar to double clunk].
19:13:23.5	96367.8	HOT-1	get that back there.
19:13:31.3	96375.6	CAM	[sound similar to increased engine noise].
19:13:36.6	96380.9	CAM	[sound similar to impact].
19:13:39.1	96383.4	CAM	[sound similar to impact].
19:13:51.5	96395.8	RDO-2	Southwest twelve forty eight went over the end.
19:13:54.3	96398.7	RDO-2	we went off the end of the runway.

The ground track composite data indicated that touchdown occurred at about 1,250 feet with the airplane just right of centerline. Speedbrakes deployed and autobrakes engaged within about 1 second. About 1,600 feet of runway remained when maximum reverse thrust was commanded and approximately 1,300 feet remained when the thrust reversers were fully deployed. By the time the engines had spooled up to maximum reverse N1, only about 400 feet of landing distance remained.

3.4 Weight and Balance

The flight 1248 FDR data indicated a BWI takeoff weight of 129,550 pounds and a MDW arrival weight of 118,280 pounds, for a fuel burn of 11,270 pounds (1,682 gallons). The loading schedule indicated N471WN weighed 129,000 pounds at takeoff of which 23,200 pounds (3,463 gallons) was fuel. If 3,463 gallons of fuel were present at takeoff, 1,682 gallons were burned enroute, and 1,646 gallons were offloaded post-accident, then as much as 135 gallons of fuel may have leaked from the airplane at the accident site.

Center of gravity location was computed using the last two digits (index units) of the zero fuel weight or the takeoff weight listed on the SWA loading schedule. Index units were converted to percent mean aerodynamic chord (%MAC) by using Equation 5 below:

$$\%MAC = [661.1 - 627.1 - (IndexUnits/10 - 6.)*(130000)*(6.5) / Weight] / 1.558 \qquad (5)$$

Based on the flight 1248 loading schedule, the center of gravity location would have been located at 21.4 percent MAC at takeoff. The FDR arrival weight of 118,280 pounds was rounded up to the nearest 100 pounds and used with the zero fuel weight to estimate that 12,600 pounds of fuel remained on arrival. Adding the adjusted wing fuel weight (12,797 pounds) to the adjusted zero fuel weight (105,765 pounds) yields an arrival center of gravity location of 62 index units or 20.9 percent MAC. Flight 1248 calculated weight and center of gravity data are summarized in Table 9.

Table 9: Calculated flight 1248 center of gravity locations

Flight 1248 Loading Schedule	Weight (LB)	Index Units	Center of Gravity (%MAC)
Zero Fuel Wt.	105,700	65	19.3
Takeoff Wt.	129,000	61	21.4
Landing Wt.	118,300[17]	62	20.9

3.5 Estimated Airplane Braking Coefficient

3.5.1 Time Varying Airplane Braking Coefficient Extraction (Method A)

The Method A time varying airplane braking coefficient results will be presented in an Addendum to the Aircraft Performance Group Study due to additional work required to validate the airplane position alignment with the runway during the respective landing rollouts.

3.5.2 Constant Equivalent Airplane Braking Coefficient (Method B)

The Method B constant airplane braking coefficient simulation results for the five Southwest Airlines flights are presented in Table 10. The constant total airplane braking coefficients were determined using braked portions of the landing rollouts where the airplane braking would have been limited by the runway friction. These

[17] The FDR arrival weight of 118,280 pounds was rounded up to the nearest 100 pounds.

constant coefficients were required to match the FDR ground speed, calculated distance, and FDR acceleration. For all the landings except N788SA a constant total airplane braking coefficient adequately described the recorded deceleration. In the N788SA landing rollout, an average total airplane braking coefficient value that increased from 0.09 at the beginning to 0.11 near the end was required to match the recorded deceleration characteristics.

Table 10: Calculated aircraft total airplane braking coefficient

Aircraft Number	Operator/ Model	Flight Number	Landing Weight (LB)	Ground Speed at T.D. (KT)	RWY 31C Exit	T.D. Time	Total Airplane Braking Coefficient
N795SW	SWA B737-700W	2920	114,560	139.5	B&N T/W	18:52:41	0.12
N213WN	SWA B737-700W	321	103,320	121.5	end	19:00:39	0.11
N482WN	SWA B737-700W	2947	110,320	132.5	end	19:02:28	0.08
N788SA	SWA B737-700W	1830	105,520	126.5	end	19:04:07	0.10*
N471WN	**SWA B737-700W**	**1248**	**118,280**	**131.5**	**overran**	**19:13:07**	**0.08**

*Average braking coefficient increases from 0.09 to 0.11 during the time history
Blue – denotes the accident flight

These constant airplane braking coefficient data were consistent with the time varying counterparts calculated in Method A. Therefore, these constant airplane braking coefficient values were considered to be representative for the respective flights and could be used for further simulation studies.

3.5.3 OPC Estimate of Airplane Braking Coefficient (Method C)

Operational landing distances with and without the use of 2 engine detent reverse thrust were calculated over a wide range of airplane braking coefficient values for the following flight 1248-based initial conditions: weight of 119,700 pounds, flaps 40, V_{REF40}, 6 knot tailwind, maximum autobrake, 1250 feet air distance, 482 feet pressure altitude, 30.07 inches of mercury, temperature -3°C, bleeds on, and engine anti-ice on. The supporting OPC data are documented in Attachment 7.

The results of the SWA OPC estimate of airplane braking coefficient are presented in Figure 2. The solid red line denotes the available landing distance on runway 31C. The solid blue line defines the estimated landing distance required to stop, assuming that the constant deceleration calculated from the ground portion of the event rollout on improved surfaces continued until the airplane came to a complete (and unobstructed) stop. The intersections of the 2 landing distance curves (i.e., with and without reverse thrust) with the 2 horizontal lines (i.e., estimated and available landing distance) define two ranges of airplane braking coefficient required to stop the airplane.

As illustrated by the 2 red vertical lines and the accompanying note, an airplane braking coefficient value between 0.09 and 0.13 was required to stop within the available landing distance on runway 31C, depending on the integrated effect of the actual thrust reverser deployment. Similarly, the 2 blue vertical lines indicate that an airplane braking coefficient range between about 0.07 and 0.105 was required to stop the airplane, subject to the constant deceleration assumption previously described.

3.6 Canadian Runway Friction Index Scenarios

The MDW decelerometer measurements and flight 1248 arrival parameters were used to calculate CRFI-based recommended landing distances from the CRFI tables included in Attachment 8. The results of these hypothetical CRFI scenarios[18] are presented in Table 11.

Table 11: Hypothetical CRFI-based landing distances for flight 1248

		With Reverse Thrust		Without Reverse Thrust	
Friction Test Time on 12/08/05	**MDW Decelerometer Measurement**	Landing Distance (feet)	Stopping Margin (feet)	Landing Distance (feet)	Stopping Margin (feet)
18:47	.67	4,791	1,035	5,127	699
19:22	.40	5,400	426	5,979	-153

If the entire CRFI reporting system had been in use at the time of the accident, flight crews may have been advised that CRFI readings could not be provided and given a less than favorable runway surface condition report. However, if the MDW decelerometer reading recorded prior to the accident (.67) had been reported to arriving flights, the most current runway 31C friction test data available to flight 1248 would have resulted in a CRFI-based runway length sufficient to land, independent of the use of reverse thrust. If the post-accident decelerometer reading (.40) had been available and reported to arriving flights, CRFI-based landing distance data would have indicated that flight 1248 required reverse thrust to land on runway 31C.

3.7 Southwest Airlines Dispatch Landing Performance Scenarios

Four hypothetical SWA dispatch release scenarios based on arrival data extracted from the flight 1248 OPC are presented in Table 12. The data columns, ordered left to right, correspond to the scenario number; wind direction and magnitude in knots; temperature in degrees Celsius; altimeter in inches of mercury; runway condition; engine bleed status; engine and wing anti-ice status; enroute icing status; landing flap position; arrival runway; maximum takeoff weight based on landing performance limitations; and maximum landing weight.

Based on a takeoff weight of 129,000 pounds, for wet-fair conditions, flight 1248 could have been dispatched with a planned flaps 40 arrival or reduced the takeoff and landing weight by 2,100 pounds for a planned flaps 30 arrival. For wet-poor

[18] The CRFI measurement and reporting system is not used at MDW.

conditions, flight 1248 would have been restricted to 4,300 and 2,100 pound reductions in the takeoff/landing weights for a planned flaps 30 or flaps 40 arrival, respectively.

Table 12: Dispatch release scenarios based on flight 1248 MDW arrival conditions.

CASE #	WIND	TEMP	QNH	R/W	BLEEDS	ENG/ WNG A/I	ICE	FP	RWY	WT	MLW
1	090/11	-3	30.07	WET-FAIR	ON	ON / OFF	YES	30	31C	126.9	118.0
2	090/11	-3	30.07	WET-FAIR	ON	ON / OFF	YES	40	31C	130.2	121.3
3	090/11	-3	30.07	WET-POOR	ON	ON / OFF	YES	30	31C	124.7	115.8
4	090/11	-3	30.07	WET-POOR	ON	ON / OFF	YES	40	31C	127.4	118.5

4.0 SUMMARY

The event flight time alignment between the Cockpit Voice Recorder (CVR), Flight Data Recorder (FDR), Air Traffic Control (ATC) radar data, ACARS data, MDW security camera video, and preceding arrival flights was determined. Flight 1248 radar data were consistent with the reported runway 31C approach and FDR data. The FDR-based landing weight of 118,280 pounds with the airplane configured at flaps 40 met the planned dispatch “wet-fair” flaps 30 landing performance limit of 120,100 pounds. Based on the loading schedule buildup and the FDR landing weight, the center of gravity was located at about 21 percent MAC, near the middle of the envelope.

The FDR data from 5 Southwest Airlines B737-700W flights arriving at MDW were time shifted to a common reference elapsed time touchdown point and plotted. The calculated accident flight ground track was overlaid on the MDW airport layout plan and annotated with significant FDR and CVR events. These data indicated that touchdown occurred at about 1,250 feet. About 1,600 feet of runway remained when maximum reverse thrust was commanded and approximately 1,300 feet remained when the thrust reversers were fully deployed. By the time the engines had spooled up to maximum reverse N1, only about 400 feet of landing distance remained.

The calculated constant equivalent airplane braking coefficient for 5 SWA flights that arrived at MDW over an approximately 20 minute period ranged from a maximum of 0.12 to a minimum of 0.08, with the accident flight at the minimum end of the band. These constant airplane braking coefficient data were consistent with the time varying coefficients calculated using the time varying method, which was validated using 5 Boeing 737-700 flight test data cases.

The OPC estimate of airplane braking coefficient indicated that a range from 0.09 to 0.13 was required to stop on runway 31C and a range from 0.07 to 0.11 was required to stop the airplane, subject to the constant deceleration assumption and OPC initial conditions used in the simplified analysis.

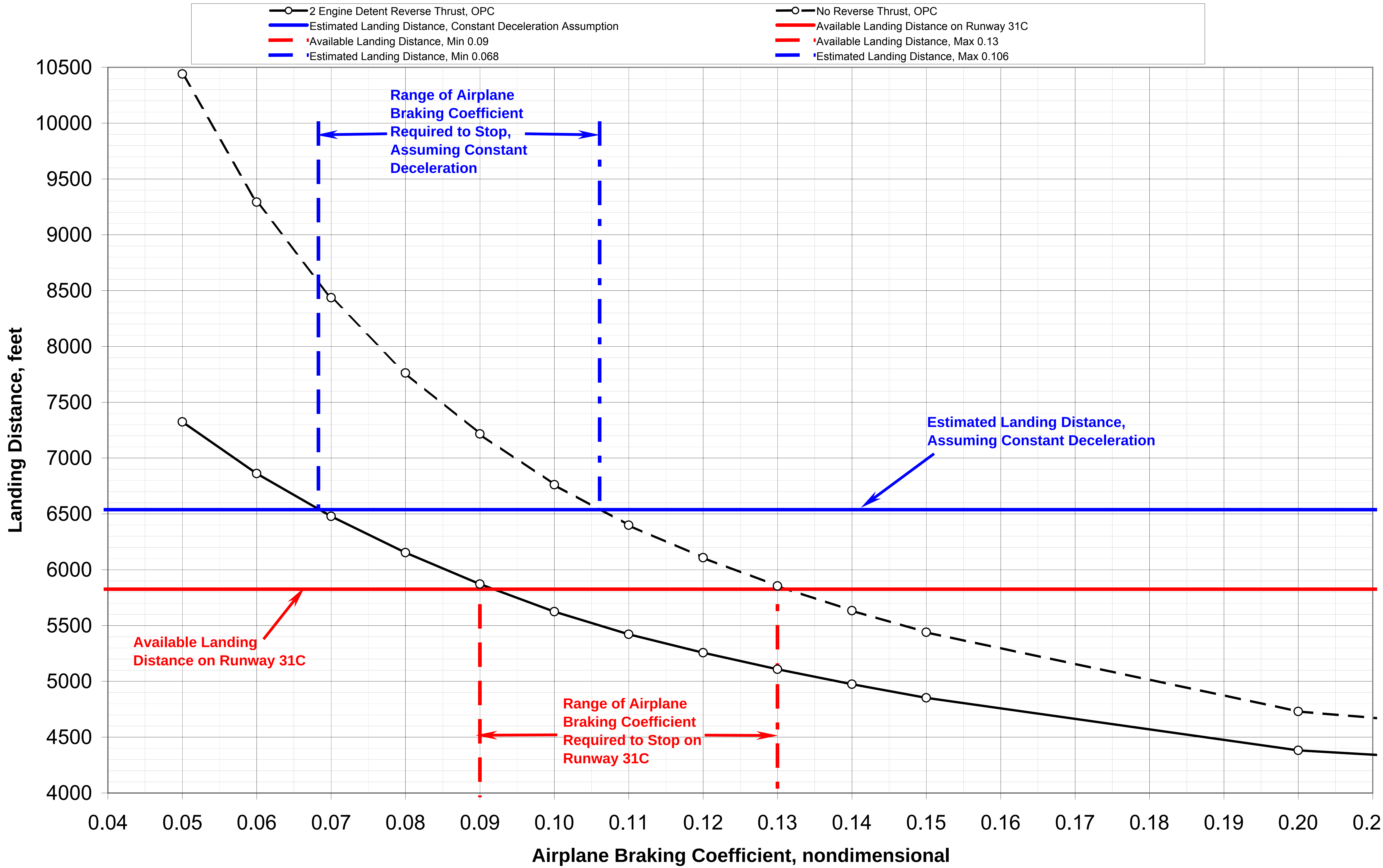
The hypothetical Canadian Runway Friction Index (CRFI) landing performance assessment based on the MDW friction measurements taken before and after the accident was inconclusive. The CRFI measurement and reporting system was not used at MDW, CRFI guidance and training were not provided to SWA flight crews, and the environmental conditions at the time of the accident may have prohibited taking or reporting a valid CRFI measurement. In the hypothetical scenario that the runway 31C friction measurement of .67 had been reported to arriving flights, the CRFI performance tables would have indicated that flight 1248 would have had sufficient landing distance, independent of the use of reverse thrust.

The SWA dispatch scenarios indicated that flight 1248 could have been dispatched for “wet-fair” conditions, a flaps 40 arrival, and the balance of OPC arrival conditions with no changes to the BWI departure loading schedule. A planned flaps 40 arrival with SWA “wet-poor” conditions would have required a takeoff and landing weight reduction of 2,100 pounds.

Figure 1: Calculated flight 1248 ground track with CVR events (blue), FDR events (green), and GPS data (purple) as noted. Elapsed FDR time in seconds, FDR ground speed, and runway 31C distance markers in feet are provided for reference.

Figure 2: OPC Estimate of Airplane Braking Coefficient, Method C (737-700W/CFM56-7B24)

(119,700 lb, flaps 40, V_{REF40}, 6 knot tailwind, autobrake max., 1250 ft. air distance, H_P 482 ft., 30.07 in. Hg, -3°C, bleeds on, engine A/I on)



Attachment 1: Flight 1248 Radar Ground Track

Figure A1.1: N471WN ground track for event flight based on radar data. Flight 1248 originated in Baltimore, MD (BWI) and arrived in Chicago, IL (MDW, upper left) on December 8, 2005. Radar data from QXM are plotted with red symbols. Blue symbols represent handheld GPS measurements (not readily visible at scale shown).

