

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



ERA22LA150

AIRCRAFT PERFORMANCE STUDY ERRATUM

by John O'Callaghan

February 16, 2024

A. ACCIDENT

Location: Pittsburgh, Pennsylvania
Date: March 9, 2022
Time: 08:27 Eastern Standard Time (EST)
13:27 Coordinated Universal Time (UTC)
Airplane: Honda Jet HA-420, registration N903JT

B. AIRCRAFT PERFORMANCE GROUP

Chairman: John O'Callaghan
National Transportation Safety Board (NTSB), RE-60
Washington, D.C.

Members: N/A

C. SUMMARY

The *Aircraft Performance Study* for this accident, dated February 5, 2024, states in section C.3, *Summary of results*, and in section E.1, *Airplane performance during the approach and landing*, that

The achieved braking performance was roughly equivalent to that underlying the recommendation in the Airplane Flight Manual (AFM, Reference 4) to increase the published dry runway landing distance by 30% to determine the wet runway landing distance.

This statement is incorrect and resulted from an error when comparing the simulation results and landing distances plotted in Figure 22 of the *Study*. The stopping simulation starting from the AFM touchdown conditions and using $\eta_{AS} = 0.52$ (corresponding to the μ_B achieved in the accident) is plotted in Figure 22 as the red thin line, and shows a total stopping distance of 5,959 ft. The AFM wet-runway landing distance, corresponding to the published AFM dry landing distance multiplied by 1.3, is 5,183 ft., as shown in Table 5 and plotted in Figure 22 as the diamond labeled "D." Consequently, the stopping distance computed using the achieved μ_B is 5,959 ft. - 5,183 ft. = 776 ft. longer than the AFM distance, and therefore the achieved μ_B is lower than that underlying the AFM distance, and is not "roughly equivalent" to it.

The attached version of the *Aircraft Performance Study* (dated February 16, 2024) corrects this error. Specifically, the language from sections C.3 and E.1 quoted above has been replaced with the following:

The achieved μ_B was lower than that underlying the recommendation in the Airplane Flight Manual (AFM, Reference 4) to increase the published dry runway landing distance by 30% to determine the wet runway landing distance.

In addition, the discussion on page 60 of the *Study* concerning the simulation results plotted in Figure 22 has been updated to include the following information:

Note that in all cases, even the §25.109(c) model with $\eta_{AS} = 0.52$ (which best matches the accident performance), the airplane stops with over 500 ft. of runway remaining when the nominal touchdown conditions are satisfied. However, the stopping distance with $\eta_{AS} = 0.52$ is 776 ft. *longer* than the AFM wet-runway distance (point "D" in Figure 22) obtained by increasing the dry distance by 30%, indicating that the μ_B achieved in the accident was *lower* than that underlying the AFM wet distance.

Finally, the discussion on p. 35 of the *Study* concerning the 30% factor used to compute the AFM wet-runway landing distance has been updated to read as follows:

Independent of the requirements of §135.385, the HA-420 AFM advises that the published dry-runway landing distances should be increased by 30% when landing on a wet runway. In this case, the resulting required runway length would have been 3,987 ft. $\times 1.3 = 5,183$ ft. Notably, $5,183 \text{ ft.} / 0.8 = 6,479 \text{ ft.}$, very close to the length of the runway (6,501 ft.), so the crew might have used this calculation to determine how much fuel could be loaded on the airplane.

The updated *Aircraft Performance Study* (dated February 16, 2024) containing these corrections is attached to this *Erratum*.

Submitted by:

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National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



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AIRCRAFT PERFORMANCE STUDY

by John O'Callaghan

February 16, 2024

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C. SUMMARY

C.1. Introduction

On March 9, 2022, about 08:27 EST¹, a Honda Jet HA-420, N903JT, was substantially damaged when it overran runway 28 after landing at Allegheny County Airport (KAGC) in Pittsburgh, Pennsylvania. The two pilots and one passenger were not injured. The airplane was operated by Jet It, LLC as a Title 14 *Code of Federal Regulations* Part 135 air taxi flight.

The training captain was flying with the first officer on day 6 of the first officer's Initial Operating Experience, during which the first officer was the pilot-flying. According to the flight crew, they checked the weather prior to departure from Teterboro Airport (KTEB), Teterboro, New Jersey, briefed for the potential winter weather conditions upon landing at KAGC, and departed around 07:20.

The training captain stated that he monitored the Automated Terminal Information Service (ATIS) once in range of KAGC and did not recall hearing any remarks pertaining to runway braking action or surface contamination reports, although he noted remarks about contamination on taxiways and ramp areas. Subsequently, he checked in with the approach controller and was advised that snowplows were on the runway. He considered this an indication that the airport was "taking care of the runway in the light snow." He "never anticipated runway contamination" and the crew based their landing distance calculations on a wet runway. The first officer flew the ILS approach to runway 28 (see Figure 1) with the autopilot engaged. The training captain visually acquired the

¹ All times in this *Study* are in EST unless otherwise noted. EST = UTC - 5 hours.

runway environment upon reaching decision altitude (150 feet above ground level), noticing the runway shoulders were obscured by snow, and the center line was visible. The first officer continued the approach.

The first officer disconnected the autopilot and continued the landing. The training captain recalled feeling “faster than normal” when the airplane touched down in the “first third” of the grooved 6,501-ft runway. The airplane began to decelerate; however, the captain called for maximum braking when he determined the deceleration to be insufficient to stop the airplane on the remaining runway. He applied the emergency brake and steered to the left to try to stay on the airport property. The airplane skidded sideways, departed the end of the runway, and travelled tail-first over the edge of a steep incline, coming to rest in trees. The pilots and passenger evacuated out the main cabin door. The fuselage and wings sustained substantial damage.

Weather conditions at the time of the accident included ½ statute mile visibility, light snow, and an overcast ceiling at 400 ft. The airport ATIS reported at the time of the approach and landing included a Braking Action Advisory with a braking action report of “good” by a Pilatus at 07:55 and a field condition NOTAM at 07:49 reporting 10% runway coverage with 1/8-inch slush on the landing runway.

The cockpit voice recorder/flight data recorder unit was recovered from the airplane and sent to the NTSB recorders laboratory in Washington, D.C. for further examination.

C.2. Objective and scope of the *Aircraft Performance Study*

The objective of this *Aircraft Performance Study* is to determine and analyze the motion of the airplane and the physical forces that produced that motion. In particular, the *Study* attempts to define the airplane’s position and orientation during the relevant portion of the flight, and determine the airplane’s response to control inputs, external disturbances, ground forces, and other factors that could have affected its trajectory.

The data used to determine and analyze the airplane motion includes the following:

- Automatic Dependent Surveillance - Broadcast (ADS-B) surveillance data.
- Ground scars and markings.
- Flight Data Recorder (FDR) data.
- Cockpit Voice Recorder (CVR) information.
- Weather information.
- Airplane performance data presented in the Airplane Flight Manual (AFM).
- Airplane thrust and aerodynamic performance information provided by Honda.
- Output from aircraft performance computer programs and simulations.

This *Study* describes the results of using the data listed above in defining, as far as possible, the position of N903JT relative to the KAGC runway 28 threshold throughout the approach, landing, and overrun. The *Study* introduces the aircraft motion data collected during the investigation, describes the methods used to extract additional aircraft motion information from the FDR, and presents the results of these calculations.

The *Study* also compares the conduct of the approach with the stabilized approach criteria specified in the Jet It *Standard Operating Procedures Manual* (SOP, Reference 1), and examines the crew's pre-flight planning (including the computation of the required landing distances) in light of the available runway length at KAGC, and the runway length requirements specified in relevant Federal Aviation Administration (FAA) regulations and Jet It's *General Operations Manual* (GOM, Reference 2).

In addition, this *Study* examines this accident within the larger context of the stopping performance of airplanes on wet runways. Findings from the NTSB's investigations of several wet-runway landing overruns are presented in Reference 3, which notes that while operational errors, such as higher than nominal airspeed or tailwind components, long touchdown distances, and delayed use of deceleration devices (such as spoilers, reverse thrust, and brakes) are often contributing factors to landing overruns, less-than-expected runway friction is also a common contributing factor in landing overruns on wet runways. In most of the overrun events considered in Reference 3, the achieved wheel braking friction coefficient (μ_B) was less than the μ_B assumed in the wet-runway landing distance advisory data provided in manufacturers' Airplane Flight Manuals (AFMs) and in guidance material provided by the FAA.

Reference 3 reviews the physics underlying an airplane's stopping performance and the factors that affect braking performance on a wet runway, and describes a method for computing μ_B from Flight Data Recorder (FDR) data. The μ_B models underlying several friction models are presented, and compared with the μ_B observed in several wet runway landing overruns. Reference 3 also describes viscous, dynamic, and reverted rubber hydroplaning on wet runways, and the causes of each. The reader is referred to Reference 3 for this information; it will only be repeated here as needed to better understand the circumstances of the KAGC accident.

C.3. Summary of results

The results of this *Study* indicate that N903JT was about 11 knots faster than the prescribed approach speed (V_{APP}) as it descended through 1,000 ft. above the touchdown zone (ATZ) on an ILS approach in instrument meteorological conditions (IMC). Technically, this speed was within Jet It's stabilized approach criterion that below 1,000 ft. ATZ the speed should not exceed $V_{APP} + 10/-5$ knots "(momentary deviations excepted)." However, the steady deceleration to V_{APP} , and subsequent power adjustments used to briefly maintain V_{APP} before again slowing to V_{REF} , likely made

precise speed control more difficult, even if the speed remained within Jet It's stabilized approach limits. Consistent with this observation, as the airplane descended below 1,000 ft. ATZ, the thrust levers and engine N1 speeds were at idle, contrary to Jet It's stabilized approach requirement that below 1,000 ft. TDZ the "power setting is appropriate for the aircraft configuration and is not at idle power." Hence the approach was not "stabilized" below 1,000 ft. TDZ. Jet It's SOPs state that "if an approach becomes unstabilized ... the crew will initiate a go-around and missed approach."

The crew did not initiate a go-around, but instead continued the approach. N903JT crossed the runway threshold 9 knots faster than V_{REF} , which contributed to a touchdown 893 ft. past the nominal touchdown zone, and increased the runway length required to stop from that predicated on the nominal touchdown location.

The increased required runway length eroded the landing distance safety margin that was already reduced from nominal Part 135 requirements through the exercise of the operator's Destination Airport Analysis Program (DAAP). The DAAP allows, at the time of dispatch, planning for 80% of the destination runway length to be used for landing, instead of the 60% of the destination runway length usually allowed. At KTEB, the crew intended to load N903JT with as much fuel as would permit the flight to be dispatched to KAGC while still meeting the DAAP 80% landing runway length requirement in case weather forced the flight divert to an alternate destination.

The results of the *Study* also indicate that the μ_B achieved during the accident was lower than that underlying the recommendation in the Airplane Flight Manual (AFM, Reference 4) to increase the published dry-runway landing distance by 30% to determine the wet-runway landing distance. The achieved μ_B was also lower than that used to determine the wet-runway landing distances published in the *HondaJet Wet and Contaminated Runway Performance* AFM supplement, though the published distances include a safety factor of 1.67 which more than compensates for the difference (Jet It did not use the AFM supplement at the time of the N903JT accident). The achieved μ_B was also lower than that specified for wet runways in FAA guidance (the Runway Condition Assessment Matrix, described in Section D.9.3). This finding is consistent with those in other NTSB wet-runway overrun investigations, as described in Reference 3.

At some point during N903JT's landing roll, the crew engaged the emergency brake fully, which likely put the airplane into a locked-wheel skid and reduced the braking and cornering performance of the tires. (Photographs of the left and right main gear tires following the accident showed evidence of reverted rubber hydroplaning, which is consistent with a locked wheel skid.) The reduced cornering performance likely contributed to the development of a large drift angle to the right as the airplane departed the end of the runway.

The friction available from the runway has to be shared between the braking and cornering demands of the airplane. If friction is used for cornering (that is, for steering the airplane to return to the centerline), then less friction will be available for braking; and if the friction is used for braking, less will be available for cornering. In other words, it is not possible to achieve the maximum available braking force from the runway while at the same time maneuvering to correct for a deviation from the centerline. Consequently, circumstances that place cornering or maneuvering demands on the tires during the landing roll (such as a correction back to centerline) can increase the required stopping distance.

The sections that follow present the data used in this *Study* (as listed above), and describe the methods used to calculate additional performance information from this data. The recorded airplane performance is compared with the landing distances published in the AFM, and with results of simulations of the stopping performance of the airplane based on different touchdown conditions and braking performance assumptions. The results of these calculations are presented in the Figures and Tables described throughout the *Study*. The *Study* also presents the operational dispatch regulations pertaining to required runway lengths at destination airports in dry and wet conditions, and discusses their application in the context of this accident.

D. DETAILS OF THE INVESTIGATION

D.1. The HondaJet Elite S HA-420 airplane

The HondaJet HA-420 is a light business jet manufactured by the Honda Aircraft Company (Honda). The airplane is powered by two GE Honda Aero Engines mounted on pylons over the wings, each producing about 2,000 lb. of thrust at sea level. The airplane seats 7-8 people (N903JT was configured for 2 pilots and 5 passengers), and has a maximum takeoff weight of 10,900 lb. Figure 2 shows a 3-view image of the HA-420, taken from the HondaJet Pilot's Operating Manual (POM, Reference 6). Table 1 provides some dimensions of the airplane, as well as relevant mass properties for N903JT on the accident flight. The mass properties reflect the weight and balance buildup in a "Trip Report" for the flight provided by Jet It (see Figure 3).

Item	Value
<i>Reference dimensions (provided by Honda Aircraft Co.):</i>	
Wing area	176.56 ft. ²
Wing span	39.76 ft.
Mean Aerodynamic Chord (MAC)	4.977 ft.
Fuselage station of the MAC leading edge (LEMAC)	232.2 inches
<i>Mass properties for N903JT:</i>	
Flight plan landing weight (for V_{REF} calculation)	9,632 pounds
Flight plan landing center of gravity	25.8% Mean Aerodynamic Chord (MAC)

Table 1. Airplane geometry and weight and balance information for N903JT (serial # 42000224).

D.2. Ground scars and markings

Per the Airport/Facility Directory published by the FAA, KAGC runway 28 is grooved concrete, 6,501 ft. long and 150 ft. wide, at an elevation of 1,250 ft. and with no gradient noted. Visual approach aids to the runway include a Medium Intensity Approach Light System with Runway Alignment Indicator Lights (MALSR), and a 4-box Visual Approach Slope Indicator (VASI) located on the left side of the runway.

The runway is situated on a flat plateau, and the terrain drops off steeply about 100 ft. past the west end of the runway. As noted above, N903JT came to rest on the steep incline past the runway end, with its tail pointed down the incline and nose pointed upwards back towards the runway (see Figure 4d).

The NTSB did not travel to KAGC following the accident. The FAA and Honda travelled to KAGC to examine the airplane shortly after the accident, and took photos of the runway, wreckage location, recovery efforts, and airplane condition after recovery to a hangar. Some of these photos are presented here in Figures 4 & 8. In addition, a KAGC surveillance video shows the airplane rolling down the runway in weather conditions that are consistent with those reported in KAGC Meteorological Terminal Air Reports (METARs) and field condition reports (FICONs) (see Section D.5.8 and Figure 4a). The wreckage location relative to the runway end shown in the photos is consistent with the final latitude and longitude coordinates recorded in the ADS-B data.

D.3. Surveillance data

Automatic Dependent Surveillance – Broadcast (ADS-B) capability enables aircraft to broadcast their three-dimensional position (latitude, longitude, and altitude) to other ADS-B equipped aircraft and to ADS-B ground stations.² ADS-B data broadcast from N903JT from takeoff to touchdown (including several returns broadcast after the airplane overran the runway) were received and recorded by FAA ADS-B ground stations.

ADS-B latitude and longitude are determined using Global Navigation Satellite System (GNSS) signals, including those from Global Positioning System (GPS) satellites, and altitudes determined both barometrically and by GNSS are included in ADS-B messages. The GNSS positions are very accurate compared to radar data; radar range uncertainty alone (without even considering azimuth uncertainty) is about $\pm 1/16$ nm, or ± 380 ft., and GNSS positions are generally accurate to within 60 ft. (see Reference 7). Furthermore, ADS-B data is available at a higher frequency (typically 1 sample/second) than radar data (at best, 1 sample every 4.5 seconds). In this *Study*, the ADS-B data for N903JT are used to confirm the latitude and longitude recorded on the

² For more information about ADS-B, see https://www.faa.gov/air_traffic/technology/adsb.

FDR (which are recorded at a lower resolution than the ADS-B data), and in the computation of kinematically consistent airplane positions through mathematical integration of the load factors (accelerations) recorded by the FDR (see Section D.5.5).

The recorded ADS-B data includes the following parameters:

- UTC time of the ADS-B report, in hours, minutes, and seconds. EST = UTC - 5 hours.
- Aircraft identifying information.
- Latitude and longitude, to a resolution of 0.01 arc-seconds (≈ 1 ft.)
- Pressure altitude in feet, to the nearest 25 ft. (an uncertainty band of ± 12.5 ft.)
- Geometric (GNSS) altitude in feet, to the nearest 25 ft.
- North-south and east-west components of ground speed, to a resolution of 1 kt.
- Rate of climb, to a resolution of 1 ft./min.
- Numerous parameters documenting the quality and accuracy of each reported GNSS position.

The time interval between ADS-B data samples is about 1 second. Because the ADS-B ground stations rely on radio line-of-sight to the airplane to receive data broadcasts from the airplane, it is possible for gaps to appear in the data as the airplane descends over hilly terrain that can obscure this line-of-sight. In this case, however, there are no gaps in the ADS-B data, except between the touchdown point and the wreckage location. This gap might be the result of the recording algorithm excluding returns determined to be aircraft on the ground; the weight-on-wheels (WOW) discrete recorded by N903JT's central maintenance computer (CMC) transitioned from "air" to "ground" after touchdown, but then transitioned back to "air" following the runway excursion (see Figure 15).³

The ADS-B data is presented along with recorded flight data in subsequent sections of this *Study* (see Figures 5 - 10). Since the runway is oriented nearly exactly east to west, the position of the airplane is described by its north and east coordinates relative to the KAGC runway 28 threshold. Latitude and longitude coordinates are transformed into north and east coordinates using the WGS84 ellipsoid model of the earth, and the coordinates of the runway 28 threshold (from *Google Earth*):

40° 21' 15.56" N latitude / 79° 55' 04.01" W longitude / elevation 1,250 ft. MSL

The true bearing of runway 28, as measured in *Google Earth*, is 269.91°.

³ Several Figures in this *Study* have an "a" and a "b" version, which present the same information but at different scales, or with different background images. When the *Study* refers to a Figure with two or more versions without specifying the version, all versions are meant to be included in the reference.

D.4. Recorded flight data

D.4.1. FDR and CVR data description

The aircraft cockpit voice recorder (CVR) and flight data recorder (FDR) were recovered and sent to the NTSB Recorders Laboratory in Washington, DC for readout.

Descriptions of the FDR and CVR and the recorder readout processes can be found in References 8 and 9, respectively. The FDR readout results in tabulated and plotted values of the recorded flight parameters versus time, as presented in the Figures throughout this *Study*. For this accident, the CVR readout results in a summary of the CVR content, as presented in Reference 9.

D.4.2. Correlation of FDR, CVR, and ADS-B times

The FDR and CVR record their information with respect to time, but these recorded times are not synchronized. To use these data sources together, their times must be synchronized to a single reference time. This reference time is based on the UTC parameters recorded on the FDR, converted into EST.

Per Reference 9, the correlation between the FDR and CVR times is based on the last five radio transmissions from N903JT (the audio of the transmission recorded on the CVR was correlated to the radio transmit microphone key parameter recorded on the FDR). The CVR summary in Reference 9 uses FDR time in EST.

The FDR time was determined to be aligned with the ADS-B time by comparing the pressure altitude parameters recorded on the FDR and in the ADS-B data. These parameters match well without any adjustment, as shown in Figure 7.

The time basis for this *Study* is ADS-B (or FDR) time in EST.

D.5. Performance Calculations based on FDR Data

D.5.1. Overview

The FDR records many, but not all, performance parameters of interest. Many additional parameters can be derived from the FDR parameters; however, the FDR parameters themselves can suffer from inherent measurement errors⁴ and must be corrected before being used in these calculations.

⁴ "Measurement error" in this context means the difference between the true value of the quantity being measured and the measured or recorded value. It does not necessarily imply defects or malfunctions in the measurement and recording equipment itself. This difference can result from, among other things, limitations in the sensor accuracy and / or resolution.

This section describes the corrections applied to the FDR data, and the calculations used to derive additional performance parameters from the corrected data. The airplane weight and CG used in these calculations are 9,632 lb. and 25.8% MAC, respectively (see Table 1). Further details about the derivation of the equations and calculation methods used in this *Study* can be found in Appendix A of Reference 10.

The corrected and additional performance parameters derived from the FDR data include:

- Position of the airplane relative to the KAGC runway 28 threshold.
- True airspeed and altitude.
- Load factors corrected for accelerometer bias.
- Kinematically consistent positions and velocities from accelerometer integration that approximately match the recorded data and at-rest location.
- Wind speed and direction while airborne, and headwind on the ground.
- Braking friction coefficient developed during the ground roll.

The results of these corrections and derivations for the period from the airplane's descent through 640 ft. above the runway to its at-rest location are presented in the Figures described throughout this *Study*.

D.5.2. True airspeed calculation

True airspeed equals Mach number multiplied by the speed of sound, and the speed of sound is a function of the static temperature. In many cases, the FDR records total temperature (not static temperature) and static temperature must be computed from total temperature and Mach number. In this case, static temperature is recorded by the FDR directly.

Mach number can be computed from calibrated airspeed and static pressure. Calibrated airspeed is recorded directly by the FDR, and the static pressure can be determined from the pressure altitude recorded by the FDR (which is based on the standard sea-level pressure of 29.92 "Hg).

Figure 10 shows the results of the true airspeed calculation, compared with the indicated (calibrated) airspeed recorded by the FDR, and the ground speeds recorded by the FDR and in the ADS-B data. Figure 10 also shows the ground speed computed from integration of the accelerometer data (this calculation is described below).

Wheel speeds can be used to determine the touchdown point (the point where the wheel speeds increase above zero), and to compute the slip ratios of the wheels, which are important parameters affecting the airplane's braking performance (see Section

D.6.). Unfortunately, wheel speeds are not recorded on the FDR, and so the slip ratios cannot be computed.

The touchdown point was determined as the start of the increase of the FDR vertical load factor above 1.0 G's towards a peak of 1.47 G's, shortly before the CMC weight-on-wheels discrete switches from "in air" to "on ground" (see Figures 11 and 15). The touchdown occurs at 08:27:33.2, about 2,300 ft. from the runway 28 threshold. This time matches sounds similar to touchdown recorded on the CVR.⁵

Per Figure 9, N903JT crossed the threshold at 08:27:22.3, and Figure 10 shows that the calibrated and true airspeeds were about 131 kt. (the true airspeed is slightly lower but within half a knot of the calibrated airspeed), and that the ground speed was about 130 kt. At touchdown, the calibrated airspeed and ground speed were about 119 kt. and 120 kt., respectively.

Per Figure 3, the planned landing weight for the flight was 9,632 lb., and the corresponding flaps TO/APP V_{REF} speed was 122 kt. (The AFM states: "use Flaps TO/APPR for landing whenever the aircraft cannot be confirmed clear of ice or if icing conditions may be encountered during approach and landing." FDR data indicates that the flaps were set to TO/APP during the accident approach and landing.)

Jet It's SOPs (Reference 1) state that

For windshear avoidance and safety, crews should calculate and fly a VAPP speed to fly on final approach. This will be calculated as: $VAPP = V_{REF} + \frac{1}{2} \text{ Headwind factor} + \text{Gust factor}$, not to exceed a total correction of 20 knots. As an example, if landing runway 36 with a V_{REF} of 109 and winds were reported as wind 360 at 10 gust 18, VAPP would be 122 ($109 + 5 (1/2 \text{ HW factor}) + 8 (\text{Gust factor})$). If calm winds, the minimum VAPP speed should be $V_{REF} + 5$ knots. In no case should the PF fly at a speed below the Approach Reference circle displayed on the airspeed indicator. The PM will monitor tower reported winds and update VAPP on final as necessary.

In this case, the winds were relatively calm, and V_{APP} was computed as $V_{REF} + 5$ knots, or 122 kt. + 5 kt. = 127 kt., which coincides with the "selected airspeed" recorded on the FDR (see Figures 3 and 10).

The SOPs also state that "the [pilot flying (PF)] should plan to slow to V_{REF} by crossing the threshold to ensure validity of calculated landing data" and that "the [pilot monitoring (PM)] should verify the thrust levers are brought to idle prior to touchdown and verbally confirm speedbrake extension per the standard callouts in ... this SOP." Note that the HA-420 POM (Reference 6) states, "at 50 ft., rapidly reduce thrust to IDLE," while the Jet It SOPs instruct the PM to "verify the thrust levers are brought to idle prior

⁵ The "accelerometer integration" line in Figure 9 is the best estimate of the airplane's position, and its calculation is described below in Section D.5.5.

to touchdown.” Hence there is a discrepancy between the POM and SOP as to when the thrust levers are required to be at idle. The POM also notes that “crew must use AFM procedures to meet charted performance.” A delay in reducing the thrust to idle will likely result in a touchdown speed greater than, or a touchdown point longer than, those assumed in the AFM landing distance tables.

As shown in Figure 10, the airspeed decelerated through the V_{APP} of 127 KCAS at 08:26:33.6, reaching 121 KCAS at 08:26:51, and then increased again to 133 KCAS at 08:27:17. N903JT’s airspeed over the threshold was 131 KCAS, or 9 knots higher than V_{REF} . However, Figure 15 indicates that the throttles did reach idle by time the airplane crossed the threshold, as specified in the POM.

Figures 9, 10, and 12 indicate that N903JT’s drift angle on the runway started to increase dramatically at about 08:27:56.5, about 5,901 ft. from the threshold (600 ft. from the runway end) at a ground speed of about 64 knots, and the airplane departed the end of the runway at 08:28:03 at a ground speed of 41 knots. The airplane came to rest at 08:28:08, about 143 ft. past the runway end, and 91 ft. to the left of the runway centerline.

The difference between the true airspeed and ground speed while on the runway is equal to the headwind, and as shown in Figure 14 is only about 1 knot. The computed in-air winds during the approach and those recorded on the FDR are also plotted in Figure 14, and are discussed further below. These winds are generally consistent with the recorded KAGC weather data presented in Section D.5.8.

D.5.3. Pressure-based true altitude and density altitude calculations

The altitude recorded by the FDR is pressure altitude; i.e., it is the altitude in the standard atmosphere corresponding to the pressure sensed at the airplane’s static pressure ports. The altitude in the actual atmosphere corresponding to the local static pressure generally does not equal the pressure altitude, and it is insufficient to simply adjust the pressure altitude for the local sea level pressure because, in general, the lapse rate of pressure with altitude does not match the lapse rate in the standard atmosphere.

To estimate the actual altitude of N903JT, the change in altitude corresponding to a change in static pressure is calculated by solving the hydrostatic equation continuously (the hydrostatic equation describes the pressure increment across a differential element of air required to balance the weight of the element). With static pressure and the static temperature values obtained as described above, the density and weight of the air elements can be calculated.

The solution of the hydrostatic equation is shown in Figures 6 and 7 as the black dashed line labeled "Temperature-corrected barometric altitude." The result is modified when the airplane is on the ground to match the runway elevation perfectly, so as to provide a better "target" altitude for the accelerometer integration calculation described below. Accounting for the lower-than-standard temperature of the day changes the rate of change of pressure with true altitude slightly, compared to the rate of change of pressure with pressure altitude.⁶

The indicated altitude shown on the airplane's altimeters is obtained by adjusting the FDR pressure altitude to account for the 29.88" Hg altimeter setting reported in the 08:34 EST SPECI for KAGC. This altimeter setting would result in an indicated altitude about 37 ft. lower than the pressure altitude plotted in Figures 6 and 7. The slope of the pressure (and indicated) altitude is slightly different than the slope of the hydrostatically derived altitude (black dashed line); this difference results from the nonstandard lapse rate of pressure with altitude.

The blue line in Figures 6 and 7 is the result of integrating the vertical speed recorded in the ADS-B data over time. This vertical speed is barometrically based, and can exhibit the same lag associated with the barometric vertical speed indicator instruments in airplane cockpits. This lag can introduce some error into the resulting integrated altitude. In Figures 6 and 7, the integrated altitude is shifted to approximately match the ADS-B geometric altitude near the runway.

The density altitude is the altitude in the standard atmosphere corresponding to the actual air density at each point in the flight. Because of the colder-than-standard day, the density altitude during the approach was about 1,500 ft. lower than the true MSL altitude.

D.5.4. True altitude based on radio altimeter and terrain elevation data

The brown dash-dot line in Figures 6 and 7 labeled "Radio altitude + terrain elevation" is the altitude that results from adding the height of the airplane's main gear tires above the ground (measured by the radio altimeter) to the elevation of the terrain underneath the airplane. The terrain elevation is determined by using the ADS-B latitude and longitude data to define the airplane's track over the ground, and then by obtaining the terrain elevation underneath the airplane's track from Shuttle Radar Topography Mission (SRTM) elevation data provided by the United States Geological Survey (USGS). The USGS provides SRTM digital elevation data with a resolution of 1 arc-second (about 100 ft.) for the United States and 3 arc-seconds (300 ft.) for global

⁶ The standard-day temperature at a field elevation of 1,250 ft. is 54.5° F. Per Figure 14, the static temperature on the ground at KAGC was between 0° and 1° C (32.0° to 33.8° F), or 22.5 to 20.7 °F lower than standard.

coverage⁷. The resolution of the terrain data used in this *Study* is 1 arc-second. The waviness in the brown dash-dot line results from undulations in the terrain (see the terrain profile in Figures 6 and 7).

The oscillations in the radio altitude data, resulting from undulations in the terrain or other terrain features (such as buildings), do not indicate variations in the airplane's MSL altitude; the black dashed barometric-based line is a better indicator of *changes* in altitude. However, the brown dash-dot line in Figures 6 and 7 (and the ADS-B geometric altitude depicted as blue circles) serve to set the proper ending altitude of the black dashed line. Described another way, the black dashed line is the result of an integration of changes in altitude, and the brown dash-dot line provides the "constant of integration" in this calculation that sets the "absolute level" of the black dashed line.

However, the "Temperature-corrected barometric altitude" (black dashed line) constructed in this way might not be perfectly kinematically consistent with the load factor data recorded on the FDR. In addition, while the FDR ground speed parameter is relatively accurate, it might not be perfectly kinematically consistent with the FDR load factor data or the FDR and ADS-B position data. "Kinematically consistent" means that the mathematical relationships between acceleration (measured by load factor parameters), speed (measured by the ground speed and heading parameters), and position (measured by the FDR and ADS-B position parameters) hold in the three dimensions of the airplane's motion. In practice, the FDR parameters as recorded are only approximately kinematically consistent, as a result of inherent measurement errors and uncertainties.

In light of these errors and uncertainties, a better, kinematically consistent solution for the airplane's altitude, position, and speed throughout the approach and landing can be obtained by integrating the load factor data recorded on the FDR. This calculation is described below.

D.5.5. Accelerometer data corrections and integration

The red line in Figures 6 and 7 labeled "Accelerometer integration" is the altitude that results from integrating⁸ the FDR load factor data twice to derive aircraft position. The positions, speeds, and accelerations defined by the integrated flight path are known to be kinematically consistent, unlike other measures of these quantities recorded on the FDR.

⁷ See <http://viewer.nationalmap.gov/viewer/>.

⁸ In the following discussion, "integrating" the load factor data refers to mathematical integration with respect to time, per the theorems of Calculus.

A kinematically consistent and accurate estimate of the flight path of the airplane during relatively short intervals (about 30 to 60 seconds) can be obtained by integrating the accelerations recorded at the CG of the airplane. In general, the accelerometers are not located exactly on the CG, and so the accelerations at the CG must be computed by adjusting the FDR-recorded load factors for the effects of angular rates and accelerations. In the present case, the angular rates and accelerations are sufficiently small that this correction is negligible.