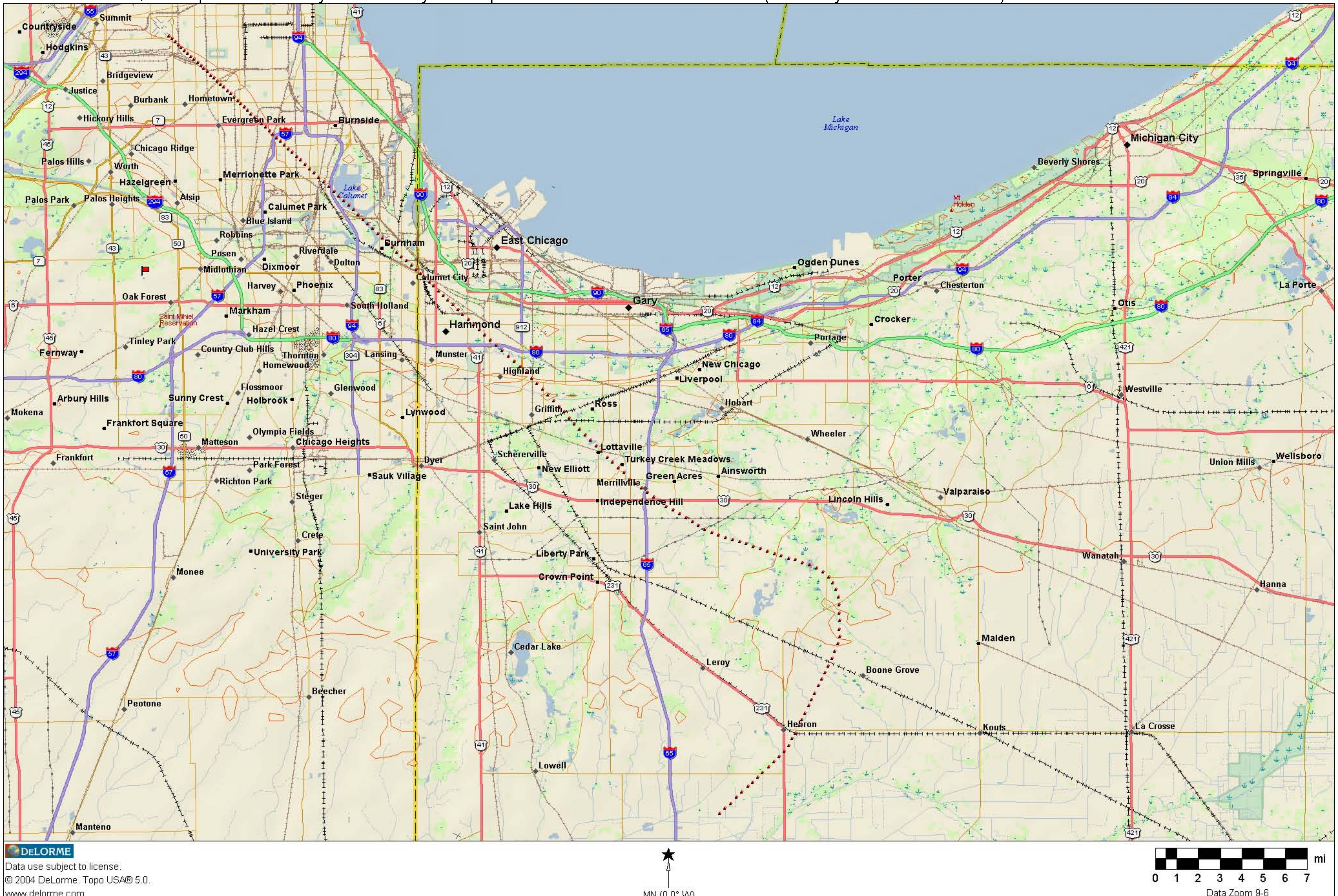
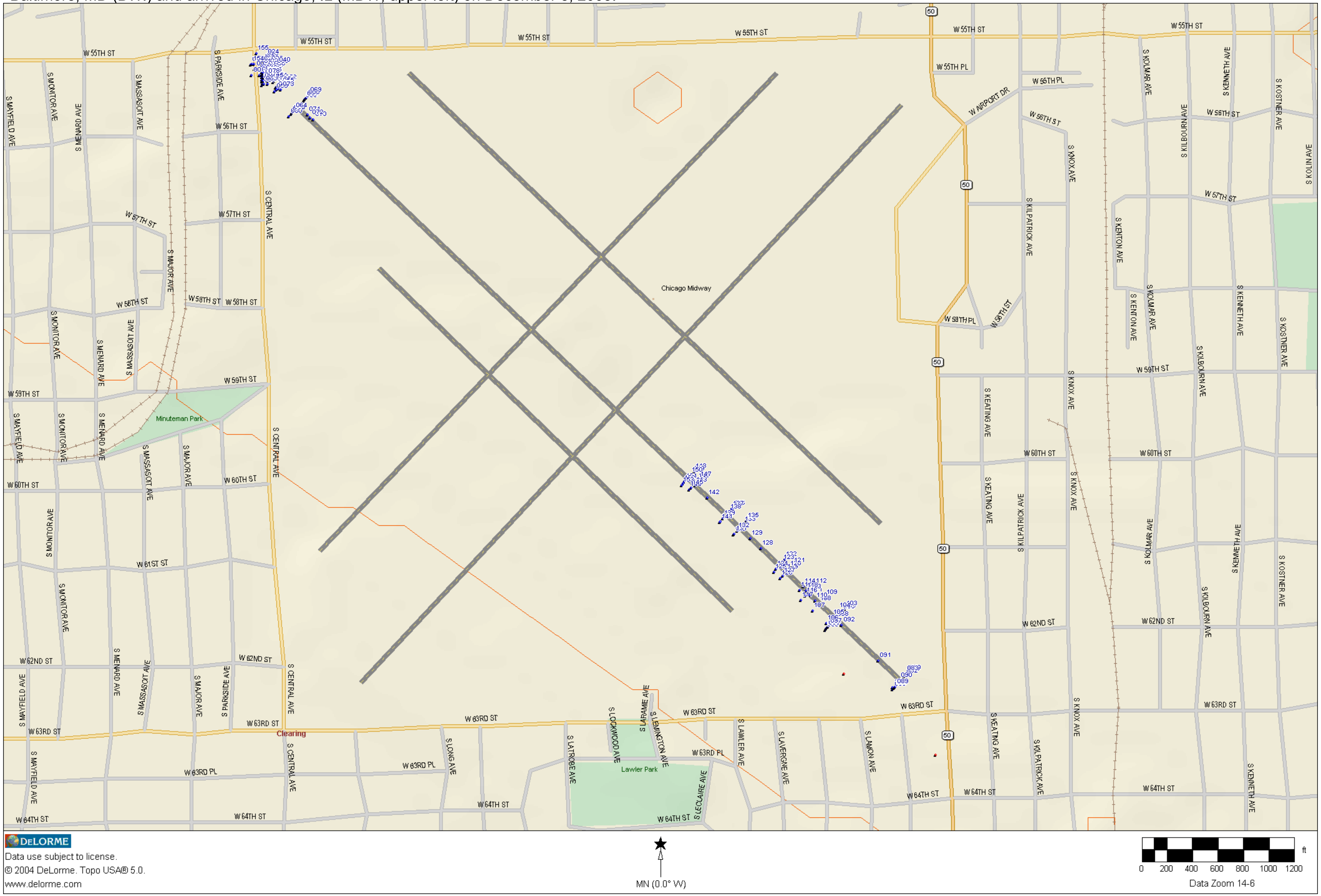
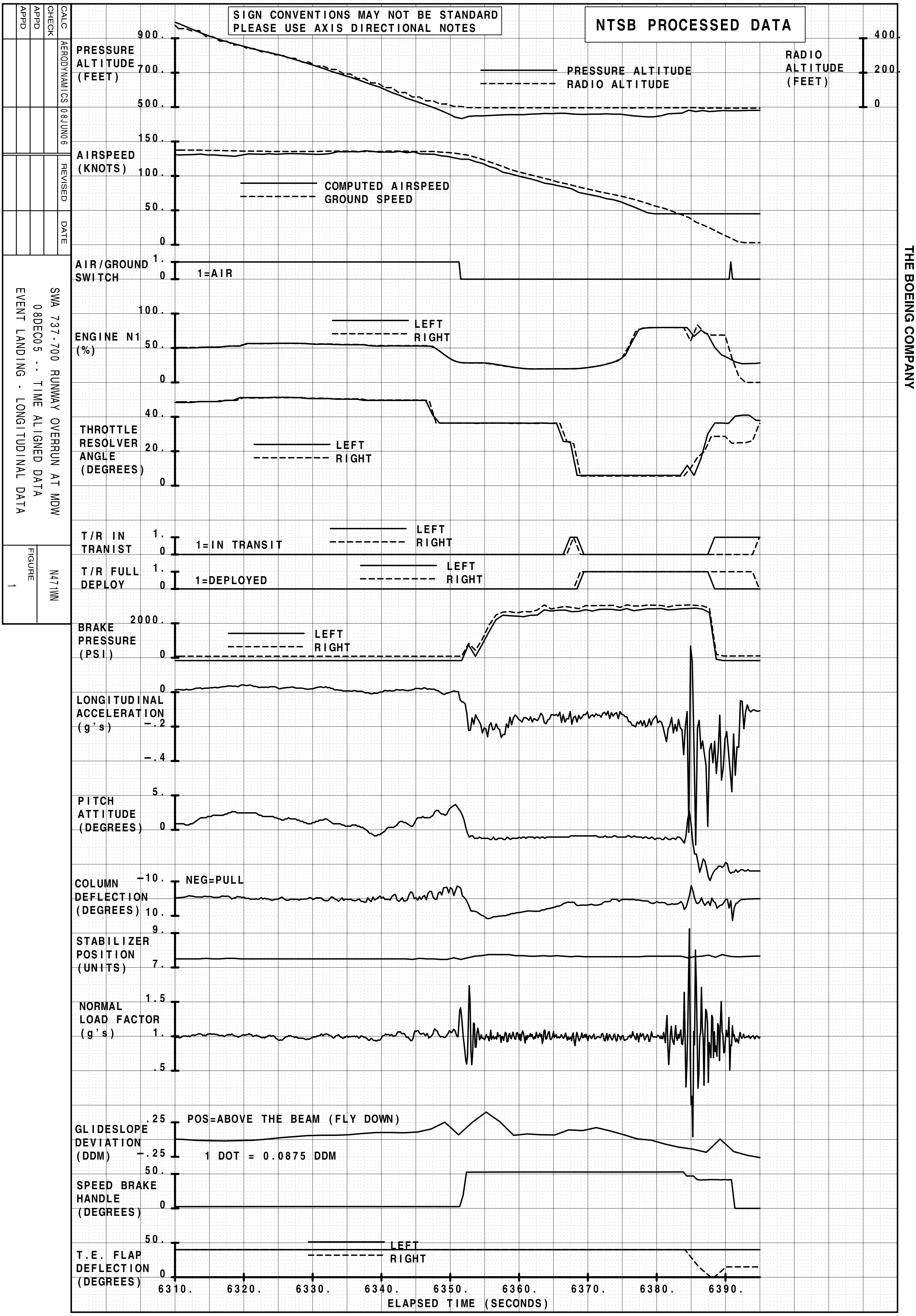
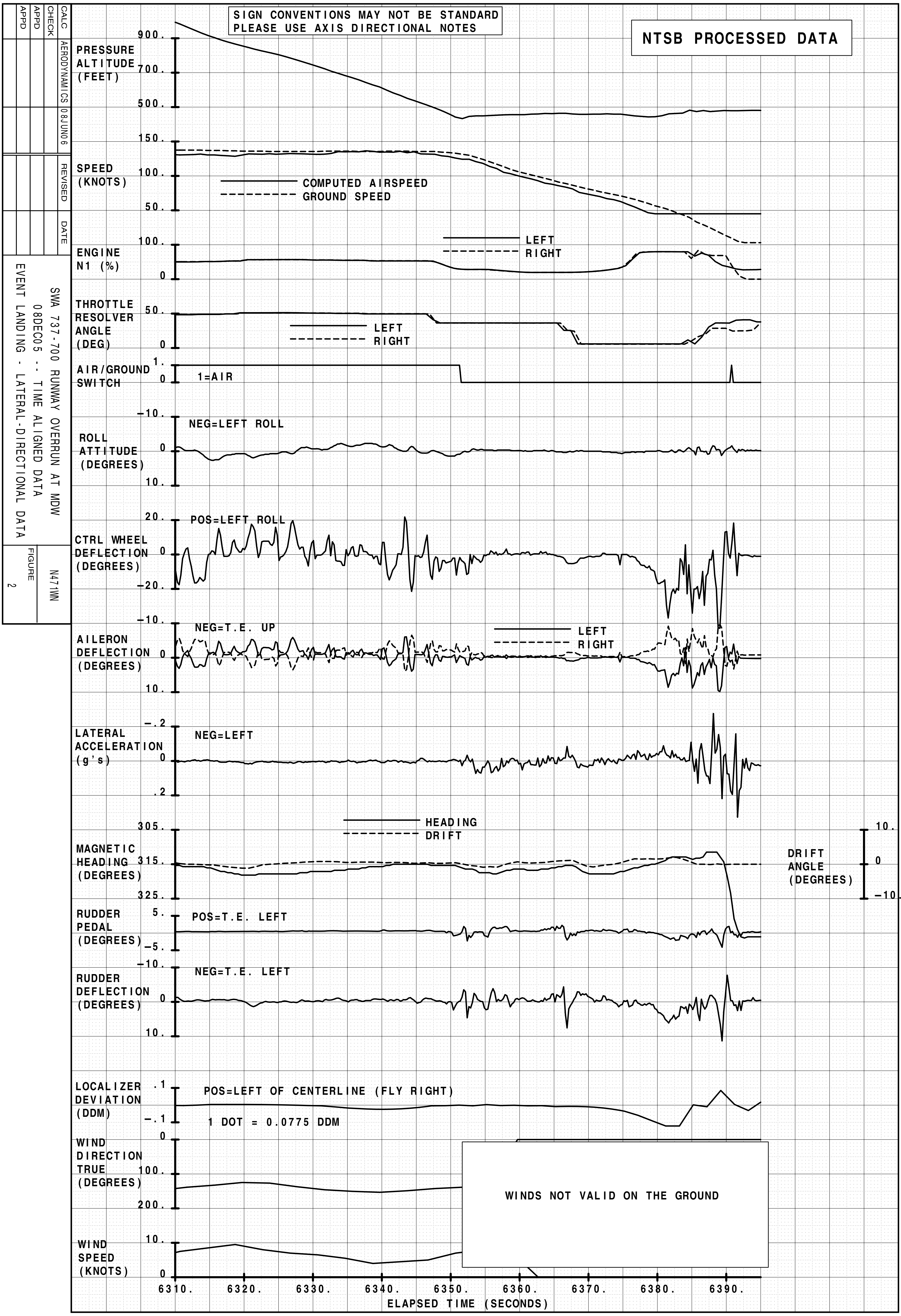


Figure A1.2: N471WN ground track for event flight based on radar data from QXM (red symbols), and handheld GPS survey data (blue symbols). Flight 1248 originated in Baltimore, MD (BWI) and arrived in Chicago, IL (MDW, upper left) on December 8, 2005.



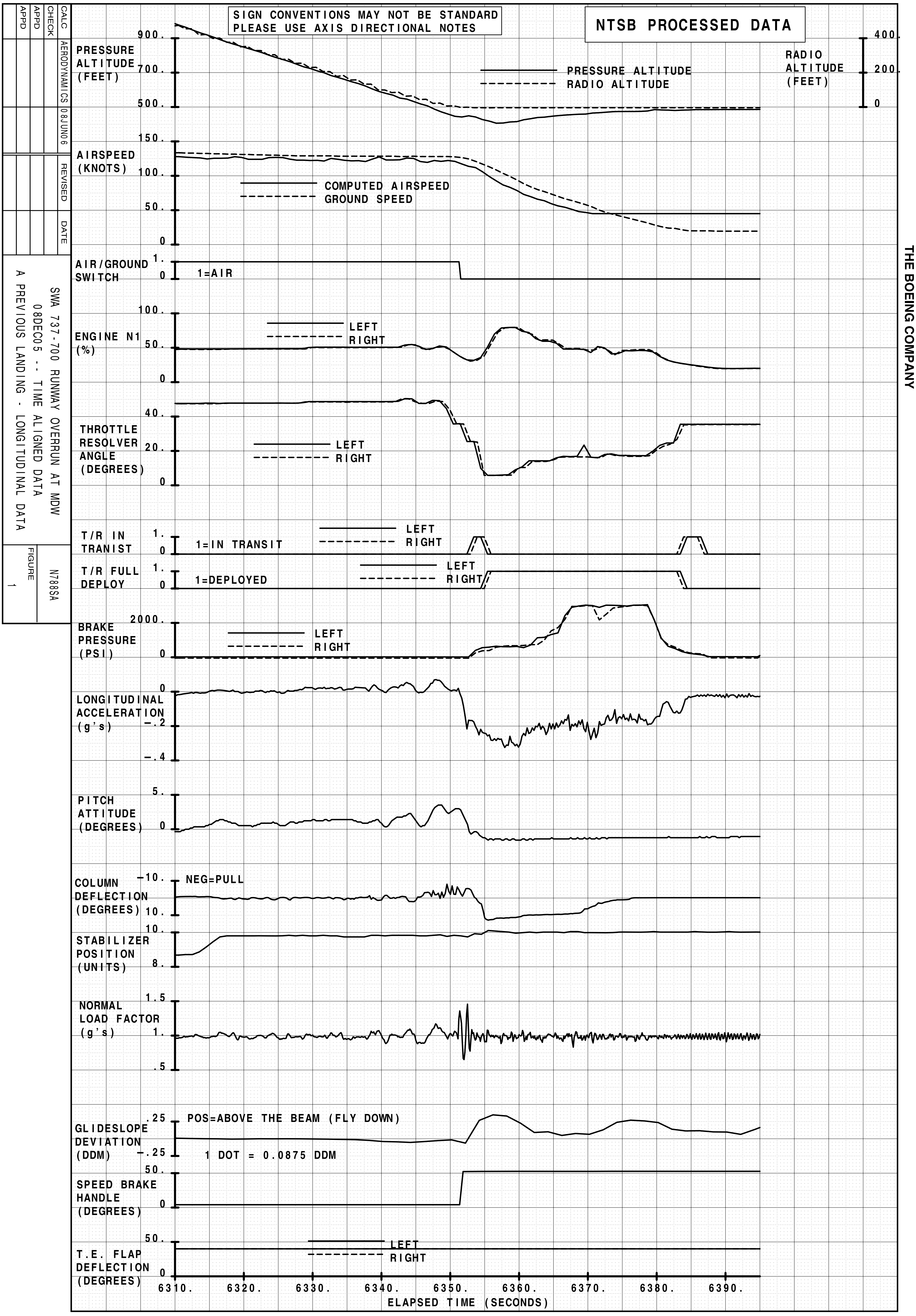
Attachment 2: N471WN Landing (Accident Flight)


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
900.
700.
500.
PRESSURE ALTITUDE
RADIO ALTITUDE
RADIO ALTITUDE (FEET)
400.
200.
0
AIRSPEED (KNOTS)
150.
100.
50.
0
COMPUTED AIRSPEED
GROUND SPEED
AIR/GROUND SWITCH
1.
0
1=AIR
ENGINE N1 (%)
100.
50.
0
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEGREES)
40.
20.
0
LEFT
RIGHT
T/R IN TRANIST
1.
0
1=IN TRANSIT
LEFT
RIGHT
T/R FULL DEPLOY
1.
0
1=DEPLOYED
LEFT
RIGHT
BRAKE PRESSURE (PSI)
2000.
0
LEFT
RIGHT
LONGITUDINAL ACCELERATION (g's)
0
-.2
-.4
PITCH ATTITUDE (DEGREES)
5.
0
COLUMN DEFLECTION (DEGREES)
-10.
10.
NEG=PULL
STABILIZER POSITION (UNITS)
9.
7.
NORMAL LOAD FACTOR (g's)
1.5
1.
.5
GLIDESLOPE DEVIATION (DDM)
.25
-.25
POS=ABOVE THE BEAM (FLY DOWN)
1 DOT = 0.0875 DDM
SPEED BRAKE HANDLE (DEGREES)
50.
0
T.E. FLAP DEFLECTION (DEGREES)
50.
0
LEFT
RIGHT
6310.
6320.
6330.
6340.
6350.
6360.
6370.
6380.
6390.
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
EVENT LANDING - LONGITUDINAL DATA
N471WN
FIGURE
1
PAGE
THE BOEING COMPANY

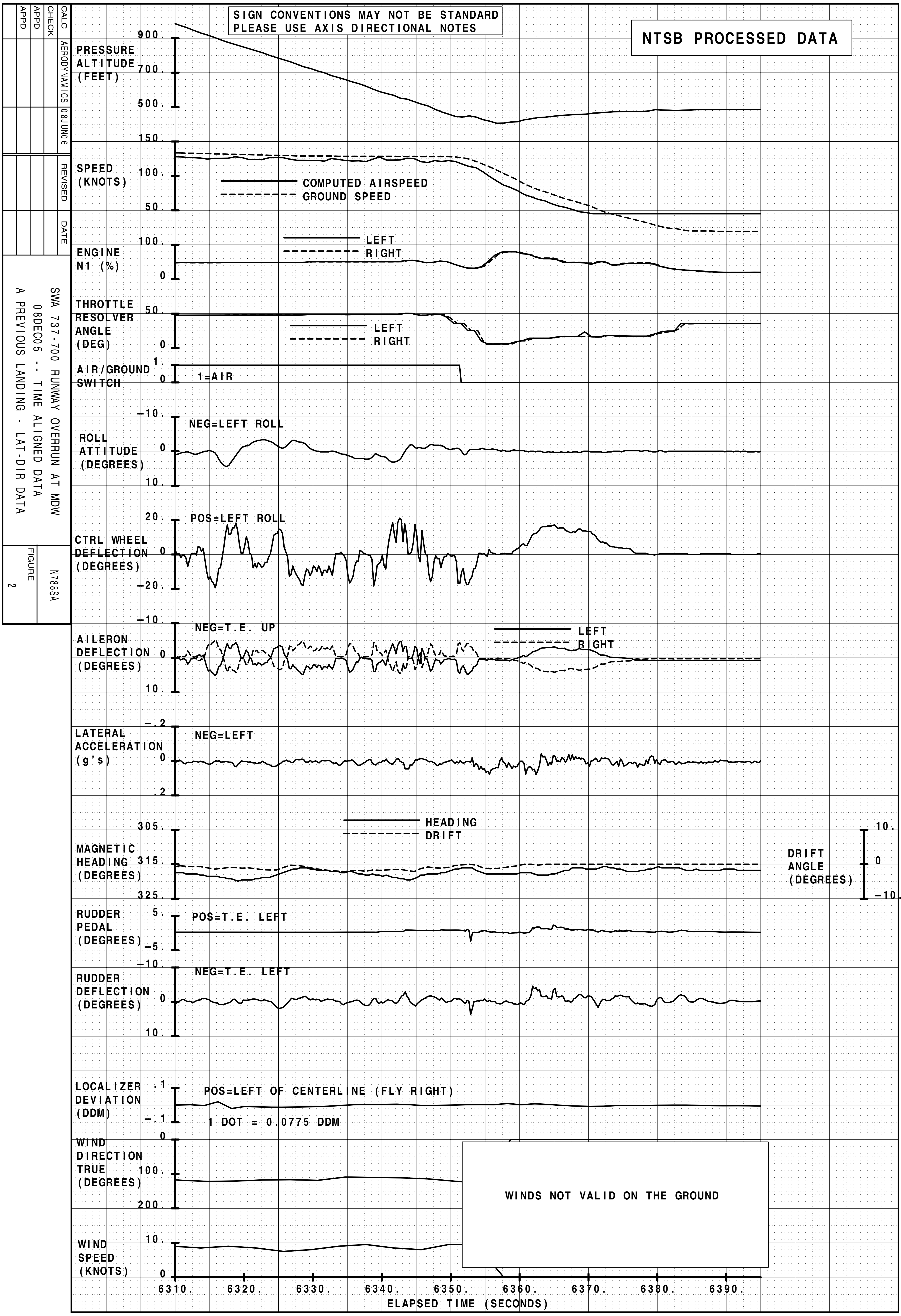


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
900.
700.
500.
SPEED (KNOTS)
150.
100.
50.
COMPUTED AIRSPEED
GROUND SPEED
ENGINE N1 (%)
100.
0
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEG)
50.
0
LEFT
RIGHT
AIR/GROUND SWITCH
1.
0
1=AIR
ROLL ATTITUDE (DEGREES)
-10.
0
10.
NEG=LEFT ROLL
CTRL WHEEL DEFLECTION (DEGREES)
20.
0
-20.
POS=LEFT ROLL
AILERON DEFLECTION (DEGREES)
-10.
0
10.
NEG=T.E. UP
LEFT
RIGHT
LATERAL ACCELERATION (g's)
-.2
0
.2
NEG=LEFT
MAGNETIC HEADING (DEGREES)
305.
315.
325.
HEADING
DRIFT
DRIFT ANGLE (DEGREES)
10.
0
-10.
RUDDER PEDAL (DEGREES)
5.
-5.
POS=T.E. LEFT
RUDDER DEFLECTION (DEGREES)
-10.
0
10.
NEG=T.E. LEFT
LOCALIZER DEVIATION (DDM)
.1
-.1
POS=LEFT OF CENTERLINE (FLY RIGHT)
1 DOT = 0.0775 DDM
WIND DIRECTION TRUE (DEGREES)
0
100.
200.
WINDS NOT VALID ON THE GROUND
WIND SPEED (KNOTS)
10.
0
6310.
6320.
6330.
6340.
6350.
6360.
6370.
6380.
6390.
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
EVENT LANDING - LATERAL-DIRECTIONAL DATA
N471WN
FIGURE
2
PAGE
THE BOEING COMPANY

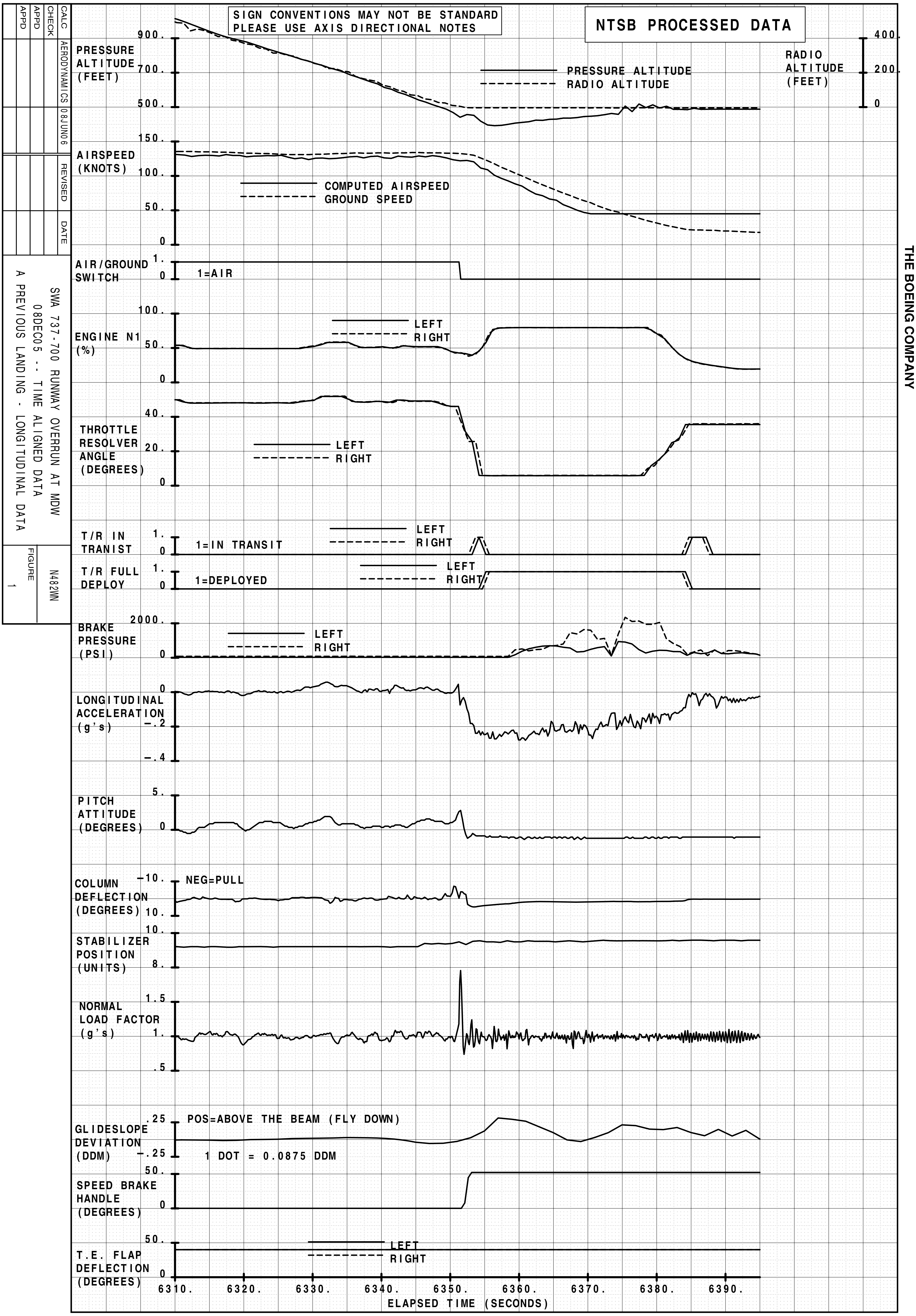
Attachment 3: N788SA Landing

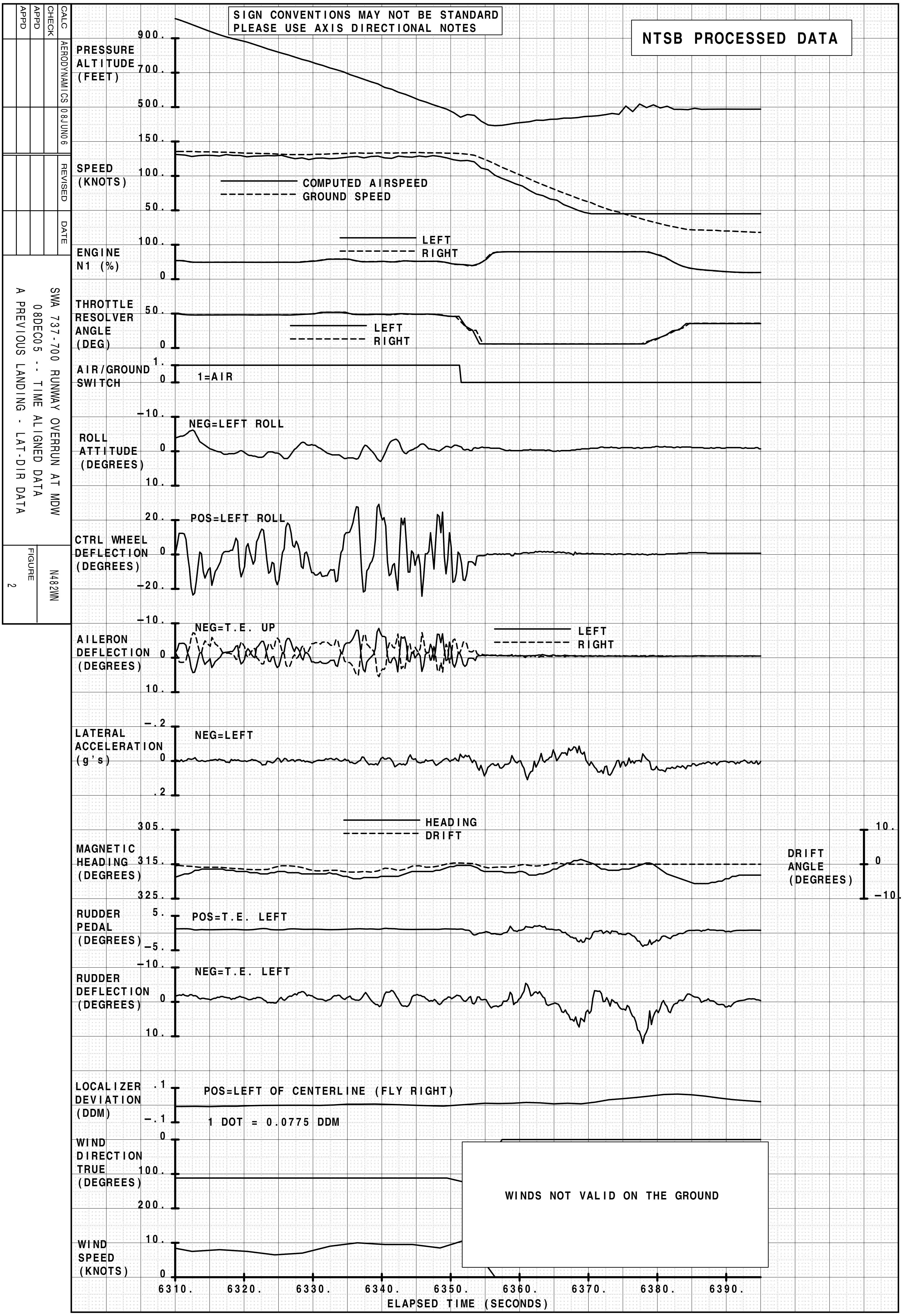


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
PRESSURE ALTITUDE
RADIO ALTITUDE
RADIO ALTITUDE (FEET)
AIRSPEED (KNOTS)
COMPUTED AIRSPEED
GROUND SPEED
AIR/GROUND SWITCH
1=AIR
ENGINE N1 (%)
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEGREES)
T/R IN TRANIST
1=IN TRANSIT
T/R FULL DEPLOY
1=DEPLOYED
BRAKE PRESSURE (PSI)
LONGITUDINAL ACCELERATION (g's)
PITCH ATTITUDE (DEGREES)
COLUMN DEFLECTION (DEGREES)
NEG=PULL
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
GLIDESLOPE DEVIATION (DDM)
POS=ABOVE THE BEAM (FLY DOWN)
1 DOT = 0.0875 DDM
SPEED BRAKE HANDLE (DEGREES)
T.E. FLAP DEFLECTION (DEGREES)
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LONGITUDINAL DATA
N788SA
FIGURE 1
PAGE
THE BOEING COMPANY


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
THE BOEING COMPANY
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LAT-DIR DATA
N788SA
FIGURE 2
PAGE
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
PRESSURE ALTITUDE (FEET)
SPEED (KNOTS)
COMPUTED AIRSPEED
GROUND SPEED
ENGINE N1 (%)
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEG)
AIR/GROUND SWITCH
1=AIR
ROLL ATTITUDE (DEGREES)
NEG=LEFT ROLL
CTRL WHEEL DEFLECTION (DEGREES)
POS=LEFT ROLL
AILERON DEFLECTION (DEGREES)
NEG=T.E. UP
LATERAL ACCELERATION (g's)
NEG=LEFT
MAGNETIC HEADING (DEGREES)
HEADING
DRIFT
DRIFT ANGLE (DEGREES)
RUDDER PEDAL (DEGREES)
POS=T.E. LEFT
RUDDER DEFLECTION (DEGREES)
NEG=T.E. LEFT
LOCALIZER DEVIATION (DDM)
POS=LEFT OF CENTERLINE (FLY RIGHT)
1 DOT = 0.0775 DDM
WIND DIRECTION TRUE (DEGREES)
WIND SPEED (KNOTS)
WINDS NOT VALID ON THE GROUND
6310. 6320. 6330. 6340. 6350. 6360. 6370. 6380. 6390.
ELAPSED TIME (SECONDS)

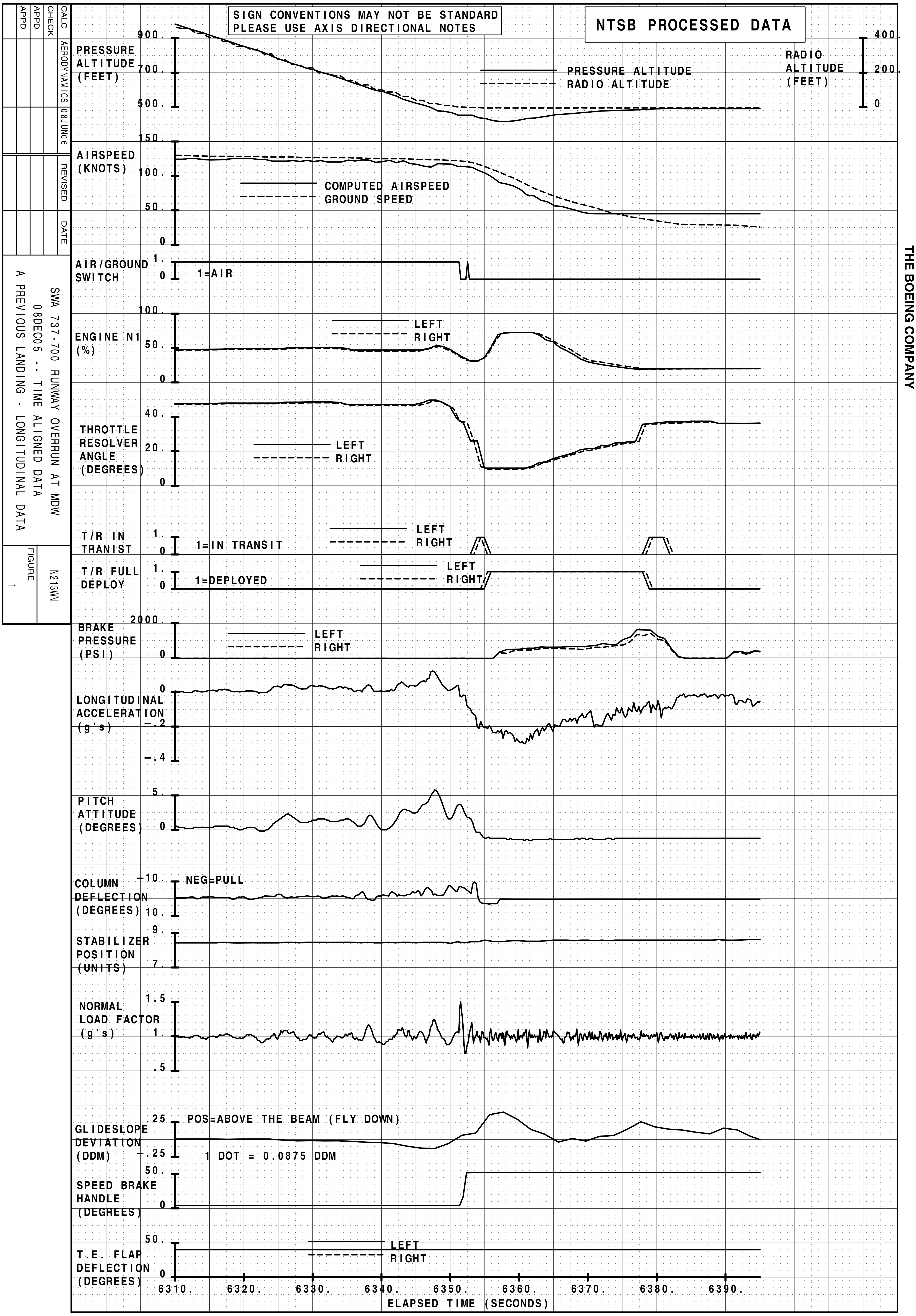
Attachment 4: N482WN Landing


NTSB PROCESSED DATA
SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
PRESSURE ALTITUDE (FEET)
PRESSURE ALTITUDE
RADIO ALTITUDE
RADIO ALTITUDE (FEET)
AIRSPEED (KNOTS)
COMPUTED AIRSPEED
GROUND SPEED
AIR/GROUND SWITCH
1=AIR
ENGINE N1 (%)
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEGREES)
T/R IN TRANIST
1=IN TRANSIT
T/R FULL DEPLOY
1=DEPLOYED
BRAKE PRESSURE (PSI)
LONGITUDINAL ACCELERATION (g's)
PITCH ATTITUDE (DEGREES)
COLUMN DEFLECTION (DEGREES)
NEG=PULL
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
GLIDESLOPE DEVIATION (DDM)
POS=ABOVE THE BEAM (FLY DOWN)
1 DOT = 0.0875 DDM
SPEED BRAKE HANDLE (DEGREES)
T.E. FLAP DEFLECTION (DEGREES)
6310. 6320. 6330. 6340. 6350. 6360. 6370. 6380. 6390.
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LONGITUDINAL DATA
N482WN
FIGURE 1
PAGE
THE BOEING COMPANY

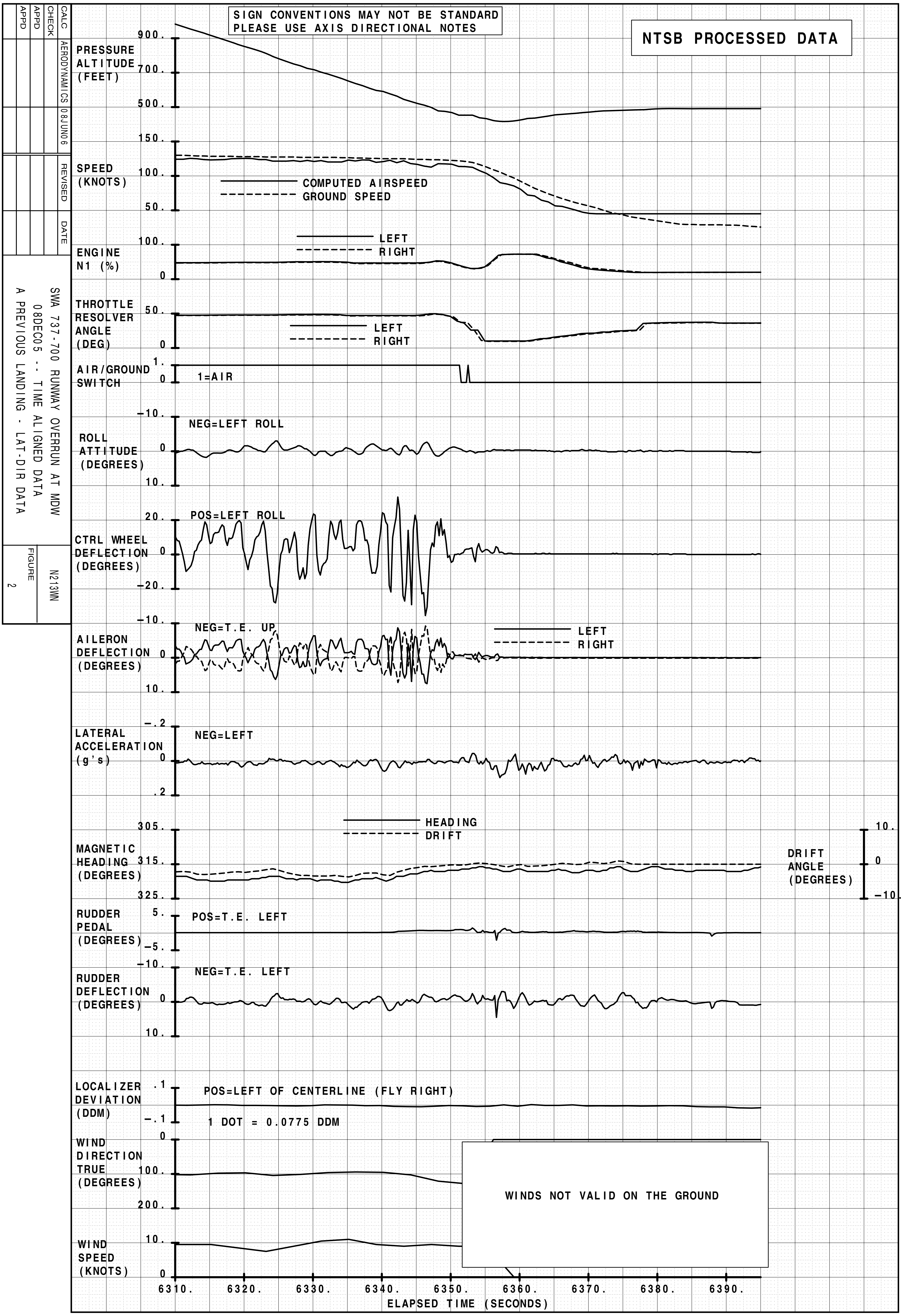


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
900.
700.
500.
SPEED (KNOTS)
150.
100.
50.
COMPUTED AIRSPEED
GROUND SPEED
ENGINE N1 (%)
100.
0
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEG)
50.
0
LEFT
RIGHT
AIR/GROUND SWITCH
1.
0
1=AIR
ROLL ATTITUDE (DEGREES)
-10.
0
10.
NEG=LEFT ROLL
CTRL WHEEL DEFLECTION (DEGREES)
20.
0
-20.
POS=LEFT ROLL
AILERON DEFLECTION (DEGREES)
-10.
0
10.
NEG=T.E. UP
LEFT
RIGHT
LATERAL ACCELERATION (g's)
-.2
0
.2
NEG=LEFT
MAGNETIC HEADING (DEGREES)
305.
315.
325.
HEADING
DRIFT
DRIFT ANGLE (DEGREES)
10.
0
-10.
RUDDER PEDAL (DEGREES)
5.
-5.
POS=T.E. LEFT
RUDDER DEFLECTION (DEGREES)
-10.
0
10.
NEG=T.E. LEFT
LOCALIZER DEVIATION (DDM)
.1
-.1
POS=LEFT OF CENTERLINE (FLY RIGHT)
1 DOT = 0.0775 DDM
WIND DIRECTION TRUE (DEGREES)
0
100.
200.
WINDS NOT VALID ON THE GROUND
WIND SPEED (KNOTS)
10.
0
6310.
6320.
6330.
6340.
6350.
6360.
6370.
6380.
6390.
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LAT-DIR DATA
FIGURE 2
N482WN
PAGE
THE BOEING COMPANY