However, accelerometers generally contain small offsets, or “biases,” that produce large errors in speed and position if not removed prior to integration.⁹ In addition, the initial values of speed, rate of climb, and track angle are required during the integration process (these are essentially the “constants of integration” when integrating acceleration to get speeds). The constants of integration and the values of the accelerometer biases can be estimated by selecting them such that the aircraft position that results from the integration agrees with known “target” positions determined from another source.

The accelerometer biases are not necessarily constant over an entire flight, but can drift over time. It is for this reason that integrating the accelerometers works best over relatively short intervals, during which the accelerometer biases are approximately constant. In order to obtain an integrated flight path for N903JT’s approach, landing, and rollout, the flight path was divided into three segments: “approach,” “landing” and “ground roll.” The accelerometer data was integrated separately for each segment. For each segment, the “target” positions for the accelerometer integration are the ADS-B latitude and longitude parameters converted into coordinates east and north of the runway 28 threshold, and by the black dashed “Temperature-corrected barometric altitude” line shown in Figures 6 and 7. In addition, the solution is forced to be continuous (no discontinuities in position or speed) at the boundaries between segments. The integration is solved in “reverse,” starting at the end of the data (with the airplane approximately at rest beyond the runway end), and progressing backwards in time, with the “ground roll” segment ending at touchdown, the “landing” segment starting at touchdown and ending about 200 ft. above the runway, and the “approach” segment starting 200 ft. above the runway and ending at about 640 ft. above the runway (at 1,890 ft. MSL). Solving the problem in reverse makes it easier to match the known rest point past the runway end.

For the “ground roll” segment, the constants of integration (the initial ground speed, track angle, and rate of climb) are selected to match the ADS-B position data, runway elevation, and FDR ground speed as well as possible. For the “landing” segment, the constants of integration are defined by the end values of the corresponding

⁹ For details about the equations to be integrated and the bias correction technique described in this *Study*, see Appendix A of Reference 10.

parameters in the “ground roll” segment, and for the “approach” segment, the constants of integration are defined by the end values of the corresponding parameters in the “landing” segment. Since the integration is performed in reverse, the “initial” conditions for the “ground roll” segment are those for the airplane approximately at rest (the actual end of the ground roll), the initial conditions for the “landing” segment are those at the start of the “ground roll” segment, and the initial conditions for the “approach” segment are those at the start of the “landing” segment. The accelerometer biases in each segment are chosen to minimize the error between the integration and the target at the end point of the integration; i.e., the biases are chosen so that the integrated path and target path coincide at the end of the integration over each segment.

Rearranging the segments to move forward in time, the “approach” segment starts at about 1,890 ft. MSL and ends at 200 ft. above the runway, the “landing” segment starts at 200 ft. above the runway and ends at touchdown, and the “ground roll” segment starts at touchdown and ends with the airplane approximately at rest beyond the runway end. The beginning and end times and accelerometer biases used for each segment are shown in Table 2.

Segment	Start time (EST)	End time (EST)	n_x bias, G's	n_y bias, G's	n_{lf} bias, G's
Approach	08:26:30.1	08:27:10.1	-0.00025	-0.00258	0.00232
Landing	08:27:10.1	08:27:32.6	0.00336	0.00629	0.00317
Ground roll	08:27:32.6	08:28:08.0	0.00023	-0.00086	-0.00056

Table 2. Time boundaries and accelerometer biases for accelerometer integrations.

D.5.6. Accelerometer integration results

The airplane position and altitude resulting from the final integrated trajectory for the air and ground segments are shown in Figures 5 - 9 as the lines with the “accelerometer integration” label. The ground speed and rate of climb resulting from the integrated trajectory are plotted in Figure 10.

The corrected load factors are compared to the load factors recorded by the FDR in Figure 11. Figures 5 and 8 indicate that the path over the runway resulting from the accelerometer integration is in generally good agreement with the ADS-B position data and the airplane’s final resting point, and is therefore a satisfactory solution.

D.5.7. Flight path angle (γ), angle of attack (α), and sideslip angle (β) calculations

The flight path angle is defined by

$$\gamma = \sin^{-1} \left(\frac{\dot{h}}{V} \right) \quad [1]$$

where γ is the flight path angle, $\dot{h}$ is the rate of climb, and V is speed. Using true airspeed gives γ relative to the airmass, and using ground speed gives γ relative to the Earth. If $\dot{h}$ and V from the pressure-based altitude¹⁰ and true airspeed calculations described above are used in Equation [1], the resulting γ is very noisy (i.e., it contains unrealistic “spikes” and oscillations). A better (smoother) calculation of γ results from using $\dot{h}$ and V from integrated accelerometer data. The γ relative to the Earth using $\dot{h}$ and ground speed from the accelerometer integration is shown as the solid red line in the top plot of Figure 12. Because the winds in this case are relatively light, the true airspeed and ground speed are within about 2 knots of each other throughout the integration period (within 640 ft. above the runway), and consequently the γ relative to the airmass is very close to the γ relative to the Earth. The inertial $\dot{h}$ used in this calculation is shown in the bottom plot of Figure 10 along with the FDR $\dot{h}$ and the $\dot{h}$ recorded in the ADS-B data.

The sideslip angle (β) is the angle that the velocity vector of the airplane relative to the airmass makes with the airplane’s plane of symmetry (see Figure 13). This angle is required to resolve the airspeed of the airplane into components along each of the airplane’s axes, which in turn are required to estimate the atmospheric wind from the FDR data. Consequently, the behavior of β during the approach is of interest.

β is not sensed or recorded by the FDR, but an estimate of β (while the airplane is airborne) can be made if the side force (Y) characteristics of the airplane are known and if the side force generated during the flight can be calculated. The most significant contributors to the side force are β and rudder deflection (δ_r):

$$C_Y = \frac{Y}{\frac{1}{2}\rho V^2 S} = \frac{\partial C_Y}{\partial \beta} \beta + \frac{\partial C_Y}{\partial \delta_r} \delta_r + \{smaller\ terms\} \quad [2]$$

Where C_Y is the side force coefficient, ρ is the air density, V is true airspeed, and S is the wing reference area. Ignoring the smaller terms, Equation [2] can be solved for an estimate of β :

$$\beta \cong \frac{C_Y - \frac{\partial C_Y}{\partial \delta_r} \delta_r}{\frac{\partial C_Y}{\partial \beta}} \quad [3]$$

¹⁰ This is the altitude labeled “Temperature-corrected barometric altitude” in Figures 6 and 7.

The derivatives $\partial C_Y / \partial \beta$ and $\partial C_Y / \partial \delta_r$ are aerodynamic characteristics of the airplane.

The side force Y can be calculated using

$$Y = (W)(n_y) \quad [4]$$

Where W is the weight of the airplane and n_y is the lateral load factor recorded by the FDR, corrected to the CG location and for accelerometer bias, as described above.

In the present case, the corrected n_y during the approach is very small (see Figure 11). The rudder angle δ_r is not recorded on the FDR and so is unknown. However, given that the roll and drift angles in the air were close to 0° (see Figure 12), the small n_y indicates that the δ_r , and consequently β , are also very small. This *Study* assumes that, in the air, $\beta \cong 0$. (On the ground, changes in β approximately match changes in the drift angle.)

Once γ and β are computed, they can be used along with the pitch angle (θ) and roll angle (ϕ) recorded by the FDR to compute the angle of attack, α :

$$\alpha = \tan^{-1} \left(\frac{\tan \theta}{\cos \phi} \right) - \sin^{-1} \left(\frac{\sin \gamma + \sin \beta \cos \theta \sin \phi}{\cos \beta \sqrt{1 - \cos^2 \theta \sin^2 \phi}} \right) \quad [5]$$

Note that when $\beta = \phi = 0$, Equation [5] simplifies to the well-known result that

$$\alpha = \theta - \gamma \quad [6]$$

The α resulting from Equation [6], using γ relative to the Earth based on $\dot{h}$ from the accelerometer integration, is presented as the green line in the top plot of Figure 12. As with γ , the computed α is of interest mainly during the approach, up to touchdown.

D.5.8. Meteorological data and wind calculations

KAGC is served by an Automated Weather Observation System (AWOS) located at the airport. The AWOS observations most relevant to this *Study* are the altimeter setting, static temperature, winds, sky condition, and precipitation at KAGC at the time N903JT landed. This information is provided to aviators through Aviation Routine Weather Reports (METAR) and Aviation Select Special Weather Reports (SPECI). KAGC METAR and SPECI reports surrounding the time of the accident are presented in Table 3.

The SPECI reports in Table 3 are consistent with ground icing conditions. The POM (Reference 6) defines “ground icing conditions” as air temperatures of 5°C or lower with visible moisture present. N903JT’s landing approach in visible moisture (cloud and snow) at temperatures of 0°C and lower (see Figure 14) are consistent with the

atmospheric icing conditions defined in 14 Code of Federal Regulations (CFR) Part 25, Appendix C.

Report Type: Time (EST):	SPECI 08:08	SPECI 08:15	SPECI 08:34	METAR 08:53
Wind direction (°true)	350	340	350	350
Wind speed (knots)	4	3	3	4
Visibility (statute miles)	0.75; RWY 28 RVR 5,000-6,000 ft.	0.5; RWY 28 RVR 4,500-5,500 ft.	0.5; RWY 28 RVR 3,500-4,500 ft.	0.25; RWY 28 RVR 3,000-3,500
Present weather ¹¹	Light snow Mist	Snow Fog	Snow Fog	Snow Fog
Sky condition (ft. AGL ¹²)	2,300 overcast	400 overcast	400 overcast	200 overcast
Temperature (°C)	0	1	1	0
Dew point (°C)	-1	-1	-1	-1
Altimeter setting ("Hg)	29.88	29.88	29.88	29.88
Precipitation (inches) ¹³	0.01	0.01	0.03	0.05

Table 3. METAR and SPECI reports generated from the KAGC AWOS data at times surrounding the accident. N903JT landed at about 08:27:30 EST. RVR = Runway Visual Range. METAR reports at KAGC are issued at 53 minutes past the hour.

A field condition (FICON) report for the day of the accident noted that at 07:49, 10% of runway 28 was observed to be covered in 1/8 inch of slush. As discussed further in Section D.9.3, slush is treated equivalently to water in current FAA guidance for evaluating the effects of runway contamination on runway friction.

The AWOS data describes weather conditions at ground level. The winds and temperatures encountered by the airplane while in the air can be determined from FDR data. Airspeed, ground speed, and wind are related as follows:

$$\vec{V}_W = \vec{V}_G - \vec{V} \quad [7]$$

where $\vec{V}$ is the airspeed vector, $\vec{V}_G$ is the ground speed vector and $\vec{V}_W$ is the wind vector. The components of $\vec{V}_G$ in body axes result from the integration of the accelerometer data described above. The components of the airspeed $\vec{V}$ in body axes, as indicated by Figure 13, are related to α and β as follows:

$$u = V \cos(\beta) \cos(\alpha) \quad [8a]$$

$$v = V \sin(\beta) \quad [8b]$$

$$w = V \cos(\beta) \sin(\alpha) \quad [8c]$$

¹¹ Per Reference 11, the "light snow" weather descriptor corresponds to visibility in snowfall greater than 0.5 statute mile. "Moderate snow" corresponds to visibility > 0.25 mile but ≤ 0.5 mile, and "heavy snow" corresponds to visibility ≤ 0.25 mile. See Reference 11 for official definitions of "mist" and "fog."

¹² AGL = Above Ground Level.

¹³ The recorded precipitation is that accumulated since the previous hourly METAR report was issued.

where in the present case $\beta \cong 0$ and α is computed using Equation [6]. Once the components of $\vec{V}_W$ in the airplane body axes are computed using Equation [7], they can be transformed into Earth axes using the known θ , ϕ , and true heading (ψ). The winds can then also be transformed into components parallel and orthogonal to the runway, using the runway true heading (269.91°). The results of the wind calculations are shown in Figure 14. Positive east wind represents a tailwind for runway 28, and positive north wind represents a right crosswind for runway 28.

Once the airplane is on the ground, it is hard to determine the true value of β , and so Equations [7] and [8] cannot be used to determine the winds. Consequently, the wind calculation in Figure 14 ends when the airplane reaches the runway. However, in the present case what is of most interest (affecting landing distance) is the headwind component, which on the runway can be computed as

$$V_{HEAD} = V_{TRUE} - V_{GROUND} \quad [9]$$

Where:

V_{HEAD} = headwind

V_{TRUE} = true airspeed

V_{GROUND} = ground speed

The red line in the top plot of Figure 14 presents the results of computing V_{HEAD} using V_{GROUND} from the accelerometer integration, and V_{TRUE} as computed above in Section D.5.2. The V_{HEAD} on the runway ranges between 0 and -1 kt. (that is, a 1 kt. tailwind).

D.5.9. Wheel braking friction coefficient calculation

Considering the lower-than-expected wheel braking friction coefficient (μ_B) achieved in previous landing overrun accidents and incidents investigated by the NTSB and by foreign agencies, it is of interest to determine the μ_B generated on the runway in this accident, and compare the μ_B levels achieved with those that would be expected on a wet runway given current industry models, and the wet runway landing distances published in the HondaJet HA-420 AFM and computed by the commercial company Aircraft Performance Group (APG, <https://flyapg.com/>) that provided operational airplane performance products to Jet It.¹⁴ This sub-section describes a method for computing μ_B using FDR-based parameters and additional information about the airplane provided by Honda. The results of the μ_B calculation are also presented. The

¹⁴ Jet It accessed APG data through its *iPreflight Genesis* iPad application. Per APG' website, among other functions "iPreflight Genesis allows pilots, dispatchers, and flight operations to plan and file a flight after loading the airplane and evaluate runway performance capabilities, which include takeoff and landing data." See <https://flyapg.com/products/ipreflight-genesis/>.

computed μ_B is compared with μ_B levels assumed in the AFM and various wet-runway friction models in Section D.9.

Several FDR, CMC, and computed parameters relevant to the airplane's braking and deceleration performance are presented in Figures 15-17, including:

- Left & right throttle resolver angles (TRA) and engine N1s
- Speedbrake position
- Wheel braking friction coefficient (μ_B)

Other parameters related to the airplane's braking and deceleration performance, such as flight control positions, brake pedal positions, brake line pressures, and wheel speeds are not recorded by the FDR or CMC and so are not available.

The μ_B calculation is described below. The result of the calculation is presented along with the longitudinal load factor (n_x) and ground speed in Figures 16 and 17. The engine thrust, which is measured by N1 (presented in Figures 15-17), and the achieved n_x are used in the μ_B calculation.

The μ_B can be computed from n_x , engine N1, and knowledge of the airplane's aerodynamic and thrust characteristics. Figure 18 is a free-body diagram showing the forces and moments acting on the airplane during the braking portion of the ground roll. The lift, pitching moment, drag, and thrust forces shown in Figure 18 can be estimated based on the recorded FDR data, and the known aerodynamic and thrust properties of the airplane. The vertical and longitudinal reaction forces at the main and nose gear (N_N , F_N , N_M , and F_M) are unknown, but can be computed by solving the following system of equations:

$$F_N = \mu_N N_N \quad [10]$$

$$F_M = \mu_B N_M \quad [11]$$

$$\sum F_x = W n_x + W_x = W(n_x - \sin \theta) \quad [12]$$

$$\sum F_z = W n_z + W_z = W(n_z + \cos \theta) \quad [13]$$

$$\sum M_y = 0 \quad [14]$$

Where:

N_N = vertical reaction at nose gear

μ_N = rolling friction coefficient at nose gear

F_N = longitudinal reaction at nose gear (rolling friction on nose gear)

N_M = vertical reaction at main gear

μ_B = wheel braking friction coefficient at main gear

F_M = longitudinal reaction at main gear (braking friction on main gear)

$\sum F_x$ = sum of forces along body x-axis

W = airplane weight

W_x = component of airplane weight along body x-axis
 n_x = longitudinal load factor
 θ = airplane pitch angle
 $\sum F_z$ = sum of forces along body z-axis
 W_z = component of airplane weight along body z-axis
 n_z = vertical load factor (= normal load factor multiplied by -1)
 $\sum M_y$ = sum of moments about body y-axis

Note from Equation [11] that the retarding force provided by the main gear tires during braking (F_M) is equal to the normal force on the gear, N_M (acting perpendicular to the runway surface), multiplied by μ_B . N_M is approximately equal to the weight of the airplane, minus the lift provided by the wings (see Figure 18). The lift depends on the flap setting, angle of attack (α), dynamic pressure (airspeed and air density), and the position of the (wing mounted) spoilers or speedbrakes (if the airplane is so equipped). Deploying wing-mounted spoilers after landing greatly improves braking by reducing the airplane's lift, thereby increasing N_M (and F_M). The HondaJet has a speedbrake mounted in the tailcone, that "splits" open into the airstream when deployed. This speedbrake provides about 26% additional drag, but only decreases lift by about 3% (in contrast, wing-mounted spoilers on similar light jets can decrease lift when on the runway by about 60%).

Assuming the rolling friction on the nose gear (μ_N) is 0.02,¹⁵ Equations [10] - [14] can be reduced to three equations for the three unknowns N_N , N_M , and μ_B . As is evident in Figure 18, the geometry of the landing gear, thrust line, CG location, and aerodynamic reference point of the airplane must be known. This geometry, as well as aerodynamic coefficient and thrust data for the HA-420, were provided to the NTSB by Honda.

For the μ_B calculation, the θ recorded on the FDR was used, and the runway is assumed to be level. Tables of forward thrust as a function of true airspeed and engine N1 for the pressure and temperature conditions of the accident were provided by Honda. The engine N1 data shown in Figures 15-17, and the true airspeed computed from the FDR calibrated airspeed and static pressure, were used with these tables to compute the forward thrust from both engines during the ground roll (the HA-420 is not equipped with thrust reversers).

The result of solving Equations [10] - [14] for μ_B is shown in Figures 16 and 17, and in subsequent Figures discussed in Section D.9.

¹⁵ The rolling friction coefficient value assumed by different manufacturers can vary; for example, Boeing assumes 0.02 at low speeds, decreasing to 0.0125 at higher speeds, and Embraer assumes a value of 0.03 at all speeds. The method used to compute the landing distances in the HondaJet AFM does not involve the rolling friction coefficient.

The μ_B developed by a tire at a given ground speed and on a given runway surface is a function of the wheel slip ratio (s). The wheel slip ratio is defined as

$$s = 1 - \frac{V_{WHEEL}}{V_G} \quad [15]$$

Where V_G is the airplane's ground speed, and V_{WHEEL} is the tangential speed of the tire:

$$V_{WHEEL} = \omega_{WHEEL} r_{TIRE} \quad [16]$$

Where ω_{WHEEL} is the angular velocity of the wheel, and r_{TIRE} is the effective radius of the tire (the distance from the center of rotation of the wheel to the point where the tire contacts the runway). Per Equation [15], when the tires are free-rolling and $V_{WHEEL} = V_G$, then $s = 0$. Conversely, when the tires are locked and $V_{WHEEL} = 0$, then $s = 1$. The FDR did not record V_{WHEEL} parameters, and so the s of the wheels are unknown. However, the captain stated in his interview (see Reference 12) that at some point during the ground roll he engaged the emergency brake fully. This action would likely have locked both wheels, so that s would have been equal to 1 for both wheels thereafter. The photos of the tires in Figure 8 show evidence of reverted rubber hydroplaning, that can only occur when $s = 1$, as discussed below.

D.6. The physics of wet-runway stopping performance and hydroplaning

As noted above, the physics underlying an airplane's stopping performance and the factors that affect braking performance on a wet runway are reviewed in detail in Reference 3. Reference 3 also describes viscous, dynamic, and reverted rubber hydroplaning on wet runways, and the causes of each. Content from Reference 3 relevant to this accident is presented below.

μ_B increases above the rolling (unbraked) coefficient of friction (μ_N in Equation [10]) when the slip ratio (s) of the main gear tires increases above 0. μ_B reaches a maximum (μ_{max}) at a slip ratio $s_{\mu,max}$, and then decreases to the locked-wheel skidding coefficient of friction (μ_{skid}) at $s = 1$ (see Figure 19). The shape of the μ_B vs. s curve is affected by surface texture and tire tread pattern and is particularly variable in the region between μ_{max} and μ_{skid} .

μ_{max} and μ_{skid} are developed at the interface between the tire and the runway, and are correspondingly affected by a number of tire and runway characteristics. Tire characteristics include tire inflation pressure, tire design and construction, tread material and pattern, and tire wear. Runway characteristics include surface texture roughness, at both large and small scales ("macrotexture" and "microtexture"), water depth on the runway, and runway deposits such as rubber, paint, and sand. Notably, when the runway is flooded (water deeper than 3 mm or 0.1 inches above the top of the surface asperities), then dynamic hydroplaning is possible (see below).

For a given tire and runway, the most significant parameter affecting μ_{max} is the airplane's forward speed (ground speed). In general, μ_{max} and μ_{skid} decrease with increase in forward speed, though this effect is much more pronounced on wet runways than on dry ones. On a wet runway, μ_B decreases precipitously with forward speed, particularly on runways with relatively low macrotexture and / or microtexture. The modeling of μ_B as a function of speed on a wet runway is described further below.

$s_{\mu,max}$ (see Fig. 19) usually lies between 0.1 and 0.2. Modern anti-skid braking systems are designed to detect and operate near $s_{\mu,max}$, but they cannot do so perfectly. The ability of these systems to operate at $s_{\mu,max}$ is a measure of their efficiency (η_{AS}). The wet-runway μ_B model used in current FAA guidance concerning operations on wet runways (discussed further below) assumes a constant η_{AS} of 80% for modern, "fully-modulating" anti-skid braking systems, over the full speed range of the airplane, and independent of the μ_{max} that can be attained on the runway. However, the research presented in Reference 13 suggests that η_{AS} can decrease as μ_{max} decreases, and may even be as low as 0.5 at $\mu_{max} = 0.3$.

Reference 3 describes three types of hydroplaning: viscous hydroplaning, dynamic hydroplaning, and reverted-rubber hydroplaning.

"Viscous hydroplaning" is associated with the buildup of water pressure under the tire due to viscosity in a thin film of water between a portion of the tire footprint and the runway surface. This is the kind of hydroplaning inferred when a surface is described as "slippery when wet," e.g., a wet bathtub. μ_{max} is greatly reduced under the water film.

"Dynamic hydroplaning" is associated with the buildup of water pressure due to water density and the tire's forward speed; in this condition, the tire is lifted entirely off the surface of the runway, and a continuous, relatively thick layer of water lies between the tire and the runway surface. Dynamic hydroplaning is commonly referred to simply as "hydroplaning," and can be experienced by driving a car through a deep puddle at high speed. Under dynamic hydroplaning conditions, μ_{max} is further reduced, with the tire developing very little braking force, and the only retarding force being that due to fluid drag.

A water depth of 3 mm (0.118 inches) above the top of the runway macrotexture is considered the minimum required to support dynamic hydroplaning. If the water depth is sufficient, dynamic hydroplaning will occur when the tire's forward speed is greater than or equal to the hydroplaning speed, which depends on the tire pressure. For rotating tires (e.g., airplanes aborting a takeoff roll), the hydroplaning speed is given by

$$V_{p,spin\ down} = 9\sqrt{p} \quad (\text{rotating tire}) \quad [17a]$$

Where V_p is in knots and p is the tire inflation pressure in psi. For nonrotating tires (e.g., airplanes on approach to landing), the hydroplaning speed is given by

$$V_{p,spin\ up} = 7.7\sqrt{p} \quad (\text{nonrotating tire}) \quad [17b]$$

The nominal main gear tire inflation pressure of the HA-420 is 220 psi, corresponding to $V_{p,spin\ down}$ = of 133 knots and $V_{p,spin\ up}$ = 114 knots. Consequently, after touchdown N903JT was above $V_{p,spin\ up}$ for about 3 seconds. Figure 16 shows μ_B increasing from about 0.05 to 0.24 about two seconds after landing, so it is possible (if the slush on that part of the runway were deep enough)¹⁶ that the airplane could have been experiencing dynamic hydroplaning during that time. However, it also possible that this timing simply reflects the pilot's application of the brakes following touchdown.

On a wet runway, μ_{max} decreases with increasing speed due to viscous hydroplaning. If the water depth is sufficient and the speed increases to V_p , then dynamic hydroplaning will occur and μ_B will decrease to a minimum value (≈ 0.05 ; the unbraked rolling μ_B is typically modeled as 0.0125 to 0.03).

"Reverted-rubber" hydroplaning occurs during locked-wheel skids on wet runways when the tire rubber in the skid patches reverts to an uncured state. In this condition, μ_{max} decreases to very low values, and the tire leaves white streaks on the runway (as opposed to black streaks on dry runways resulting from molten rubber deposited in the wheel track). The low μ_{max} during reverted-rubber hydroplaning is relatively insensitive to airplane speed and runway texture. The photos of N903JT's tires shown in Figure 8 show evidence of reverted rubber, which would be consistent with a locked-wheel condition following the engagement of the emergency brake.

D.7. Sequence of events during the approach and landing

As N903JT descended through 2,250 ft. MSL (1,000 ft. above the runway 28 threshold) at 08:26:06, FDR data indicate it was configured for landing in icing conditions, with the gear down and flaps set to TO/APPR. The airspeed was 138 KCAS, 11 knots faster than the planned approach reference speed of 127 KCAS (see Figure 10), and the engines were at flight idle until 08:26:25 (contrary to Jet It's stabilized approach criteria for approaches below 1,000 ft. AGL in IMC; see Figure 15 and Section D.8.6). The airplane decelerated throughout the descent, reaching 121 KCAS at 08:26:51, but then accelerated to 133 KCAS at 08:27:17. The airspeed was 131 KCAS, or 9 knots higher than V_{REF} , as N903JT crossed the runway threshold with the throttle levers at idle. At touchdown, the airspeed was 119 KCAS. The throttle and N1 variations shown in Figure 15 are consistent with these airspeed variations on short final approach.

¹⁶ As noted in Section D.5.8, the FICON on the morning of the accident reported that 10% of runway 28 was observed to be covered in 1/8 (0.125) inch of slush.

The landing distances published in the AFM are based on several assumptions about touchdown speed and location. Among these are that the touchdown airspeed will be about 95% of V_{REF} , and that the touchdown will occur within about 1,400 ft. of the threshold. In the N903JT accident, 95% of V_{REF} was $(122) \times (0.95) = 116$ knots, so at 119 knots N903JT touched down 3 knots above the assumed touchdown speed. More significantly, N903JT touched down 2,300 ft. from the threshold, or 900 ft. past the touchdown point assumed in the AFM distances. At the threshold, N903JT was 55 ft. above the runway, only 5 ft. above the 50 ft. crossing height assumed in the AFM distances. Hence, the long touchdown likely resulted from the 9 knot airspeed exceedance rather than the 5 foot altitude exceedance over the threshold; the airplane used the additional air distance to bleed off this excessive speed, so the touchdown speed was only 3 knots above that assumed in the AFM distances.

The airplane's tailcone-mounted speedbrake was deployed about two seconds after touchdown. The increase in μ_B from about 0.05 to 0.24 within the same time indicates application of the wheel brakes, and that the pilot's application of the available deceleration devices was timely. As shown in Figures 16 and 17, the calculation of the μ_B achieved during the landing roll mirrors the n_x recorded on the FDR, including the oscillations in that parameter. Between 08:27:35 and 08:27:47 (2,650 and 4,700 feet from the threshold, respectively), the average μ_B was about 0.17, but then decreased to about 0.10 between 08:27:47 and 08:27:53 (4,700 and 5,500 from the threshold). Between 08:27:53 and the airplane's departure off the end of the runway at 08:28:03, the average μ_B was back up to about 0.16 (including during the time after 08:27:57, when the drift angle increased from 0° to 60° at the end of the runway). The μ_B achieved during the ground roll is compared with the μ_B underlying the AFM wet-runway stopping distances in Section D.9.5.

The dip in μ_B between 08:27:47 and 08:27:53 might be the result of a cornering friction demand from the tires associated with an attempt to arrest the airplane's progressive movement towards the right (north) side of runway 28, and steer it back towards the centerline (see Figure 9b). The FDR records a relatively sudden -1.75° left shift in the magnetic heading (from 281.25° to 279.50°) between 08:27:46.2 and 08:27:48.2, around the same time that Figure 9b shows that the movement towards the right edge of the runway stops. As described above, the friction available from the runway has to be shared between the braking and cornering demands of the airplane, so if friction is used for cornering, then less friction will be available for braking. This phenomenon might explain the dip in μ_B at the time the track of the airplane shifts towards the left.

As shown in Figures 12, 16, and 17, the drift angle (the difference between the airplane's heading and its track angle) started to increase dramatically to the right starting at about 08:27:57 (5,960 ft. from the runway threshold, and 541 ft. from the end), while decelerating through a ground speed of 64 knots. This increase in drift angle could be the result of an attempt to steer the airplane back towards the

centerline, combined with a substantial loss of cornering friction. The loss of friction might be associated with the engagement of the emergency brake, resulting in locked wheels and reverted-rubber hydroplaning (in his interview, the captain stated that “he started to apply emergency brake slowly and gradually . . . there was no change although he locked it to its detent. After that, they were ‘along for the ride.’”). The oscillations in n_x and μ_B decreased starting at about 08:27:55 (5,740 ft. from the threshold / 761 ft. from the end), suggesting that it is here that the emergency brake might have locked the wheels (stopping any modulating of the brakes by the anti-skid system that could have been the source of the oscillations).

N903JT departed the end of the runway at 08:27:03, 50 ft. to the left of centerline, at a ground speed of 41 knots and with a drift angle of 60° right and increasing. The airplane eventually came to rest on a steep incline about 143 ft. past the runway end and 91 ft. to the left of the runway centerline, with its tail pointed down the incline and nose pointed back upwards towards the runway on a final recorded heading of 113° and pitch angle of 31° (see Figures 4d and 12b).

D.8. Regulations and guidance concerning operations on wet runways

D.8.1. Overview

Section D.9 of this *Study* compares the actual μ_B achieved during the landing roll (as described above and presented in Figures 16 and 17) with the μ_B that would be predicted on a wet runway by the models specified in certain airplane certification regulations and guidance materials, and with the μ_B assumed in the unfactored¹⁷ landing distances published in the HA-420 AFM and AFM contaminated runway supplement (References 4 and 5), for a wet runway under the weight, configuration, and environmental conditions of the accident. In addition, the landing distance that would be required given the actual μ_B achieved during the landing roll is compared to the AFM distances and to the distances computed using the μ_B models specified in the guidance materials.

To provide context for the presentation of the wet-runway μ_B models and the landing distances that follow from those models, this Section will briefly outline the airplane certification standards that govern the landing distance information presented in the AFM, and the operating regulations that govern how that information is to be used.

Since October 2016, within the U.S.A. runway surface conditions and associated braking performance at federally obligated airports (and many others) have been described and reported using the Takeoff And Landing Performance Assessment

¹⁷ As described further below, the “unfactored” landing distance means the actual distance from the runway threshold required to land the airplane and bring it to a stop, without any safety factors applied.

(TALPA) Runway Condition Assessment Matrix (RCAM) framework. This framework can differ from those used in airplane AFMs to present landing distances for different runway conditions (as is the case for the HA-420). Operators who wish to take advantage of the RCAM must use an accepted method to “translate” RCAM “Runway Condition Codes” (RwyCCs) into the appropriate AFM runway condition and associated landing distances.

The relevance of different μ_B models and of the landing distances they imply is determined both by the accuracy of the models and data, and by how they are used to operate the airplane. The landing distance data that must be provided in the AFM are specified by the certification requirements of the airplane itself; and the use of this information during the operation of the airplane is governed by the type of operation in question. The HA-420 is certificated to the normal category airworthiness standards¹⁸ specified in 14 CFR Part 23 (as opposed to the transport category standards in Part 25), and therefore, in the USA, the airplane is restricted to Part 91 and Part 135 operations. It cannot be used for Part 121 operations. Consequently, the operational requirements of Part 121 are not directly relevant to this airplane, except by way of comparison, and in the manner that certain Part 121 requirements are used to derive the factored landing distances in the AFM.¹⁹

D.8.2. Required AFM landing distance data for turbine-powered airplanes

14 CFR §23.1587, “Performance Information,” dictates the landing distance information that must be presented in the AFMs of airplanes certificated under Part 23:²⁰

Unless otherwise prescribed, performance information must be provided over the altitude and temperature ranges required by §23.45(b).