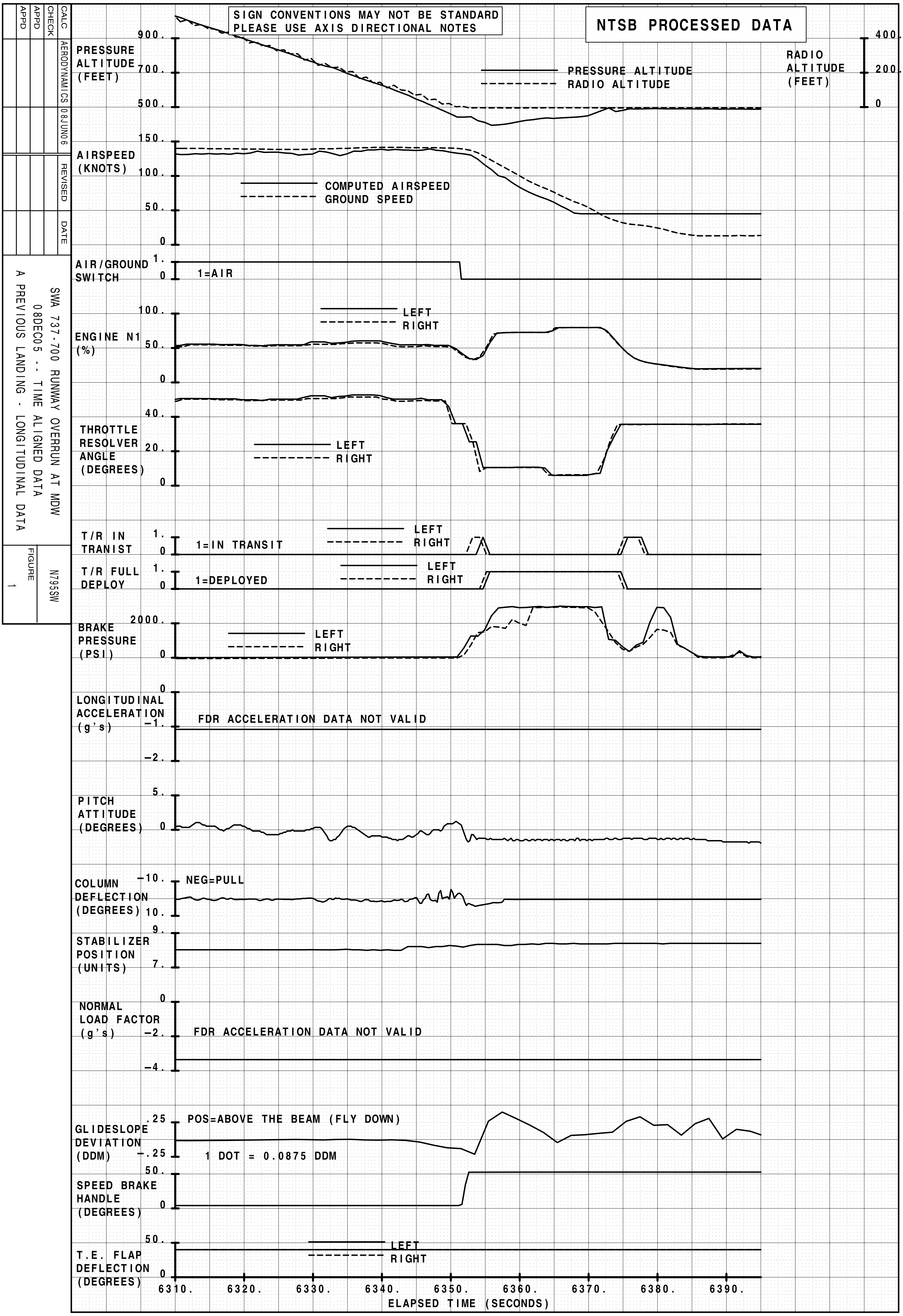
Attachment 5: N213WN Landing

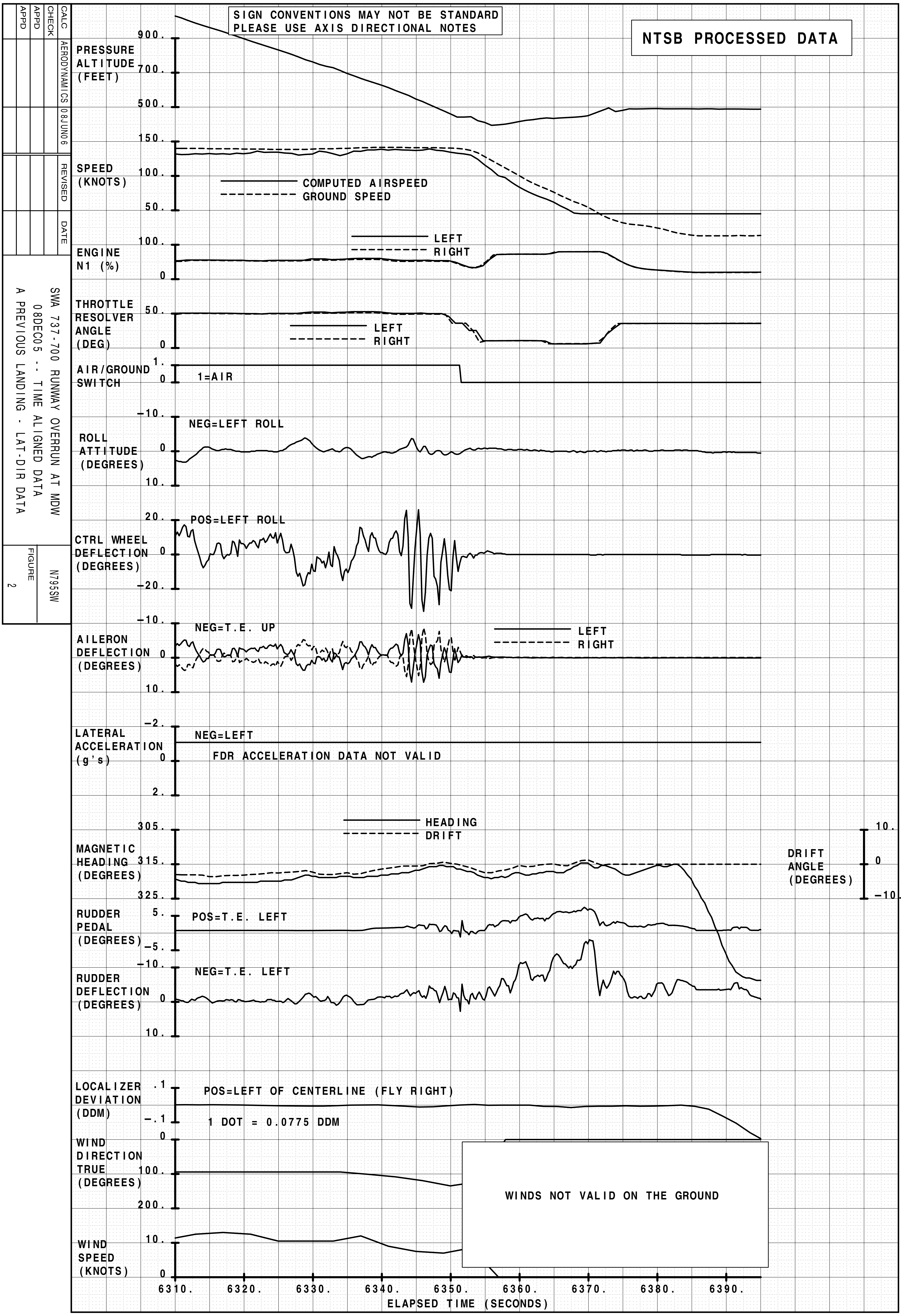


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
PRESSURE ALTITUDE
RADIO ALTITUDE
RADIO ALTITUDE (FEET)
AIRSPEED (KNOTS)
COMPUTED AIRSPEED
GROUND SPEED
AIR/GROUND SWITCH
1=AIR
ENGINE N1 (%)
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEGREES)
T/R IN TRANIST
1=IN TRANSIT
T/R FULL DEPLOY
1=DEPLOYED
BRAKE PRESSURE (PSI)
LONGITUDINAL ACCELERATION (g's)
PITCH ATTITUDE (DEGREES)
COLUMN DEFLECTION (DEGREES)
NEG=PULL
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
GLIDESLOPE DEVIATION (DDM)
POS=ABOVE THE BEAM (FLY DOWN)
1 DOT = 0.0875 DDM
SPEED BRAKE HANDLE (DEGREES)
T.E. FLAP DEFLECTION (DEGREES)
6310. 6320. 6330. 6340. 6350. 6360. 6370. 6380. 6390.
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LONGITUDINAL DATA
N213WN
FIGURE
1
PAGE
THE BOEING COMPANY


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
THE BOEING COMPANY
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LAT-DIR DATA
N213WN
FIGURE
2
PAGE
PRESSURE ALTITUDE (FEET)
900.
700.
500.
SPEED (KNOTS)
150.
100.
50.
COMPUTED AIRSPEED
GROUND SPEED
ENGINE N1 (%)
100.
0
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEG)
50.
0
LEFT
RIGHT
AIR/GROUND SWITCH
1.
0
1=AIR
ROLL ATTITUDE (DEGREES)
-10.
0
10.
NEG=LEFT ROLL
CTRL WHEEL DEFLECTION (DEGREES)
20.
0
-20.
POS=LEFT ROLL
AILERON DEFLECTION (DEGREES)
-10.
0
10.
NEG=T.E. UP
LEFT
RIGHT
LATERAL ACCELERATION (g's)
-.2
0
.2
NEG=LEFT
MAGNETIC HEADING (DEGREES)
305.
315.
325.
HEADING
DRIFT
DRIFT ANGLE (DEGREES)
10.
0
-10.
RUDDER PEDAL (DEGREES)
5.
-5.
POS=T.E. LEFT
RUDDER DEFLECTION (DEGREES)
-10.
0
10.
NEG=T.E. LEFT
LOCALIZER DEVIATION (DDM)
.1
-.1
POS=LEFT OF CENTERLINE (FLY RIGHT)
1 DOT = 0.0775 DDM
WIND DIRECTION TRUE (DEGREES)
0
100.
200.
WINDS NOT VALID ON THE GROUND
WIND SPEED (KNOTS)
10.
0
6310.
6320.
6330.
6340.
6350.
6360.
6370.
6380.
6390.
ELAPSED TIME (SECONDS)

Attachment 6: N795SW Landing


SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
PRESSURE ALTITUDE
RADIO ALTITUDE
RADIO ALTITUDE (FEET)
AIRSPEED (KNOTS)
COMPUTED AIRSPEED
GROUND SPEED
AIR/GROUND SWITCH
1=AIR
ENGINE N1 (%)
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEGREES)
T/R IN TRANIST
1=IN TRANSIT
T/R FULL DEPLOY
1=DEPLOYED
BRAKE PRESSURE (PSI)
LONGITUDINAL ACCELERATION (g's)
FDR ACCELERATION DATA NOT VALID
PITCH ATTITUDE (DEGREES)
COLUMN DEFLECTION (DEGREES)
NEG=PULL
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
FDR ACCELERATION DATA NOT VALID
GLIDESLOPE DEVIATION (DDM)
POS=ABOVE THE BEAM (FLY DOWN)
1 DOT = 0.0875 DDM
SPEED BRAKE HANDLE (DEGREES)
T.E. FLAP DEFLECTION (DEGREES)
ELAPSED TIME (SECONDS)
CALC
CHECK
APPD
APPD
AERODYNAMICS
08JUN06
REVISED
DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LONGITUDINAL DATA
N795SW
FIGURE
1
PAGE
THE BOEING COMPANY

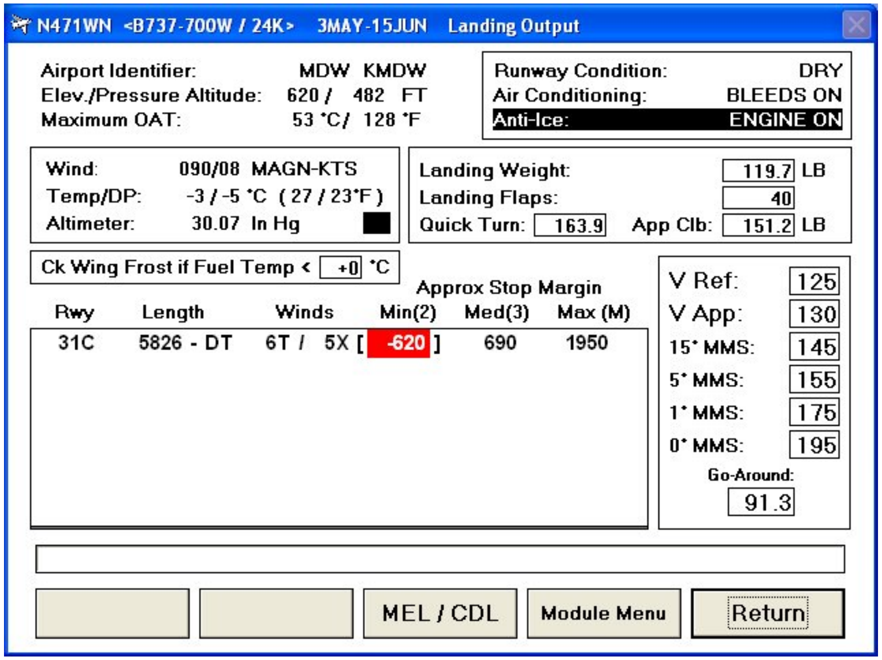

SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
NTSB PROCESSED DATA
PRESSURE ALTITUDE (FEET)
900. 700. 500.
SPEED (KNOTS)
150. 100. 50.
COMPUTED AIRSPEED
GROUND SPEED
ENGINE N1 (%)
100. 0
LEFT
RIGHT
THROTTLE RESOLVER ANGLE (DEG)
50. 0
AIR/GROUND SWITCH
1. 0
1=AIR
ROLL ATTITUDE (DEGREES)
-10. 0 10.
NEG=LEFT ROLL
CTRL WHEEL DEFLECTION (DEGREES)
20. 0 -20.
POS=LEFT ROLL
AILERON DEFLECTION (DEGREES)
-10. 0 10.
NEG=T.E. UP
LATERAL ACCELERATION (g's)
-2. 0 2.
NEG=LEFT
FDR ACCELERATION DATA NOT VALID
MAGNETIC HEADING (DEGREES)
305. 315. 325.
HEADING
DRIFT
DRIFT ANGLE (DEGREES)
10. 0 -10.
RUDDER PEDAL (DEGREES)
5. -5.
POS=T.E. LEFT
RUDDER DEFLECTION (DEGREES)
-10. 0 10.
NEG=T.E. LEFT
LOCALIZER DEVIATION (DDM)
.1 -.1
POS=LEFT OF CENTERLINE (FLY RIGHT)
1 DOT = 0.0775 DDM
WIND DIRECTION TRUE (DEGREES)
0 100. 200.
WIND SPEED (KNOTS)
10. 0
WINDS NOT VALID ON THE GROUND
6310. 6320. 6330. 6340. 6350. 6360. 6370. 6380. 6390.
ELAPSED TIME (SECONDS)
CALC CHECK APPD APPD
AERODYNAMICS 08JUN06
REVISED DATE
SWA 737-700 RUNWAY OVERRUN AT MDW
08DEC05 -- TIME ALIGNED DATA
A PREVIOUS LANDING - LAT-DIR DATA
FIGURE 2
N795SW
PAGE
THE BOEING COMPANY

Attachment 7: Southwest Airlines B737-700 OPC Data

These data do not include a 5 knot tailwind clamp. The 6 knot calculated tailwind simulates a 9 knot tailwind after the factor of 1.5 is applied.

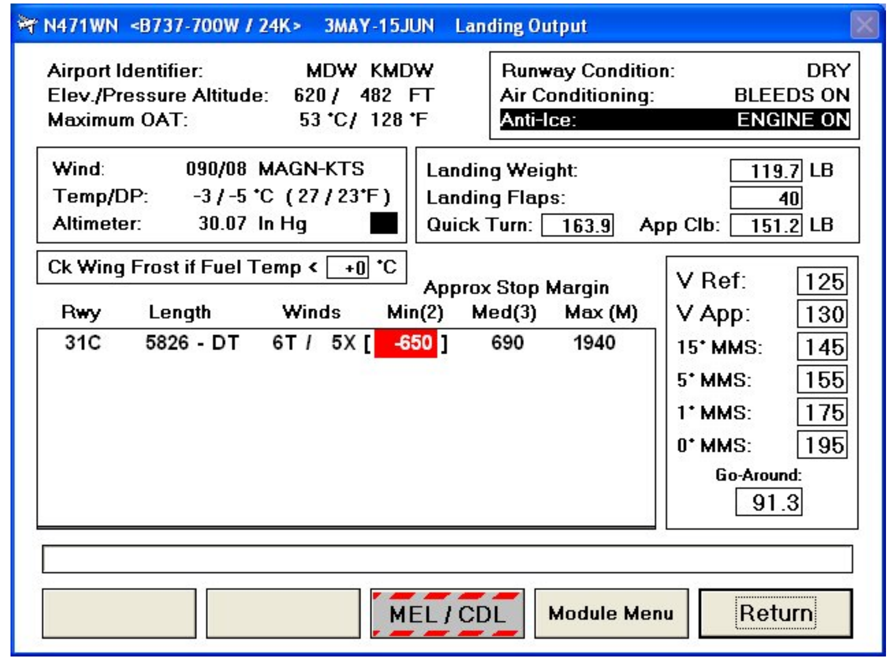
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Dry Runway (Mu = 0.40)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4938	6438	-612
3	1500	3624	5124	702
Max	1500	2362	3862	1964

Thrust Reversers Inoperative



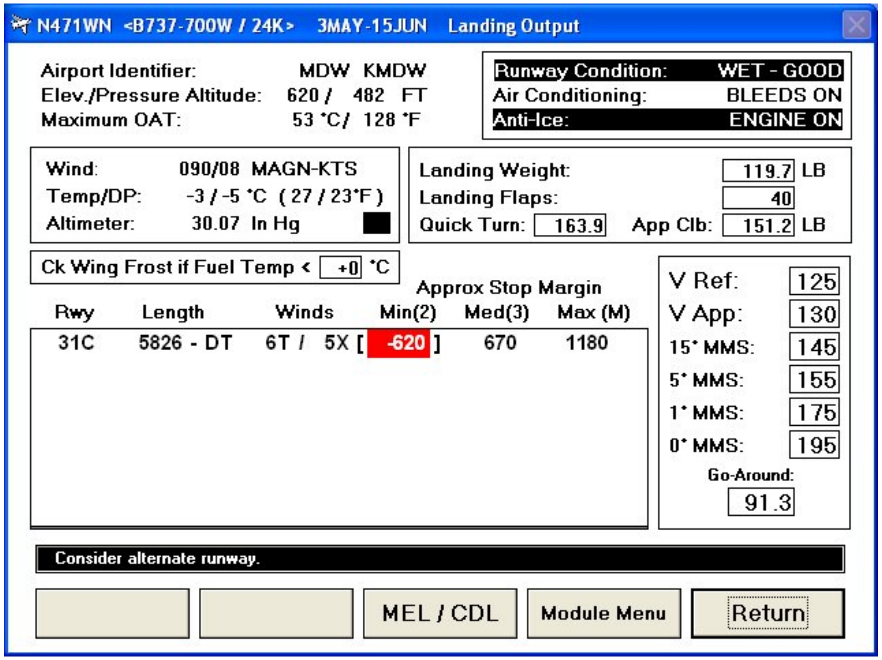
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4969	6469	-643
3	1500	3624	5124	702
Max	1500	2375	3875	1951

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

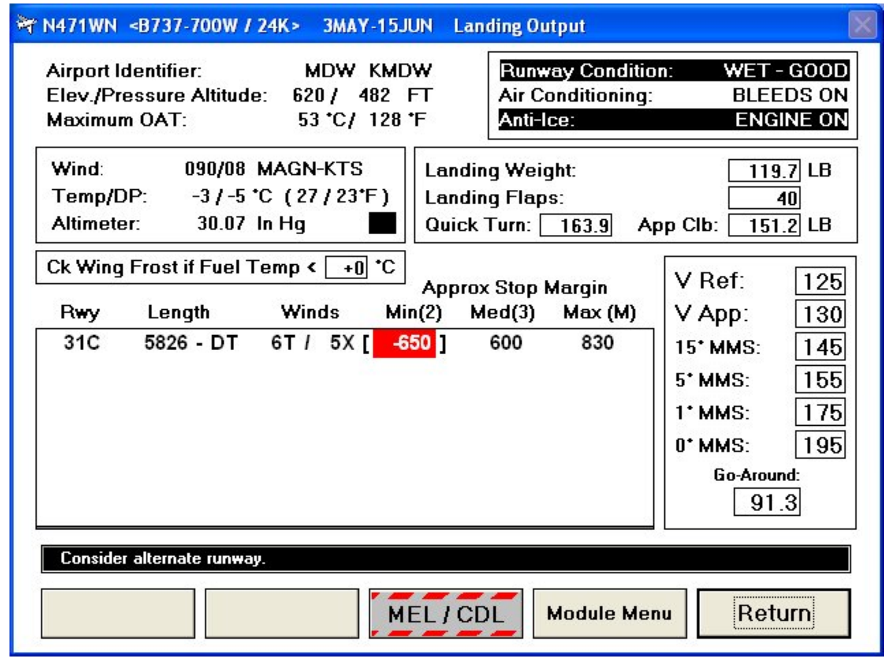
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Good Braking Action (Mu = 0.20)

With 2 Thrust Reversers



Thrust Reversers Inoperative



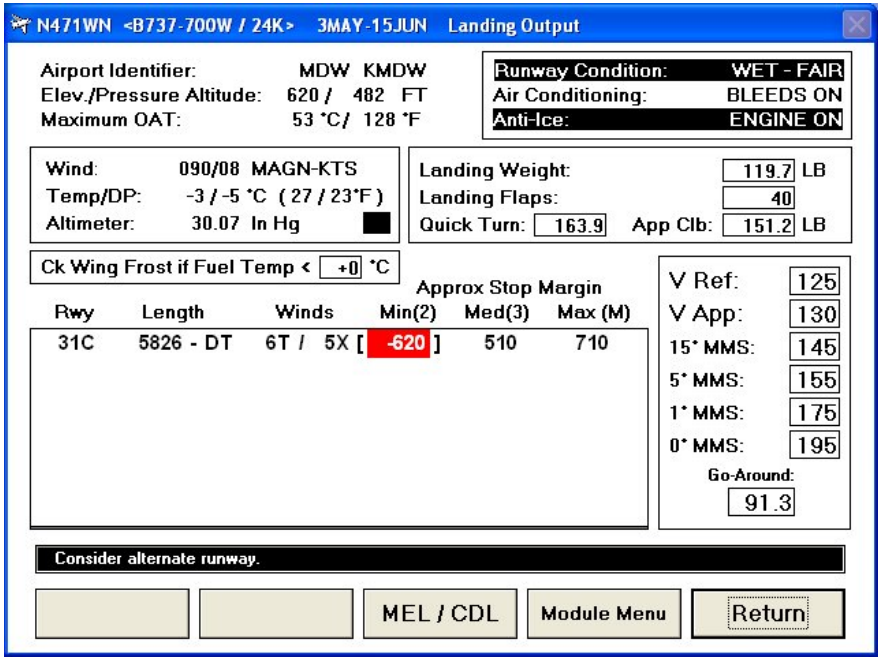
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4938	6438	-612
3	1500	3640	5140	686
Max	1500	3132	4632	1194

Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4969	6469	-643
3	1500	3717	5217	609
Max	1500	3480	4980	846