(a) For all airplanes, the following information must be furnished—

...

(3) The landing distance, determined under §23.75 for each airport altitude and standard temperature, and the type of surface for which it is valid ...

¹⁸ The FAA issued Type Certificate No. A00018AT to the HA-420 on 12/08/2015, using 14 CFR Part 23, *Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Airplanes* as the certification basis.

¹⁹ In what follows, “Part” refers to Parts of Title 14 of the Code of Federal Regulations (14 CFR), governing Aeronautics and Space. Part 23 specifies airworthiness standards for normal, utility, acrobatic, and commuter category airplanes. Part 25 specifies airworthiness standards for transport category airplanes. Part 91 specifies general operating and flight rules, and includes Part 91K, governing fractional ownership operations. Part 135 specifies operating requirements for commuter and on-demand operations. Part 121 specifies operating requirements for domestic, flag, and supplemental operations. See 14 CFR for further details about airplane categories and the different types of operations.

²⁰ The parallel requirement for Part 25 airplanes is §25.1587, and refers to landing distances determined under §25.125.

The landing distance is defined in §23.75 as “the horizontal distance necessary to land and come to a complete stop from a point 50 feet above the landing surface.” Furthermore, §23.45(g) states that the landing distance of §23.75 “must be determined on a smooth, dry, hard-surfaced runway.”

Advisory Circular (AC) 23-8C, *Flight Test Guide for Certification of Part 23 Airplanes* (Reference 15) “sets forth an acceptable means, but not the only means, of showing compliance with [Part 23] concerning flight tests and pilot judgements.” Regarding §23.1587 as it applies to turbine and commuter category airplanes (such as the HA-420²¹), AC 23-8C states

Landing Distance. The landing distance from a height of 50 feet should be presented together with associated ambient temperature, altitude, wind conditions, and weights up to the maximum landing weight. Operational landing distance data should be presented for smooth, dry, and hard-surfaced runways. At the option of the applicant, with concurrence by the FAA, additional data may be presented for wet or contaminated runways and for other than smooth, hard-surfaced runways.

In general, the dry-runway landing distances are *required* to be published in airplane AFMs (for both Part 23 and Part 25 airplanes), and are based on performance demonstrated during flight tests on smooth, dry, hard-surfaced runways. The regulations do *not* require the publication of landing distances on other than dry runways, though applicants may choose to present this information as well. In this case, the information is not necessarily based on flight tests (largely because of the difficulty of achieving a consistent “wet” or “contaminated” runway surface), but is derived by calculations based on assumptions agreed to by the regulator. The HA-420 AFM does not include landing distance tables on other than dry runways, but it does include the following note:

The landing field length provided is based on a dry runway. If landing on a wet runway, it is recommended to increase the predicted landing field length by 30 %.

The European Aviation Safety Agency (EASA) does require the publication of landing distances on other than dry runways, if the airplane is to be operated on such runways (see EASA Certification Specification (CS) 23.1587(a)(4), and the discussion of CS 25.1591 in Reference 16). Therefore, in order to certify the airplane in Europe, in 2021 Honda published the *HondaJet Elite S Model HA-420 Wet and Contaminated Runway Performance Airplane Flight Manual Supplement* (Reference 5). The Introduction of this document states:

This AFM supplement provides aircraft performance data for the Honda Model HA-420 Elite S, fitted with two GE Honda Aero Engines Model HF120 engines, required for EASA Air Operations Part-CAT and recommended for Part-NCC. This data includes dry runway takeoff performance,

²¹ The HA-420 was certificated in the “normal” category, but it is a turbine-powered airplane.

which considers the effect of an all engines operating (AEO) rejected takeoff, as well as wet and contaminated runway performance. Landing distances include a 1.67 operational factor.

The document is stamped with a note that it is “FAA APPROVED on behalf of EASA.”

Honda provided the NTSB with information describing how the landing distances published in the HA-420 AFM (and supplement) are computed. The total landing distance is the sum of an air distance (from 50 ft. above the threshold to touchdown), a transition distance (the distance travelled in the 1.3 seconds assumed to be required to apply maximum braking following touchdown), and a ground roll distance (the distance required to come to a stop after full braking is applied).

Honda computes the air distance using the “Parametric Analysis Data Reduction” method specified in section 4.11.2.3 of Advisory Circular (AC) 25-7D, *Flight Test Guide for Certification of Transport Category Airplanes* (Reference 17). The air and transition distances assume that the following conditions specified in the POM (Reference 6) are satisfied: “at 50 ft, rapidly reduce thrust to IDLE and touchdown with minimal flare. Lower the nose to the runway and apply maximum braking.”

For the ground distance with full braking, Honda assumes a constant *airplane* braking friction coefficient (μ_{AP}) of 0.35 on a dry runway (in the basic AFM), and a constant μ_{AP} of 0.24 on a wet runway (in the “*Wet and Contaminated Runway*” supplement). Note that μ_{AP} differs from μ_B , as explained below.

The airplane braking friction coefficient (μ_{AP}) is similar to the wheel braking friction coefficient (μ_B) in that it quantifies the runway friction force acting on the airplane’s tires, but it differs in that it is a simpler calculation that does not isolate the braking forces and corresponding friction on the braked main gear alone, but accounts for the total frictional forces acting on the airplane, which result from both the braked main gear and the free-rolling nose gear:

$$\mu_{AP} = \frac{F_M + F_N}{N_M + N_N} = \frac{\mu_B N_M + \mu_N N_N}{N_M + N_N} \quad [18]$$

Whereas, from Equation [11],

$$\mu_B = \frac{F_M}{N_M} \quad [19]$$

Note that as μ_B approaches the rolling friction coefficient μ_N , $\mu_B \cong \mu_N$, $F_M \cong \mu_N N_M$ and

$$\mu_{AP} \cong \frac{\mu_N N_M + \mu_N N_N}{N_M + N_N} = \frac{\mu_N (N_M + N_N)}{N_M + N_N} = \mu_N \cong \mu_B \quad [20]$$

For the HA-420 at the accident CG location (25.8% MAC, per Table 1), μ_B is about 20%-25% greater than μ_{AP} , as determined from simulations of the airplane's stopping performance (these are described further below).

The landing distances computed as described above are *unfactored* landing distances – that is, they are physics-based calculations of the actual distances it will take the airplane to stop. The distances published in the AFM and supplement are *factored* distances – that is, they are based on the computed unfactored distances, but include a safety factor that increases the required distance to account for “operational factors including crosswind and landing technique” and other uncertainties. The dry landing distances published in the AFM include a 15% factor (the unfactored distances are multiplied by 1.15), and the wet landing distances published in the supplement include a 67% factor (the unfactored distances are multiplied by 1.67). As noted above, the original AFM (not the supplement) recommends multiplying the published (factored) dry distances by 1.3 to account for landings on wet runways.

14 CFR Parts 135 and 121 specify the required destination runway lengths for dispatching an airplane to a runway that is forecasted to be either dry or wet upon arrival (these factors are discussed further below).

Interestingly, in its discussion of §23.75, AC 23-8C notes that

Adverse Landing Conditions. The airplane should be satisfactorily controllable when landing under the most unfavorable conditions to be encountered in service, including crosswinds, wet runway surfaces, and with one engine inoperative. Demonstration of landing with an adverse crosswind of at least 0.2 V_{SO} is addressed in § 23.233. Operations on wet (but not contaminated) runway surfaces have been simulated by disconnecting the nosewheel steering on large part 23 airplanes. The effect of weight on the landing distance due to its influence on controllability of reverse thrust should be considered. The criticality of the adverse landing conditions should guide the level of complexity applicants use in determining controllability. Existing flight test practices have proven adequate for propeller driven part 23 airplanes, but they may not be adequate for small jets. Additional guidance may be found in AC 25-7B. *Part 23 jets typically have higher landing speeds and little drag to help slow the airplane. Landing accidents dominate the non-fatal accidents for small jets. This is a critical phase of flight for small jets and adequate attention should be given to adverse landing conditions such as wet runways* [emphasis added].

It should be noted that Part 23 does not specify any μ_B models for wet runways, unlike Part 25. §25.109 defines the accelerate-stop distance for transport category airplanes, and describes how this distance is to be determined. In particular, §25.109(c) defines the μ_B to be assumed in the calculation of the accelerate-stop distance for a smooth (ungrooved), wet runway; however, Part 25 does not prescribe the μ_B to be used when calculating the *landing* distance on a wet runway. As with Part 23, Part 25 does not require the publication of wet-runway landing distances in the AFM, though applicants may choose to provide this information as advisory data. The calculation of the μ_B prescribed by §25.109(c) is presented in Section D.9.2, and a proposal that would

require wet-runway landing distances to be published in the AFMs of Part 25 airplanes is described in Section D.8.8.

In December 2015, the FAA published AC 25-32, titled *Landing Performance Data for Time-of-Arrival Landing Performance Assessments* (Reference 18). This AC prescribes using the §25.109 μ_B model for computing wet landing distances that are (optionally) provided in Part 25 AFMs, and is discussed in greater detail below.²²

D.8.3. Regulations concerning dispatch and arrival landing distance assessments

The accident flight was conducted under the provisions of Part 135. For Part 135 operations, the use of the AFM landing distances required by §23.1587 is mandated by §135.385²³, which states, in part,

(b) Except as provided in paragraph (c), (d), (e), or (f) of this section, no person operating a turbine engine powered large transport category airplane may take off that airplane unless its weight on arrival, allowing for normal consumption of fuel and oil in flight (in accordance with the landing distance in the Airplane Flight Manual for the elevation of the destination airport and the wind conditions expected there at the time of landing), would allow a full stop landing at the intended destination airport within 60 percent of the effective length of each runway described below from a point 50 feet above the intersection of the obstruction clearance plane and the runway.

If, prior to takeoff, the destination runway is not forecast to be dry, then §135.385(d) applies:

(d) Unless, based on a showing of actual operating landing techniques on wet runways, a shorter landing distance (but never less than that required by paragraph (b) of this section) has been approved for a specific type and model airplane and included in the Airplane Flight Manual, no person may take off a turbojet airplane when the appropriate weather reports or forecasts, or any combination of them, indicate that the runways at the destination airport may be wet or slippery at the estimated time of arrival unless the effective runway length at the destination airport is at least 115 percent of the runway length required under paragraph (b) of this section.

The landing distances presented in the accident flight's "Trip Report" shown in Figure 3 do not reflect the requirements of §135.385 or of Jet It's GOM, though it does present the AFM landing distance required on a dry runway (3,987 ft., which includes the 15% safety factor described in section D.8.2), and the available runway length required to

²² In April 2009, the Takeoff and Landing Performance Assessment Aviation Rulemaking Committee (TALPA ARC) presented several recommendations to the FAA to increase the safety of operations on wet and contaminated runways. Among these recommendations was a requirement for manufacturers of Part 25 airplanes to provide wet-runway landing distances based on the μ_B computed per the method described in §25.109. The TALPA ARC recommendations were ultimately implemented through ACs 25-31 and AC 25-32, which are non-regulatory documents.

²³ The parallel requirement for Part 121 operations is in §121.195.

dispatch to a dry runway while taking advantage of Jet It's DAAP ($3,987 \text{ ft.} / 0.8 = 4,984 \text{ ft.}$) To dispatch to a wet runway, an additional 15% runway length is required (per §135.385(d)), bringing the total required length to $4,984 \text{ ft.} \times 1.15 = 5,732 \text{ ft.}$, which is consistent with the first officer's statement that "his final runway-needed number was 5,800 ft for runway 28" (see Reference 19).

Note that the runway length that would have been required to dispatch to a dry runway under the basic §135.385 rule would have been $3,987 \text{ ft.} / 0.6 = 6,645 \text{ ft.}$, 144 ft. longer than KAGC runway 28's length of 6,501 ft. Starting from the unfactored AFM runway length of $3,987 \text{ ft.} / 1.15 = 3,467 \text{ ft.}$, the required dry runway length would have been $3,467 \text{ ft.} / 0.6 = 5,778 \text{ ft.}$, 723 ft. shorter than runway 28. But the wet-runway length requirement would restore the extra 15%, bringing the required length back to 6,645 ft. So N903JT could only dispatch to KAGC under wet conditions taking advantage of the DAAP (as intended by the crew when loading as much fuel as possible at KTEB).

Independent of the requirements of §135.385, the HA-420 AFM advises that the published dry-runway landing distances should be increased by 30% when landing on a wet runway. In this case, the resulting required runway length would have been $3,987 \text{ ft.} \times 1.3 = 5,183 \text{ ft.}$ Notably, $5,183 \text{ ft.} / 0.8 = 6,479 \text{ ft.}$, very close to the length of the runway (6,501 ft.), so the crew might have used this calculation to determine how much fuel could be loaded on the airplane.

Note that §135.385 refers to a "turbine engine powered large transport category airplane." Nonetheless, §135.385 also applies to commuter category airplanes, per §135.398(c):

(c) No person may operate a commuter category airplane unless that person complies with the landing limitations prescribed in §§135.385 and 135.387 of this part. For purposes of this paragraph, §§135.385 and 135.387 are applicable to all commuter category airplanes notwithstanding their stated applicability to turbine-engine-powered large transport category airplanes.

The HA-420 is a turbine-powered, normal category airplane (not commuter category), so arguably §135.398(c) (and §§135.385 and 135.387) do not apply to it. Nonetheless, Section 2.6.1 of Jet It's GOM specifies that the company's operations will comply with the equivalent of §135.385, except as provided for by the DAAP (see Section D.8.5).

D.8.4. En-route landing distance assessments

European operational regulation CAT.OP.MPA.300 requires what amounts to an en-route landing distance assessment, i.e., a determination by the pilot while in flight as to whether or not a successful landing can be made at the intended destination, considering the best information available concerning the expected weather and condition of the runway at the time of arrival. However, other than specifying that this

determination must be made "having regard to the performance information contained in the operations manual," CAT.OP.MPA.300 does not provide guidance for making the determination. Challenges pilots may face in this regard include evaluating the runway condition based on weather, friction, or braking action reports, and selecting a safety factor to apply to landing distances computed from AFM guidance material.

There is no equivalent to CAT.OP.MPA.300 in the 14 CFR. However, following the Southwest Airlines landing overrun accident involving a Boeing 737-700 at Chicago Midway Airport (KMDW) in December 2005, the FAA performed an internal audit of regulations and guidance information concerning landing distance requirements, and on August 31, 2006 issued Safety Alert For Operators (SAFO) 06012, titled *Landing Performance Assessments at Time of Arrival (Turbojets)*. While a SAFO is not regulatory, it "contains important safety information and may include recommended action. SAFO content should be especially valuable to air carriers in meeting their statutory duty to provide service with the highest possible degree of safety in the public interest." SAFO 06012

urgently recommends that operators of turbojet airplanes develop procedures for flightcrews to assess landing performance based on conditions actually existing at time of arrival, as distinct from conditions presumed at time of dispatch. Those conditions include weather, runway conditions, the airplane's weight, and braking systems to be used. Once the actual landing distance is determined an additional safety margin of at least 15% should be added to that distance. Except under emergency conditions flightcrews should not attempt to land on runways that do not meet the assessment criteria and safety margins as specified in this SAFO.

The SAFO also notes that "the FAA has undertaken rulemaking that would explicitly require the practice described above." In December 2015, the FAA issued ACs 25-31 and 25-32 in lieu of the rulemaking contemplated in SAFO 06012.

SAFO 06012 points out that the dry-runway landing distances established during flight test, and that are the basis for the factored landing distances used for dispatch, are shorter than the landing distances achieved in practice. In addition, AFM landing distances for wet and contaminated runways may also be based on the minimum dry distances obtained during flight tests. Consequently, landing distances on wet or contaminated runways computed from AFM data with little or no additional safety margin may be too short for normal operations. The SAFO recommends a conservative approach to assessing the landing distance requirements, including using the most adverse reliable braking action report or expected conditions for the runway, and using values for air distances and approach speeds that are representative of actual operations. The SAFO recommends that a 15% safety margin be then added to the computed (unfactored) landing distance, as "the FAA considers a 15% margin between the expected actual airplane landing distance and the landing distance available at the time of arrival as the minimum acceptable safety margin for normal operations."

Reference 13 discusses NTSB recommendations concerning en-route landing distance assessments and SAFO 06012, as well as NTSB comments on the content of ACs 25-31 and 25-32.

SAFO 06012 was cancelled and replaced by SAFO 19001, published on March 11, 2019. SAFO 19001 updates the information presented in SAFO 06012 to incorporate the TALPA RCAM framework and the corresponding contaminated runway performance guidance provided in ACs 25-31 and 25-32. As stated in SAFO 19001,

After a Boeing 737-700 runway overrun accident at Chicago Midway Airport in December 2005, the FAA convened the Takeoff and Landing Performance Assessment (TALPA) Aviation Rulemaking Committee (ARC). The Federal Aviation Administration (FAA) adopted certain recommendations of the ARC (which became known as "TALPA"), and implemented them into the National Airspace System on October 1, 2016. This SAFO provides information and guidelines to airplane operators on utilizing the safety benefits TALPA provides.

In addition,

The TALPA ARC discovered significant gaps in information needed to determine if a safe landing can be made. The ARC produced consistent terminology and runway assessment criteria, and recommended usage of non-dry, non-wet [i.e., contaminated] performance data for takeoff and time of arrival landing calculations. The TALPA ARC did not recommend any changes in the *preflight* landing distance requirements.²⁴

Like SAFO 06012, SAFO 19001 recommends a conservative approach to assessing landing distance requirements, including using the most adverse reliable braking action report or runway condition code, values for air distances and approach speeds that are representative of actual operations, and a safety margin of at least 15%. However, compliance with SAFOs is not mandatory, and so the FAA can only "encourage" operators to adopt the practices recommended in the SAFO:

There is no specific regulation requiring operators to assess landing distance requirements at time of arrival, however the FAA encourages operators to adopt such procedures to ensure that a safe landing can be made. Additionally, the FAA highly encourages operators to use their FAA-approved landing performance data and any associated manufacturer-provided supplemental/advisory data in concert with the AC 91-79-generated RCAM Braking Action Codes to conduct an adequate landing distance assessment at the time of arrival. This is particularly important when the landing runway is contaminated or not the same runway analyzed for preflight calculations.

²⁴ A subsequent Aviation Rulemaking Advisory Committee (ARAC) has in fact recommended an addition to preflight (or dispatch) landing distance requirements, to account for the shortfall in the expected runway friction observed in a number of wet runway landing overruns; see Section D.8.8.

D.8.5. Jet It Operations Specifications & General Operations Manual

The certification of air carriers and commercial operators in the USA is governed by 14 CFR Part 119 §119.33(b)(3), which states that “a person other than a direct air carrier may not conduct any commercial passenger or cargo aircraft operation for compensation or hire under part 121 or part 135 of this chapter unless that person ... obtains operations specifications that prescribe the authorizations, limitations, and procedures under which each kind of operation must be conducted.” The content of operations specifications is defined in §119.49.

Jet It held²⁵ operations specifications (OpSpecs) for its operations conducted under Parts 91 and 135. Jet It’s *General Operations Manual* (GOM, Reference 2) states that

The purpose of this manual is to provide firm guidelines to enable all Company personnel to carry out their assigned duties and responsibilities in accordance with Company policies and FAA regulations. All employees and agents of Protocom Aviation, LLC must adhere to the policies, procedures, direction, and guidance contained in the General Operations Manual. Protocom Aviation, LLC, a Title 14 CFR Part 135 on-demand air carrier, air carrier certificate number 4PMA001O and Jet It LLC, a Title 14 CFR Part 91, Subpart K (part 91K) air operator certificate number RJTK480Q. This manual is applicable to operations conducted under 14 CFR Part 91, Part 91 Subpart K (91K) and Part 135. All flight operations will be conducted IAW the policies and procedures found in this manual.

The GOM specifies requirements and procedures for Jet It operations that comply with the requirements of 14 CFR Part 135 described above. Section 2.6 of the GOM, “Runway Limitations for Takeoff and Landing,” states that

The Pilot-in-Command prior to takeoff or landing at any destination, alternate, diversionary or departure airport shall ensure the usable portion of the active runway at the airport of intended landing or departure is of appropriate length to guarantee compliance with the Aircraft Manufacturer's Performance Data and the Federal Aviation Regulations that are applicable for that aircraft.

Regarding landing criteria specifically, Section 2.6.1 of the GOM specifies that the company’s operations will comply with the equivalent of §135.385, “except for Eligible On-Demand operations” as described in Section 2.6.2 of the manual. That Section states:

The following procedure is the Destination Airport Analysis Program (DAAP) allowing for a full stop landing at the intended destination airport within 80 percent of the effective length of each runway described below from a point 50 feet above the intersection of the obstruction clearance plane and the runway. For the purpose of determining the allowable landing weight at the destination airport, the following is assumed:

²⁵ Per an email to the NTSB Investigator in Charge (IIC) of the N903JT accident from the FAA Principal Operations Inspector (POI) assigned to Jet It, the company ceased operations in May 2023.

- The airplane is landed on the most favorable runway and in the most favorable direction, in still air.
- The airplane is landed on the most suitable runway considering the probable wind velocity and direction and the ground handling characteristics of the airplane, and considering other conditions such as landing aids and terrain.
- The operation is authorized by operations specifications or management specifications.

Additional requirements for DAAP.

1. Two Pilot operations, PIC must have at least 100 hours in category, class and type. No High Minimums PIC.

Total flight time for all pilots:

- Pilot in command (PIC)—A minimum of 1,500 hours, Airline Transport Pilot rated, category, class and type.
- Second in command (SIC)—A minimum of 500 hours, Commercial, Instrument rated, category, class and type.

2. Pilot Operating Limitations, if the SIC of a fixed-wing aircraft has fewer than 100 hours of flight time as SIC flying in the aircraft make and model, a type rating is required in the type of aircraft being flown, and the PIC is not an appropriately qualified check pilot, the PIC will make all takeoffs and landings in any of the following situations:

Landings at the destination airport when a Destination Airport Analysis is required by Part 91K and Part 135, §135.385(f), §91.1025(o) or §91.1037(c); and in any of the following conditions:

- The prevailing visibility for the airport is at or below three-quarters of a mile;
- The Runway Visual Range (RVR) for the runway to be used is at or below 4,000 feet;
- The runway to be used has water, snow, slush, ice, or similar contamination that may adversely affect aircraft performance;
- The braking action on the runway to be used is reported to be less than "good";
- The crosswind component for the runway to be used is in excess of 15 knots;
- Wind shear is reported in the vicinity of the airport; and
- Any other condition in which the PIC determines it to be prudent to exercise the PIC's authority.

3. Aircraft performance data to include normal, abnormal and emergency procedures as supplied by the aircraft manufacturer; and accomplished using iPreflight (APG) or RocketRoute prior to departure.

4. Airport facilities and topography, must be reviewed using iPreflight (APG) or RocketRoute to ensure obstacle clearance.

5. Runway conditions (including contamination); Review destination airport NOTAMs with emphasis to runway conditions (Dry, Wet, or contaminated).

6. Airport or area weather reporting;

7. Appropriate additional runway safety margins, if required;

All Protocom Aviation crew member utilizing this DAAP MUST meet and utilize the qualifications requirements of §135.4 and/or §91.1053 and §91.1055.²⁶

In addition, a Jet It *Flight Operations Bulletin* dated January 21, 2021, titled *Procedures and considerations for landings on Wet & Contaminated Runways*, stated in part:

Policy:

This policy is relevant to all flight operations personnel. Dispatchers and crews will use the below procedures for proving compliance with CFR requirements and ensuring adequate safety margins for landing on wet and contaminated runways. These procedures are applicable to all flight operations, including flights under Part 91 and Part 135.

On wet runways, the AFM recommended 130% landing distance factor [(LDF)] will be utilized instead of the 115% from CFR 135.385 and 91.1037, which is considered the *minimum* additional safety factor.

Procedures and landing distance factors for different Runway Condition Codes (RwyCC) are detailed below.

Landings on runways with RwyCC less than 4 are not permitted.

Procedures:

All pilots operating Jet It owned and/or operated aircraft must ensure compliance with CFR 135.385, or CFR 91.1037 as applicable, prior to dispatch to evaluate the suitability of the landing field at the expected time of arrival.

The primary method for proving compliance for dry and wet runways will be through *iPreflight Genesis*. In the air, crews may utilize the aircraft [Control Display Units (CDU)] to reassess compliance with changing weather/runway conditions as needed.

For both dry and wet runways, crews will always first assess whether conditions will allow for a full stop landing at the intended destination within 60 percent of the effective length of the runway. If unable to make these restrictions or otherwise adjust gross weight to comply, crews may be able to utilize Eligible On-Demand/91K provisions to increase the required landing distance up to 80% of the effective runway length provided they also meet the other restrictions associated with those provisions.

For contaminated runways, RwyCC less than 5, the below landing distance factor will be utilized. Crews may not further reduce the LDF.

** NOTE: There is an increased, and insidious, risk posed by moderate or heavy rain. The 1/8-inch threshold that separates a wet runway with a RwyCC of 5 from runway contaminated with water depth greater than 1/8-inch a RwyCC of 2 is based on possibility of dynamic hydroplaning. This can be especially true in moderate rain if the runway is not properly crowned, grooved, constructed with a porous friction course (PFC) overlay, or when water run-off becomes overwhelmed. During heavy rain events, this may be true even on a properly maintained grooved or PFC runway. Crews must exercise extreme caution when heavy rain is occurring or forecast and should hold or divert if the RwyCC is questionable.*

²⁶ These regulations specify the applicability of rules for eligible on-demand operations, and are essentially the conditions previously specified in Section 2.6.2 of Jet It's GOM.

The *Flight Operations Bulletin* includes the following table of landing distance factors:

The following factors are multipliers to the unfactored dry AFM demonstrated landing distances:					
Braking Action	Runway Condition Code				
	6 (Dry)	5 Good	4 Good to Medium	3 Medium	2 Medium to Poor
Normal Compliance	1.67	2.17	2.8	Not Authorized	Not Authorized
Eligible On-Demand	1.25	1.625	Not Authorized	Not Authorized	Not Authorized
Note: The Takeoff And Landing Performance Assessment (TALPA) Aviation Rulemaking Committee (ARC) developed, and the NBAA has endorsed the usage of, Landing Distance Factors to assess aircraft landing performance on contaminated runways when aircraft manufacturer information may be lacking or inadequate.					

Table 4. Landing Distance Factors specified in Jet It's January 27, 2021 *Flight Operations Bulletin*.

The table specifies that the multipliers are to be applied to the *unfactored dry* AFM landing distances (that is, the published distances divided by 1.15). For the accident case, the unfactored dry AFM landing distance is 3,467 ft. (see Section D.8.3). Consequently, for a Runway Condition Code 5 runway (corresponding to wet and slush-covered runways; see Section D.9.3), the required landing distance for "Normal Compliance" would have been 3,467 ft. x 2.17 = 7,523 ft., more than 1,000 ft. over the length of KAGC runway 28. The required landing distance for "Eligible On-Demand" (the DAAP) would have been 3,467 ft. x 1.625 = 5,634 ft., or 1,889 ft. (25%) less than the length required by "Normal Compliance." Note that the ratio of the RwyCC 5 factors to the RwyCC 6 factors is 1.3, the factor that the HA-420 AFM recommends applying to the dry distances to account for a wet runway.

In the KAGC accident, the first officer's computation of the required landing distance was equal to the published dry landing distances (including a 1.15 safety factor), multiplied by 1.25 to account for the runway length required by the DAAP, and finally multiplied by 1.15 to account for the wet runway. Hence the total safety factor he applied to the *unfactored* dry runway AFM distance was $(1.15)(1.25)(1.15) = 1.653$, which is slightly higher than the "Eligible On-Demand" factor of 1.625 factor applicable to RwyCC = 5 runways listed in Table 4. In this case, the difference between the two distances is $(3,467 \text{ ft.})(1.653 - 1.625) = 97 \text{ ft.}$

The note in the *Flight Operations Bulletin* describing the "increased and insidious risk" posed by heavy rain repeats the language of SAFO 19003, described below.

D.8.6. Jet It stabilized approach criteria

Jet It's Standard Operating Procedures Manual (SOP, Reference 1) and General Operations Manual (GOM, Reference 2) describe the company's policies and procedures concerning stabilized approach criteria. The GOM describes the "Stabilized Approach Concept" in Section 10.19, which states

It is essential that a stabilized approach to the landing runway be flown. A stabilized approach must be established before descending below the following minimum stabilized approach altitudes:

- 500 feet (152.4 meters) above the airport elevation during visual flight rules (VFR) or visual approaches and during straight in instrument approaches in VFR weather conditions.
- Minimum descent altitude (MDA) or 500 feet (152.4 meters) above airport elevation, whichever is lower, if a circling maneuver is to be conducted after completing an instrument approach.
- 1000 feet (304.8 meters) above the airport or touchdown zone elevation during any straight-in instrument approach in instrument flight conditions.
- 1000 feet (304.8 meters) above the airport during contact approaches.
- It is essential that the aircraft touchdown in the first one-third of the available landing distance (ALD), but in no case greater than 3000 feet (914.4 meters) down the runway, whichever is less.
- If touchdown in the first one-third of the ALD, but in no case greater than 3000 feet (914.4 meters) down the runway is not ensured, a rejected landing must be executed.

Appendix 3 to Jet It's SOPs is titled *Stabilized Approach*, and states, in part:

Stabilized Approach Guidance. Failure to recognize the need for a missed approach and to execute a missed approach is a major cause of approach and landing accidents. The following guidance provides a standardized method of determining when a go-around and missed approach is appropriate.

An approach is considered stabilized when all of the following criteria are met:

- All briefings and checklists have been completed.
- The aircraft is on the correct flight path.
- Only small changes in heading/pitch are required to maintain the correct flight path.
- The aircraft speed is not more than target airspeed + 10 knots and not less than target airspeed -5 knots (momentary deviations excepted).
- The aircraft is in the correct landing configuration.
- Sink rate is no greater than 1,000 feet per minute. If an approach requires a sink rate greater than 1,000 feet per minute, the target sink rate as briefed in the approach briefing will be the maximum sink rate.
- Power setting is appropriate for the aircraft configuration and is not at idle power.

The criteria above will be met and checked by the following windows:

- 1,000 feet AGL if the weather is at or below 1000/3.
- 500 feet AGL if the weather is above 1000/3.
- 300 feet AGL in the VFR pattern or during a circling approach.
- If an approach becomes unstabilized below these altitudes, the crew will initiate a go-around and missed approach.

During N903JT's ILS approach to KAGC runway 28, it was in IMC, and the crew did not visually acquire the runway environment until the decision height (see Reference 12). Consequently, Jet It's stabilized approach criteria were required to be "met and checked" by 1,000 ft. AGL. Per Figures 7 and 10, N903JT descended through 2,250 ft. MSL (1,000 ATZ) at about 08:26:06, while decelerating through an airspeed of 138 KCAS (11 knots above the V_{APP} of 127 KCAS). Ignoring the 1 knot exceedance, this speed was technically within Jet It's stabilized approach criterion that the speed should not exceed $V_{APP} + 10/-5$ knots "(momentary deviations excepted)."

However, the steady deceleration to V_{APP} , and subsequent power adjustments used to briefly maintain V_{APP} before again slowing to V_{REF} , likely made precise speed control more difficult, even if the speed remained within Jet It's stabilized approach limits. Consistent with this observation, as the airplane descended below 1,000 ft. ATZ, the thrust levers and engine N1 speeds were at idle, contrary to Jet It's stabilized approach requirement that below 1,000 ft. TDZ the "power setting is appropriate for the aircraft configuration and is not at idle power." Hence the approach was not "stabilized" below 1,000 ft. TDZ, and Jet It's SOPs required "a go-around and missed approach," which did not occur.

D.8.7. Wet runway performance guidance: SAFOs 15009 and 19003

Reference 3 presents the μ_B achieved in eight accidents in which the airplane overran the runway after landing in wet conditions. In all but one of these accidents, the achieved μ_B was significantly lower than the μ_B predicted by industry-standard models, and the μ_B required to match the manufacturer's published unfactored, wet-runway landing distances.

In recognition of the unexpectedly low μ_B achieved in some of the accidents described in Reference 3 (among others), the FAA issued SAFOs 15009 and 19003 in August 2015 and July 2019, respectively. SAFO 15009 "warns airplane operators and pilots that the advisory data for wet runway landings may not provide a safe stopping margin under all conditions," and states that

Landing overruns which occur on wet runways typically involve multiple contributing factors such as long touchdown, improper use of deceleration devices, tailwind and less available friction than expected. Several recent runway landing incidents/accidents have raised concerns

with wet runway stopping performance assumptions. Analysis of the stopping data from these incidents/accidents indicates the braking coefficient of friction in each case was significantly lower than expected for a wet runway as defined by the Federal Aviation Administration (FAA) in Federal Air Regulation (FAR) 25.109 and Advisory Circular (AC) 25-7C methods. These incidents/accidents occurred on both grooved and un-grooved or non-Porous Friction Course overlay (PFC) runways. The data indicates that applying a 15% safety margin to wet runway time-of-arrival advisory data, as recommended by SAFO 06012, may be inadequate in certain wet runway conditions.

This statement summarizes the findings in the wet-runway overrun events described in Reference 3. The SAFO states that there are typically "multiple contributing" factors to wet-runway overruns, only one of which is "less available friction than expected." The other contributors include a long touchdown, tailwind, and "improper use of deceleration devices."

SAFO 15009 goes on to say that

The root cause of the wet runway stopping performance shortfall is not fully understood at this time; however issues that appear to be contributors are runway conditions such as texture (polished or rubber contaminated surfaces), drainage, puddling in wheel tracks and active precipitation. Analysis of this data indicates that 30 to 40 percent of additional stopping distance may be required in certain cases where the runway is very wet, but not flooded.

Based on examinations of the runways involved, rubber contamination, drainage, and puddling in wheel tracks were *not* contributors in the overrun accidents described in Reference 3.²⁷

SAFO 15009 states that "data contained in the Aircraft Flight Manuals (and/or performance supplemental materials) may underestimate the landing distance required to land on wet, ungrooved runways." The SAFO recommends that

Directors of safety and directors of operations (Part 121); directors of operations (part 135, and 125), program managers, (Part 91K), and Pilots (Part 91) should take appropriate action within their operation to address the safety concerns with landing performance on wet runways discussed in this SAFO.

The SAFO also suggests some ways of taking "appropriate action" to address the safety concerns, such as "assuming a braking action of medium or fair when computing time-of-arrival landing performance or increasing the factor applied to the wet runway time-of-arrival landing performance data."

²⁷ For one of the accidents described in Reference 13, it is not possible to exclude drainage and puddling problems or rubber deposits on the runway as contributors to the accident, though dynamic hydroplaning in that event can be ruled out.

SAFO 19003 “cancels and replaces SAFO 15009 and warns airplane operators and pilots that the advisory data for wet runway landings may not provide a safe stopping margin especially in conditions of Moderate or Heavy Rain.” This language is nearly identical to that in SAFO 15009, but specifies that the loss of friction might be associated with moderate or heavy rain conditions. In addition, SAFO 19003 updates the discussion in SAFO 15009 to refer to SAFO 19001 (which replaced SAFO 06012) and address the TALPA RCAM framework, and focuses on the risk of heavy rain events transitioning runways from a “wet” condition to a flooded (“contaminated”) condition:

These [landing] incidents/accidents occurred on both grooved and un-grooved runways. The data indicates that applying a 15% safety margin to wet runway time-of-arrival advisory data, as recommended by SAFO 19001 (or current guidance), may be inadequate in certain wet runway conditions. Takeoff and Landing Performance Assessment (TALPA) procedures implemented by the FAA on October 1, 2016, added new insight as to how flightcrews can evaluate runway braking performance prior to landing. TALPA defines WET as “includes damp and 1/8-inch depth or less of water,” while CONTAMINATED is “greater than 1/8-inch of water.”

Discussion: These overruns have occurred on grooved and smooth runways during periods of moderate to heavy rain. Analysis of these incidents/accidents indicates that the braking coefficient of friction in each case was significantly lower than expected, and that 30 to 40 percent of additional stopping distance may be required if the runway transitions from wet to contaminated based on the rainfall intensity or reported water contamination (greater than 1/8-inch depth). For the operational in-flight landing assessment, determining whether the runway is wet or potentially contaminated is the pilot’s responsibility.

In this accident, it is not likely that the runway “transition[ed] from wet to contaminated based on the rainfall intensity” present shortly before the landing, because the achieved μ_B during the landing roll, while not as high as that specified by the TALPA RCAM RwyCC 5 (Good), is not as low as that corresponding to a water depth close to or above 1/8 inch (see additional discussion in Section D.9).

SAFO 19003 continues:

The FAA recommends that airports report “Wet” conditions. However, airports are not required to report when a runway is only wet. Further, an airport may not be able to generate a Field Condition NOTAM (FICON) for sudden rain showers that result in water on the runway more than 1/8 of an inch in depth (contaminated). Rainfall intensity may be the only indication available to the pilot that the water depth present on the runway may be excessive. The 1/8-inch threshold that separates a wet runway with a RwyCC of 5 from runway contaminated with water depth greater than 1/8-inch a RwyCC of 2 is based on possibility of dynamic hydroplaning. This can be especially true in moderate rain if the runway is not properly crowned, grooved, constructed with a porous friction course (PFC) overlay, or when water run-off becomes overwhelmed. During heavy rain events, this may be true even on a properly maintained grooved or PFC runway.

The TALPA RCAM recommends using landing performance data associated with medium to poor braking or RwyCC of 2, if greater than 1/8-inch of water is anticipated to be on the runway. When planning to land on a smooth runway under conditions of moderate or heavy rain, or when

landing on a grooved or PFC runway under heavy rain, pilots should consider that the surface may be contaminated with water at depth greater than 1/8 inch and adjust their landing distance assessment accordingly. Pilots should use all available resources to determine what condition they may expect upon landing to include Air Traffic Control (ATC), FICONs (as some airports do report Wet conditions), flight visibility, and/or onboard weather radar.

Note: A Special Weather Observation (SPECI) will only be generated if a Thunderstorm begins. A SPECI is not generated when rainfall rates simply change.

Knowing ahead of time whether your aircraft can or cannot stop within the Landing Distance Available if runway conditions deteriorate to a medium to poor condition (RwyCC = 2) is critical when operating in moderate or heavy rain. Go-around, holding, or diversion may be necessary if rainfall intensity increases beyond what might be acceptable for the intended operation.

...

Unless the pilot or operator is knowledgeable of the runway's maintenance program, and that the runway is grooved or is a PFC surface that can provide good runway friction during periods of active moderate or heavy rain, they should consider basing their time-of-arrival assessment on the above recommendations. Aircraft operators should also clarify their reporting needs to the airport operator as it relates to "Wet" runway conditions.

Significantly, SAFO 19003 notes that pilots cannot rely on the airport to know of and / or inform them of flooded (standing water) conditions resulting from heavy rainfall, and it is the rainfall intensity itself that "may be the only indication available to the pilot that the water depth present on the runway may be excessive." Hence, the pilot's observation of heavy rain and recognition of its potential effect on braking performance is the last line of defense against sudden flooded conditions that can defeat the dispatch landing distance safety factors required by 14 CFR §121.195 and the operator's Operations Manual.²⁸

As argued more fully in Reference 3, in some extreme rainfall conditions μ_B is reduced to such an extent that landings in these conditions are best avoided. Prudently avoiding landings in dangerous rainfall conditions without unnecessarily disrupting operations will require identifying and communicating the presence of such conditions to flight crews. This in turn will likely require new rainfall rate descriptors that identify rainfall rates that can be several multiples of the current "heavy" rain threshold used in aviation weather reports, and updating the RCAM to incorporate these descriptors.

In this accident, the runway was not contaminated with liquid water due to heavy rain, but was covered with a certain amount of slush (the FICON active at the time reported 10% of the runway covered with 1/8 inch of slush; see also the photos in Figure 4). The RCAM Runway Condition (RwyCC) 5 includes both runways that are "wet (includes damp and 1/8 inch (3 mm) depth or less of water)" and runways covered with "1/8 inch (3 mm) depth or less of: slush; dry snow; wet snow." Hence, slush and water on the

²⁸ One accident in which heavy rain resulted in viscous hydroplaning and a severe shortfall in μ_B is the Miami Air Flight 293 accident in Jacksonville, Florida on 05/03/2019 (see Reference 23).

runway (up to a depth of 1/8 inch) are treated equivalently in the RCAM as RwyCC 5. The corresponding μ_B is described in Section D.9.2.

As discussed in Section D.9.2, in this accident the achieved μ_B was about 35% lower than that specified by the RCAM RwyCC 5 for a “wet” or slush-covered runway. In addition, assuming a nominal touchdown speed and air distance, the total landing distance that would have been required with the actual achieved μ_B is 5,970 ft. or 787 ft. longer than the distance recommended in the HA-420 AFM (1.3 times the dry runway distance, or 3,987 ft. $\times$ 1.3 = 5,183 ft.) The achieved μ_B is also significantly lower than that assumed in the wet runway landing distances published in the *Wet and Contaminated Runway* AFM supplement. The less-than-expected μ_B observed in this case and other wet-runway overruns investigated by the NTSB supports the argument in Reference 3 that operators would be prudent to determine wet-runway landing distances (or landing weight limitations) assuming a RwyCC less than 5.

D.8.8. FTHWG wet runway regulatory recommendations

As indicated by SAFOs 15009 and 19003, the FAA has recognized that the actual μ_B achieved on some wet runways may be less than that specified in §25.109(c), and that the runway length required to stop on these runways might exceed the lengths specified in AFMs. On March 8, 2013, the FAA assigned an additional task addressing wet runway stopping performance to the Transport Airplane Performance and Handling Characteristics Aviation Rulemaking Advisory Committee (ARAC). The notice in the *Federal Register* announcing this assignment (Reference 20) states:

The FAA tasked ARAC to consider several areas within the airplane performance and handling qualities requirements of the 14 CFR part 25 airworthiness standards and guidance for possible revision. The task includes prioritizing the list of topic areas provided in this notice based on prioritization criteria established by the [Flight Test Harmonization Working Group (FTHWG)]. The prioritization criteria should consider harmonization of regulatory requirements and associated guidance material for airworthiness certification of airplane designs. Recommendations may result in subsequent ARAC taskings for standards recommendations in follow-on phases. ARAC may also recommend additional topics in the general area of airplane performance and handling qualities that are not on the list provided in this notice.

The working group will provide a draft report to ARAC recommending focus areas and work plans to address those areas the FTHWG identified as high priorities for airworthiness standards development relative to new airplane designs. This report will provide the rationale for the priority recommended as well as identify those items for which coordination with other working groups or experts outside the FTHWG may be needed. The report will also include a proposed schedule for accomplishment of the plan, including whether multiple topics can be worked simultaneously. If there is disagreement within the working group, those items should be documented, including the rationale from each party and the reasons for the disagreement. The following subject areas should be considered:

1. *Fly-by-wire (FBW) Flight Controls.* ...

2. *Takeoff and Landing Performance*. Regulatory requirements and associated guidance material for airworthiness certification in the following areas listed below. (Note: This topic area excludes items addressed by the Takeoff and Landing Performance Assessment Aviation Rulemaking Committee.)

a. Flight test methods used to determine maximum tailwind and crosswind capability. ...

b. Wet runway stopping performance. Recent landing overruns on wet runways have raised questions regarding current wet runway stopping performance requirements and methods. Analyses indicate that the braking coefficient of friction in each case was significantly lower than expected for a wet runway (i.e., lower than the level specified in FAA regulations). Consideration should also be given to the scheduling of landing performance on wet porous friction course and grooved runway surfaces. Recommendations may include the need for additional data gathering, analysis, and possible rulemaking.

Because the tasking assigned to the FTHWG was very broad, the FTHWG decided to conduct the technical deliberations on each topic individually, and adopted the topic numbers from the original list of topics as identifiers for each topic. Wet runway landing performance was identified as "Topic 9."²⁹

The FTHWG started its review of wet runway stopping performance and associated μ_B models in September, 2015. In March 2018, the FTHWG published its final report on this topic, titled *FAA Aviation Rulemaking Advisory Committee FTHWG Task 9: Wet Runway Stopping Performance Final Report: Recommendation Report, March 16, 2018* (Reference 22). The report recommends the creation of a new 14 CFR Part 25 transport airplane certification requirement (§25.126) to determine landing distances on wet runways, to supplement the existing requirement to determine landing distances on dry runways (§25.125). In addition, the report proposes modifying the 14 CFR 121.195 operating rule to account for the wet runway landing distances required by the new §25.126 rule when dispatching airplanes to runways forecast to be wet at the time of arrival.

In general, the wet landing distances required by the recommended new §25.126 rule would have to be determined by calculation, assuming the μ_B defined by §25.109(c), and incorporate a 10% safety margin (see Reference 22 for details about exceptions to this requirement, such as the use of μ_B values determined by flight test). In addition, reverse thrust could be used when determining the wet-runway landing distances (in contrast to the dry-runway landing distances required by §25.125, which must be determined without the use of reverse thrust).

The recommended change to the §121.195 operating rule would require that to dispatch a flight to a runway forecast to be wet at the time of arrival, the landing distance available must be at least 115% of the wet-runway landing distance

²⁹ See Reference 21.

determined per the recommended new §25.126 rule. Hence, the landing distance required at dispatch to a wet runway would be equal to the unfactored landing distance determined using the μ_B defined by §25.109(c) and including the effect of reverse thrust, multiplied by a total safety factor of $1.1 \times 1.15 = 1.265$. (The 1.1 factor is from the recommended new §25.126 rule, and the 1.15 factor is from the recommended change to §121.195.)

One of the landing roll simulations described in Section D.9.5 indicates that the landing distance with TO/APPR flaps at a weight of 9,632 lb., with zero wind and runway slope, and using the μ_B defined by §25.109(c), is 4,660 ft. To use KAGC runway 28 with the DAAP 80% factor requires that the landing distance be no more than $6,501 \text{ ft.} \times 0.8 = 5,201 \text{ ft.}$; consequently, with landing distances based on the §25.109(c) μ_B model, the flight would still have been able to be dispatched with the expected landing weight. If the 1.265 safety factor on the wet runway landing distance computed per §25.109(c) had been applied, as envisioned by the FTHWG recommendations, the required landing distance would still only have been $4,660 \text{ ft.} \times 1.265 = 5,895 \text{ ft.}$, well within the 6,501 ft. length of runway 28.

As noted above, Jet It did not use the *Wet and Contaminated Runway* AFM supplement that provides landing distance tables for wet and contaminated runways. The wet runway landing distances in this supplement are based on a constant μ_{AP} of 0.24 (equivalent to a constant μ_B of about 0.29 in this case), and include a safety factor of 1.67. The resulting landing distance for the accident conditions is 7,097 ft., 596 ft. longer than the length of runway 28. The *unfactored* distance from the supplement tables is $7,097 \text{ ft.} / 1.67 = 4,250 \text{ ft.}$, or within 80% of the available runway length allowed by the DAAP ($6,501 \text{ ft.} \times 0.8 = 5,201 \text{ ft.}$)

D.9. Comparison of wet-runway μ_B models and resulting landing distances

D.9.1. Overview

This Section consolidates and compares in one place the several wet-runway μ_B models implicit in, and the landing distances for the accident conditions resulting from, the following sources (introduced above in separate Sections of the *Study*):

- The recommendation in the basic HA-420 AFM to add 30% to the published dry-runway distances to account for wet runways.
- The assumption of $\mu_{AP} = 0.24$ constant on wet runways in the HA-420 *Wet and Contaminated Runways* AFM supplement.
- The 14 CFR 25.109(c) μ_B model specified in the RCAM for RwyCC = 5 (water and slush covered runways for contaminant depths up to 1/8 inch)

- Jet It's *Flight Operations Bulletin: Procedures and considerations for landings on Wet and Contaminated Runways*.
- The method used by N903JT's first officer to compute the required runway length for the accident runway at KAGC.
- The actual μ_B achieved during the accident, as computed from the FDR data.

This Section also summarizes the historical development of the TALPA RCAM in the context of other TALPA recommendations, and its presentation in AC 25-32.

It will be shown that the μ_B achieved in the accident was about 35% lower than that specified by §25.109 for smooth (ungrooved) runways (KAGC runway 28 is grooved)³⁰, and substantially lower than the μ_B implied by the $\mu_{AP} = 0.24$ assumed in the *Wet and Contaminated Runways* AFM supplement (though the 1.67 safety factor applied to the published distances in the supplement more than makes up for the overestimated μ_B underlying the unfactored distances). As described in Reference 3, the μ_B achieved in other wet runway overrun accidents investigated by the NTSB has been as low as 50% of the §25.109 levels, and in one case (the 2019 Miami Air International flight 293 Boeing 737-800 accident in Jacksonville, Florida), extreme rainfall reduced the achieved μ_B even further (see Reference 23).

While the shortfall in μ_B in this accident is not as severe as has been observed in other wet runway overruns, it is yet another event indicating that the §25.109 model (which underlines the RCAM RwyCC 5 for wet and slushy runways) can overestimate the μ_B achievable on some wet or slushy runways, even in the absence of moderate or heavy rainfall. In addition, this accident, like others, indicates that depending on the safety factors applied, the μ_B underlying the wet runway landing distances published in the AFM can significantly overestimate the μ_B actually achievable on some wet runways, and consequently underpredict the landing distance required on such runways.

D.9.2. Definition of 14 CFR §25.109 wet runway braking friction coefficients

14 CFR §25.109 defines the accelerate-stop distance for transport-category airplanes, and describes how this distance is to be determined. The accelerate-stop distance is the distance required to accelerate from a stop to V_1 ,³¹ and then bring the airplane back

³⁰ As discussed below, the μ_B specified in §25.109 for grooved runways is higher than that for smooth runways; however, the maximum wet-runway μ_B modeled in the RCAM corresponds to the §25.109 smooth runway μ_B . To take credit for the higher μ_B modeled for grooved runways, operators have to determine that the runways in question can in fact provide this higher μ_B (see below).

³¹ Per 14 CFR 1.2, V_1 "means the maximum speed in the takeoff at which the pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes) to stop the airplane within the accelerate-stop distance. V_1 also means the minimum speed in the takeoff, following a failure of the critical engine

to a stop in the remaining runway length.³² §25.109(a) defines the accelerate-stop distance on a dry runway, and §25.109(b) defines the accelerate-stop distance on a wet runway. §25.109(c) defines the μ_B to be assumed in the calculation of the accelerate-stop distance for a smooth, wet runway. The μ_B for wet runways that are grooved or treated with porous friction course material are defined in §25.109(d).

For a smooth, wet runway, §25.109(c) defines the μ_B as follows:

The wet runway braking coefficient of friction for a smooth wet runway is defined as a curve of friction coefficient versus ground speed and must be computed as follows:

(1) The maximum tire-to-ground wet runway braking coefficient of friction is defined as:

<u>Tire pressure (psi)</u>	<u>Maximum braking coefficient (tire-to-ground)</u>
50	$\mu_{max} = -0.0350 \left(\frac{V_G}{100} \right)^3 + 0.306 \left(\frac{V_G}{100} \right)^2 - 0.851 \left(\frac{V_G}{100} \right) + 0.883$
100	$\mu_{max} = -0.0437 \left(\frac{V_G}{100} \right)^3 + 0.320 \left(\frac{V_G}{100} \right)^2 - 0.805 \left(\frac{V_G}{100} \right) + 0.804$
200	$\mu_{max} = -0.0331 \left(\frac{V_G}{100} \right)^3 + 0.252 \left(\frac{V_G}{100} \right)^2 - 0.658 \left(\frac{V_G}{100} \right) + 0.692$
300	$\mu_{max} = -0.0401 \left(\frac{V_G}{100} \right)^3 + 0.263 \left(\frac{V_G}{100} \right)^2 - 0.611 \left(\frac{V_G}{100} \right) + 0.614$

Where—

Tire Pressure = maximum airplane operating tire pressure (psi);

μ_{max} = maximum tire-to-ground braking coefficient;

V_G = airplane true ground speed (knots); and

Linear interpolation may be used for tire pressures other than those listed.

(2) The maximum tire-to-ground wet runway braking coefficient of friction must be adjusted to take into account the efficiency of the anti-skid system on a wet runway. Anti-skid system operation must be demonstrated by flight testing on a smooth wet runway, and its efficiency must be determined. Unless a specific anti-skid system efficiency is determined from a quantitative analysis of the flight testing on a smooth wet runway, the maximum tire-to-ground wet runway braking coefficient of friction determined in paragraph (c)(1) of this section must be multiplied by the efficiency value associated with the type of anti-skid system installed on the airplane:

Type of anti-skid system	Efficiency value [η_{AS}]
On-Off	0.30
Quasi-Modulating	0.50
Fully Modulating	0.80

at V_{EF} , at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance.”

³²This simplified definition suffices for the intent of this *Study*; §25.109 defines additional details regarding how this maneuver is to be accomplished, which account for engine failures and pilot reaction times.

Consequently, §25.109(c) defines the wet runway braking coefficient as

$$\mu_B = (\mu_{t/gMAX})(\eta_{AS}) \quad [21]$$

Where μ_{max} and the anti-skid efficiency η_{AS} are defined in the rule as shown above.

FAA AC 25-7D, *Flight Test Guide for Certification of Transport Category Airplanes*, dated 05/04/2018 (Reference 17), describes the three types of anti-skid braking systems identified in §25.109.³³ The HA-420 is equipped with a “fully modulating” anti-skid system, and so the applicable η_{AS} is 0.80 for this airplane.

The history of the §25.109 μ_B model described above, and its development from a μ_B model documented in Reference 14, is described in Reference 24.

The nominal loaded inflation pressure of the main tires for the HA-420 (serial #s 207 and up) is 215 to 225 psi.³⁴ Interpolating the μ_{max} tables above for a tire pressure of 220 psi gives

$$\mu_{max} = -0.0345 \left(\frac{V_G}{100} \right)^3 + 0.254 \left(\frac{V_G}{100} \right)^2 - 0.649 \left(\frac{V_G}{100} \right) + 0.676 \quad [22]$$

Where V_G is the ground speed in knots. The μ_B resulting from multiplying the μ_{max} defined in Equation [22] by the nominal η_{AS} of 0.80 (for a fully-modulating anti-skid braking system) is shown in Figure 20 as the blue dashed line labeled “25.109(c) μ_B , 220 psi, $\eta_{AS} = 0.8$.” The other lines in Figure 20 are described below.

14 CFR §25.109(d) defines the μ_B to be assumed in the calculation of the accelerate-stop distance for wet runways that are grooved or treated with porous friction course material. The method is similar to that prescribed in §25.109(c) for smooth wet runways, except that the polynomials defining μ_{max} as a function of V_G for different tire pressures are 5th order rather than 3rd order. The resulting μ_B is higher than that for a smooth runway, but an operator can only take credit for this higher μ_B if “the operator determines [that the grooved runways] are designed, constructed, and maintained in a manner acceptable to the Administrator” (see §121.189(e)). The TALPA RCAM does not refer to the higher μ_B specified in §25.109(d) for grooved runways.

³³ See AC 25-7D, paragraph 4.3.7.4, “Classification of Types of Anti-Skid Systems.”

³⁴ Per the HA-420 Aircraft Maintenance Manual. N903JT was serial # 224 (i.e., 42000224).

D.9.3. The TALPA RCAM and AC 25-32

As noted in SAFO 06012, following the Southwest Airlines accident at KMDW, the FAA initiated rulemaking that would require the practice recommended in the SAFO. In October 2007, FAA order 1110.149 established the "Takeoff/Landing Performance Assessment Aviation Rulemaking Committee." According to the order, the objectives and scope of the ARC were to

... provide a forum for the U.S. aviation community to discuss the landing performance assessment methods provided in SAFO 06012. Additionally, takeoff performance for contaminated runway operations and issues relevant to part 139, Certification of Airports, will be discussed. These discussions will be focused on turbine powered aircraft including both turbojet and turboprop airplanes operated under parts 121, 135, 125, and 91 subpart K.

In addition, the TALPA ARC "will provide advice and recommendations to the Associate Administrator for Aviation Safety. The committee will act solely in an advisory capacity." Furthermore,

the committee will discuss and present information, guidance, and recommendations that the members of the committee consider relevant to disposing of issues. Discussion will include, but is not limited to, the following:

- (1) Operational objectives, recommendations, and requirements.
- (2) Recommendations for rulemaking necessary to meet objectives.
- (3) Guidance material and the implementation process.
- (4) Global harmonization issues and recommendations.

The TALPA ARC presented landing performance recommendations to the FAA in April, 2009; these recommendations are presented in detail in Reference 16. Reference 16 also describes internal disagreements between TALPA ARC participants representing Part 91K, 125, and 135 operators on the one hand, and the FAA and most other TALPA ARC participants on the other, concerning the operational assumptions and safety margins to be used for landing distance assessments on contaminated runways.

As described in Reference 16, the regulatory changes proposed by the TALPA ARC would codify many of the provisions of SAFO 06012, and introduce a new "Runway Condition and Braking Action Reports" table that would provide a mapping between a six-level runway "code" and corresponding runway contaminant type and depth, Continuous Friction Measuring Equipment (CFME)³⁵ measured friction coefficient values, airplane wheel braking coefficient values, and pilot braking action reports. The runway codes range from "6," for a dry runway, to "0," for runways contaminated with

³⁵ CFME are ground vehicles that measure surface friction, typically by measuring the forces exerted on a test tire that is driven or towed down the test surface at a set slip ratio. In addition, CFME vehicles apply a film of water ahead of the test tire (typically 1 mm deep) in order to measure wet surface friction. More details about CFME, including their qualification and use in monitoring runway friction, can be found in Reference 16. No CFME data is available for KAGC runway 28.

various forms of wet ice, and for which braking action is “minimal to non-existent.” Aircraft manufacturers would have to supply data from which “operational” (i.e., unfactored) landing distances could be calculated for runway codes 6 through 1; operations would be prohibited on code “0” runways. The methods and assumptions to be used for generating this data would be specified in new regulations added to 14 CFR Part 25, “airworthiness standards: transport category airplanes.” Specifically, the new rules would require that the braking coefficients on wet, ungrooved runways be computed per the method described in 14 CFR §25.109(c).

In addition, pilots would be required to perform an en-route landing distance assessment prior to landing. This assessment would “consider the runway surface condition, aircraft landing configuration, and meteorological conditions, using approved operational landing performance data in the Airplane Flight Manual supplemented as necessary with other data acceptable to the Administrator.” A 15% safety margin would be added to the computed operational landing distance to determine the runway length required for landing.

The FAA declined to pursue rulemaking to codify the TALPA ARC recommendations, deciding instead to encourage adoption of the practices recommended by the TALPA ARC through non-regulatory means (see Reference 16 for a detailed description of this evolution). These efforts culminated in the publication of AC 25-32, *Landing Performance Data for Time-of-Arrival Landing Performance Assessments*, in December 2015.³⁶ This AC provides guidance and standardized methods that data providers, such as type certificate (TC) holders, supplemental type certificate (STC) holders, applicants, and airplane operators can use when developing contaminated runway landing performance data for transport category airplanes. In addition, the AC includes a Runway Condition Assessment Matrix (RCAM) that is the outgrowth of the “Runway Condition and Braking Action Reports” table proposed by the TALPA ARC. The RCAM promotes the use of consistent terminology for runway surface conditions used among data providers and FAA personnel, and is presented here as Figure 21. The FAA officially started reporting runway conditions for Part 139 airports using the RCAM in October 2016.

Note that while AC 25-32 provides guidance for the development of airplane landing performance data on contaminated runways, it does not include any operational guidance as to how this data should be used for en-route landing distance assessments, or recommend that any specific safety factor be applied to the data (whereas the TALPA ARC specifically recommended *requiring* that a safety margin of 15% be added to landing distance assessments). Similarly, the 15% safety margin and

³⁶ At the same time, the FAA published *Advisory Circular AC 25-31, Takeoff Performance Data for Operations on Contaminated Runways*, containing guidance for developing takeoff performance data on contaminated runways.

en-route landing distance assessment practice is *recommended* by SAFO 19001, but is not *required*. The NTSB expressed concern regarding these points, and about the non-regulatory approach to the TALPA ARC recommendations in general, in comments submitted to the FAA during the AC 25-32 draft comment period (see Reference 16).

The runway condition code (RwyCC) and corresponding μ_B model listed in Figure 21 that is most relevant to the N903JT accident is RwyCC 5. This RwyCC is associated with a pilot-reported braking action of “good,” and includes a runway surface that is “wet (includes damp and $\frac{1}{8}$ ” (3 mm) depth or less of water)” and “ $\frac{1}{8}$ ” (3 mm) depth or less of slush.” The slushy condition describes KAGC runway 28 at the time of the accident.

For a RwyCC 5 runway, Figure 21 indicates that the μ_B should be computed “per [the] method defined in §25.109(c).” As stated above and discussed in detail in Reference 3, and acknowledged in SAFOs 19003 and 15009, the §25.109(c) μ_B model can significantly overestimate the μ_B available on some wet runways. In comments on the draft versions of ACs 25-31 and 25-32 (Reference 25), the NTSB expressed concern with the use of the §25.109(c) μ_B model for code 5 runways, given the evidence from multiple events that this model is insufficiently conservative:

One technical problem that should be addressed within the ACs is their reliance, in part, on the wheel braking coefficient model codified in Section 25.109(c) for wet runway stopping performance calculations. However, the Section 25.109(c) model has never been validated by flight test data. To its credit, the FAA has recognized that the wheel braking coefficient model in Section 25.109(c) might be insufficiently conservative, as evidenced by the recent FAA Aviation Rulemaking Advisory Committee (ARAC) tasked to provide recommendations regarding new or updated standards for airplane performance and handling qualities. Under the subject area of Takeoff and Landing Performance, subtask (b) addresses wet runway stopping performance

The NTSB encourages the FAA to perform flight tests on representative domestic and international runways that support turbine-powered airplane operations in order to validate the wet-ungrooved and wet-grooved wheel braking coefficient models in Section 25.109(c). ...

The results of the ARAC task mentioned in these comments are the FTHWG wet runway regulatory proposals discussed in Section D.8.8. In their response to the NTSB’s comments, the FAA also noted that “FAA Flight Standards (AFS-200) has also addressed this topic to some degree in SAFO 15009, dated 8/11/15.”

D.9.4. HA-420 AFM stopping distances for the accident conditions

Perhaps the most relevant μ_B model, from an operational point of view, is that underlying the wet-runway stopping distances specified or recommended in the AFM. As described above, it is this information that operators use to ensure compliance with dispatch requirements and to perform a landing distance performance assessment, when required.

As noted in Section D.8.2, the basic HA-420 AFM does not include landing distance tables on other than dry runways, but it does include a note recommending that the published dry runway landing distances be increased by 30% when landing on a wet runway. The *AFM Wet and Contaminated Runways* supplement contains landing distances on wet runways, based on a constant μ_{AP} of 0.24 and a safety factor of 1.67.

Table 4 in Section D.8.5 describes the factors that Jet It applied to the (unfactored) AFM dry runway landing distances for their operations on dry and wet runways, and under both “normal compliance” §135 rules and the decreased runway lengths allowed by the “Eligible On-Demand” (DAAP) rules. However, the required landing runway length calculation described by the first officer appears to be a combination of the DAAP dispatch requirement to a dry runway and an application of the 15% additional runway length for dispatching to a wet runway required by §135.385(d).

The many possible combinations of these operating rules, landing distance data sources, and safety factors can be confusing. Table 5 summarizes combinations of these elements that are relevant to N903JT’s accident landing at KAGC. The resulting landing distances listed in Table 5 are also depicted in Figure 22 as the black diamonds along the x-axis of the plot.