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

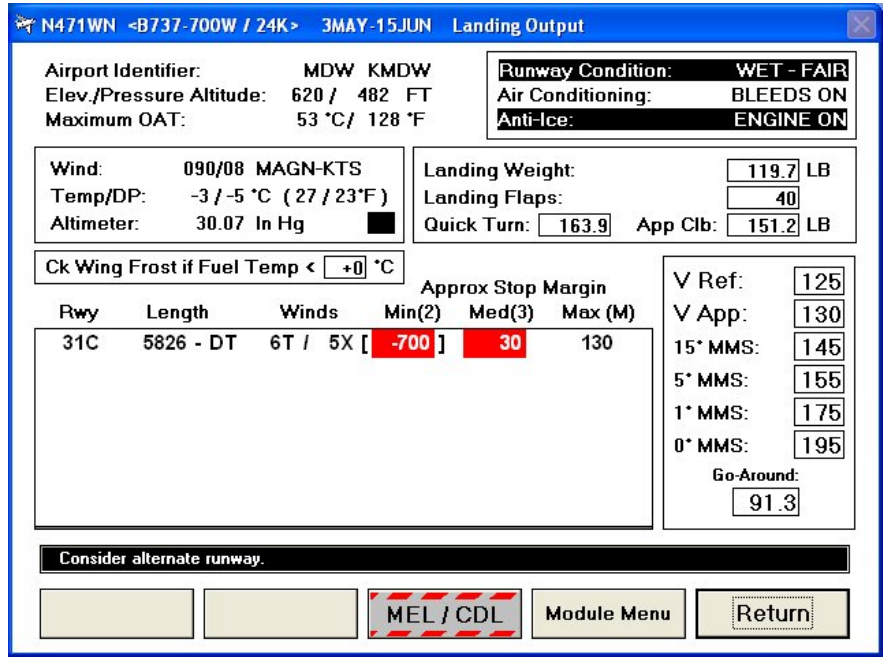
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Fair Braking Action (Mu = 0.15)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4938	6438	-612
3	1500	3809	5309	517
Max	1500	3603	5103	723

Thrust Reversers Inoperative



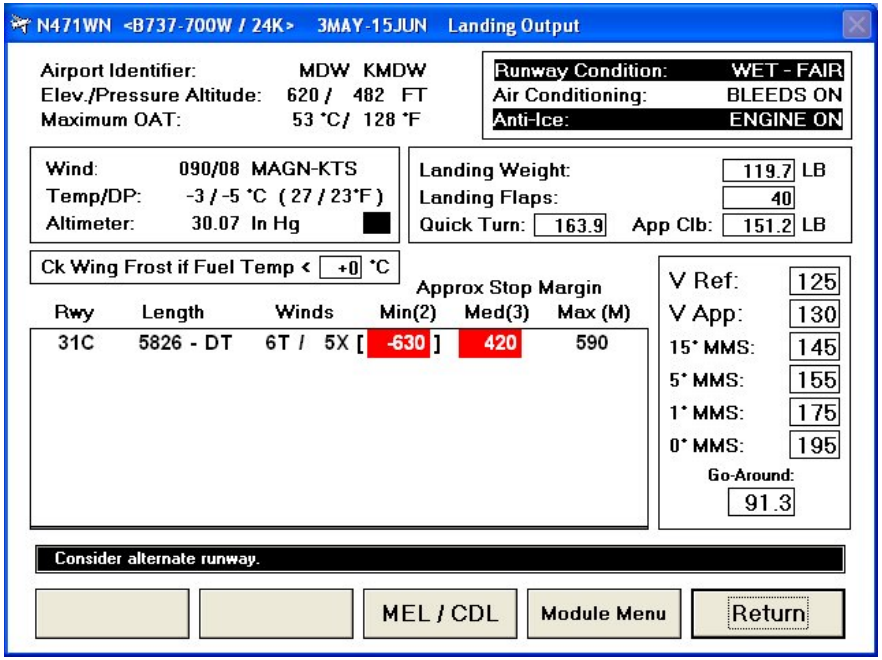
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5017	6517	-691
3	1500	4287	5787	39
Max	1500	4190	5690	136

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

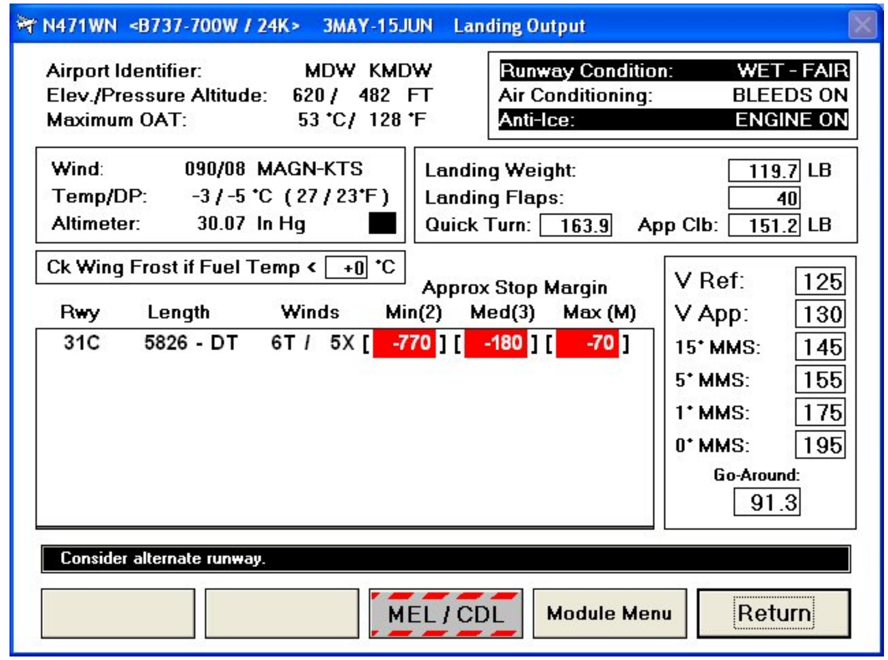
Wet Runway - Braking Action (Mu = 0.14)

With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4948	6448	-622
3	1500	3891	5391	435
Max	1500	3724	5224	602

Thrust Reversers Inoperative



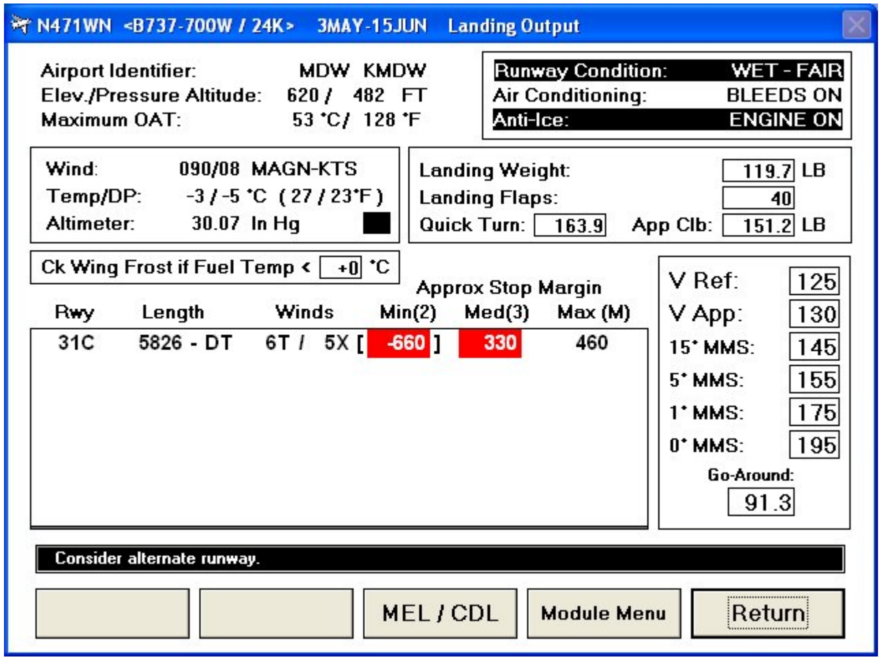
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5087	6587	-761
3	1500	4492	5992	-166
Max	1500	4384	5884	-58

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

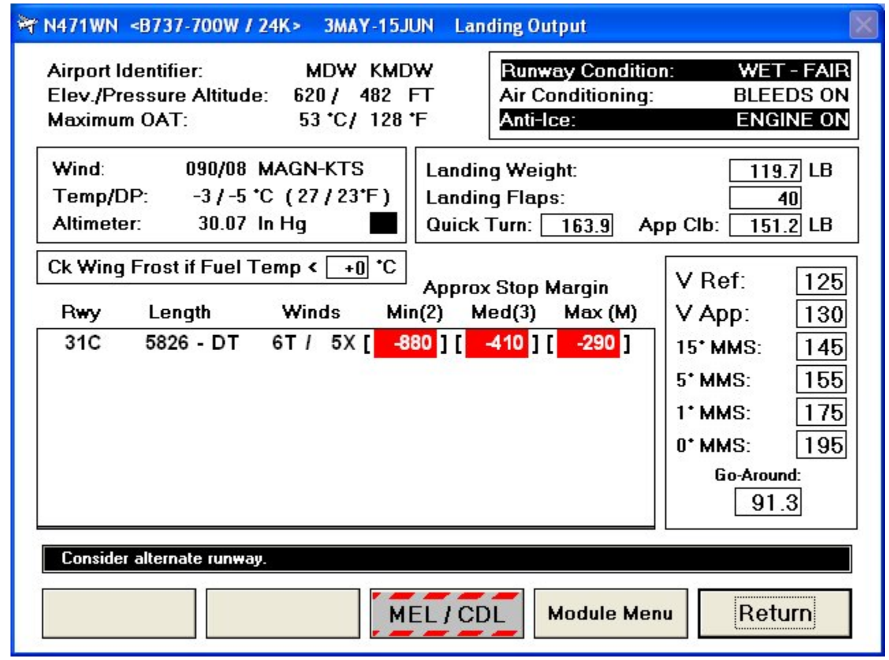
Wet Runway - Braking Action (Mu = 0.13)

With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	4978	6478	-652
3	1500	3988	5488	338
Max	1500	3858	5358	468

Thrust Reversers Inoperative

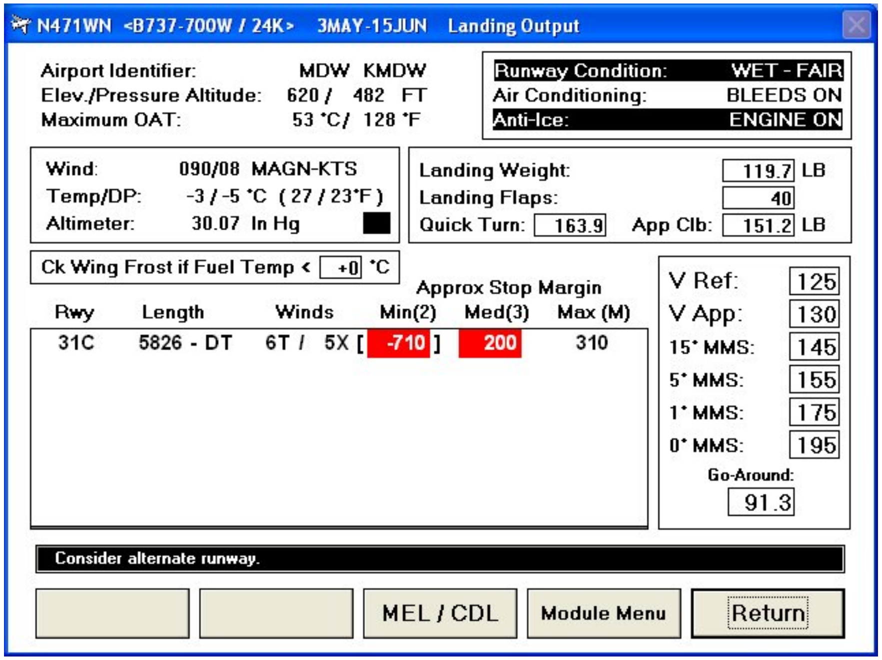


Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5194	6694	-868
3	1500	4724	6224	-398
Max	1500	4605	6105	-279

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

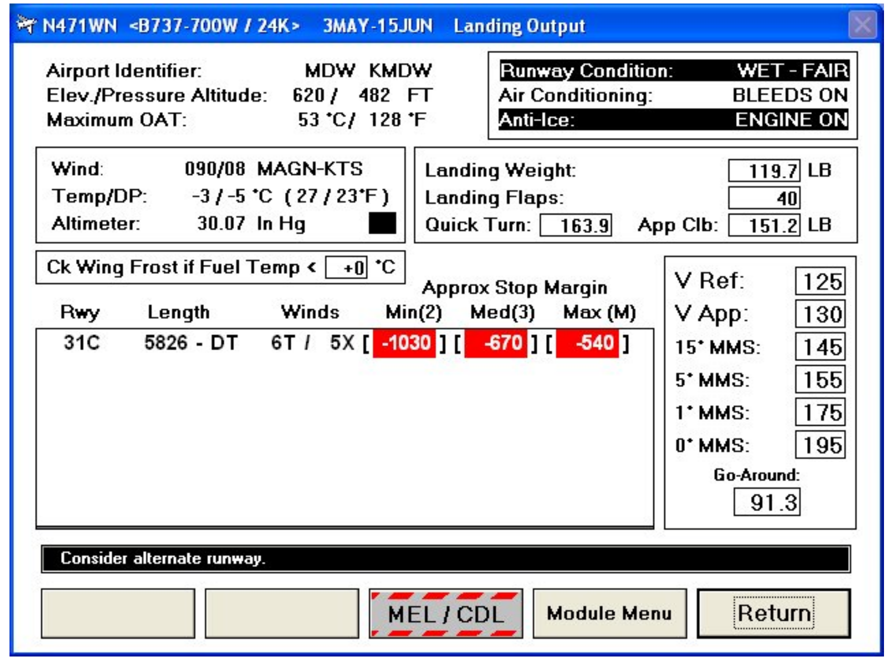
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Braking Action (Mu = 0.12)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5021	6521	-695
3	1500	4110	5610	216
Max	1500	4007	5507	319

Thrust Reversers Inoperative



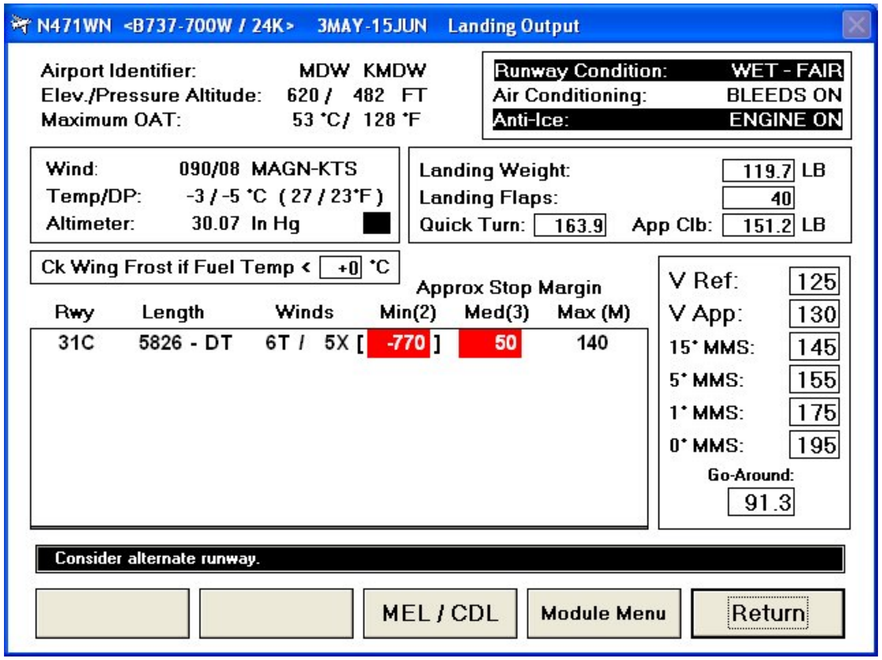
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5345	6845	-1019
3	1500	4989	6489	-663
Max	1500	4858	6358	-532

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

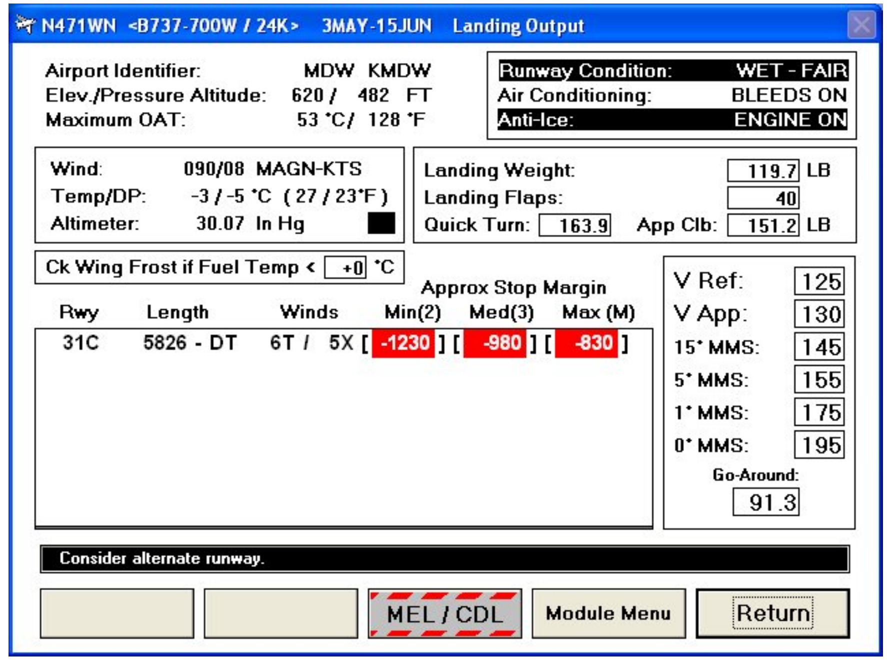
Wet Runway - Braking Action (Mu = 0.11)

With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5080	6580	-754
3	1500	4261	5761	65
Max	1500	4172	5672	154

Thrust Reversers Inoperative

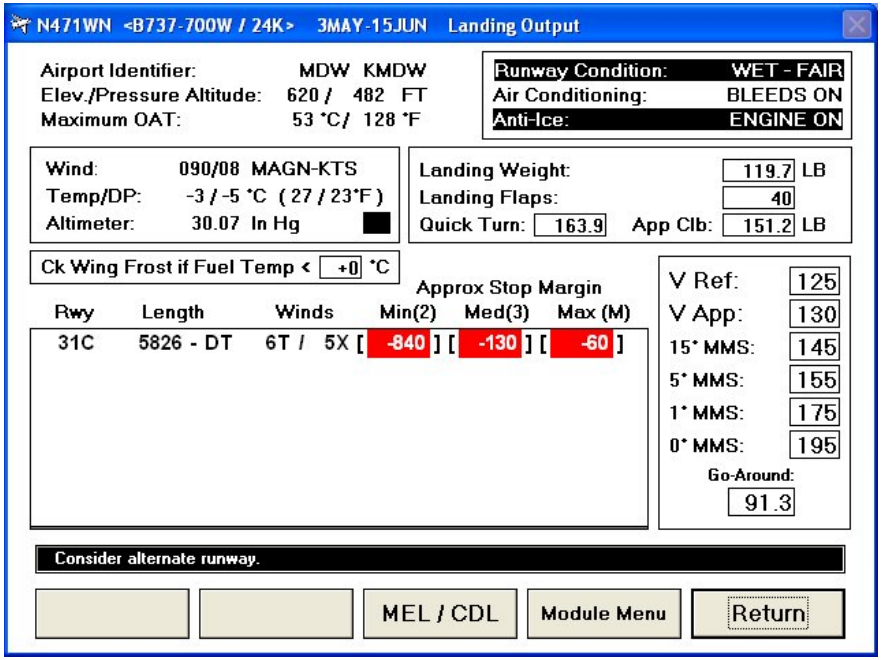


Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5548	7048	-1222
3	1500	5295	6795	-969
Max	1500	5149	6649	-823

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

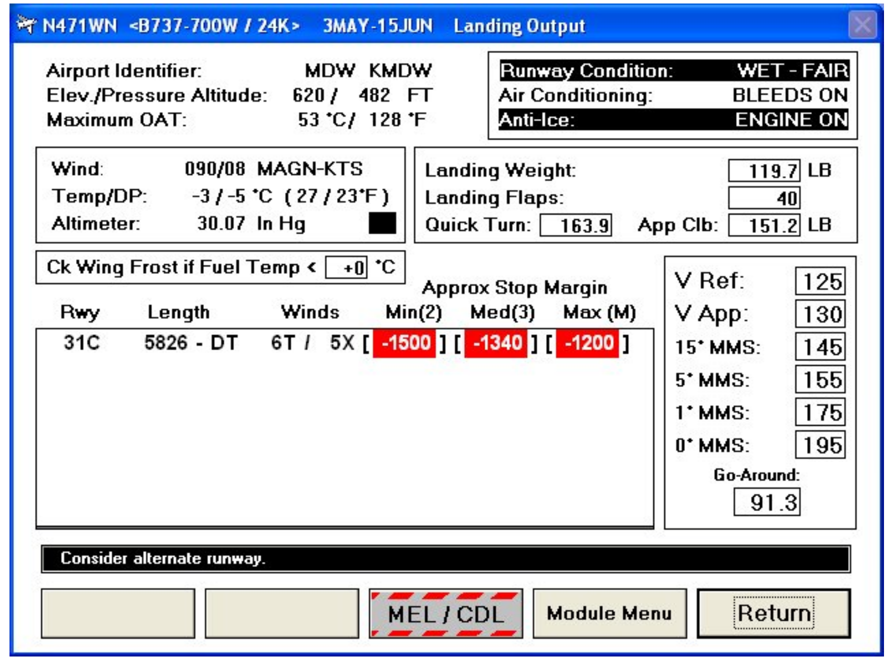
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Poor Braking Action (Mu = 0.10)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5156	6656	-830
3	1500	4441	5941	-115
Max	1500	4374	5874	-48

Thrust Reversers Inoperative

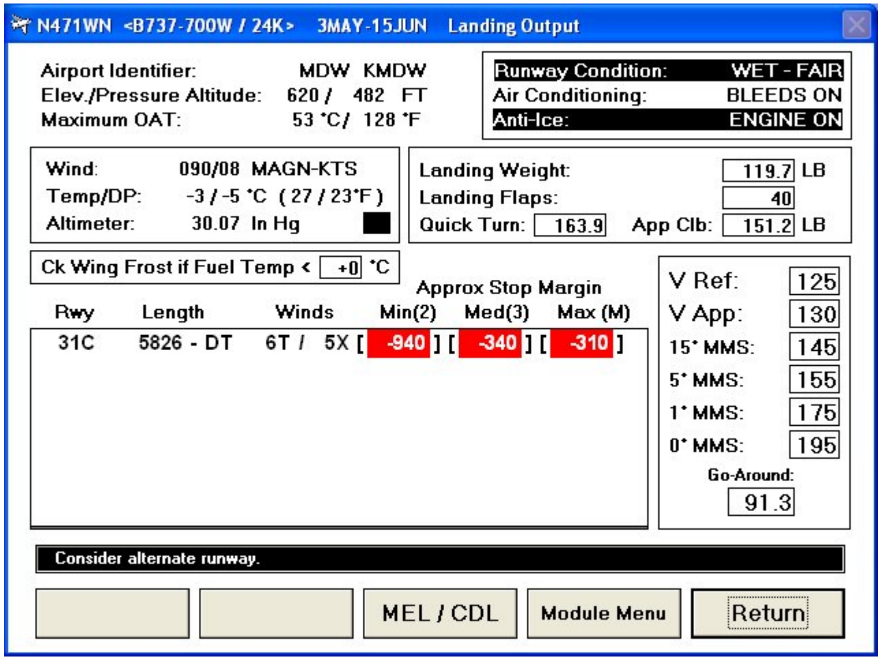


Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5820	7320	-1494
3	1500	5652	7152	-1326
Max	1500	5512	7012	-1186

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

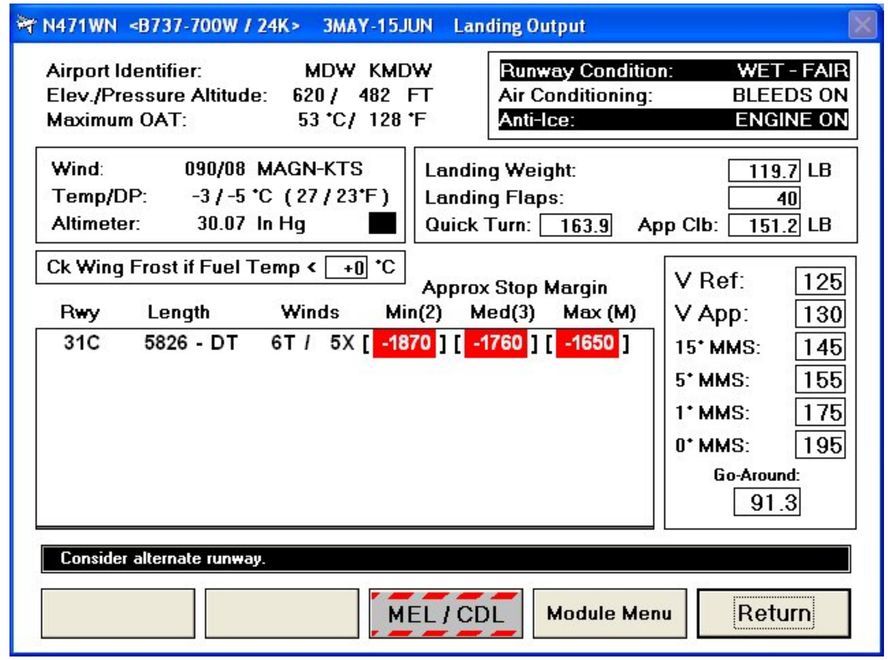
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Braking Action (Mu = 0.09)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5258	6758	-932
3	1500	4655	6155	-329
Max	1500	4621	6121	-295

Thrust Reversers Inoperative

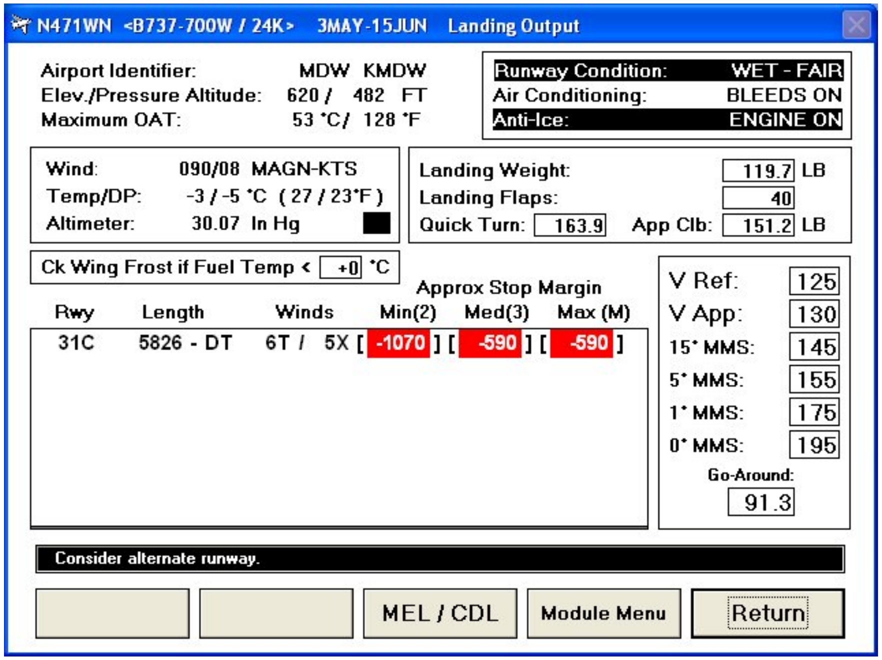


Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	6182	7682	-1856
3	1500	6077	7577	-1751
Max	1500	5966	7466	-1640

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

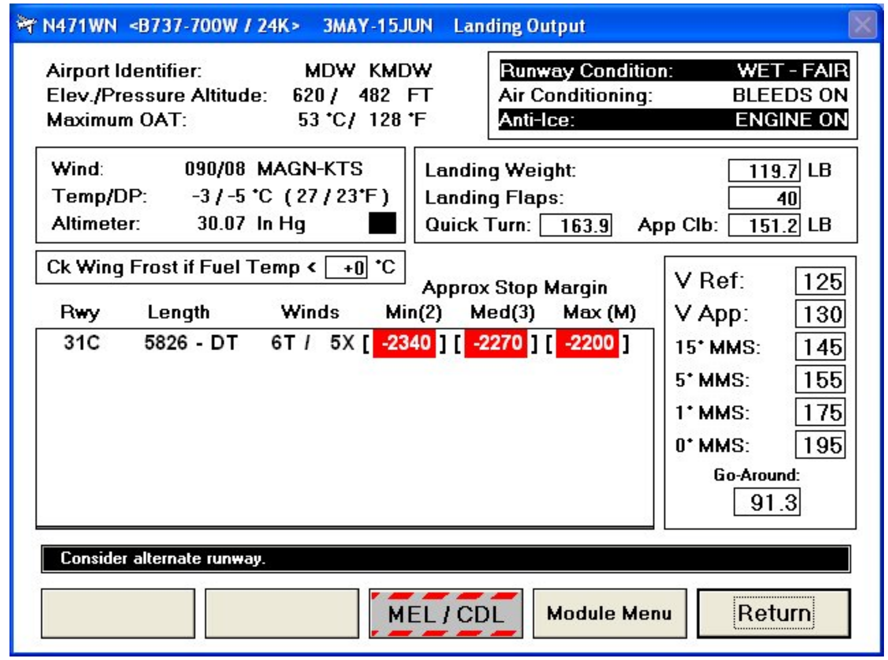
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Braking Action (Mu = 0.08)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5390	6890	-1064
3	1500	4909	6409	-583
Max	1500	4903	6403	-577

Thrust Reversers Inoperative



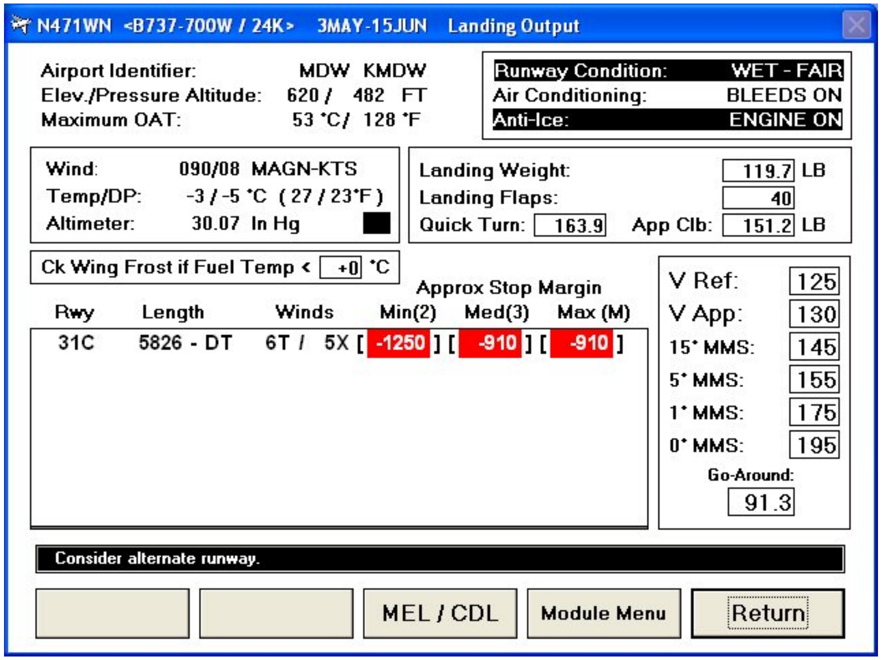
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	6655	8155	-2329
3	1500	6590	8090	-2264
Max	1500	6512	8012	-2186

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

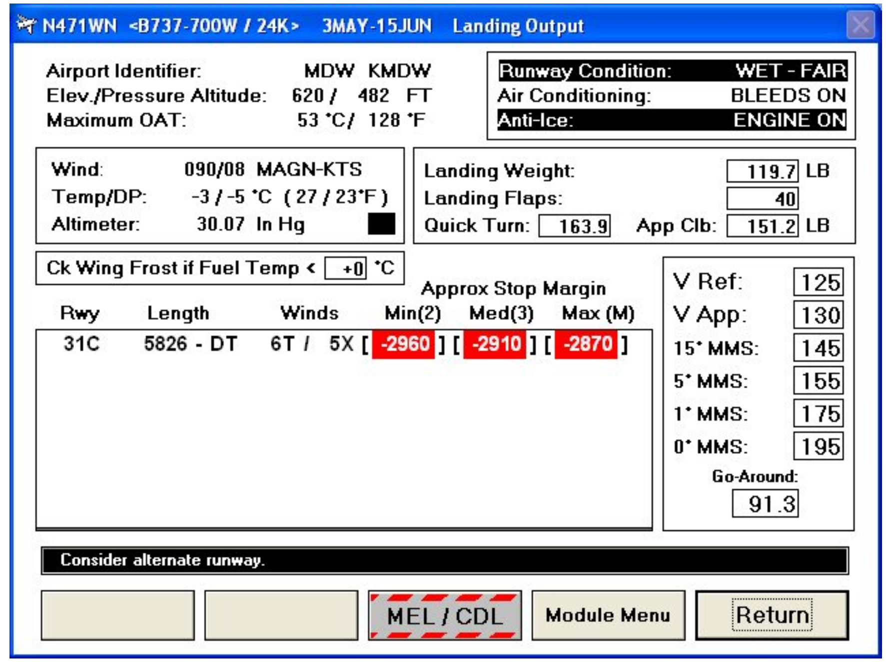
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Braking Action (Mu = 0.07)

With 2 Thrust Reversers



Thrust Reversers Inoperative



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5564	7064	-1238
3	1500	5205	6705	-879
Max	1500	5228	6728	-902

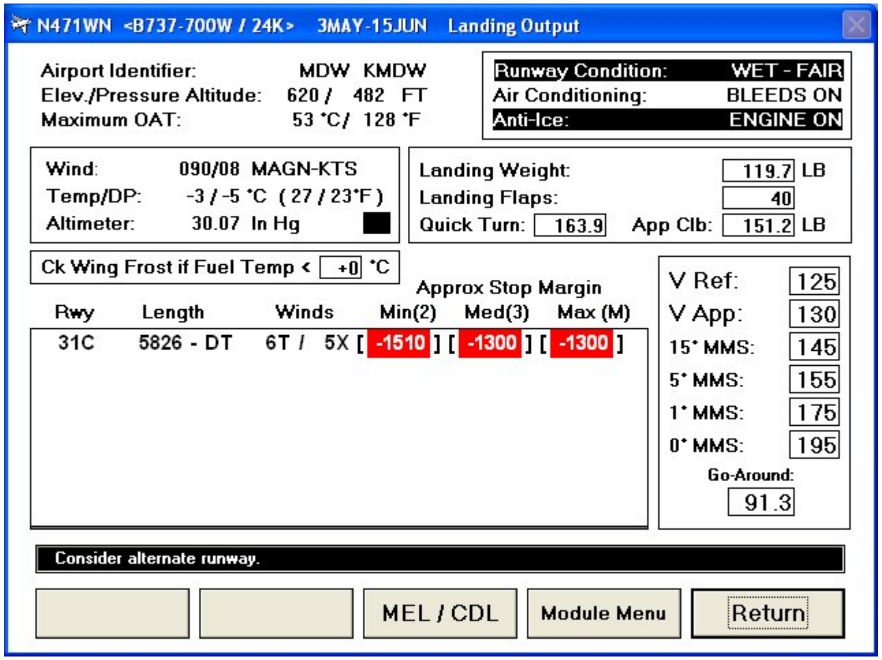
Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	7273	8773	-2947
3	1500	7227	8727	-2901
Max	1500	7186	8686	-2860

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

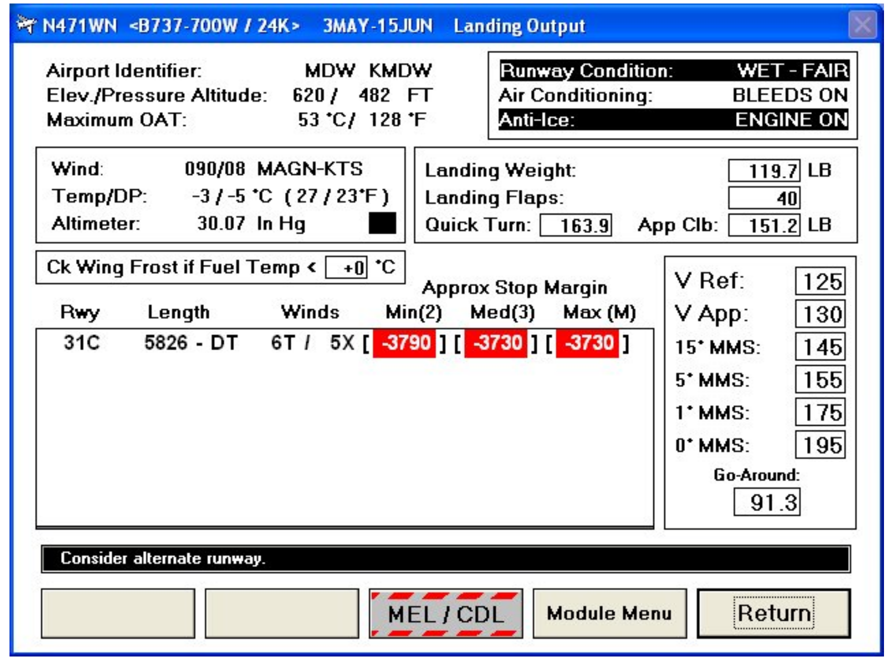
Wet Runway - Braking Action (Mu = 0.06)

With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	5826	7326	-1500
3	1500	5557	7057	-1231
Max	1500	5611	7111	-1285

Thrust Reversers Inoperative

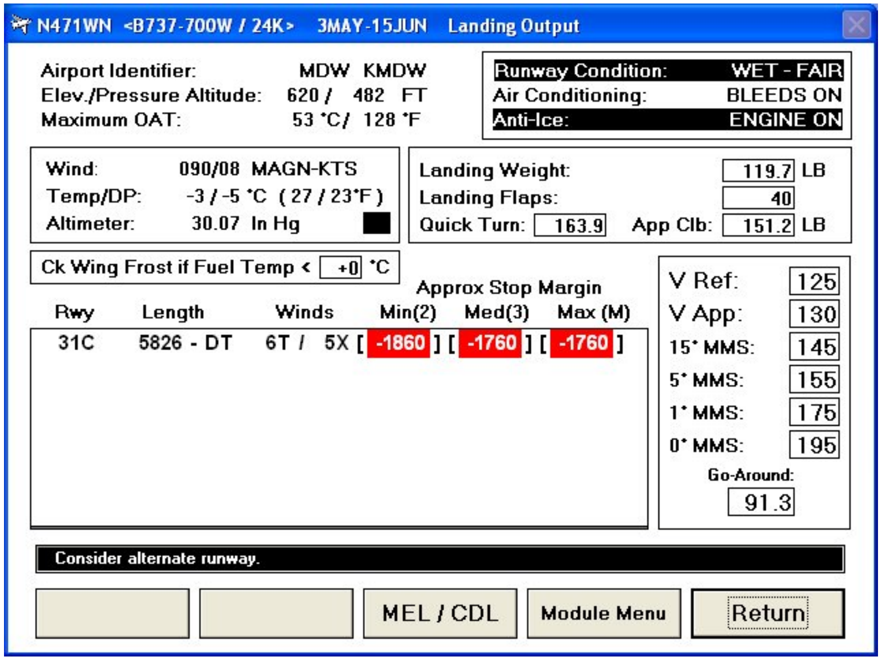


Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	8109	9609	-3783
3	1500	8044	9544	-3718
Max	1500	8043	9543	-3717

Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

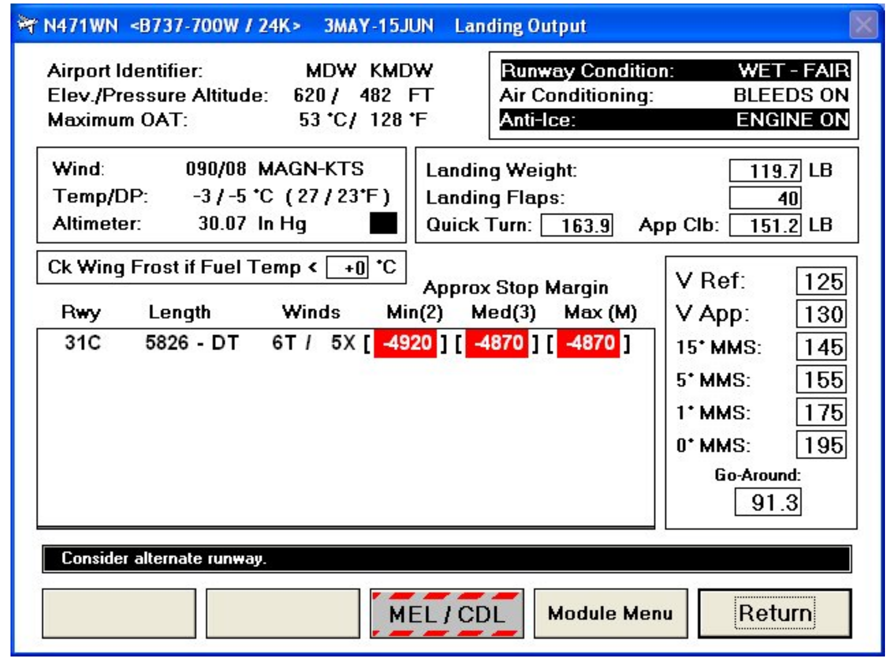
Southwest Airlines Onboard Performance Computer
Braking Coefficient and Thrust Reverser Comparison (calculated tailwinds are multiplied by a factor of 1.5)

Wet Runway - Nil Braking Action (Mu = 0.05)
With 2 Thrust Reversers



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	6170	7670	-1844
3	1500	5999	7499	-1673
Max	1500	6074	7574	-1748

Thrust Reversers Inoperative



Autobrake Setting	Air Dist, ft	Ground Dist, ft	Total Dist, ft	Stop Margin, ft
2	1500	9234	10734	-4908
3	1500	9164	10664	-4838
Max	1500	9190	10690	-4864

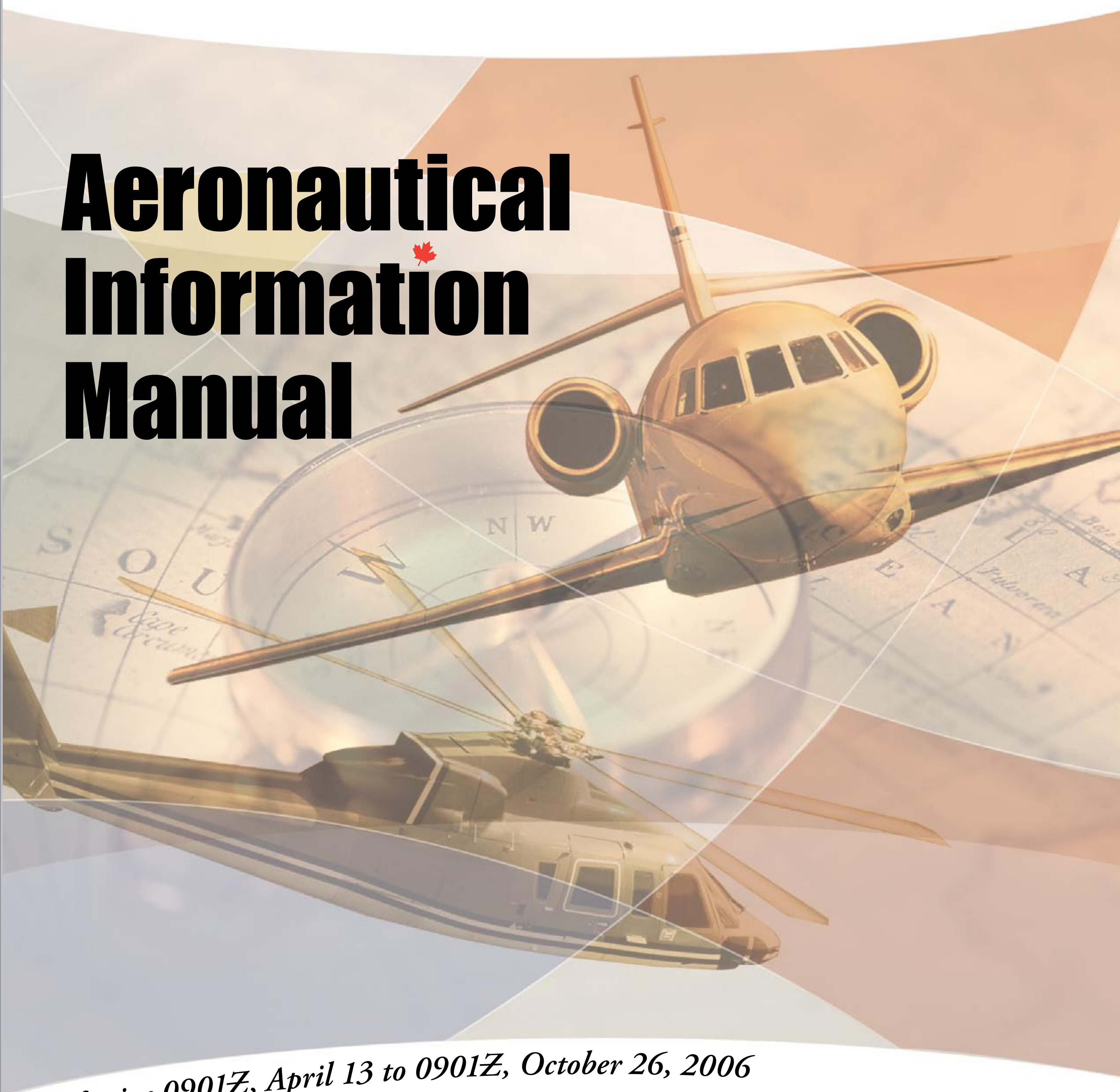
Notes:
- Air distance is from 50 ft above threshold to touchdown.
- Ground distance is actual (unfactored) distance.
- For display purposes, the Approx Stop Margin shown on the Landing Output screen is conservatively rounded to the next lower multiple of 10.