Calculation description	Runway length required (feet)	Letter code in Figure 22
AFM unfactored dry	3,467	A
AFM factored dry (published data = unfactored dry x 1.15)	3,987	B
AFM Supplement unfactored wet (based on $\mu_{AP} = 0.24$ constant)	4,250	C
AFM factored dry x 1.3 (AFM recommendation for wet runways)	5,183	D
Jet It FOB, RwyCC 5 Eligible On-Demand (unfactored dry x 1.25 x 1.3)	5,634	E
FO’s calculation (AFM factored dry x 1.25 x 1.15)	5,731	F
§135.385(b) dry runway dispatch requirement (AFM unfactored dry / 0.6)	5,778	-
§135.385(d) wet runway dispatch requirement (§135.385(b) x 1.15)	6,645	-
AFM Supplement unfactored wet x 1.67 factor (published data)	7,097	G
Jet It FOB, RwyCC 5 normal compliance (unfactored dry x 1.67 x 1.3)	7,523	H

Table 5. Required runway lengths resulting from different combinations of data sources and safety factors. The available landing length on KAGC runway 28 is 6,501 ft.

As indicated in Table 5, the required runway lengths for the accident landing (wet or slushy runway) range from 5,183 ft. (the basic AFM recommendation) to 7,523 ft. (the length required by Jet It’s FOB, using normal compliance with §135 rules). These distances are between 1,318 ft. less than and 1,022 ft. greater than the 6,501 ft. length of KAGC runway 28.

The μ_B underlying the distances presented in Table 5 are plotted as a function of ground speed in Figure 20. Note that, as explained in Section D.8.2, the constant μ_{AP} assumed in the basic AFM and the AFM supplement for dry and wet conditions (0.35 and 0.24, respectively) correspond to higher μ_B values, as depicted in Figure 20.

The unfactored dry and wet landing distances presented in the AFM and the AFM supplement are physics-based, resulting from the parametric landing distance calculations described in Section D.8.2. These calculations are predicated on a height over the threshold of 50 ft., and an airspeed over the threshold of V_{REF} , resulting in a touchdown point 1,407 ft. from the threshold (for $V_{REF} = 122$ KCAS). As noted in Section D.5.2, the actual airspeed over the threshold was 131 KCAS, or 9 knots higher than V_{REF} , and the actual touchdown point was 2,300 ft. from the threshold, or 893 ft. past the nominal touchdown point. To determine the effect of these exceedances (combined with different μ_B models) on the required landing distance, simulations of the landing ground roll can be used, as described below.

D.9.5. Ground roll simulations assuming different μ_B models and conditions

Figure 20 compares the μ_B achieved during the accident landing roll ("Computed μ_B " (also plotted in Figures 16 and 17) with the μ_B defined by Equation [22] and η_{AS} values of 0.80 and 0.52. As discussed above, the $\eta_{AS} = 0.80$ value corresponds to that specified in §25.109 (and underlying RCAM RwyCC 5), and the $\eta_{AS} = 0.52$ value is that required for a simulation to approximately match N903JT's deceleration after touchdown (see Figure 22, discussed below). This value is 35% lower than the $\eta_{AS} = 0.80$ assumed in §25.109.

Figure 20 also plots the dry-runway $\mu_{AP} = 0.35$ (constant) assumed in the basic AFM, and the wet-runway $\mu_{AP} = 0.24$ (constant) assumed in the *Wet and Contaminated Runways* AFM supplement. As explained in Section D.8.2, μ_B is higher than μ_{AP} ; the corresponding μ_B values that result in μ_{AP} values of 0.35 and 0.24 for the accident landing conditions are shown in Figure 20 as the lines labeled "HA-420 AFM dry equivalent $\mu_B = 0.436$ " and "HA-420 AFM supplement wet equivalent $\mu_B = 0.29$." Note that the wet-runway equivalent μ_B of 0.29 matches the §25.109(c) μ_B with $\eta_{AS} = 0.80$ (that is, the RCAM RwyCC 5 μ_B) at 63 knots ground speed, but becomes progressively higher than the RwyCC 5 μ_B as speed increases above 63 knots, and progressively lower than the RwyCC 5 μ_B as speed decreases below 63 knots.

Most of the required ground roll distance is covered at higher speeds. Therefore, because the AFM supplement μ_B is higher than the RwyCC = 5 μ_B at higher speeds (and results in greater deceleration), the unfactored AFM supplement wet-runway ground roll distance is less than the distance resulting from the RwyCC 5 μ_B , and much less than the distance resulting from the §25.109(c) μ_B with $\eta_{AS} = 0.52$ (the μ_B actually achieved in the accident).

Figure 22 plots distance from the threshold vs. ground speed for several landing ground rolls, assuming two different touchdown conditions (those assumed in the AFM and those actually achieved in the accident), and several μ_B models. These results were computed using a simulation that solves Equations [10]-[14] for the deceleration of the

airplane, and then integrates deceleration over time to get ground speed. The ground speed is integrated to get ground roll distance.

All the simulations use the following conditions and assumptions:

- Flaps TO/APPR
- Speedbrake deployed and stowed (both conditions simulated)
- Weight = 9,632 lb.
- CG = 25.8% MAC
- Wind calm³⁷
- Runway elevation = 1,251 ft., level
- Temperature = 32° F
- Engine thrust as a function of true airspeed as provided by Honda
- Lift, drag, and pitching moment coefficients as provided by Honda
- Rolling friction coefficient of 0.02
- Step change in braking from zero to full braking at 0.5 seconds after touchdown

The timing of the step-input brake application in the simulation makes the simulation dry-runway landing distance for the AFM touchdown conditions match the unfactored AFM dry-runway distance. As noted in Section D.8.2, Honda's "parametric analysis" of the landing assumes a 1.3 second delay to achieve full braking after touchdown. However, the application of the brakes in Honda's calculation might not be a step input, as in the NTSB simulation; a step input at 0.5 seconds might be equivalent to a ramp input starting at touchdown that reaches maximum braking in 1.3 seconds. In any case, the step-input at 0.5 seconds in the NTSB simulation also results in a match (within 50 ft.) of the unfactored AFM supplement wet-runway landing distance.

Two different sets of initial conditions are considered in the simulation results shown in Figure 22. The first corresponds to the actual accident conditions:

- Initial ground speed = 118 knots
- Runway location = 2,600 ft. from runway 28 threshold
- Speedbrake = deployed
- Braking = immediate

The touchdown point in the accident was 2,300 ft. from the threshold, but the simulations that use the accident initial conditions start at 2,600 ft. from the threshold, and assume that the speedbrake is deployed and brakes fully engaged at this point.

³⁷ Per Figure 3, the landing was planned with 1 knot of headwind, but this only reduces the dry-runway landing distance by 5 ft. (3,467 ft. vs. 3,472 ft. for calm winds).

The simulation results corresponding to this set of initial conditions are depicted with thick lines in Figure 22.

The second set of initial conditions corresponds to the touchdown conditions assumed in the AFM and the AFM supplement (per Honda's "parametric analysis"):

- Touchdown airspeed = 116 KCAS
- Touchdown location = 1,407 ft. from runway 28 threshold
- Speedbrake = stowed (solid thin lines in Figure 22) & deployed (dashed lines)
- Braking: step input from zero to full braking 0.5 seconds after touchdown

The simulation results corresponding to this set of initial conditions are depicted with thin lines in Figure 22.

The thick black line labeled "FDR ground speed vs. ADS-B position" and the thick red line labeled "Accelerometer integration" in Figure 22 plot N903JT's ground speed as a function of position on the runway (its "deceleration profile"), based on FDR / ADS-B data and the kinematically consistent accelerometer integration described in Sections D.5.5 and D.5.6. The thick solid blue and dash-dot blue lines depict simulated deceleration profiles that would result from achieved μ_B levels equal to the §25.109(c) model with η_{AS} values of 0.80 and 0.52, respectively, starting from the actual touchdown conditions.

Note that the deceleration profile with $\eta_{AS} = 0.52$ approximately matches the actual deceleration profile, whereas the deceleration profile with $\eta_{AS} = 0.80$ (corresponding to RCAM RwyCC = 5) has the airplane stopping about 5,650 ft. from the threshold, or about 850 ft. before the end of the runway. Hence, even though N903JT touched down 893 ft. beyond the nominal touchdown point and 1 knot above the nominal touchdown ground speed, had it achieved the μ_B associated with an RCAM RwyCC 5 runway, it should have stopped with 850 ft. remaining. However, the simulation with $\eta_{AS} = 0.52$ has the airplane crossing the end of the runway at a ground speed of 44 knots, closely matching what occurred in the accident.

The thin lines plotted in Figure 22 depict simulated deceleration profiles with several μ_B models, starting from the nominal touchdown point (1,407 ft. from the threshold) and airspeed (116 KCAS). The μ_B models simulated include:

- $\mu_B = 0.436$ corresponding to the dry-runway $\mu_{AP} = 0.35$ assumed in the AFM
- $\mu_B = 0.29$ corresponding to the wet-runway $\mu_{AP} = 0.24$ assumed in the *Wet and Contaminated Runways* AFM supplement
- §25.109(c) μ_B model with $\eta_{AS} = 0.80$ (RCAM RwyCC = 5 model)
- §25.109(c) μ_B model with $\eta_{AS} = 0.52$ (model that matches accident performance)

Each case was run with both the speedbrake stowed (results plotted as solid lines in Figure 22) and with the speedbrake deployed (results plotted as dashed lines). The benefit of the speedbrake becomes more pronounced as μ_B decreases, as shown in Figure 22.

The timing of the wheel brakes application (step input from zero to maximum braking 0.5 seconds after touchdown) in all the simulations was set so as to make the total stopping distance in the speedbrake stowed, dry-runway simulation ($\mu_B = 0.436$) match the *unfactored* dry-runway landing distance determined from the AFM.

Note that in all cases, even the §25.109(c) model with $\eta_{AS} = 0.52$ (which best matches the accident performance), the airplane stops with over 500 ft. of runway remaining when the nominal touchdown conditions are satisfied. However, the stopping distance with $\eta_{AS} = 0.52$ is 776 ft. *longer* than the AFM wet-runway distance (point “D” in Figure 22) obtained by increasing the dry distance by 30%, indicating that the μ_B achieved in the accident was *lower* than that underlying the AFM wet distance.

The total stopping distances associated with the different combinations of μ_B models and safety factors presented in Table 5 are plotted along the x-axis of Figure 22 as black diamonds. The letter codes on the diamonds correspond to those in Table 5.

The simulation results presented in Figure 22 indicate that:

- Even with the longer-than-nominal touchdown point, the airplane would still have stopped on the runway had it achieved the μ_B corresponding to RCAM RwyCC = 5 (the §25.109(c) model with $\eta_{AS} = 0.80$);
- Even with the reduced μ_B actually achieved (the §25.109(c) model with $\eta_{AS} = 0.52$), the airplane would still have stopped on the runway had it touched down at the nominal touchdown point (1,407 ft. from the threshold).

These observations underscore the need for *both* computed landing distances that reflect the true performance capabilities of the airplane and runway combination, *and* the execution of the landing in accordance with the assumptions underlying the computed landing distances.

The HA-420 AFM and POM do not mention a target touchdown point for landing. However, the AFM landing checklist notes that prior to landing the airspeed should be V_{REF} (Reference 4, p. 4-20), and the POM states

At 50 ft, rapidly reduce thrust to IDLE and touchdown with minimal flare. Lower the nose to the runway and apply maximum braking. Deploy the speedbrake (if installed) and maintain maximum braking until the aircraft has stopped (Reference 6, p. 3-43).

In addition, in October 2022 (7 months after the accident) Honda issued Service Letter SL-420-42-011, titled *Determining landing distance on wet and contaminated runways* (Reference 26). This Service Letter states in part:

The landing field length provided in the HA-420 AFM Section 5 Performance is based on the following flight profile:

1. The airplane on approach is established at VREF prior to 50 feet above the runway, with the flaps set for landing and gear down, using thrust to maintain a 3-degree glideslope.
2. Thrust levers are rapidly reduced to IDLE at 50 feet above the runway, followed by a firm touchdown with little or no flare. This will result in a touchdown speed at approximately 0.95 VREF.
3. Prompt de-rotation after touchdown, then rapid application of maximum braking until the airplane stops.
4. The airplane is landed on a dry runway.

Deviations from the above, typical of everyday operational procedures, will result in increased landing distances. ...

... AFM landing distances assume minimal flare and landing at the runway aiming point (approximately 1,000 feet from the runway threshold). An extended flare will result in landing beyond the touchdown zone with a corresponding increase in landing distance.

Honda's Service Letter is consistent with Jet It's SOPs that state that "the [pilot flying (PF)] should plan to slow to V_{REF} by crossing the threshold to ensure validity of calculated landing data." However, the SOPs appear to indicate that the throttles only need to be reduced to idle by touchdown, as opposed to "rapidly reducing" them to idle at 50 ft. as instructed in the HA-420 POM and Honda's Service Letter.

Jet It's "stabilized approach concept" outlined in Section D.8.6 states that "it is essential that the aircraft touchdown in the first one-third of the available landing distance." KAGC runway 28 is 6,501 ft. long, so a touchdown in the first one-third of the runway would allow a touchdown up to $6,501 \text{ ft.} / 3 = 2,167 \text{ ft.}$ from the threshold, or 760 ft. past the nominal touchdown point assumed in the AFM landing distances (1,407 ft. from the threshold), and 1,167 ft. past the "approximately 1,000 ft. from the runway threshold" aiming point advocated in Honda's October 2022 Service Letter. Even so, the actual touchdown was 2,300 ft. from the threshold, or 133 ft. past the "first one-third" limit specified in Jet It's "stabilized approach concept." The concept further states that "if touchdown in the first one-third ... down the runway is not ensured, a rejected landing must be executed."

Jet It's policy that allowed a touchdown point well past the touchdown point assumed in the AFM landing distance data increased the risk of a landing overrun on a wet runway. It is not known how Jet It established the "first one-third" limit for the landing touchdown point, but the company might have simply been citing FAA AC 91-79A,

Mitigating the Risks of a Runway Overrun Upon Landing (Reference 27), which defines the “touchdown zone” as

a point 500-3,000 ft beyond the runway threshold *not to exceed the first one-third of the runway*. This reference is not used in landing distance performance calculations. [Emphasis added]

In addition, in describing stabilized approaches, AC 91-79A states that

the typical operational touchdown point *is in the first third of the runway, and it may be farther down the runway than the 1,000-ft. aiming point*. This additional distance should be accounted for in the landing distance assessment at time of arrival (TOA). [Emphasis added]

AC 91-79B (Reference 28) superseded AC 91-79A on August 28, 2023. Regarding the landing touchdown point, AC 91-79B does not refer to “the first one-third of the runway:”

Touchdown Point. The touchdown point used in the landing distance assessment reflects the assumed air distance. Operational landing data usually includes an allowance for 1,500 ft. or 7 seconds of air distance from the threshold to touchdown. An air distance as short as 1,000 ft. may be used provided an operator’s landing assessment procedures include enhancements to minimize the risk of overruns or undershoots

In addition, AC 91-79B identifies “landing beyond the intended touchdown point” as a “runway overrun hazard:”

Landing Beyond the Intended Touchdown Point. AFM/POH distances are based on a touchdown point determined through flight testing procedures outlined in AC 23-8, AC 25-7, and AC 25-32. If the airplane does not touch down within the air distance included in the AFM/POH landing distance, it may not be possible to achieve the calculated landing distance.

As noted above, the μ_B achieved in the accident landing was consistent with the §25.109(c) μ_B model with $\eta_{AS} = 0.52$, a reduction of 35% from the RCAM RwyCC 5 μ_B level computed using $\eta_{AS} = 0.80$. However, in this case as in the other wet-runway overrun events discussed in Reference 3, is difficult to determine whether the μ_B shortfall is actually due to a reduction in η_{AS} , or to a reduction in μ_{max} of the runway, or a combination of these factors. Anti-skid manufacturers often insist that the η_{AS} of their modern, fully-modulating systems remains above 80% (or higher) in all circumstances, even on runways with low μ_{max} . However, research described in Reference 13 indicates that η_{AS} decreases as μ_{max} decreases, even for fully-modulating systems. The next Section of this *Study* explores this tension between the claims of anti-skid system manufacturers and researchers, and provides a possible explanation for the apparent contradictions.

D.9.6. Some considerations concerning anti-skid system efficiency

As noted in Section D.9.2, in the §25.109(c) μ_B model described by Equation [21], the anti-skid system efficiency (η_{AS}) is a constant determined by the type of anti-skid system installed, equal to 0.80 for “fully modulating” systems (the type of system installed on the HA-420 and on all the airplanes considered in Reference 3). However, other μ_B models treat η_{AS} differently. Reference 3 describes a NASA μ_B model that also computes the final μ_B using Equation [21], but in which μ_{max} is based on CFME friction measurements, and η_{AS} is generally not constant. Instead, η_{AS} is modeled as follows:

$$\text{For } \mu_{max} < 0.7: \quad \eta_{AS} = \mu_B / \mu_{max} = 0.2 + 0.7143 \mu_{max} \quad [23a]$$

$$\text{For } \mu_{max} \geq 0.7: \quad \eta_{AS} = \mu_B / \mu_{max} = 0.7 \quad [23b]$$

Note that the η_{AS} defined by these equations is a function of μ_{max} (and is never greater than 0.7), and does not depend on the type of anti-skid braking system, as does the anti-skid efficiency value defined in §25.109. Significantly, Equation [23a] indicates that η_{AS} deteriorates with μ_{max} ; so, as the runway gets more slippery, the anti-skid system becomes less able to take advantage of the available friction that remains – in effect, a double penalty.

Reference 24 indicates that η_{AS} may also deteriorate with decreasing μ_{max} even for “fully-modulating” anti-skid systems, such as that on the Boeing 737-200 ADV.³⁸ In analyzing the results of several wet-runway landing tests conducted at Roswell, NM, in 1973 with a Lockheed L-1011 airplane and a Boeing 737-200 ADV airplane (originally documented in Reference 29), Reference 24 concludes that the B737 landing data “indicate that the η_{AS} of even fully-modulating systems decreases as the runway becomes more slippery.”

The authors of Reference 29 arrived at a similar conclusion by examining the relationships between the μ measured by ground vehicles and the stopping performance of various aircraft during flight tests (including the L-1011 and 737 tested at Roswell):

The theoretical aircraft braking efficiency, η , lines ... are related to a μ_{max} value for a low friction wet surface and have been obtained from a current NASA/FAA digital computer simulation study. This comparison indicates a considerable reduction in braking efficiency of the aircraft as the wet runway surface exhibits lower friction values. This trend is confirmed by the data previously shown in [the Roswell B737-200 ADV μ_B data] wherein the aircraft effective braking friction coefficient was shown to be closer to the level of μ_{skid} than to μ_{max} .

³⁸ Per an email from Boeing to NTSB dated 12/08/2010, the B737-200 ADV is equipped with a Hydro-Aire Mark III anti-skid braking system, which is an analog, fully modulating system.

ESDU 71026 (Reference 14) also addresses anti-skid system efficiency, and includes the chart duplicated here as Figure 23, which shows the range of η_{AS} values for “on-off” and “adaptive” type anti-skid systems. The chart indicates that, for values of μ_{max} from 0.25 - 0.30, “adaptive” systems have a “maximum likely value” of η_{AS} from 0.80 - 0.85, comparable to the η_{AS} specified by §25.109(c). However, these maximum values do “not allow for installation and undercarriage suspension effects.” In discussing this chart, ESDU 71026 states that

Values of μ_{eff} [equivalent to μ_B in this paper] and μ_{max} obtained or deduced from tests with a ground vehicle and aircraft are shown as the shaded areas in [Figure 23]. The scatter indicated by these shaded areas reflects differences between types of brake system and also the differences resulting from the application of these systems to particular undercarriage and test vehicle configurations.

The efficiencies that may be expected from current automatic braking systems are represented in [Figure 23] by the curves labelled, “adaptive system” and “on-off system”. These curves are derived principally from dynamometer tests and do not include any measure of the effects introduced when a brake system is incorporated as part of an aircraft undercarriage Where no further information is available, these curves should be used to estimate μ_{eff} once μ_{max} has been determined [emphasis in original].

ESDU 71026 goes on to include an equation for the effective braking force that is equivalent to modeling η_{AS} as follows:

$$\eta_{AS} = (k)(\eta_{AS, Fig. 23}) \quad [24]$$

Where $\eta_{AS, Fig. 23}$ is the η_{AS} determined from Figure 23, and

The factor k is included in [Equation [24]] to allow for possible reductions in braking efficiency due to, for example, normal load fluctuations, undercarriage vibration and suspension effects - none of which are usually simulated in dynamometer tests. Experience and the data presented as shaded areas in [Figure 23], suggest that until values of η_{AS} based on aircraft trials are available, k should be assumed to lie in the range $0.8 \leq k < 1.0$ Where more precise information is available, either from aircraft braking trials or from brake manufacturers' tests, it should be used.

In allowing an η_{AS} of 0.80 for “fully-modulating” anti-skid systems, §25.109(c) effectively assumes that *both* terms in Equation [24] ($\eta_{AS, Fig. 23}$ and k) will achieve the maximum values contemplated in ESDU 71026, implying that these systems will always operate at the “maximum likely value” level shown in Figure 23, and that there will be no reduction in efficiency due to “normal load fluctuations, undercarriage vibration and suspension effects.” However, Figure 23 indicates that when these effects are taken into account, the resulting η_{AS} can be as low as 0.50 at $\mu_{max} = 0.3$. If the lower bound of k given in ESDU 71026 (0.8) is applied to the §25.109(c) η_{AS} of 0.80, the overall η_{AS} is $(0.8)^2 = 0.64$, closer to the η_{AS} values that make the §25.109(c) μ_B match the actual μ_B achieved during the overrun events discussed in Reference 13 (and in this accident, as

well). This is further evidence that the $\eta_{AS} = 0.80$ value allowed by §25.109(c) regardless of the value of μ_{max} might be unreasonably high.

In contrast to the research described in Reference 24, the NASA η_{AS} model (Equation [23a]), and the guidance in ESDU 71026, anti-skid system manufacturers have maintained (in conversations with NTSB staff) that their systems can achieve and maintain efficiencies of 80% and higher, even in low runway friction conditions. These assertions are usually based on the manufacturers' hardware-in-the-loop simulations of stopping performance with various runway friction levels.

In general, it is difficult to determine η_{AS} from the values of μ_B obtained during a landing roll, because μ_B is the product of η_{AS} and μ_{max} , and μ_{max} is generally unknown. However, the amplitude and frequency of oscillations in μ_B can be used to obtain a measure of η_{AS} ; this method assumes that rapid, large fluctuations in μ_B are the result of oscillations in the slip ratio s of the tires (see Figure 19), and not of close-spaced variations in the μ_{max} of the runway. Under this assumption, the peaks of the μ_B oscillations correspond to points where s is close to $s_{\mu, max}$, and consequently μ_B is close to μ_{max} (a high η_{AS} condition). The troughs of the μ_B oscillations correspond to points where s is further away from $s_{\mu, max}$ (likely as a result of a release of brake pressure) and μ_B is further away from μ_{max} (a low η_{AS} condition). The overall η_{AS} of the stop can be ascertained by comparing the μ_B level, without oscillations, that results in the same stopping distance as the actual stop, with the μ_B level represented by the peaks of the μ_B oscillations and that hint at the actual level of μ_{max} .

The μ_B obtained during the N903JT accident exhibits high-frequency oscillations (driven by the oscillations in the FDR n_x), which suggest an η_{AS} of less than 80%. A clearer example of the HA-420 anti-skid system operating at $\eta_{AS} < 80\%$ is available in the data from an accelerate-stop flight-test on a "wet-fair broken" runway, shown in Figure 24.³⁹ The flight-test distance traveled, ground speed, and longitudinal load factor (n_x) are presented in Figure 24 with red lines. A polynomial curve fit of the distance travelled vs. time, and the first and second derivatives (speed and deceleration) of this curve fit, are shown as black lines. Note in Figure 24 that the highest ground speed attained during the test was about 87 knots (significantly lower than the N903JT touchdown ground speed of 120 knots).

The flight-test n_x plotted in Figure 24 exhibits large oscillations about the "curve fit" n_x that results in equivalent stopping performance. The flight-test data also contain several points where the n_x is close to zero, indicating little or no deceleration (or

³⁹ The flight test data was provided by Honda. The test referred to here involved normal braking with anti-skid at high speed on a "wet, broken" runway at KRWI (Rocky Mount/Wilson Regional Airport, Rocky Mount, North Carolina). The test consisted of an acceleration to about 88 knots ground speed, followed by heavy braking to a stop.

braking). At other points (necessarily), the flight-test n_x is much more negative (greater deceleration) than the “curve fit” value.

It is most likely that the variations in the flight-test n_x are due to variations in the braking force on the tires, rather than due to variations in drag or thrust. The variation in braking force can result from variations in μ_B and / or normal force on the gear (see Equation [11]). Variations in μ_B can result from variations in the μ_{max} of the runway, or variations in η_{AS} (i.e., the ability of the anti-skid system to maintain s near $s_{\mu,max}$). Given the relatively high variations in n_x over very short periods (for example, from -0.36 G's to -0.02 G's at time 118 seconds in Figure 24), it is most likely that the n_x oscillations are due to variations in s (and consequently μ_B) resulting from variations in brake pressure.

It follows that the most-negative flight test n_x values in Figure 24, where deceleration and brake forces are the highest, reflect conditions where μ_B is close to the μ_{max} of the runway. The dashed green line in Figure 24 labeled “ n_x available?” joins the peaks of the maximum n_x values, and suggests the n_x that could have been achieved by the airplane had μ_B remained consistently close to μ_{max} (and s to $s_{\mu,max}$). The “curve fit” n_x is an indicator of the “average” n_x actually achieved in the flight-test, and is only 60%-70% of the “ n_x available?” line. This indicates that the η_{AS} achieved during this test, on an airplane equipped with a fully-modulating anti-skid system, was well below 80%, and is further evidence that the §25.109(c) μ_B model is insufficiently conservative.

The above discussion comparing the “ n_x available?” line to the average n_x achieved in the flight-test is analogous to the description of the “torque method” for computing η_{AS} from flight test data contained in Section 4.3.7.6.10 of AC 25-7D (Reference 17).

D.9.7. Honda's post-accident actions

As a result of this accident and other overrun events involving HondaJet airplanes, Honda Aircraft Co. has taken a several actions to address the risk of landing overruns on wet runways. These include recommending that operators install the existing *Wet and Contaminated Runway Performance* AFM supplement, as well as developing plans to amend the wet runway guidance in the current AFM, and to eventually publish new wet runway landing distances based on an improved wet runway landing model.

Specifically, in October 2022 (7 months after the accident), Honda issued Service Letter SL-420-42-011, titled *Determining landing distance on wet and contaminated runways* (Reference 26). The purpose of the Service Letter is “to discuss factors affecting landing distance on wet and contaminated runways, and recommend use of *Wet and Contaminated Runway Performance* AFM Supplement data and [Take Off and Landing Distance] software, if applicable.”

In addition, Honda has shared an overview of the company's "countermeasures plan" for improving wet and contaminated runway guidance in the AFM with the NTSB. According to this plan, Honda intends to:

- Revise the HondaJet AFM and Quick Reference Handbook (QRH) to recommend using the *Wet and Contaminated Runway Performance AFM Supplement* data instead of the recommendation to add 30% of the dry landing distance.
- Improve the wet runway model used to compute the required landing distance in the *Wet and Contaminated Runway Performance AFM Supplement*.

E. CONCLUSIONS

The material in this Study supports a number of observations and conclusions regarding the performance of N903JT during its approach and landing on KAGC runway 28, and about the information and procedures available to the crew for their pre-flight planning.

E.1. Airplane performance during the approach and landing

Sections C.3 and D.7 of this *Study* summarize the motion of the airplane during its approach and landing, and the braking performance achieved during the landing roll. Sections D.7 and D.8.6 identify several ways in which the accident approach and landing differed from some of the assumptions underlying the landing distances published in the AFM and violated some of the stabilized approach criteria published in Jet It's SOPs.

Specifically,

- As the airplane descended below 1,000 ft. ATZ, the thrust levers and engine N1 speeds were at idle, contrary to Jet It's stabilized approach requirement that below 1,000 ft. TDZ the "power setting is appropriate for the aircraft configuration and is not at idle power." Hence the approach was not "stabilized" below 1,000 ft. TDZ. Jet It's SOPs state that "if an approach becomes unstabilized ... the crew will initiate a go-around and missed approach." The crew did not initiate a go-around, but instead continued the approach.
- Even though N903JT's approach speed remained approximately within Jet It's stabilized approach criteria of $V_{APP} +10/-5$ knots below 1,000 ft. AGL, the airplane's steady deceleration to V_{APP} , and the subsequent power adjustments

used to briefly maintain V_{APP} before again slowing to V_{REF} , likely made precise speed control more difficult.

- N903JT crossed the runway threshold 9 knots faster than V_{REF} , which contributed to a touchdown 893 ft. past the nominal touchdown zone, and increased the runway length required to stop.

As noted in Section C.3, the increased required runway length eroded the landing distance safety margin that was already reduced from nominal Part 135 requirements through the exercise of the operator's Destination Airport Analysis Program.

The *Study* indicates that, regarding the braking performance during the landing roll,

- The achieved μ_B was lower than that underlying the recommendation in the Airplane Flight Manual (AFM, Reference 4) to increase the published dry runway landing distance by 30% to determine the wet runway landing distance.
- The achieved μ_B was also lower than the μ_B underlying the unfactored landing distances published in the *HondaJet Wet and Contaminated Runway Performance* AFM supplement. However, the distances published in the AFM supplement are multiplied by a safety factor of 1.67, which more than covers for the effects of this difference.
- The achieved μ_B was also lower than that specified by 14 CFR §25.109(c), which corresponds to the RCAM runway condition code 5 for a "wet" runway. Prior to the large yaw to the left, while the airplane was tracking the runway heading and maximum braking was maintained, the achieved μ_B was consistent with that predicted by the §25.109(c) model, but with an η_{AS} of 0.52 instead of 0.8. This lower-than-expected μ_B result is not surprising; as documented in Reference 3, even greater reductions in the achieved μ_B below the nominal §25.109(c) μ_B have been observed in other NTSB wet-runway landing overrun investigations.
- At some point during the landing roll, perceiving that the airplane likely would not stop on the runway, the crew engaged the emergency brake fully, which likely put the airplane into a locked-wheel skid and reduced the braking and cornering performance of the tires. The reduction in cornering performance likely contributed to the large left yaw and drift to the right that developed as the airplane neared and crossed over the end of the runway.

- Simulations of the stopping performance indicate that even with the longer-than-nominal touchdown point, the airplane would still have stopped on the runway had it achieved the μ_B corresponding to RCAM RwyCC = 5 (the §25.109(c) model with $\eta_{AS} = 0.80$).
- Conversely, even with the reduced μ_B actually achieved (the §25.109(c) model with $\eta_{AS} = 0.52$), the airplane would still have stopped on the runway had it touched down at the nominal touchdown point (1,407 ft. from the threshold).

The simulation results underscore the need for *both* computed landing distances that reflect the true performance capabilities of the airplane and runway combination, *and* the execution of the landing in accordance with the assumptions underlying the computed landing distances.

E.2. Pre-flight (dispatch) landing distance requirements

The destination airport runway length requirements for dispatching flights under 14 CFR §135 are described in Section D.8.3, and the incorporation of these requirements into Jet It's GOM is described in Section D.8.5. As described in these sections, N903JT could only be dispatched to KAGC under wet conditions at its planned landing weight of 9,632 lb. using the increased runway length (and reduced safety margin) provisions of the DAAP (the DAAP allows 80% of the available runway length to be used for landing, instead of the 60% allowed by §135.385 (b)).

Jet It's requirements for dispatching to a wet runway under the provisions of the DAAP are described in the company's January 21, 2021 *Flight Operations Bulletin*, titled *Procedures and considerations for landings on Wet & Contaminated Runways*. To dispatch to a wet runway under the "Eligible On-Demand" provisions of the DAAP, the required runway length specified by the *Bulletin* is 1.625 times the *unfactored* dry-runway landing distance.

For the accident flight, the first officer's computation of the required landing distance was equal to the dry landing distances published in the AFM (including a 1.15 safety factor), multiplied by 1.25 to account for the runway length required by the DAAP, and finally multiplied by 1.15 to account for the wet runway. Hence the total safety factor he applied to the *unfactored* dry runway AFM distance was $(1.15)(1.25)(1.15) = 1.653$, which is slightly higher than the "Eligible On-Demand" factor of 1.625 factor that Jet It's *Flight Operations Bulletin* required for wet runways. Nonetheless, the FO's calculation appears to conflate the requirements of §135.385 and the provisions of the DAAP, rather than to follow the requirements of the *Bulletin*, and could be evidence that the proper application of the operational regulations, provisions of the DAAP, and

company procedures governing operations on wet runways might have been confusing to Jet It's pilots.

As noted in Section D.9.4, the many possible combinations of operating rules, landing distance data sources, and safety factors applicable to wet-runway landings can indeed be confusing. The landing distances for the accident conditions determined using various combinations of these elements are presented in Table 5, and range from 1,318 ft. less than to 1,022 ft. greater than the 6,501 ft. length of KAGC runway 28.

As noted above, the achieved μ_B in this accident (and others) is less than the μ_B modeled in §25.109(c) and assumed for RwyCC = 5 (wet runway and good braking action) in AC 25-32. In addition, the simulations described in Section D.9.5 indicate that, for the accident conditions, the landing distance corresponding to RwyCC = 5 is greater than the (unfactored) wet-runway landing distance specified in the HondaJet *Wet and Contaminated Runways* AFM Supplement (though much shorter than the distance published in the Supplement, which includes a 1.67 factor). These observations indicate that the additional airplane certification and operational dispatch requirements proposed by the FTHWG (described in Section D.8.8) have merit, and could benefit not only Part 121 operators of transport category airplanes, but Part 135 operators of all airplane types as well.

Section D.9.7 of this *Study* describes actions Honda has taken to address the risk of landing overruns on wet runways. Significantly, the company has plans to revise the HondaJet AFM and QRH to remove the recommendation to add 30% of the dry landing distance to account for the distance required on a wet runway, and replace it with a caution to use the *Wet and Contaminated Runway Performance* AFM Supplement data, including the 1.67 factor, to compute the required landing distance on a wet runway. The company ultimately plans to revise the AFM Supplement with data computed using an improved wet runway model based on the methods of 14 CFR §25.109(c).

Since the dispatch requirements of 14 CFR §135.385 are predicated on factors applied to the demonstrated *dry* landing distances published in the AFM, and not any "advisory" distances for wet runways, the wet-runway distance data provided in the AFM Supplement does not affect regulatory dispatch criteria. However, this data could inform the wet-runway landing distance requirements specified in operators' standard operating procedures, and be used for en-route landing distance assessments when conditions at the destination change from those assumed at dispatch.

The results of the investigation of this and many other wet-runway overruns indicates that operators would be prudent to ensure, at the time of dispatch to a potentially wet runway, that the available runway length at the destination is at least as long as the RwyCC = 5 distances computed per the methods of AC 25-32, including the 15% safety margin recommended by SAFO 19001. If active precipitation is possible at the time of landing, operators might want to consider computing the required landing distance

and safety margin assuming $RwyCC = 4$ or lower, depending on the intensity of the precipitation (see Reference 3 and 23 and SAFOs 19001 and 19003). Operators of airplanes for which landing distances computed per the methods of AC 25-32 are not available might want to consider requesting that the Type Certificate holders of their airplanes develop and provide such data.

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G. GLOSSARY

G.1. Acronyms

AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance - Broadcast
AFM	Airplane Flight Manual
AGL	Above ground level
ARAC	Aviation Rulemaking Advisory Committee
AWOS	Automated Weather Observing Station
CFR	Code of Federal Regulations
CG	Center of Gravity
CVR	Cockpit Voice Recorder
DAAP	Destination Airport Analysis Program
EASA	European Aviation Safety Agency
EST	Eastern Standard Time
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FTHWG	Flight Test Harmonization Working Group
GNSS	Global Navigation Satellite System
GOM	General Operations Manual
GPS	Global Positioning System
IMC	Instrument Meteorological Conditions
MAC	Mean Aerodynamic Chord
METAR	Meteorological Terminal Air Report
KAGC	Allegheny County Airport, Pittsburgh, Pennsylvania
KTEB	Teterboro Airport, Teterboro, New Jersey
NTSB	National Transportation Safety Board
OpSpec	Operations Specification(s)
PIC	Pilot In Command
POM	Pilot's Operating Manual
RCAM	Runway Condition Assessment Matrix
SAFO	Safety Alert For Operators
SIC	Second In Command
SRTM	Shuttle Radar Topography Mission
TALPA ARC	Takeoff/Landing Performance Assessment Aviation Rulemaking Committee
TC	Type Certificate
USGS	United States Geological Survey
UTC	Universal Coordinated Time
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules

G.2. English symbols

C_Y	Side force coefficient
F_N	Longitudinal reaction force at nose gear
F_M	Longitudinal reaction force at main gear
F_x	Force along body x-axis
F_z	Force along body z-axis
$\dot{h}$	Rate of climb
M_y	Moment about body y-axis
n_x	Longitudinal load factor
n_y	Lateral load factor
N_N	Vertical reaction force at nose gear
N_M	Vertical reaction force at main gear
r_{TIRE}	Effective tire radius
s	Wheel slip ratio
S	Wing reference area
u	Component of airspeed along body x-axis
v	Component of airspeed along body y-axis
V	Airplane speed (airspeed or ground speed depending on context)
$\vec{V}$	Airspeed vector
V_1	Takeoff decision speed
V_G	Ground speed
$\vec{V}_G$	Ground speed vector
$\vec{V}_W$	Wind speed vector
V_{WHEEL}	Tangential speed of tire
V_{REF}	Landing reference speed
w	Component of airspeed along body z-axis
W	Airplane weight
W_x	Component of airplane weight along body x-axis
W_z	Component of airplane weight along body z-axis
Y	Side force

G.3. Greek symbols

α	Angle of attack
β	Sideslip angle
δr	Rudder deflection
γ	Flight path angle
η_{AS}	Anti-skid braking system efficiency
θ	Pitch angle
μ_B	Wheel braking friction coefficient
μ_N	Rolling friction coefficient at nose gear
μ_{max}	Maximum μ available on runway
ρ	Air density
ϕ	Roll angle
ψ	True heading angle
ω_{WHEEL}	Wheel angular velocity

FIGURES

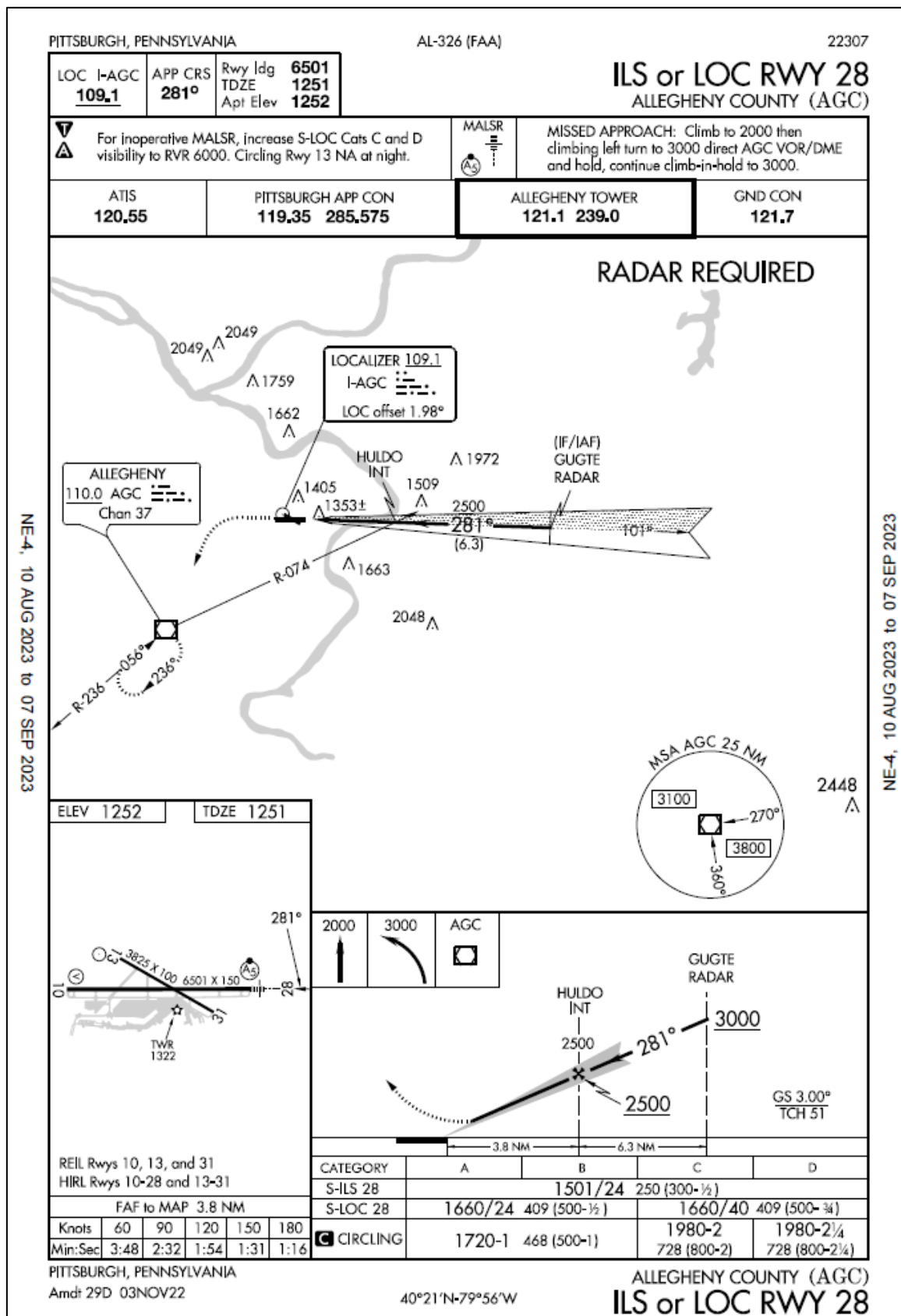


Figure 1. KAGC ILS or LOC runway 28 approach plate.

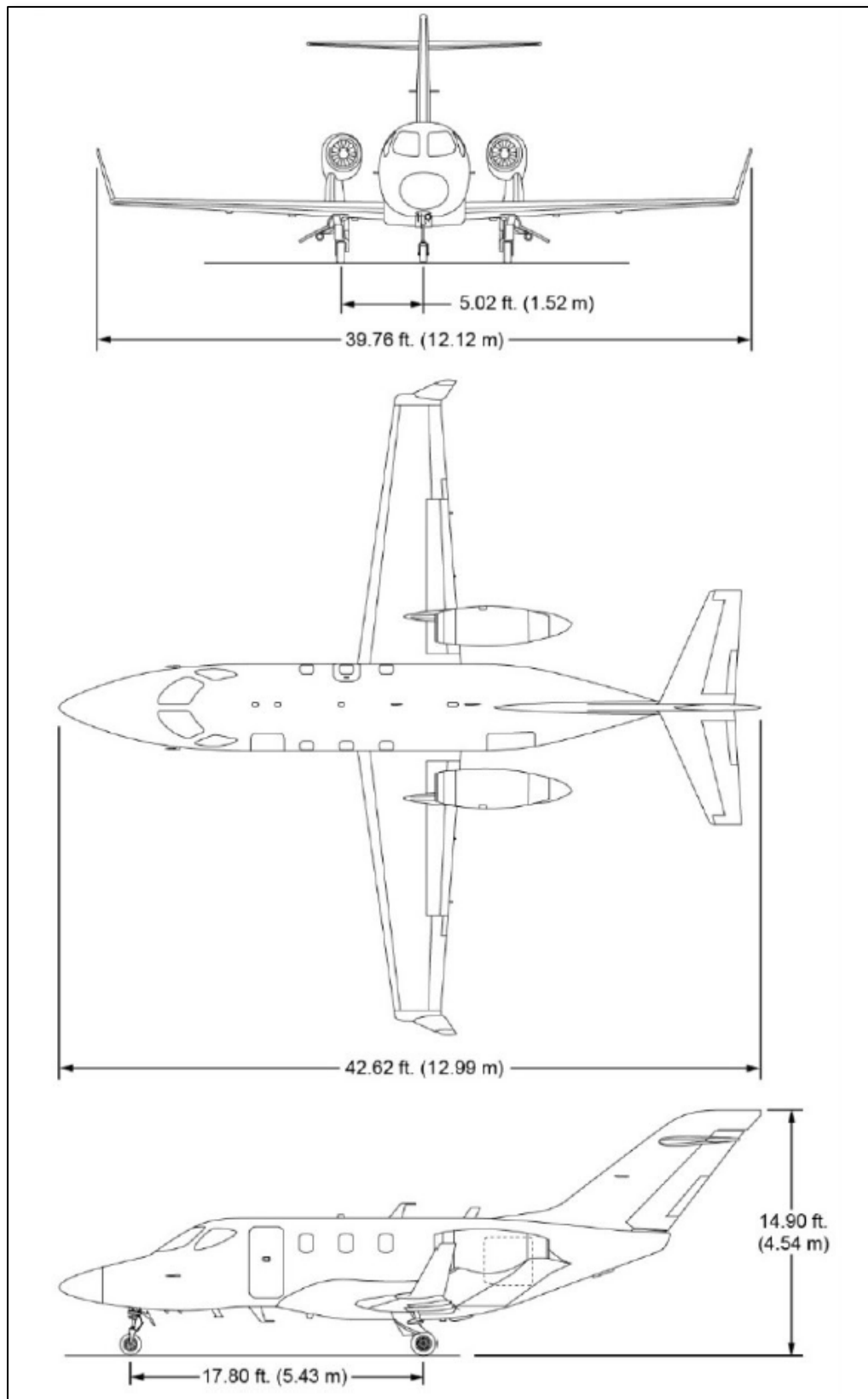
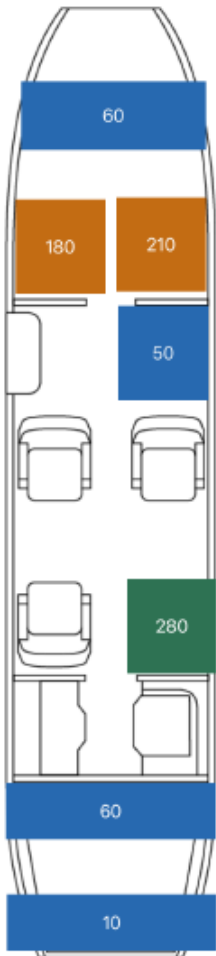


Figure 2. 3-view of HondaJet Elite S HA-420 airplane (from Reference 6).

N903JT / HondaJet Elite S / Honda GE HF-120

Generated Thu, 10 March 2022 15:56 with version 4.8.4

Flight Plan not filed



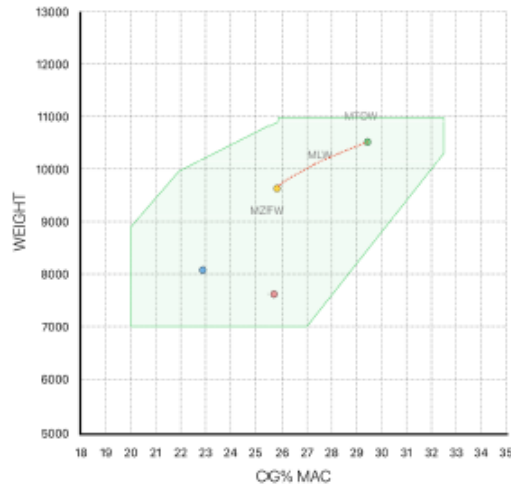
	Weight (lb)	FWD CG %MAC	CG %MAC	AFT CG %MAC
BEW	7190		37.53	
Pilots	390			
Aircraft Items	35			
BOW	7615		25.67	
Passengers	330			
Cabin Items	0			
Cargo	130			
ZFW	8075	20.00	22.88	28.79
Fuel	2520			
TAXI	10595	24.57	29.88	32.50
Taxi Burn	80			
TOW	10515	24.24	29.43	32.50
Takeoff Limit	10900	Structural		
Enroute Burn	883			
LDW	9632	21.33	25.80	31.39
Landing Limit	9993	Climb		

	Departure	Arrival
ICAO	KTEB	KAGC
Runway	01	28
Shortened		
TORA/LDA	7000 ft	6501 ft
Wind	10005 T	36004 M
Crosswind	5	4
Headwind	-1	1
Temp C	3	0
Altimeter	30.15	29.89
Flap	TO/APPR	TO/APPR (ICING)
Limit Weight	10900 lb	9993 lb
Reason	Structural	Climb

01	Departure	Reduced Thrust
Weight	10515 lb	
V1	104	N/A
VR	109	N/A
V2	115	N/A
VFTO	140	N/A
Power	0.00	N/A
TO Dist	3384 ft	N/A
L/O Altitude	1508 ft	1508 ft
Assumed Temp C	N/A	N/A

Departure Options

DRY, ANTI-ICE ON



28	Arrival	Emerg Ret (06)
Weight	9632 lb	10515 lb
VFS	140	140
VAPP	127	125
VREF	122	120
LD Dist	3987 ft	3153 ft
1.25 Dist	4984 ft	(1.00 LD) 3153 ft
MA Grad	2.8	6.0
Flap	TO/APPR (ICING)	LDG
Limit Weight	9993 lb	10900 lb
Reason	Climb	Structural

Arrival Options

WET 115%, ANTI-ICE ON, 80%
Landing Factor

Emergency Return Options

DRY, ANTI-ICE OFF, Unfactored
Landing Distance

Flight ID	
Flight Date	Mar 9, 2022 1200 Z
PIC	
SIC	
Jumpseat	
Dept Alternate	
Arrv Alternate	
SOB/CREW/PAX/Infants	3/2/1/0
Prepared By	
Notes	

Figure 3. Weight and balance form from the "Trip Report" for N903JT's accident flight (provided by Jet It).



(a)



(b)



(c)

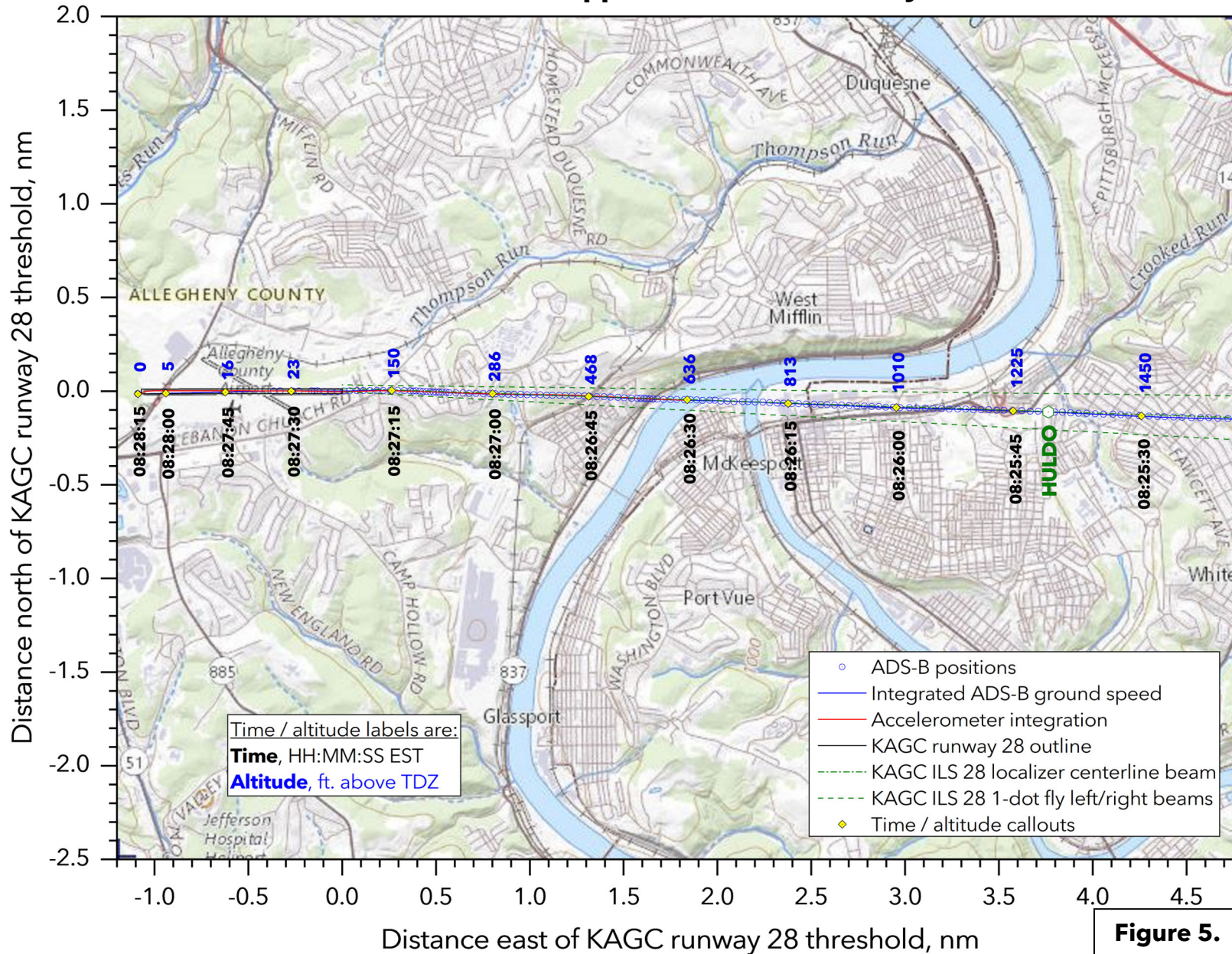


(d)

Figure 4. Images of N903JT from (a) a surveillance camera while on the runway and (b-d) at rest off the departure end of runway 28.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Plan view of approach to KAGC runway 28



ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Profile view of approach to KAGC runway 28

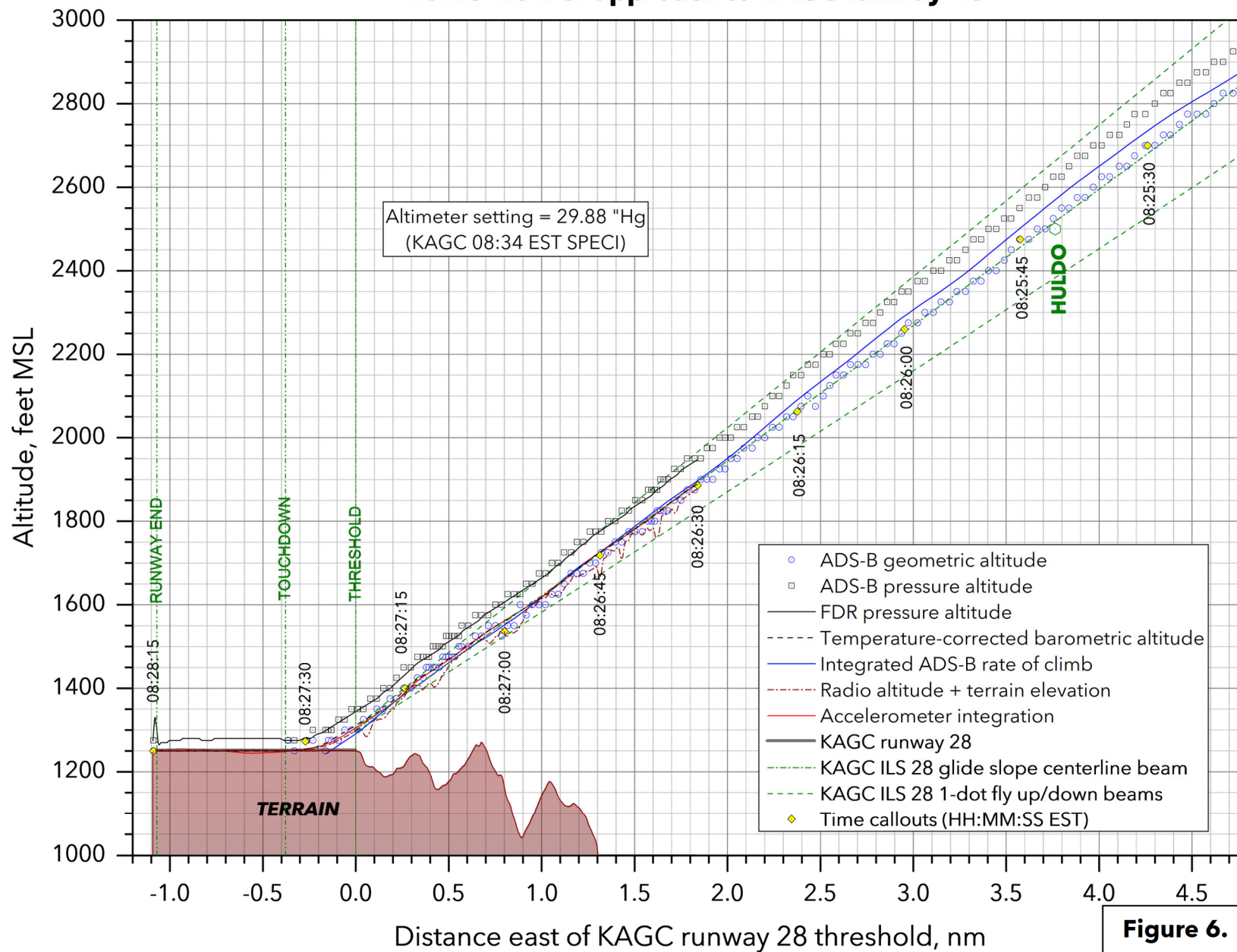


Figure 6.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Altitude vs. time during approach to KAGC runway 28

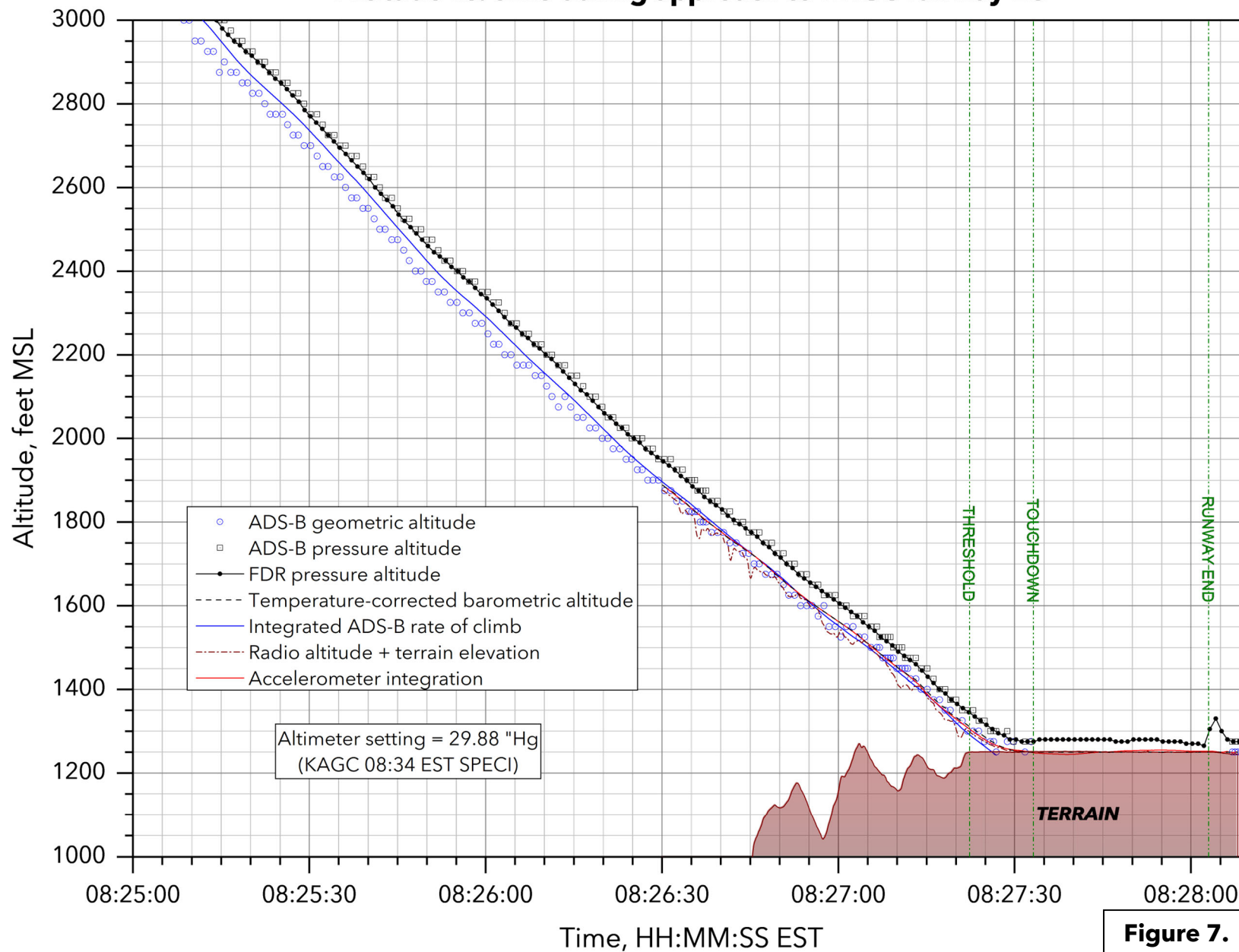
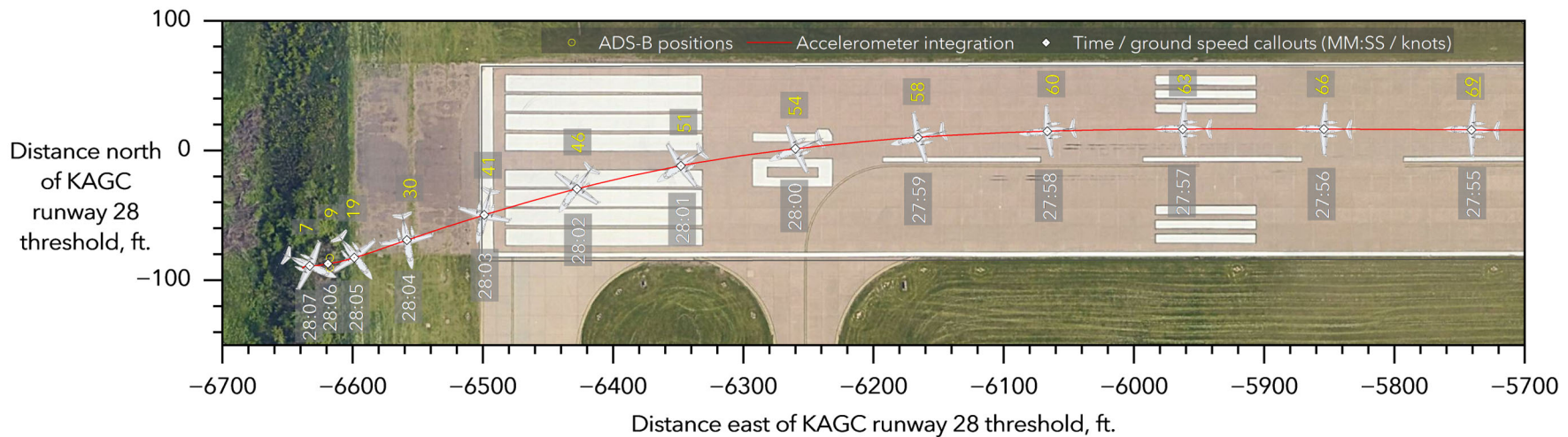
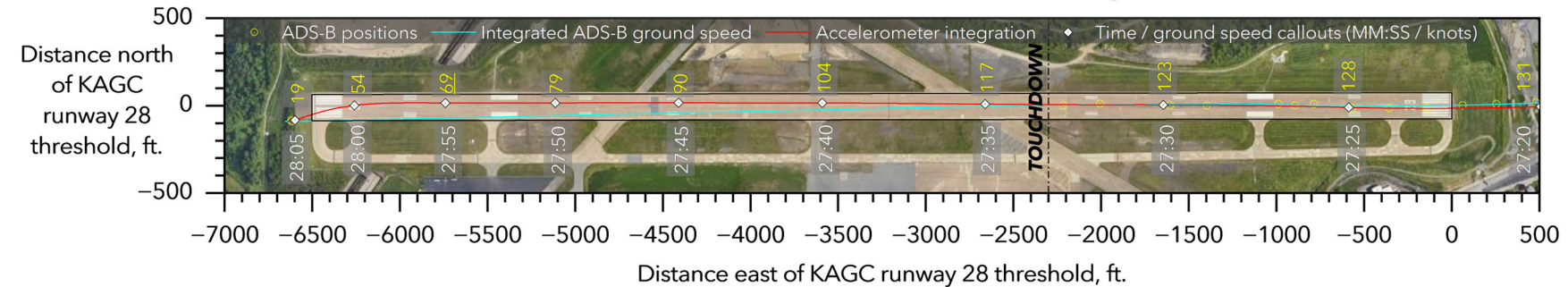