Attachment 8: Canadian Runway Friction Index (CRFI)

Transport Canada / Transports Canada

TP 14371E
(2006-1)

Aeronautical Information Manual



Effective 0901Z, April 13 to 0901Z, October 26, 2006

Canada

Aeronautical Information Manual

APRIL 13, 2006

TC-1001601
04/2006

1.5.6 Effect of Mountains

Winds which are deflected around large single mountain peaks or through the valleys of mountain ranges tend to increase speed which results in a local decrease in pressure (Bernoulli's Principle). A pressure altimeter within such an airflow would be subject to an increased error in altitude indication by reason of this decrease in pressure. This error will be present until the airflow returns to "normal" speed some distance away from the mountain or mountain range.

Winds blowing over a mountain range at speeds in excess of about 50 KT and in a direction perpendicular (within 30°) to the main axis of the mountain range often create the phenomena known as "Mountain" or "Standing Wave". The effect of a mountain wave often extends as far as 100 NM downwind of the mountains and to altitudes many times higher than the mountain elevation. Although most likely to occur in the vicinity of high mountain ranges such as the Rockies, mountain waves have occurred in the Appalachians, elevation about 4 500 feet ASL (the height of the ridge of our example).

Aware and the *Air Command Weather Manual* (TP 9352E) cover the mountain wave phenomena in some detail; however, aspects directly affecting aircraft "altitude" follow.

1.5.7 Downdraft and Turbulence

Downdrafts are most severe near a mountain and at about the same height as the top of the summit. These downdrafts may reach an intensity of about 83 ft. per second (5 000 ft. per minute) to the lee of high mountain ranges, such as the Rockies. Although mountain waves often generate severe turbulence, at times flight through waves may be remarkably "smooth" even when the intensity of downdrafts and updrafts is considerable. As these smooth conditions may occur at night, or when an overcast exists, or when no distinctive cloud has formed, the danger to aircraft is enhanced by the lack of warning of the unusual flight conditions.

Consider the circumstances of an aircraft flying parallel to a mountain ridge on the downwind side and entering a smooth downdraft. Although the aircraft starts descending because of the downdraft, as a result of the local drop in pressure associated with the wave, both the rate of climb indicator and the altimeter will not indicate a descent until the aircraft actually descends through a layer equal to the altimeter error caused by the mountain wave, and, in fact, both instruments may actually indicate a "climb" for part of this descent; thus the fact that the aircraft is in a downdraft may not be recognized until after the aircraft passes through the original flight pressure level which, in the downdraft, is closer to the ground than previous to entering the wave.

1.5.8 Pressure Drop

The "drop" in pressure associated with the increase in wind speeds extends throughout the mountain wave, that is downwind and to "heights" well above the mountains. Isolating the altimeter error caused solely by the mountain wave from error caused by non-standard temperatures would be of little value to a pilot. Of main importance is that the combination of mountain waves and non-standard temperature may result IN AN ALTIMETER OVERREADING BY AS MUCH AS 3 000 FT. If the aircraft in our example had been flying upwind on a windy day, the actual ground separation on passing over the crest of the ridge may well have been very small.

1.5.9 Abnormally High Altimeter Settings

Cold dry air masses can produce barometric pressures in excess of 31.00 in. of mercury. Because barometric readings of 31.00 in. of mercury or higher rarely occur, most standard altimeters do not permit setting of barometric pressures above that level and are not calibrated to indicate accurate aircraft altitude above 31.00 in. of mercury. As a result, most aircraft altimeters cannot be set to provide accurate altitude readouts to the pilot in these situations.

When aircraft operate in areas where the altimeter setting is in excess of 31.00 in. of mercury and the aircraft altimeter cannot be set above 31.00 in. of mercury, the true altitude of the aircraft will be HIGHER than the indicated altitude.

Procedures for conducting flight operations in areas of abnormally high altimeter settings are detailed in RAC 12.12.

1.6 Canadian Runway Friction Index

1.6.1 General

The following paragraphs discuss the slippery runway problem and suggest methods of applying runway coefficient of friction information to flight manual data.

1.6.2 Reduced Runway Coefficients of Friction and Aircraft Performance

The accelerate-stop distance, landing distance and crosswind limitations (if applicable) contained in the aircraft flight manual are demonstrated in accordance with specified performance criteria on runways that are bare, dry, and that have high surface friction characteristics. Unless some factor has been applied, these distances are valid only under similar runway conditions. Whenever a contaminant, such as water, snow or ice, is introduced to the runway surface, the effective coefficient of friction between the aircraft tire and runway is substantially reduced. The stop portion of the accelerate-stop distance will increase, the landing distance will increase and a crosswind may present directional control difficulties. The problem has been to identify, with some accuracy, the effect that the contaminant has had on reducing the runway coefficient of friction and to provide meaningful information to the pilot, e.g., how much more runway is needed to stop and what maximum crosswind can be accepted.

1.6.3 Description of Canadian Runway Friction Index (CRFI) and Method of Measurement

The decelerometer is an instrument that is mounted in a test vehicle and measures the decelerating forces acting on the vehicle when the brakes are applied. The instrument is graduated in increments from 0 to 1, the top number being equivalent to the theoretical maximum decelerating capability of the vehicle on a dry surface. These numbers are referred to as the CRFI. It is evident that small numbers represent low braking coefficients of friction while numbers on the order of 0.8 and above indicate the braking coefficients to be expected on bare and dry runways.

The brakes are applied on the test vehicle at 300-m (1000-ft) intervals along the runway within a distance of 10 m (30 ft) from each side of the runway centreline at that distance from the centreline where the majority of aircraft operations take place at each given site. The readings taken are averaged and reported as the CRFI number.

1.6.4 Aircraft Movement Surface Condition Reports (AMSCR)

AMSCRs are issued to alert pilots of natural surface contaminants, such as snow, ice or slush, that could affect aircraft braking performance. The RSC section of the report provides information describing the runway condition in plain language, while the CRFI section describes braking action quantitatively using the numerical format described in AIR 1.6.3.

Because of mechanical and operational limitations, runway friction readings produced by decelerometer devices may result in inaccurate readings under certain surface conditions. As a result, runway friction readings will not be taken and a CRFI will not be provided to ATS or pilots when any of the following conditions are present:

(a) the runway surface is simply wet with no other type of contamination present;

(b) there is a layer of slush on the runway surface with no other type of contamination present; or

(c) there is loose snow on the runway surface exceeding 2.5 cm (1 in.) in depth.

A NOTAM is distributed on AFTN/ADIS upon any of the following runway conditions:

(a) slush or wet snow on the runway;

(b) loose snow on the runway exceeding 1/4 in. in depth;

(c) the runway is not cleared to the full width. When the runway is partially cleared the report will also include a description of the uncleared portion of the runway (depth of snow, windrows, snowbanks, etc.);

(d) compacted snow, ice or frost on the runway; or

(e) the CRFI reading is 0.40 or less.

When available, a CRFI reading will be issued along with the RSC in order to provide an overall descriptive picture of the runway condition and to quantify braking action.

When a contaminant is such that it meets the conditions for AFTN/ADIS distribution and clearing is not underway or expected to begin within the next 30 min, a notation such as “Clearing expected to commence (time in UTC)” will be added to the RSC report. When the meteorological conditions are such that the runway surface conditions are changing frequently, the AMSCR NOTAM will include the agency and telephone number to contact for the current runway conditions.

The full range of RSC/CRFI information will be available as a voice advisory from the control tower at controlled aerodromes and from the FSS at uncontrolled aerodromes.

Each new AMSCR report issued supersedes the previous report for that aerodrome, and when the RSC or CRFI measurements for all runways no longer meet the previously listed conditions for AFTN/ADIS distribution, a cancellation NOTAM will be issued using the word “cancelled” as a key word.

The format of the CRFI portion of the report is as follows: location indicator, title (CRFI), runway number, temperature in degrees Celsius, runway average CRFI reading, and time (UTC) when readings were taken using a ten-figure time group in the year-month-day-hour-minute (YYMMDDHHMM) format.

Examples of RSC and CRFI reports for paved runways:

(a) CYGK RSC ALL RWYS 100 PERCENT LOOSE SNOW 4 INS 0201190630 CLEARING EXPECTED TO COMMENCE 0201191000

(b) CYFB RSC 17/35 100 PERCENT LOOSE SNOW 1 IN 0201190630

CYFB CRFI 17/35 –22 .34 0201190630

(c) CYFB RSC 17/35 100 PERCENT SNOW DRIFTS 3-4 INS 0201191050

CYFB CRFI 17/35 –10 .30 0201191055

(d) CYFB RSC/CRFI CANCELLED 0201191400

(e) CYHZ RSC 06/24 160 FT CENTERLINE 40 PERCENT COMPACTED SNOW 60 PERCENT FROST REMAINDER 80 PERCENT COMPACTED SNOW 20 PERCENT FROST SANDED 100 FT CENTERLINE 0202131240

CYHZ RSC 15/33 160 FT CENTERLINE 20 PERCENT COMPACTED SNOW 80 PERCENT FROST REMAINDER 80 PERCENT COMPACTED SNOW 20 PERCENT FROST SANDED 100 FT CENTERLINE 0202131240

CYHZ CRFI 06/24 0 .22 0202131234

CYHZ CRFI 15/33 0 .29 0202131210

Examples of RSC and CRFI report for gravel runways:

(a) CYRB RSC 17T/35T 1/2 IN LOOSE SNOW ON TOP OF COMPACTED SNOW 0112190640

CYRB CRFI 17T/35T -22 .30 0112190645

(b) CYRB RSC 17T/35T 100 PERCENT ICE COVERED 0112210740

CYRB CRFI 17T/35T -8 .20 0112210745

(c) CYGW RSC 04/22 1/2 IN LOOSE SNOW ON TOP OF ICE 0112220630

CYGW CRFI 04/22 -14 .18 0112220635

1.6.5 Wet Runways

Runway friction values during the summer period and when it is raining are not provided at this time. Consequently, some discussion of wet runways is in order to assist pilots in developing handling procedures when these conditions are encountered.

A packed snow or ice condition at a fixed temperature presents a relatively constant coefficient of friction with speed, but this is not the case for a liquid (water or slush) state. This is because water cannot be completely squeezed out from between the tire and the runway and, as a result, there is only partial tire-to-runway contact. As the aircraft speed is increased, the time in contact is reduced further, thus braking friction coefficients on wet surfaces fall as the speed increases, i.e., the conditions in effect become relatively more slippery, but will again improve as the aircraft slows down. The situation is further complicated by the susceptibility of aircraft tires to hydroplane on wet runways.

Hydroplaning is a function of the water depth, tire pressure and speed. Moreover, the minimum speed at which a non-rotating tire will begin to hydroplane is lower than the speed at which a rotating tire will begin to hydroplane because a build up of water under the non-rotating tire increases the hydroplaning effect. Pilots should therefore be aware of this since it will result in a substantial difference between the takeoff and landing roll aircraft performance under the same runway conditions. The minimum speed, in knots, at which hydroplaning will commence can be calculated by multiplying the square root of the tire pressure (PSI) by 7.7 for a non-rotating tire, or by 9 for a rotating tire.

This equation gives an approximation of the minimum speed necessary to hydroplane on a smooth, wet surface with tires that are bald or have no tread. For example, the minimum hydroplaning speeds for an aircraft with tires inflated to 49 PSI are calculated as:

NON-ROTATING TIRE: 7.7 X √49 = 54 KT.; or
ROTATING TIRE: 9 X √49 = 63 KT.

When hydroplaning occurs, the tires of the aircraft are completely separated from the actual runway surface by a thin water film and they will continue to hydroplane until a reduction in speed permits the tire to regain contact with the runway. This speed will be considerably below the speed at which hydroplaning commences. Under these conditions, the tire traction drops to almost negligible values and in some cases the wheel will stop rotating entirely. The tires will provide no braking capability and will not contribute to the directional control of the aircraft. The resultant increase in stopping distance is impossible to predict accurately, but it has been estimated to increase as much as 700 percent. Further, it is known that a 10-kt. crosswind will drift an aircraft off the side of a 200-ft wide runway in approximately 7 sec under hydroplaning conditions.

Notwithstanding the fact that friction values cannot be given for a wet runway and that hydroplaning can cause pilots serious difficulties, it has been found that the well-drained runways at most major Canadian airports seldom allow pooling of sufficient water for hydroplaning to occur. The wet condition associated with rain may produce friction values on the order of a CRFI of 0.3 on a poorly maintained or poorly drained runway, but normally produces a value of 0.5. These figures can be used as a guide in conjunction with pilot and other reports.

1.6.6 CRFI Application to Aircraft Performance

The information contained in Tables 1 and 2 has been compiled and is considered to be the best data available at this time, because it is based upon extensive field test performance data of aircraft braking on winter-contaminated surfaces. The information should provide a useful guide to pilots when estimating aircraft performance under adverse runway conditions. The onus for the production of information, guidance or advice on the operation of aircraft on a wet and/or contaminated runway rests with the aircraft manufacturer. The information published in this TC AIM does not change, create any additional, authorize changes in, or permit deviations from regulatory requirements. These tables are intended to be used at the pilot's discretion.

Because of the many variables associated with computing accelerate-stop distances and balanced field lengths, it has not been possible to reduce the available data to the point where CRFI corrections can be provided, which would be applicable to all types of operations. Consequently, only corrections for landing distances and crosswinds are included pending further study of the take-off problem.

It should be noted that in all cases the tables are based on corrections to flight manual dry runway data and that the certification criteria does not allow consideration of the extra decelerating forces provided by reverse thrust or propeller reversing. On dry runways, thrust reversers provide only a small portion of the total decelerating forces when compared to wheel braking. However, as wheel braking becomes less effective, the portion of the stopping distance attributable to thrust reversing becomes greater. For this reason, if reversing is employed when a low CRFI is reported, a comparison of the actual stopping distance with that shown in Table 1 will make the estimates appear overly conservative. Nevertheless, there are circumstances, such as crosswind conditions, engine-out situations or reverser malfunctions, that may preclude their use.

Table 1 recommended landing distances are intended to be used for aeroplanes with no discing and/or reverse thrust capability and are based on statistical variation measured during actual flight tests.

Notwithstanding the above comments on the use of discing and/or reverse thrust, Table 2 may be used for aeroplanes with discing and/or reverse thrust capability and is based on the Table 1 recommended landing distances with additional calculations that give credit for discing and/or reverse thrust. In calculating the distances in Table 2, the air distance from the screen height of 50 ft to touchdown and the delay distance from touchdown to the application of full braking remain unchanged from Table 1. The effects of discing and/or reverse thrust were used only to reduce the stopping distance from the application of full braking to a complete stop.

The recommended landing distances stated in Table 2 take into account the reduction in landing distances obtained with the use of discing and/or reverse thrust capability for a turboprop-powered aeroplane and with the use of reverse thrust for a turbojet-powered aeroplane. Representative low values of discing and/or reverse thrust effect have been assumed and; therefore, the data may be conservative for properly executed landings by some aeroplanes with highly effective discing and/or thrust reversing systems.

The crosswind limits for CRFI shown at Table 3 contain a slightly different display range of runway friction index values from those listed for Tables 1 and 2. However, the CRFI values used for Table 3 are exactly the same as used for Tables 1 and 2 and are appropriate for the index value increments indicated.

TABLE 1

Canadian Runway Friction Index (CRFI) Recommended Landing Distances (No Discing/Reverse Thrust)

Landing Distance (Feet) Bare and Dry Un-factored	Reported Canadian Runway Friction Index (CRFI)													
	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.27	0.25	0.22	0.20	0.18	Landing Field Length (Feet) Bare and Dry	Landing Field Length (Feet) Bare and Dry
	Recommended Landing Distances (no Discing/Reverse Thrust)												60% Factor	70% Factor
1 800	3 120	3 200	3 300	3 410	3 540	3 700	3 900	4 040	4 150	4 330	4 470	4 620	3 000	2 571
2 000	3 480	3 580	3 690	3 830	3 980	4 170	4 410	4 570	4 700	4 910	5 070	5 250	3 333	2 857
2 200	3 720	3 830	3 960	4 110	4 280	4 500	4 750	4 940	5 080	5 310	5 490	5 700	3 667	3 143
2 400	4 100	4 230	4 370	4 540	4 740	4 980	5 260	5 470	5 620	5 880	6 080	6 300	4 000	3 429
2 600	4 450	4 590	4 750	4 940	5 160	5 420	5 740	5 960	6 130	6 410	6 630	6 870	4 333	3 714
2 800	4 760	4 910	5 090	5 290	5 530	5 810	6 150	6 390	6 570	6 880	7 110	7 360	4 667	4 000
3 000	5 070	5 240	5 430	5 650	5 910	6 220	6 590	6 860	7 060	7 390	7 640	7 920	5 000	4 286
3 200	5 450	5 630	5 840	6 090	6 370	6 720	7 130	7 420	7 640	8 010	8 290	8 600	5 333	4 571
3 400	5 740	5 940	6 170	6 430	6 740	7 110	7 550	7 870	8 100	8 500	8 800	9 130	5 667	4 857
3 600	6 050	6 260	6 500	6 780	7 120	7 510	7 990	8 330	8 580	9 000	9 320	9 680	6 000	5 143
3 800	6 340	6 570	6 830	7 130	7 480	7 900	8 410	8 770	9 040	9 490	9 840	10 220	6 333	5 429
4 000	6 550	6 780	7 050	7 370	7 730	8 170	8 700	9 080	9 360	9 830	10 180	10 580	6 667	5 714

Application of the Canadian Runway Friction Index (CRFI)

1. The recommended landing distances in Table 1 are based on a 95 percent level of confidence. A 95 percent level of confidence means that in more than 19 landings out of 20, the stated distance in Table 1 will be conservative for properly executed landings with all systems serviceable on runway surfaces with the reported CRFI.

2. Table 1 will also be conservative for turbojet and turboprop–powered aeroplanes with reverse thrust, and additionally, in the case of turboprop–powered aeroplanes, with the effect obtained from discing.

3. The recommended landing distances in the CRFI Table 1 are based on standard pilot techniques for the minimum distance landings from 50 ft, including a stabilized approach at V_{ref} using a glideslope of 3° to 50 ft or lower, a firm touchdown, minimum delay to nose lowering, minimum delay time to deployment of ground lift dump devices and application of brakes, and sustained maximum antiskid braking until stopped.

4. Landing field length is the landing distance divided by 0.6 (turbojets) or 0.7 (turboprops). If the Aeroplane Flight Manual (AFM) expresses landing performance in terms of landing distance, enter the table from the left-hand column. However, if the AFM expresses landing performance in terms of landing field length, enter the table from one of the right-hand columns, after first verifying which factor has been used in the AFM.