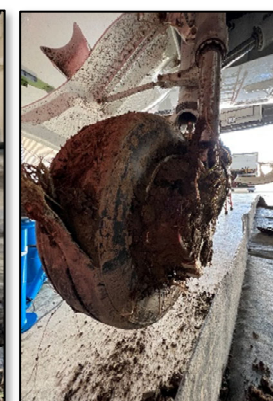
Figure 7.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Plan view of track on KAGC runway 28



27:74



ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

North & east coordinates during approach to KAGC runway 28

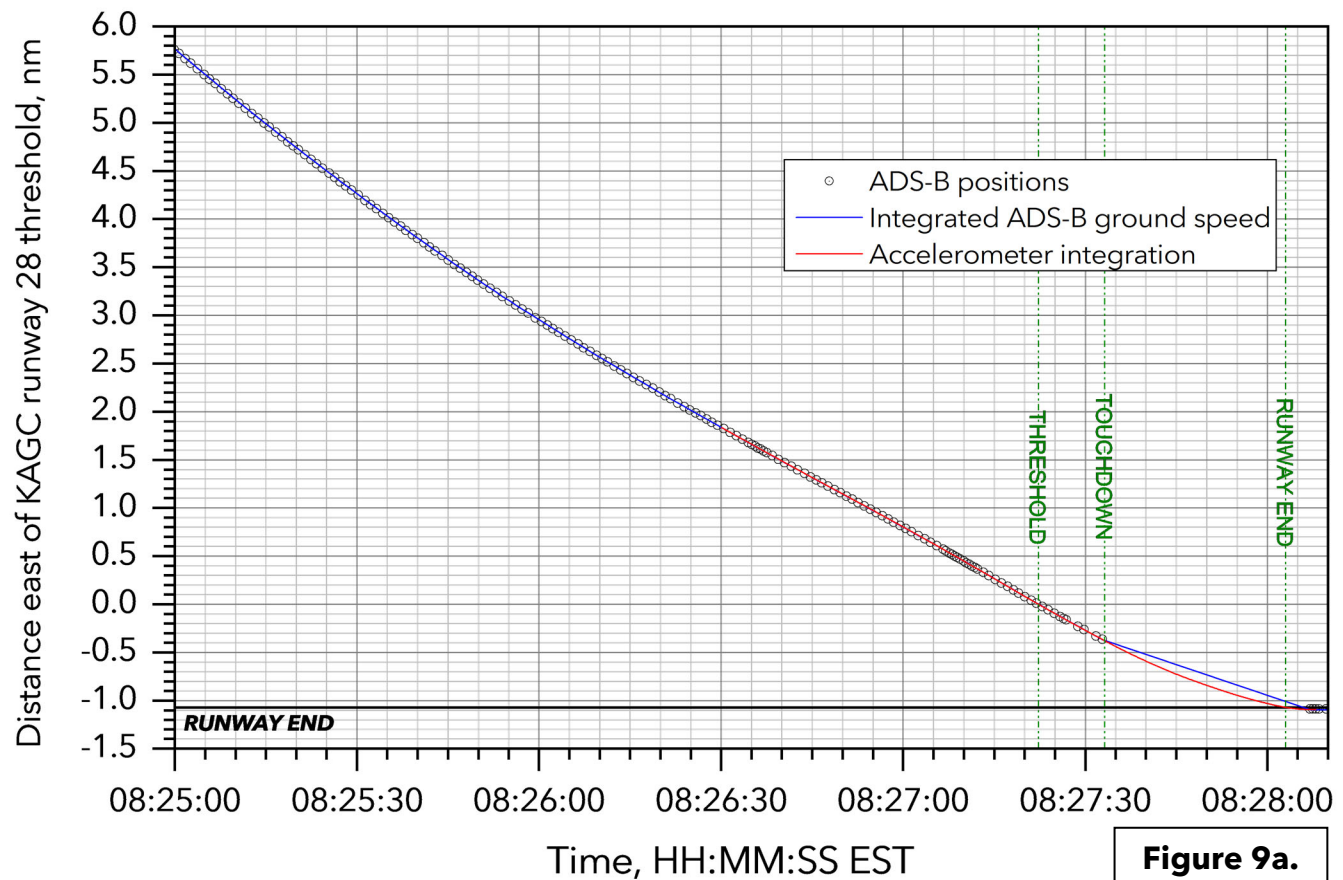
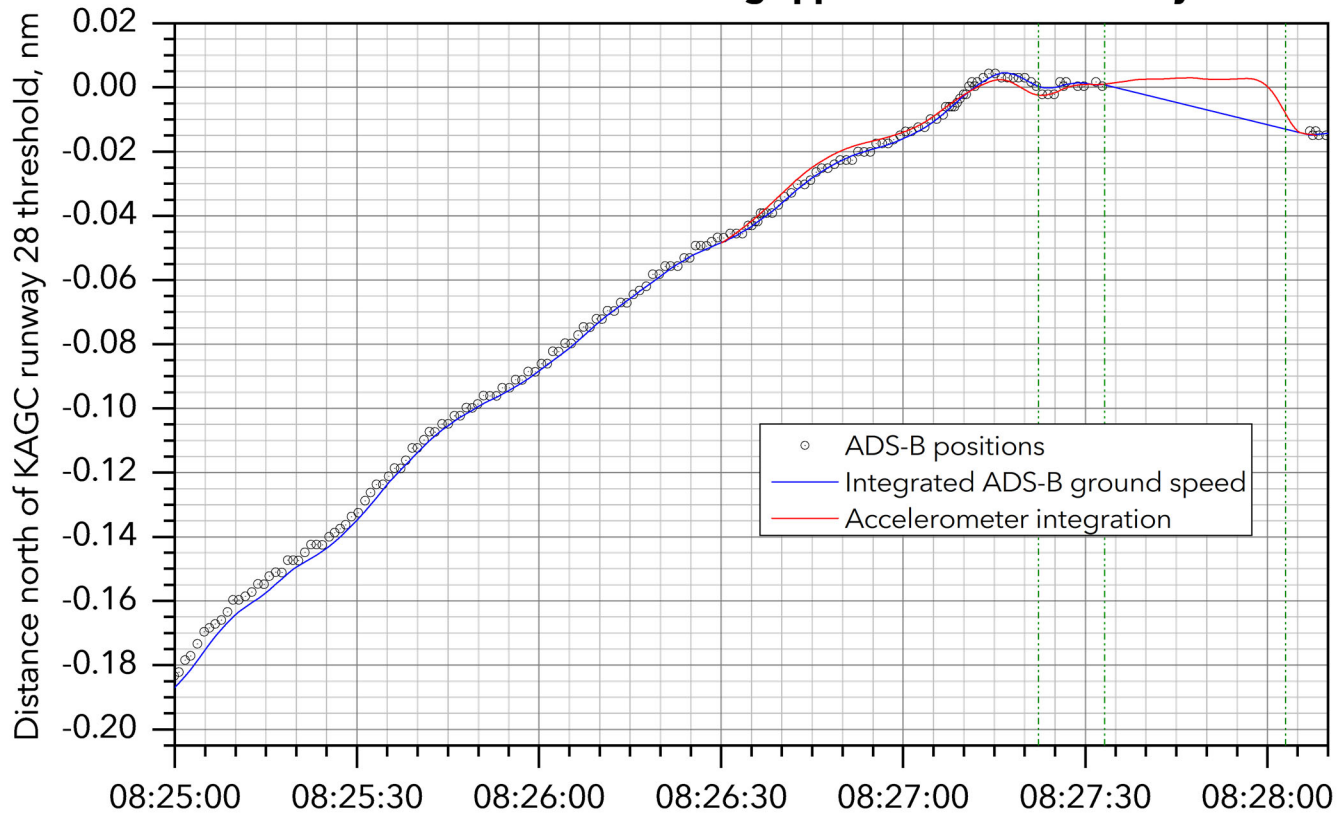


Figure 9a.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

North & east coordinates while on KAGC runway 28

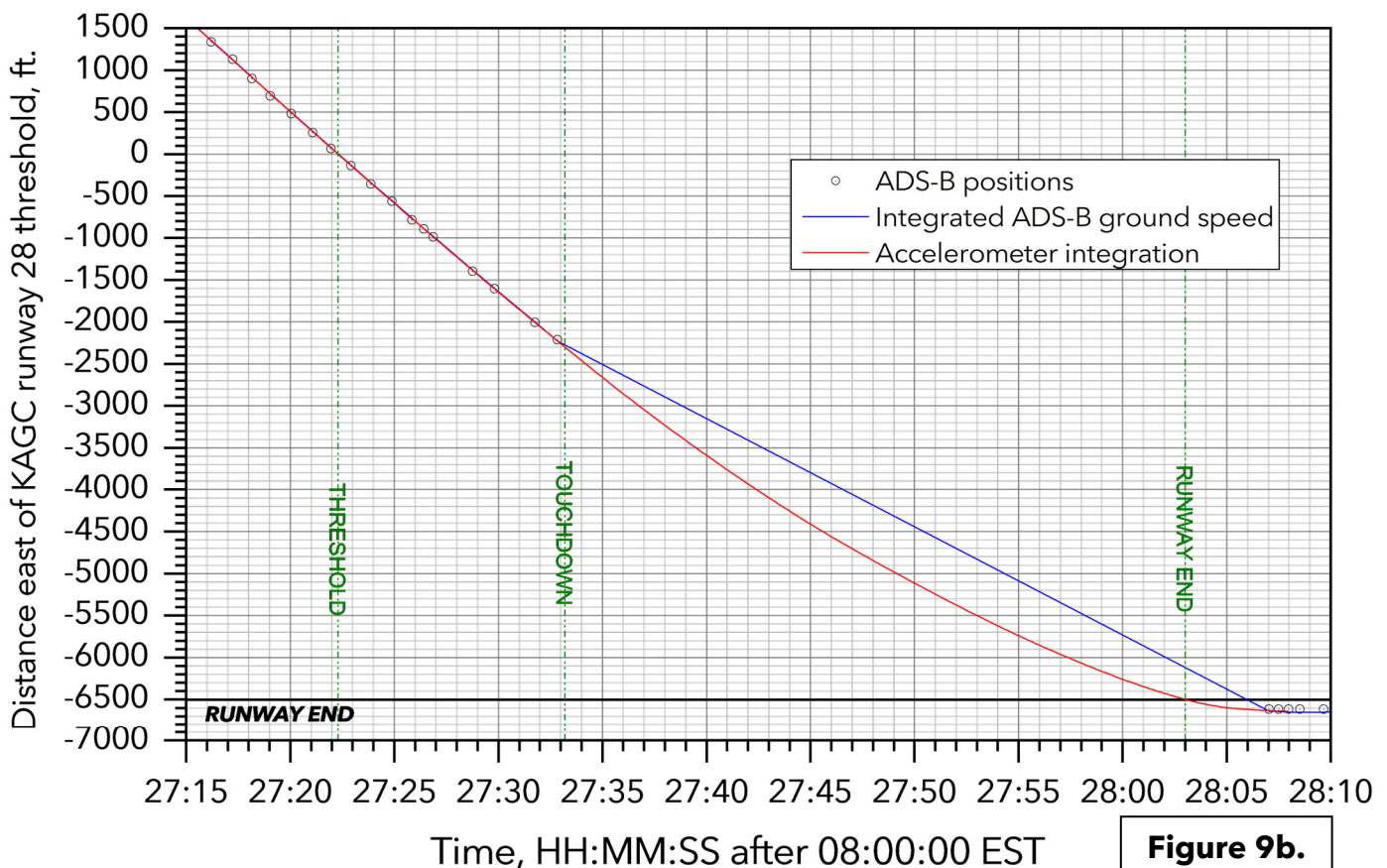
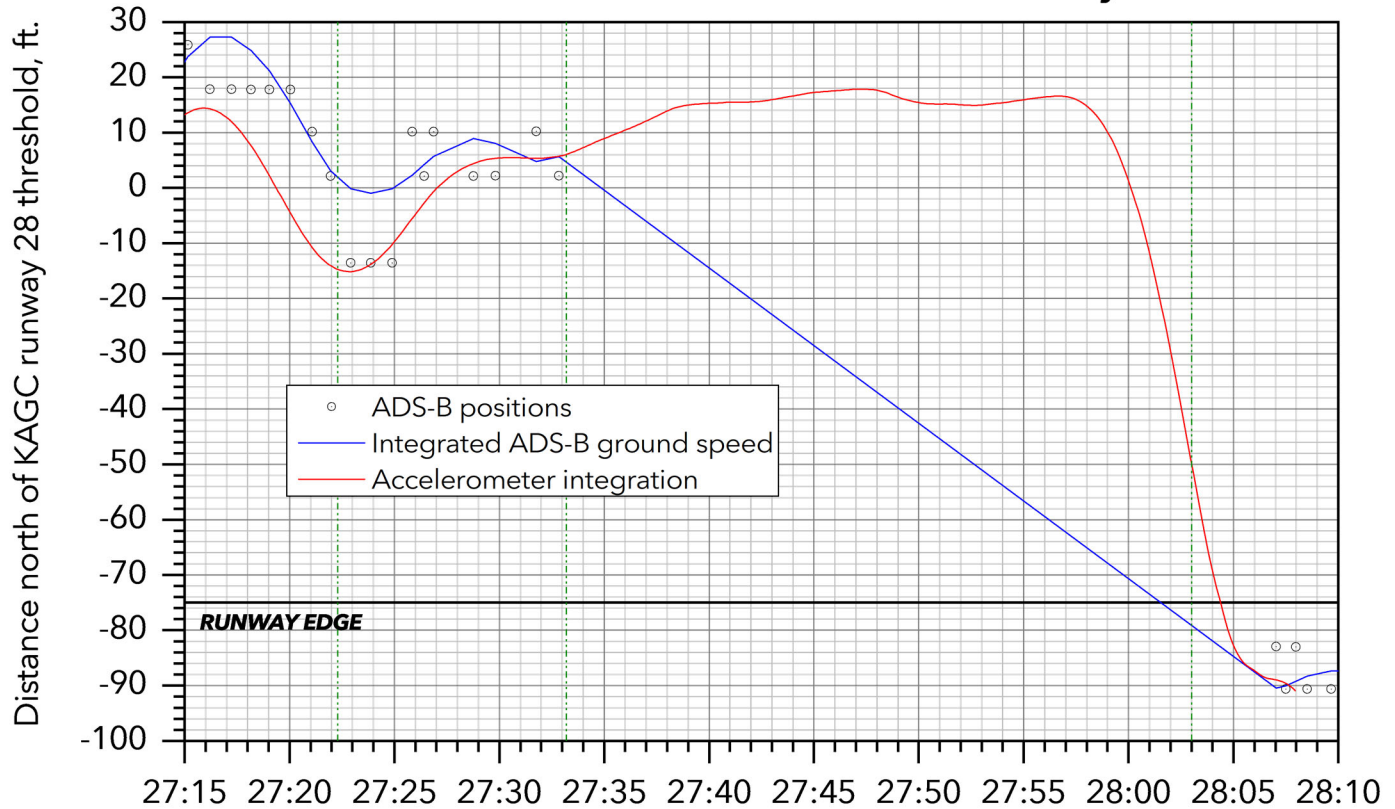


Figure 9b.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Speeds & rate of climb during approach to KAGC runway 28

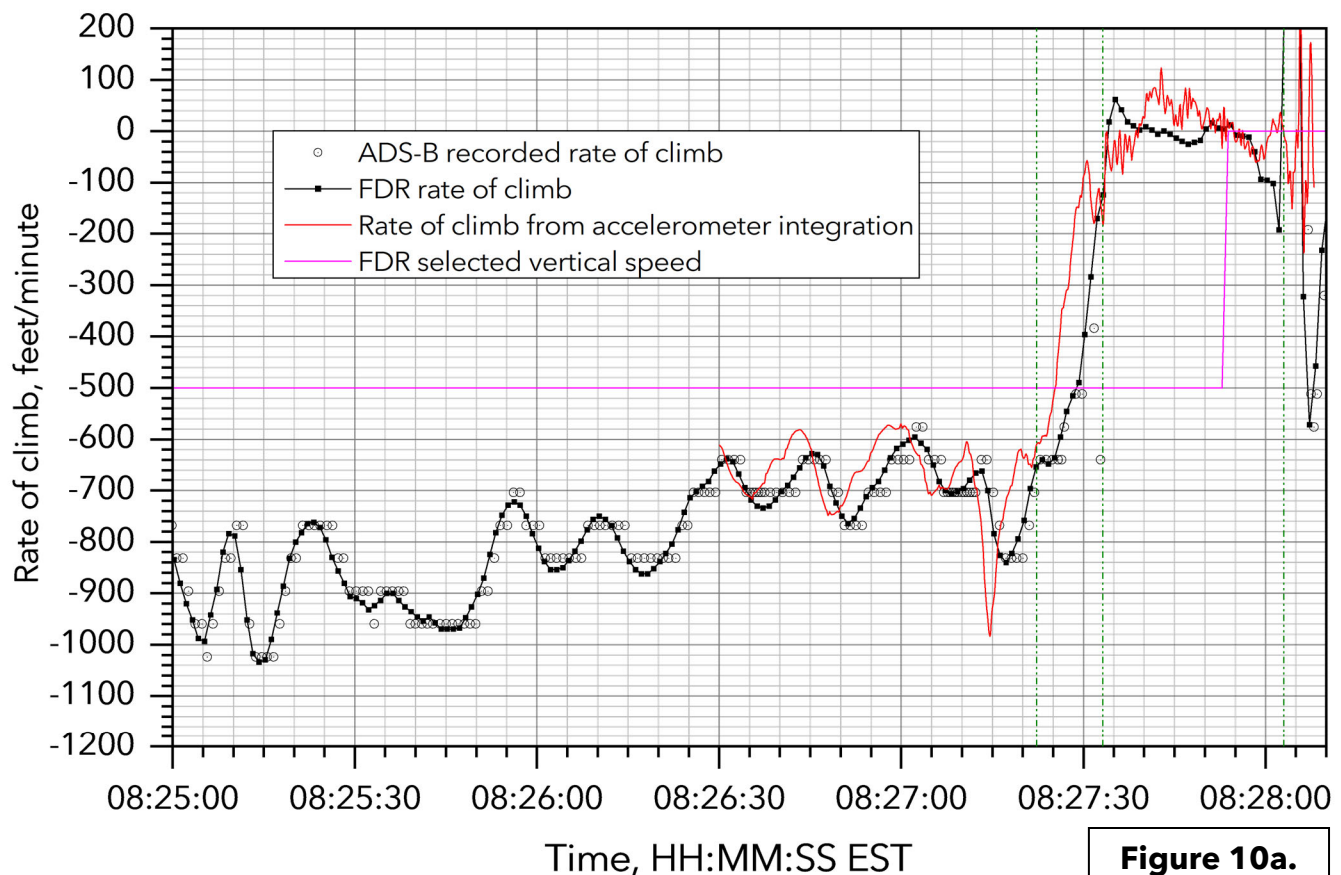
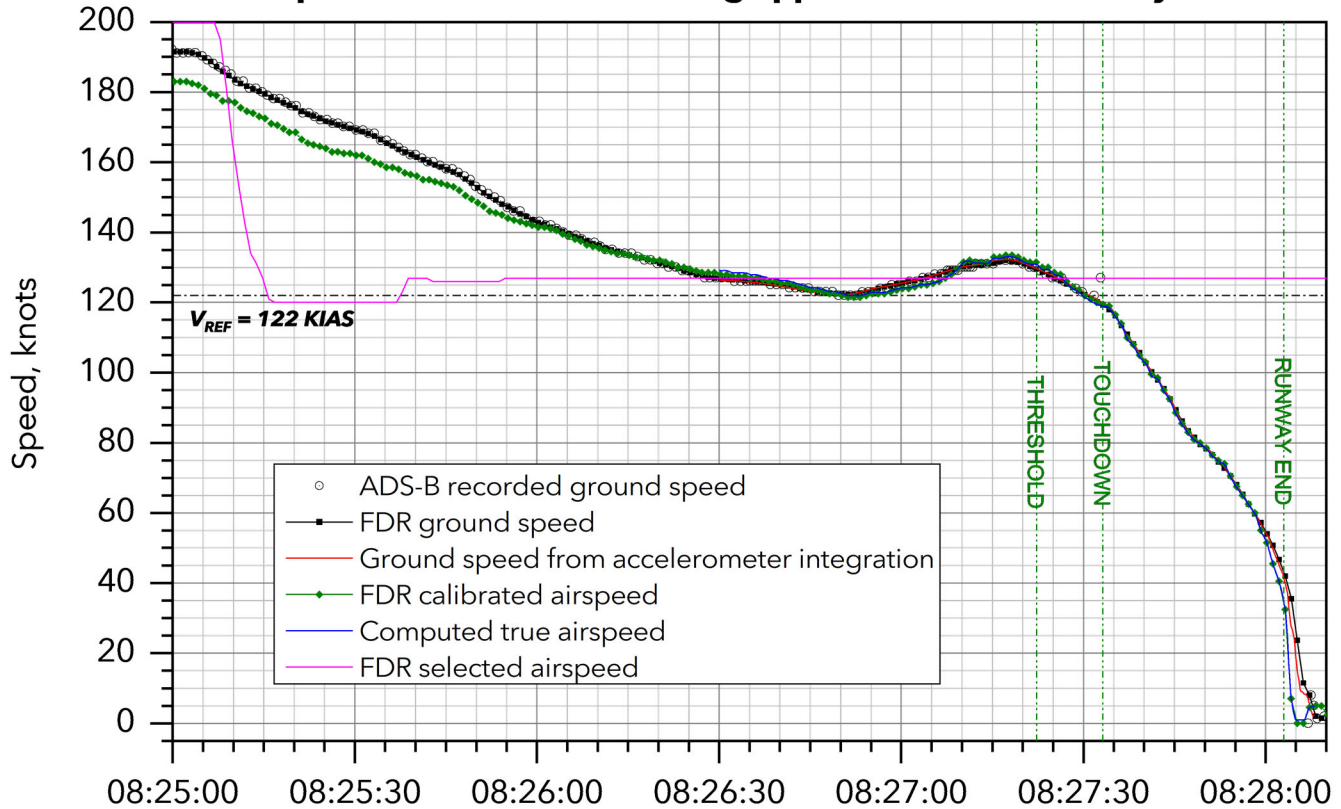
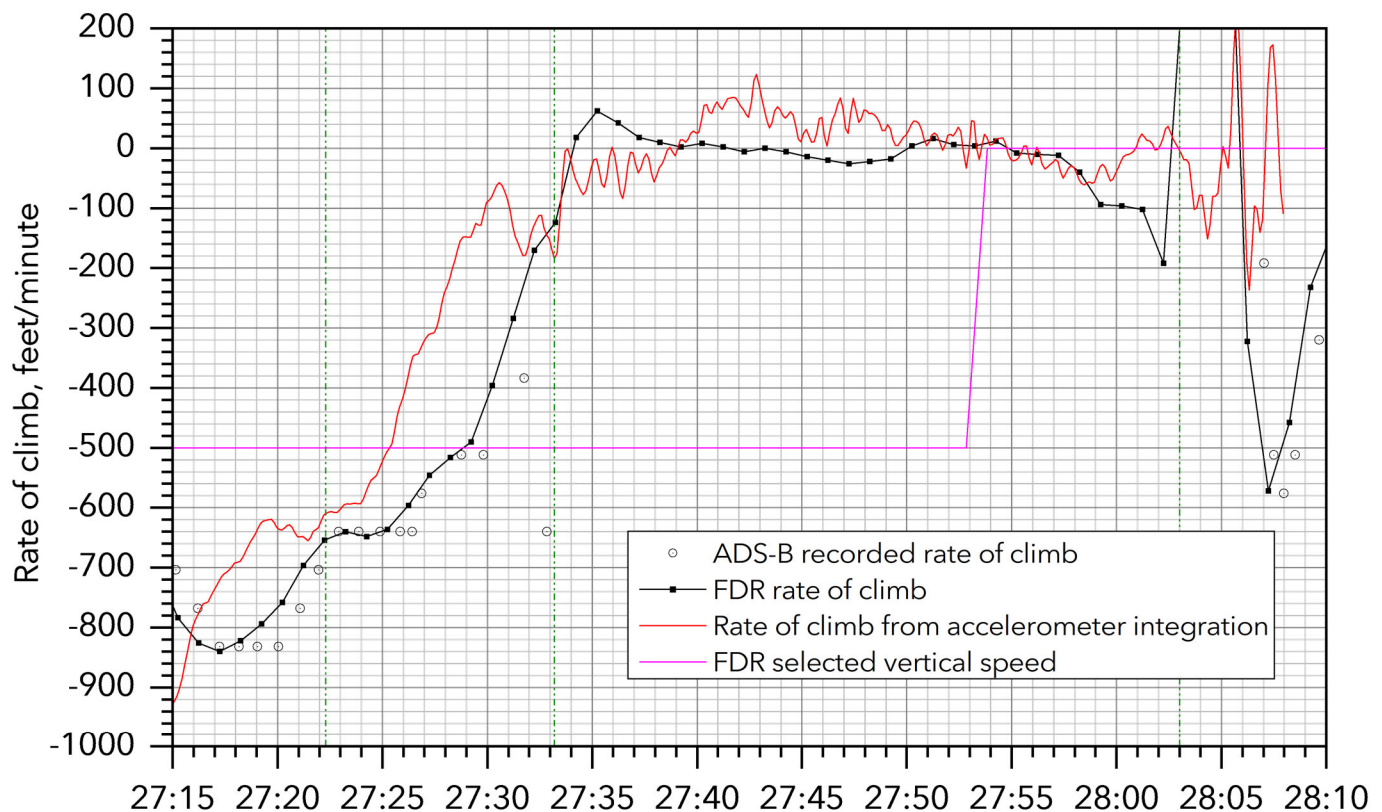
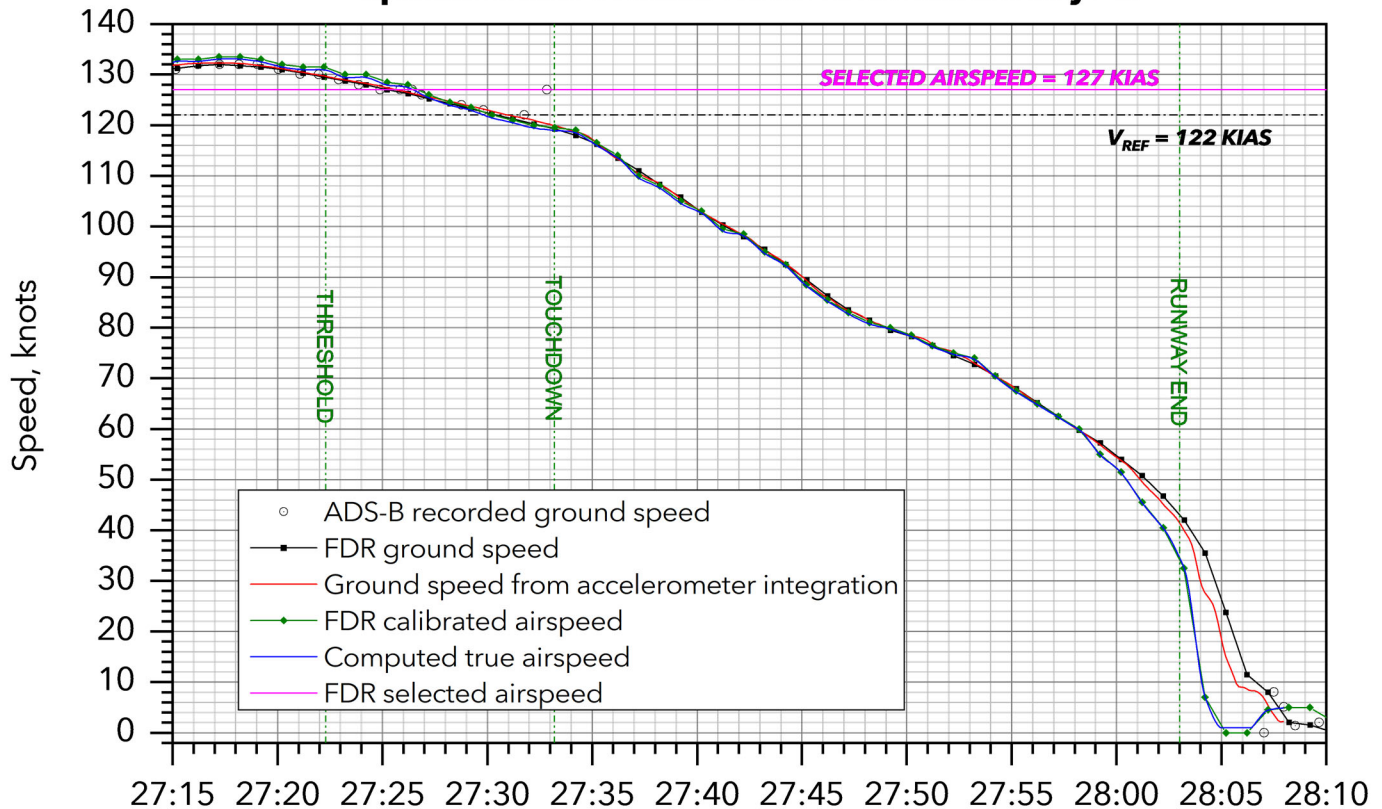


Figure 10a.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Speeds & rate of climb while on KAGC runway 28



Time, HH:MM:SS after 08:00:00 EST

Figure 10b.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Load factors during approach to KAGC runway 28