TABLE 2

Canadian Runway Friction Index (CRFI) Recommended Landing Distances (Discing/Reverse Thrust)

Reported Canadian Runway Friction Index (CRFI)														
Landing Distance (Feet) Bare and Dry Unfactored	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.27	0.25	0.22	0.20	0.18	Landing Field Length (Feet) Bare and Dry	Landing Field Length (Feet) Bare and Dry
	Recommended Landing Distances (Discing/Reverse Thrust)												60% Factor	70% Factor
1 200	2 000	2 040	2 080	2 120	2 170	2 220	2 280	2 340	2 380	2 440	2 490	2 540	2 000	1 714
1 400	2 340	2 390	2 440	2 500	2 580	2 660	2 750	2 820	2 870	2 950	3 010	3 080	2 333	2 000
1 600	2 670	2 730	2 800	2 880	2 970	3 070	3 190	3 280	3 360	3 460	3 540	3 630	2 667	2 286
1 800	3 010	3 080	3 160	3 250	3 350	3 480	3 630	3 730	3 810	3 930	4 030	4 130	3 000	2 571
2 000	3 340	3 420	3 520	3 620	3 740	3 880	4 050	4 170	4 260	4 400	4 510	4 630	3 333	2 857
2 200	3 570	3 660	3 760	3 880	4 020	4 170	4 360	4 490	4 590	4 750	4 870	5 000	3 667	3 143
2 400	3 900	4 000	4 110	4 230	4 380	4 550	4 750	4 880	4 980	5 150	5 270	5 410	4 000	3 429
2 600	4 200	4 300	4 420	4 560	4 710	4 890	5 100	5 240	5 350	5 520	5 650	5 790	4 333	3 714
2 800	4 460	4 570	4 700	4 840	5 000	5 190	5 410	5 560	5 670	5 850	5 980	6 130	4 667	4 000
3 000	4 740	4 860	5 000	5 160	5 340	5 550	5 790	5 950	6 070	6 270	6 420	6 580	5 000	4 286
3 200	5 080	5 220	5 370	5 550	5 740	5 970	6 240	6 420	6 560	6 770	6 940	7 110	5 333	4 571
3 400	5 350	5 500	5 660	5 850	6 060	6 310	6 590	6 790	6 930	7 170	7 340	7 530	5 667	4 857
3 600	5 620	5 780	5 960	6 160	6 390	6 650	6 960	7 170	7 320	7 570	7 750	7 950	6 000	5 143
3 800	5 890	6 060	6 250	6 460	6 700	6 980	7 310	7 540	7 700	7 970	8 160	8 380	6 333	5 429
4 000	6 070	6 250	6 440	6 660	6 910	7 210	7 540	7 780	7 950	8 220	8 430	8 650	6 667	5 714

Application of the Canadian Runway Friction Index (CRFI)

1. The recommended landing distances in Table 2 are based on a 95% level of confidence. A 95% level of confidence means that in more than 19 landings out of 20, the stated distance in Table 2 will be conservative for properly executed landings with all systems serviceable on runway surfaces with the reported CRFI.

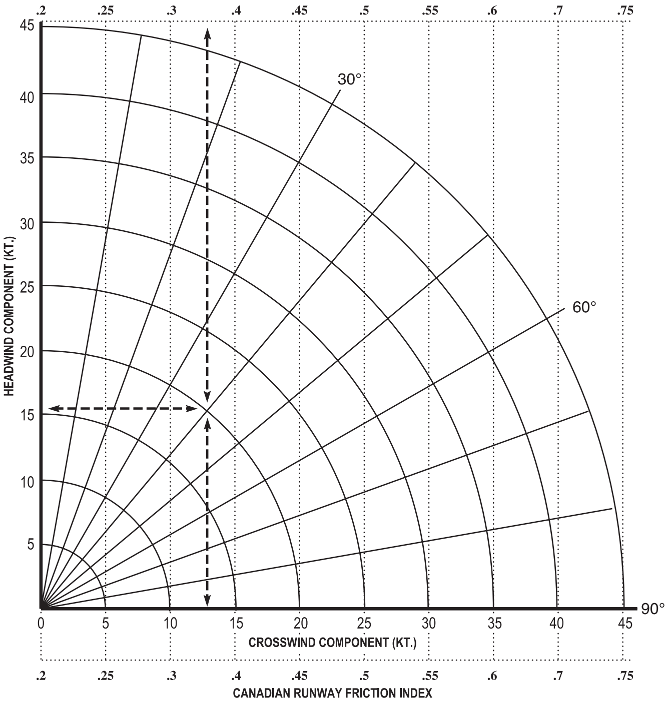
2. The recommended landing distances in Table 2 take into account the reduction in landing distances obtained with the use of discing and/or reverse thrust capability for a turboprop-powered aeroplane and with the use of reverse thrust for a turbojet-powered aeroplane. Table 2 is based on the Table 1 recommended landing distances with additional calculations that give credit for discing and/or reverse thrust. Representative low values of discing and/or reverse thrust effect have been assumed, hence the data will be conservative for properly executed landings by some aeroplanes with highly effective discing and/or thrust reversing systems.

3. The recommended landing distances in CRFI Table 2 are based on standard pilot techniques for the minimum distance landings from 50 ft, including a stabilized approach at Vref using a glideslope of three degrees to 50 ft or lower, a firm touchdown, minimum delay to nose lowering, minimum delay time to deployment of ground lift dump devices and application of brakes and discing and/or reverse thrust, and sustained maximum antiskid braking until stopped. In Table 2, the air distance from the screen height of 50 ft to touchdown and the delay distance from touchdown to the application of full braking remain unchanged from Table 1. The effects of discing/reverse thrust were used only to reduce the stopping distance from the application of full braking to a complete stop.

4. Landing field length is the landing distance divided by 0.6 (turbojets) or 0.7 (turboprops). If the AFM expresses landing performance in terms of landing distance, enter the table from the left-hand column. However, if the AFM expresses landing performance in terms of landing field length, enter the table from one of the right-hand columns, after first verifying which factor has been used in the AFM.

TABLE 3

CROSSWIND LIMITS FOR CANADIAN RUNWAY FRICTION INDEX (CRFI)



This chart provides information for calculating headwind and crosswind components and the vertical lines indicate the recommended maximum crosswind component for reported CRFI.

Example: *CYOW CRFI RWY 07/25 – 4 .3 930119l200*

Tower Wind 110° 20 KT.

The wind is 40° off the runway heading and produces a headwind component of l5 kt. and a crosswind component of l3 kt. The recommended minimum CRFI for a l3-kt crosswind component is .35. A takeoff or landing with a CRFI of .3 could result in uncontrollable drifting and yawing.

The CRFI depends on the surface type, as shown in Table 4a. It should be noted that:

(a) the CRFI values given in Table 4a are applicable to all temperatures. Extensive measurements have shown that there is no correlation between the CRFI and the surface temperature. The case where the surface temperature is just at the melting point (i.e. about 0°C) may be an exception, as a water film may form from surface melting, which could induce slippery conditions with CRFIs less than those in Table 4a.

(b) the CRFI may span a range of values for various reasons, such as variations in texture among surfaces within a given surface class. The expected maximum and minimum CRFIs for various surfaces are listed in Table 4b. Note that these values are based on a combination of analyses of extensive measurements and sound engineering judgment.

(c) the largest range in CRFI is to be expected for a thin layer (3 mm or less in thickness) of loose snow on pavement (Table 4a). This variation may occur due to: (i) non-uniform snow coverage; and/or (ii) the tires breaking through the thin layer. In either case, the surface presented to the aircraft may range from snow to pavement.

AIR

Table 4a
Expected Range of CRFIs by Surface Type

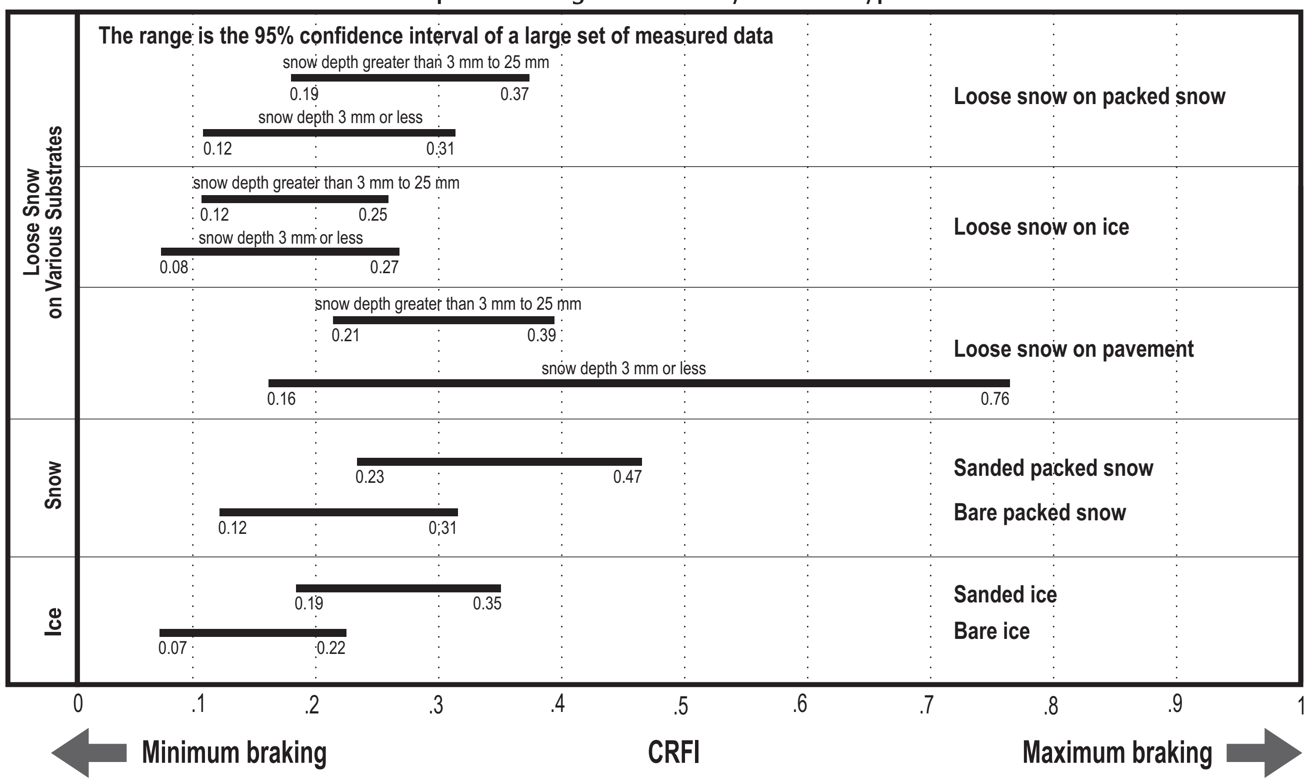
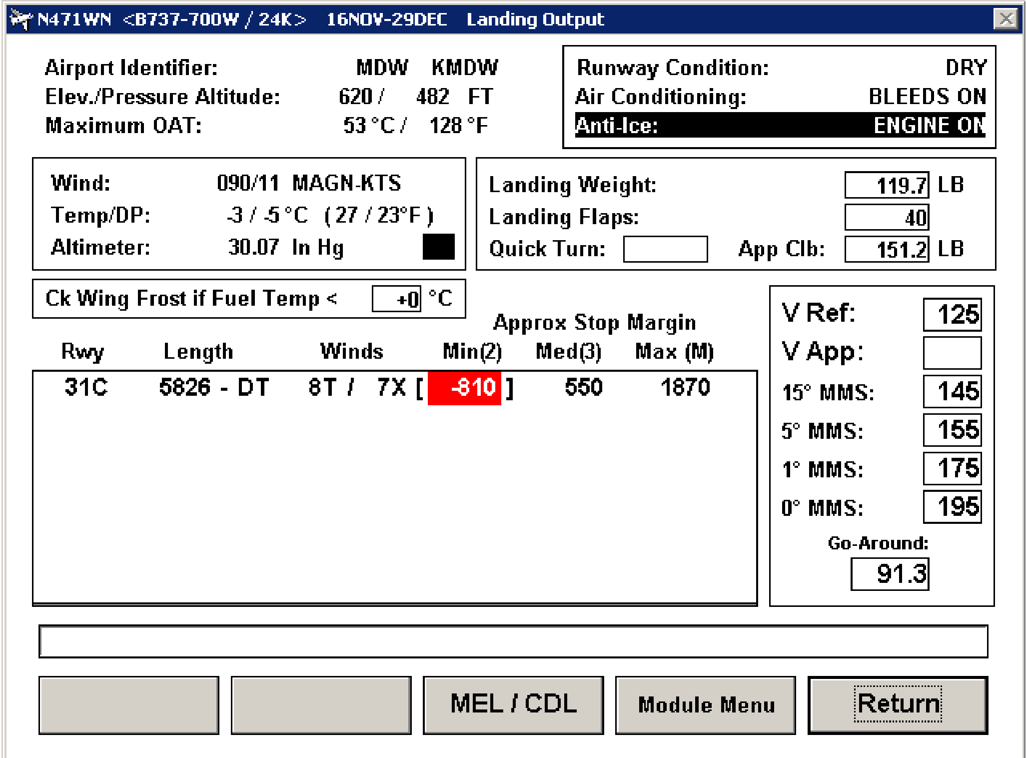


Table 4b
Minimum and Maximum CRFIs for Various Surfaces

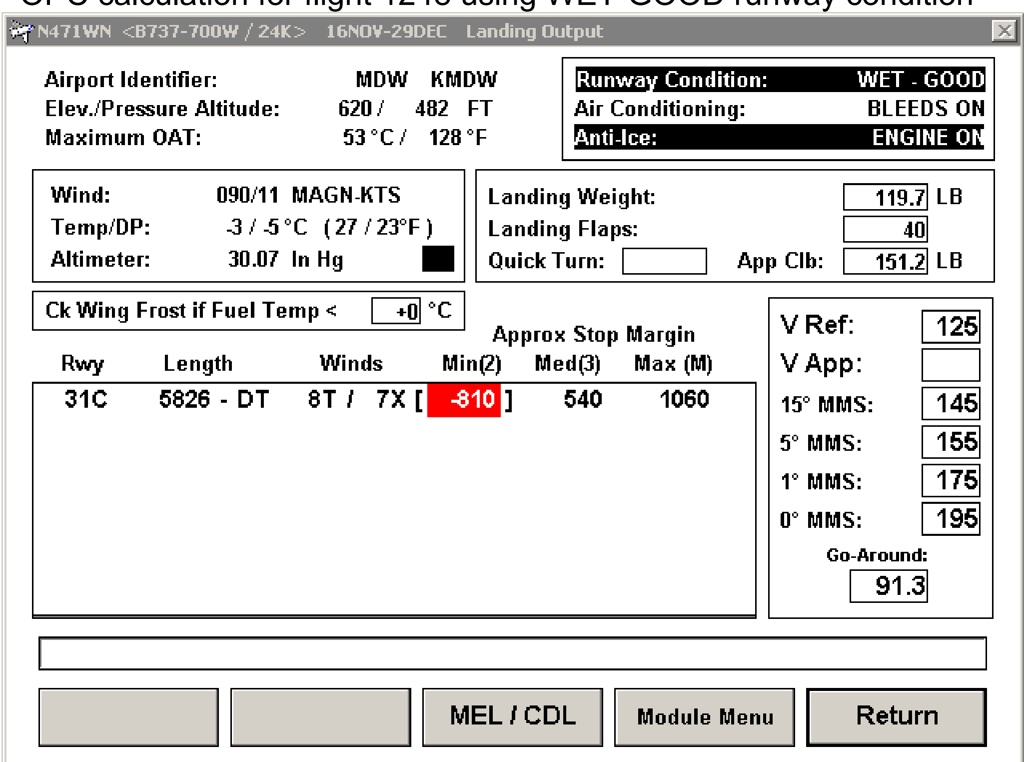
SURFACE	LOWER CFRI LIMIT	UPPER CRFI LIMIT
Bare Ice	No Limit	0.3
Bare Packed Snow	0.1	0.4
Sanded Ice	0.1	0.4
Sanded Packed Snow	0.1	0.5
Loose Snow on Ice (depth 3 mm or less)	No Limit	0.4
Loose Snow on Ice (depth 3 to 25 mm)	No Limit	0.4
Loose Snow on Packed Snow (depth 3 mm or less)	0.1	0.4
Loose Snow on Packed Snow (depth 3 to 25 mm)	0.1	0.4
Loose Snow on Pavement (depth 3 mm or less)	0.1	Dry Pavement
Loose Snow on Pavement (depth 3 mm to 25 mm)	0.1	Dry Pavement

Attachment 9: Flight 1248 OPC Scenarios

OPC calculation for flight 1248 using DRY runway condition



OPC calculation for flight 1248 using WET-GOOD runway condition



OPC calculation for flight 1248 using WET-FAIR runway condition

N471WN <B737-700W / 24K> 16NOV-29DEC Landing Output

Airport Identifier: MDW KMDW
Elev./Pressure Altitude: 620 / 482 FT
Maximum OAT: 53 °C / 128 °F

Runway Condition: WET - FAIR
Air Conditioning: BLEEDS ON
Anti-Ice: ENGINE ON

Wind: 090/11 MAGN-KTS
Temp/DP: -3 / -5 °C (27 / 23°F)
Altimeter: 30.07 In Hg

Landing Weight: 119.7 LB
Landing Flaps: 40
Quick Turn:
App Clb: 151.2 LB

Ck Wing Frost if Fuel Temp < +0 °C

Approx Stop Margin

Rwy	Length	Winds	Min(2)	Med(3)	Max (M)
31C	5826 - DT	8T / 7X	[-810]	350	560

V Ref: 125
V App:
15° MMS: 145
5° MMS: 155
1° MMS: 175
0° MMS: 195
Go-Around: 91.3

MEL / CDL | Module Menu | Return

OPC calculation for flight 1248 using WET-POOR runway condition

N471WN <B737-700W / 24K> 16NOV-29DEC Landing Output

Airport Identifier: MDW KMDW
Elev./Pressure Altitude: 620 / 482 FT
Maximum OAT: 53 °C / 128 °F

Runway Condition: WET - POOR
Air Conditioning: BLEEDS ON
Anti-Ice: ENGINE ON

Wind: 090/11 MAGN-KTS
Temp/DP: -3 / -5 °C (27 / 23°F)
Altimeter: 30.07 In Hg

Landing Weight: 119.7 LB
Landing Flaps: 40
Quick Turn:
App Clb: 151.2 LB

Ck Wing Frost if Fuel Temp < +0 °C

Approx Stop Margin

Rwy	Length	Winds	Min(2)	Med(3)	Max (M)
31C	5826 - DT	8T / 7X	[-730]	[-30]	40

V Ref: 125
V App:
15° MMS: 145
5° MMS: 155
1° MMS: 175
0° MMS: 195
Go-Around: 91.3

Wind limits: 5T / 10X.

MEL / CDL | Module Menu | Return

Attachment 10: B737-700W QRH Advisory Landing Data

ADVISORY INFORMATION

Normal Configuration Landing Distances

Flaps 40

Dry Runway

	LANDING DISTANCE AND ADJUSTMENT (FT)											
	REF DIST	WT ADJ	ALT ADJ	WIND ADJ PER 10 KTS		SLOPE ADJ PER 1%		TEMP ADJ PER 10°C		VREF ADJ	REVERSE THRUST ADJ	
BRAKING CONFIGURATION	130000 LB LANDING WEIGHT	PER 10000 LB ABOVE/ BELOW 130000 LB	PER 1000 FT STD/ HIGH*	HEAD WIND	TAIL WIND	DOWN HILL	UP HILL	ABV ISA	BLW ISA	PER 10 KTS ABOVE VREF40	ONE REV	NO REV
MAX MANUAL	2820	170/-130	60/80	-100	370	40	-30	60	-60	220	60	120
MAX AUTO	3390	170/-160	80/100	-130	440	10	0	70	-70	340	0	20
AUTOBRAKE 3	4660	280/-270	130/170	-210	720	0	-10	120	-120	540	0	0
AUTOBRAKE 2	5980	380/-380	180/240	-290	1010	80	-100	170	-170	540	110	110
AUTOBRAKE 1	6670	460/-450	210/300	-340	1190	180	-190	190	-190	520	500	640

Good Reported Braking Action

MAX MANUAL	3780	210/-200	100/130	-170	620	90	-80	90	-90	310	190	420
MAX AUTO	4120	230/-220	100/150	-180	640	80	-60	90	-90	360	210	460
AUTOBRAKE 3	4670	280/-270	130/170	-210	740	20	-10	120	-120	540	10	50
AUTOBRAKE 2	5980	380/-380	180/280	-290	1010	80	-100	170	-170	540	110	110

Medium Reported Braking Action

MAX MANUAL	5100	330/-310	150/220	-280	1020	240	-190	130	-130	400	510	1230
MAX AUTO	5290	330/-320	150/220	-280	1020	210	-160	130	-130	460	500	1210
AUTOBRAKE 3	5370	340/-320	160/210	-280	1030	180	-120	140	-140	540	450	1200
AUTOBRAKE 2	6140	400/-390	180/260	-320	1150	160	-160	170	-170	540	240	600

Poor Reported Braking Action

MAX MANUAL	6590	460/-440	210/310	-420	1620	570	-370	170	-180	470	1090	2870
MAX AUTO	6870	460/-440	210/310	-410	1600	570	-360	170	-180	470	1100	2900
AUTOBRAKE 3	6870	470/-440	220/300	-420	1610	560	-350	170	-180	510	1090	2880
AUTOBRAKE 2	6990	480/-460	220/320	-430	1650	510	-340	190	-190	530	880	2620

Reference distance is for sea level, standard day, no wind or slope, VREF40 approach speed and two engine detent reverse thrust.
Max manual braking data valid for auto speedbrakes. Autobrake data valid for both auto and manual speedbrakes.
For max manual braking and manual speedbrakes, increase reference landing distance by 170 ft.
Actual (unfactored) distances are shown.
Includes distance from 50 ft above threshold (1000 ft of air distance).
***For landing distance at or below 8000 ft pressure altitude, apply the STD adjustment. For altitudes higher than 8000 ft, first apply the STD adjustment to derive a new reference landing distance for 8000 ft then apply the HIGH adjustment to this new reference distance.**