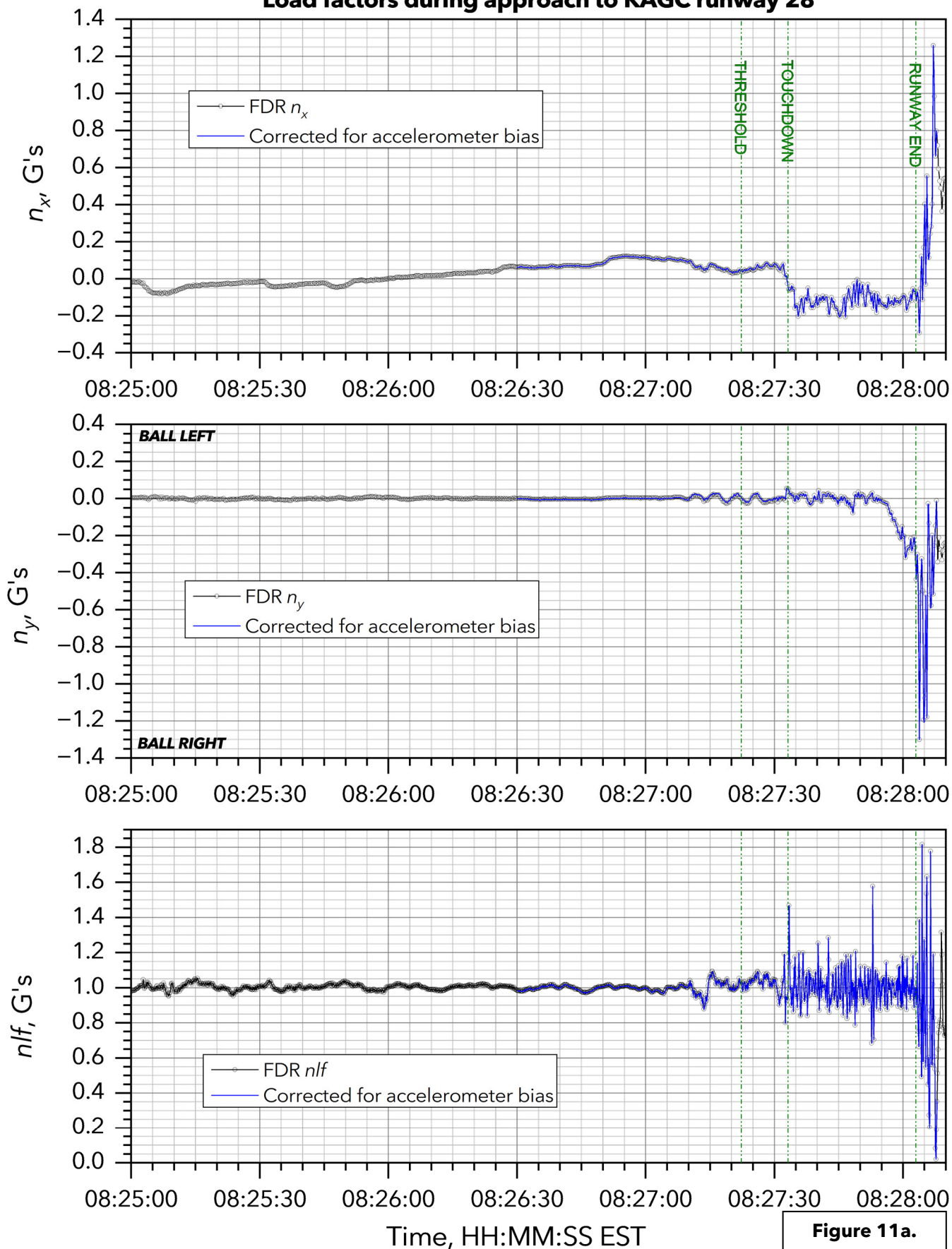


Figure 11a.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Load factors while on KAGC runway 28

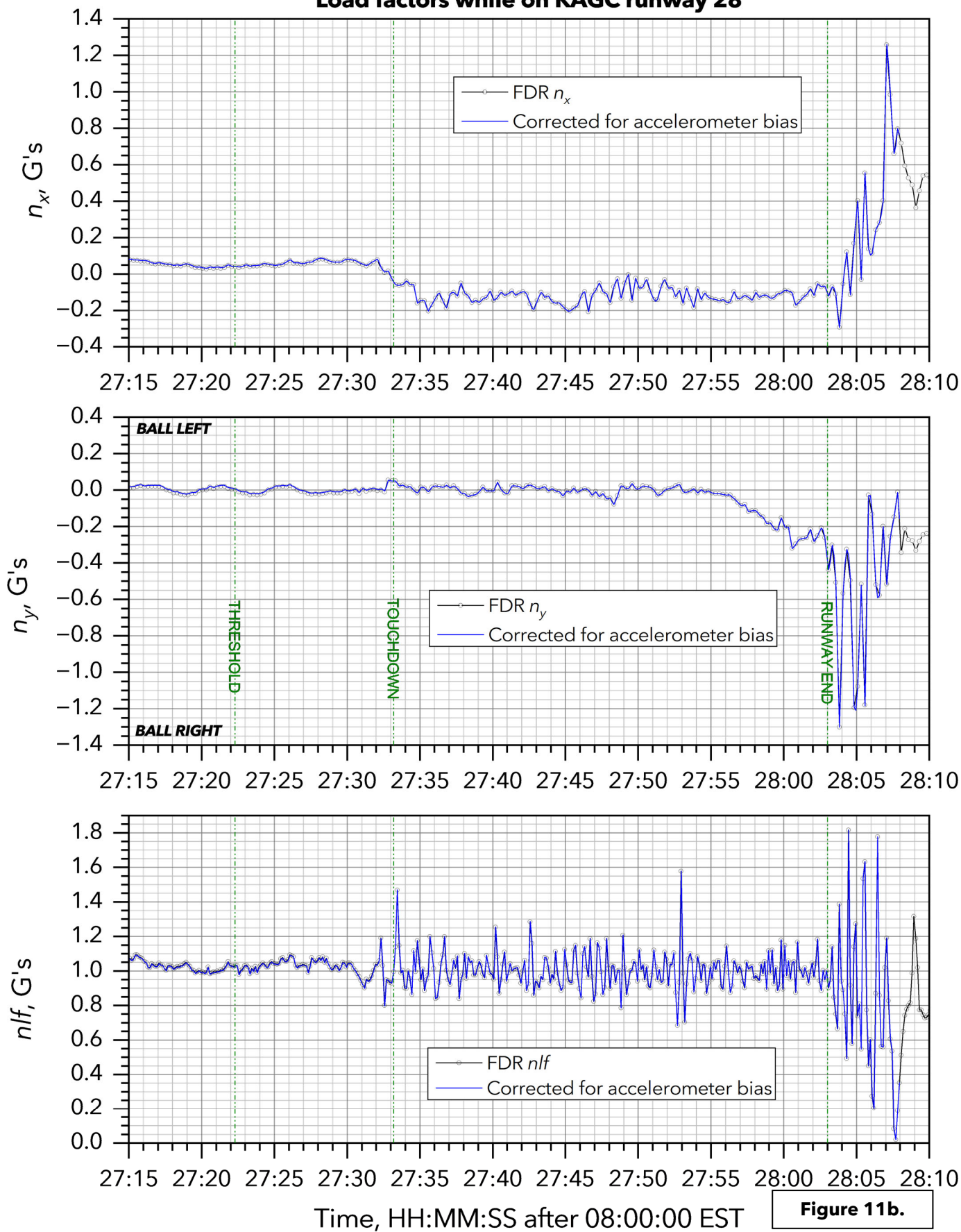


Figure 11b.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Euler angles during approach to KAGC runway 28

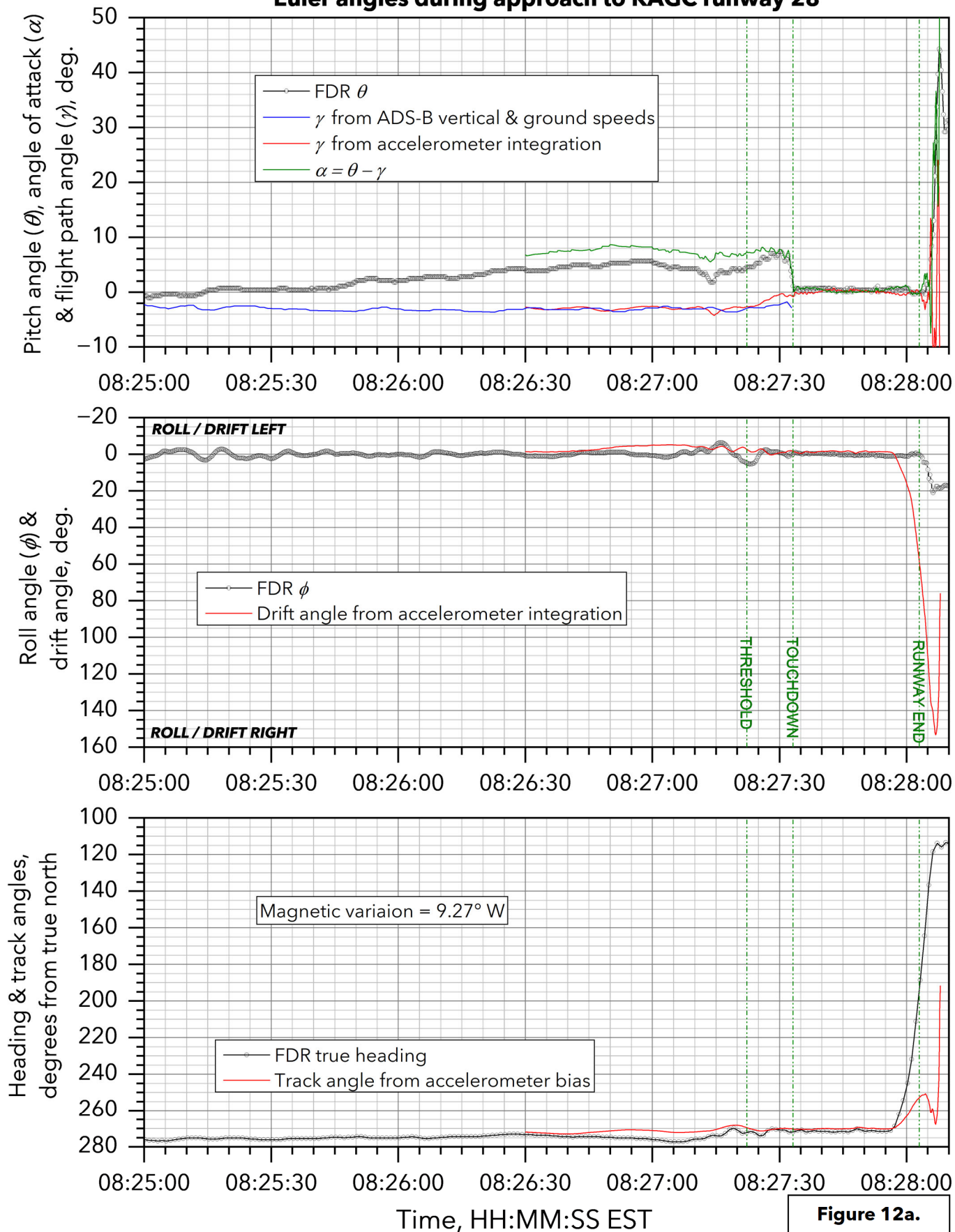


Figure 12a.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Euler angles while on KAGC runway 28

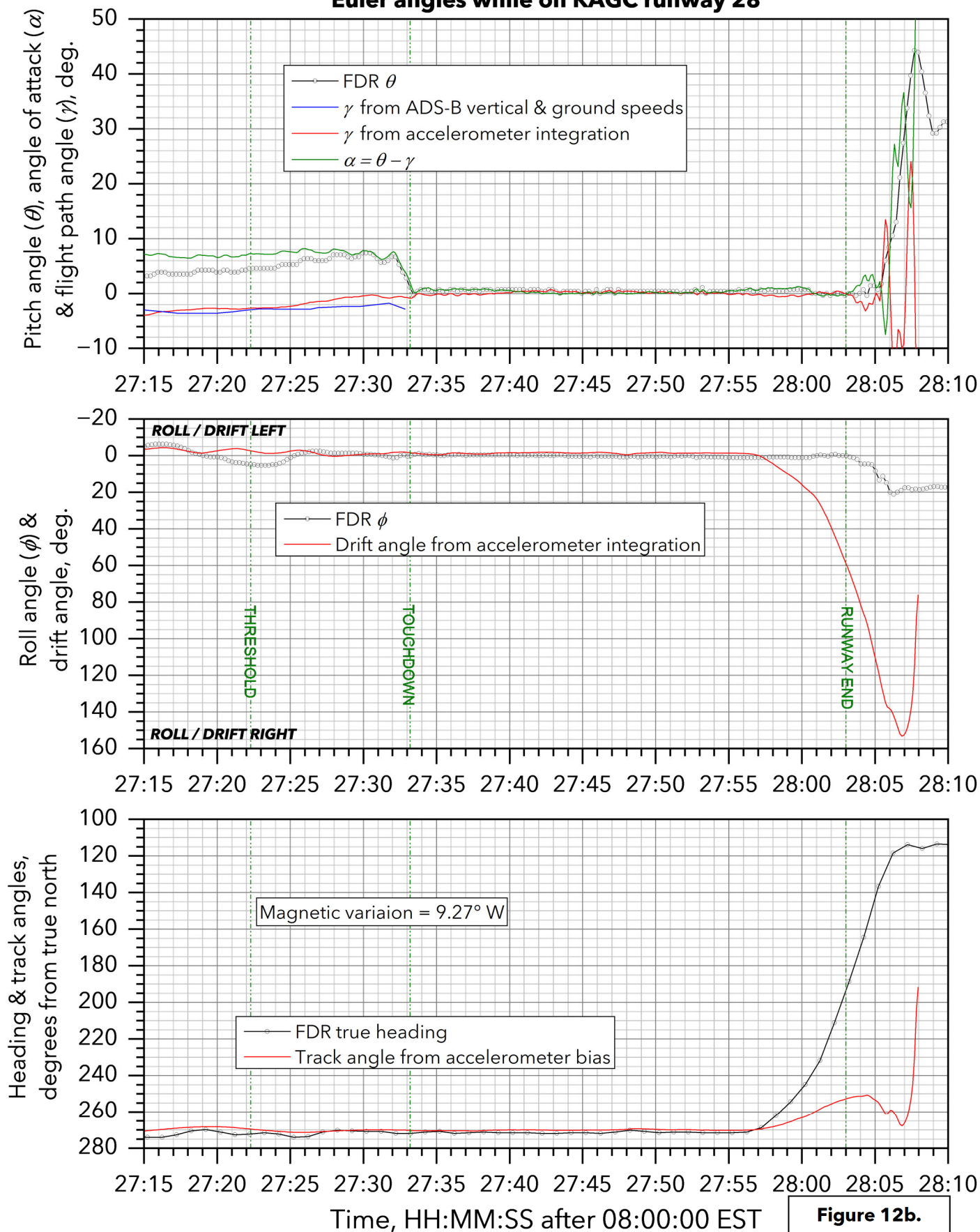
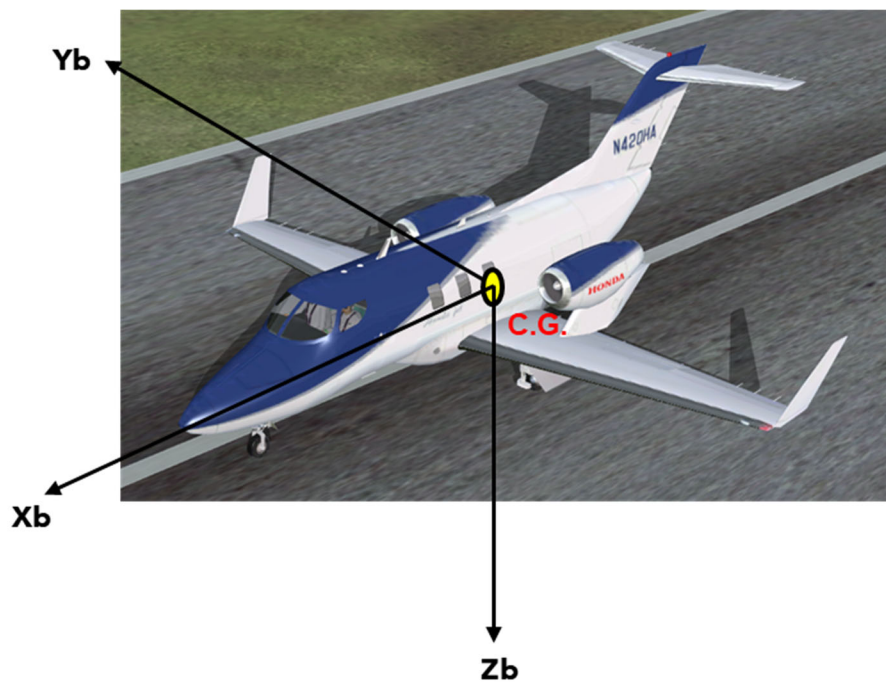
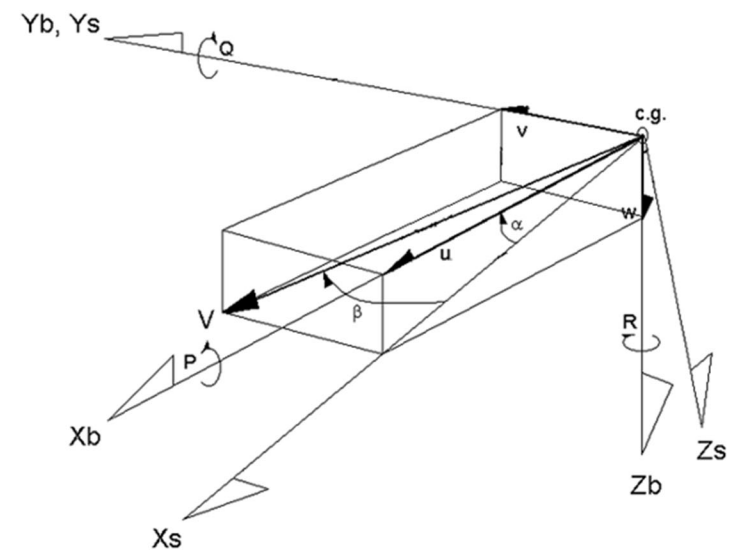


Figure 12b.



C.G. = center of gravity
 $\{X_b, Y_b, Z_b\}$ = body axis system
 $\{X_s, Y_s, Z_s\}$ = stability axis system
 V = velocity vector
 α = angle of attack
 β = sideslip angle



P = body axis roll rate
 Q = body axis pitch rate
 R = body axis yaw rate
 u = component of V along X_b
 v = component of V along Y_b
 w = component of V along Z_b

Figure 13. Airplane body axis system, body-axis components of linear and angular velocities, and definitions of α and β .

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Winds during approach to KAGC runway 28

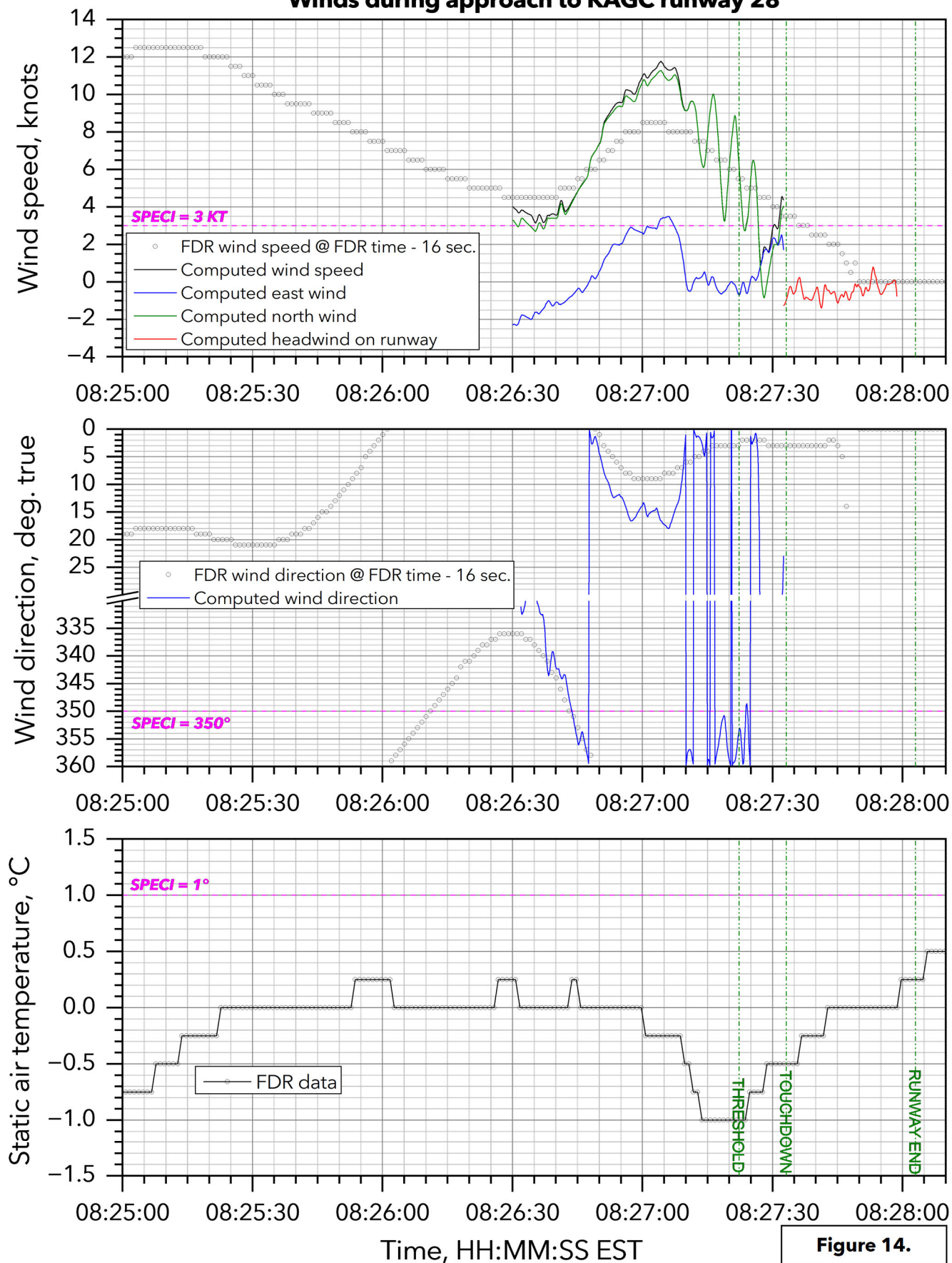


Figure 14.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Configuration and engine N1 during approach to KAGC runway 28

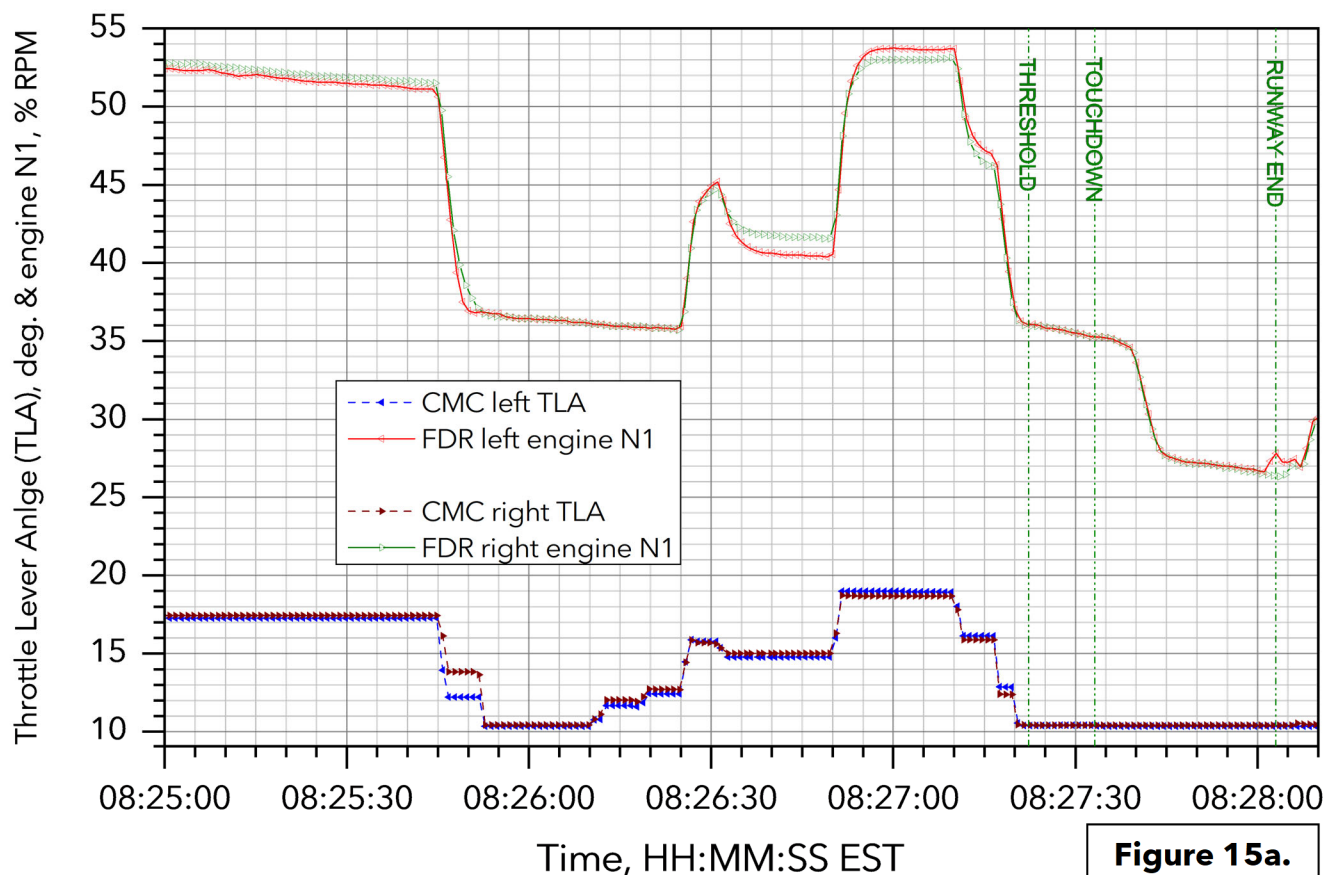
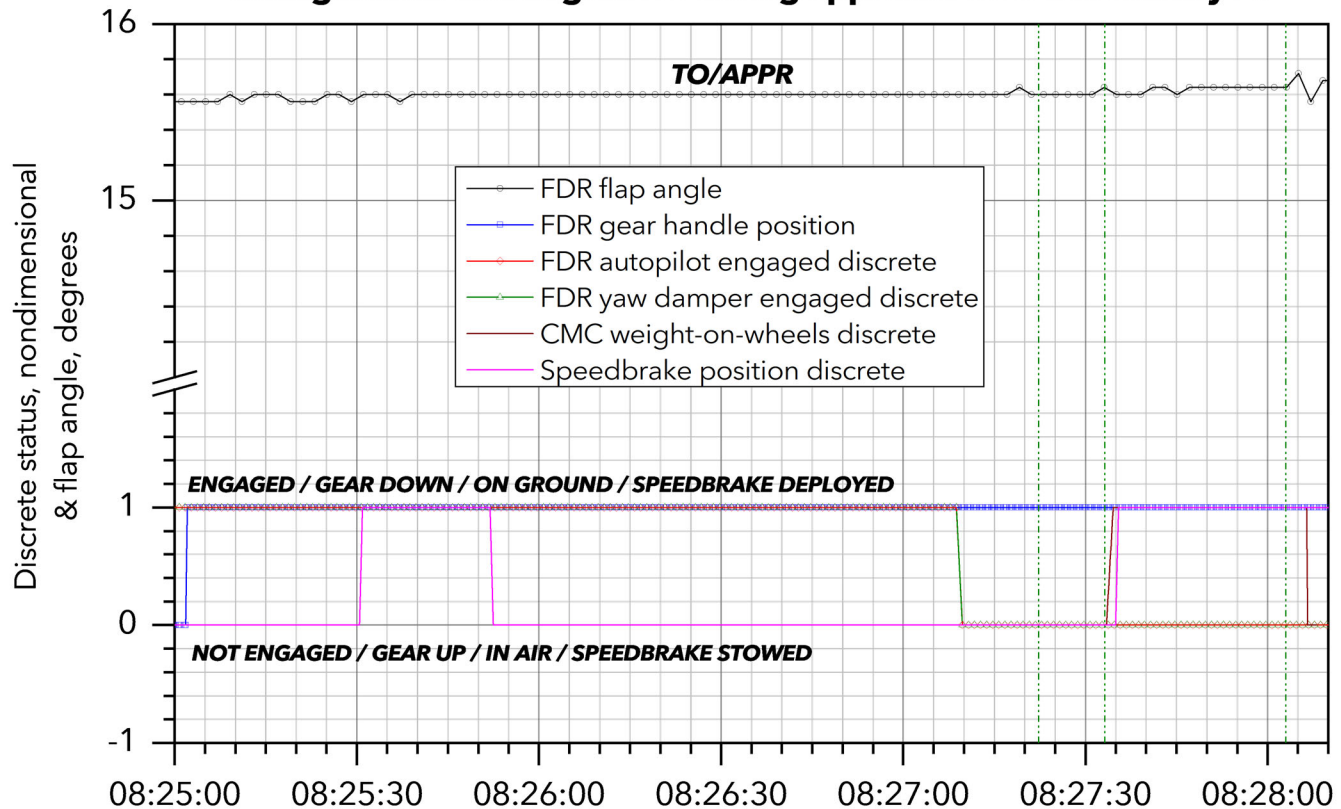


Figure 15a.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Configuration and engine N1 while on KAGC runway 28

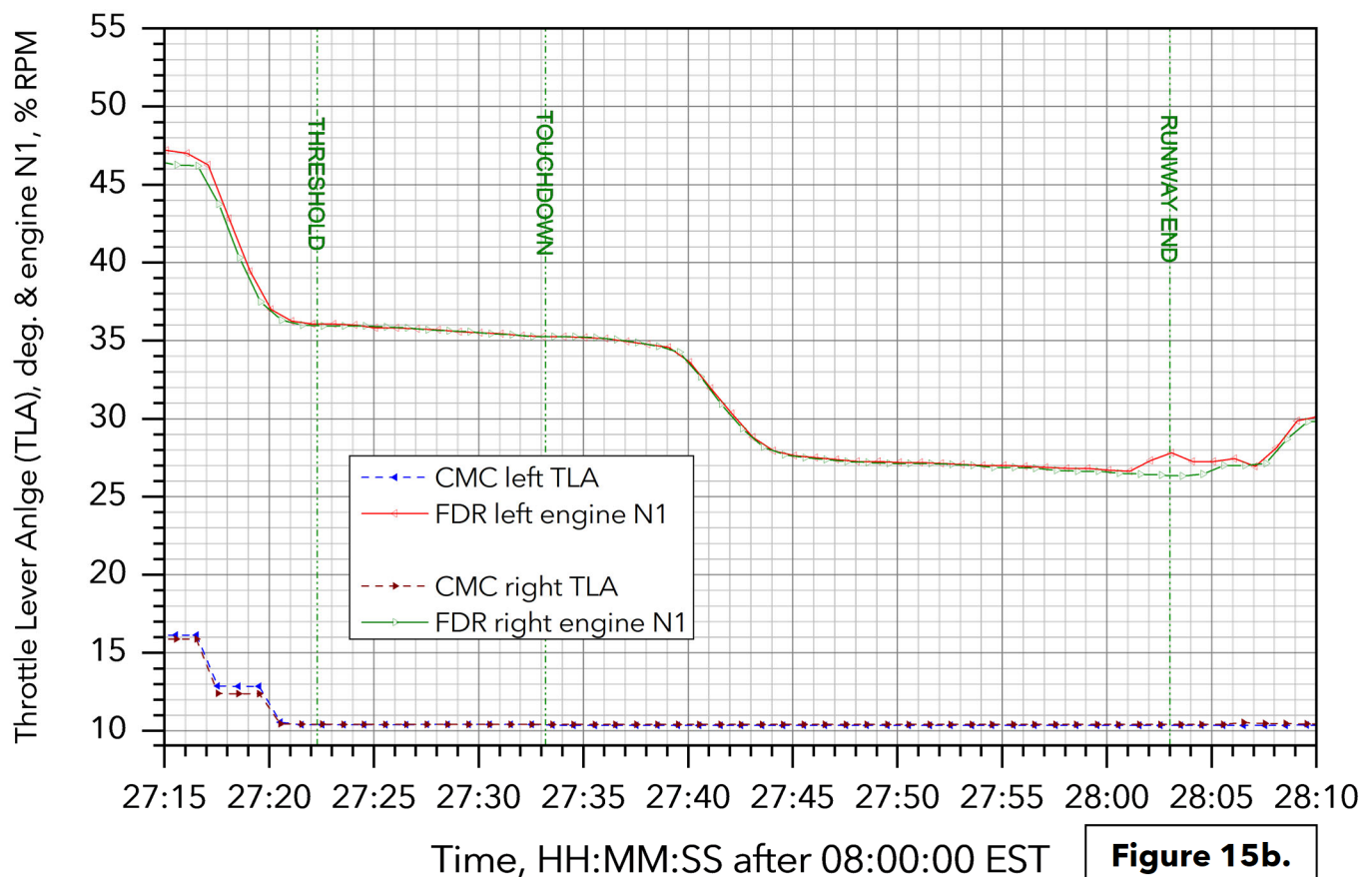
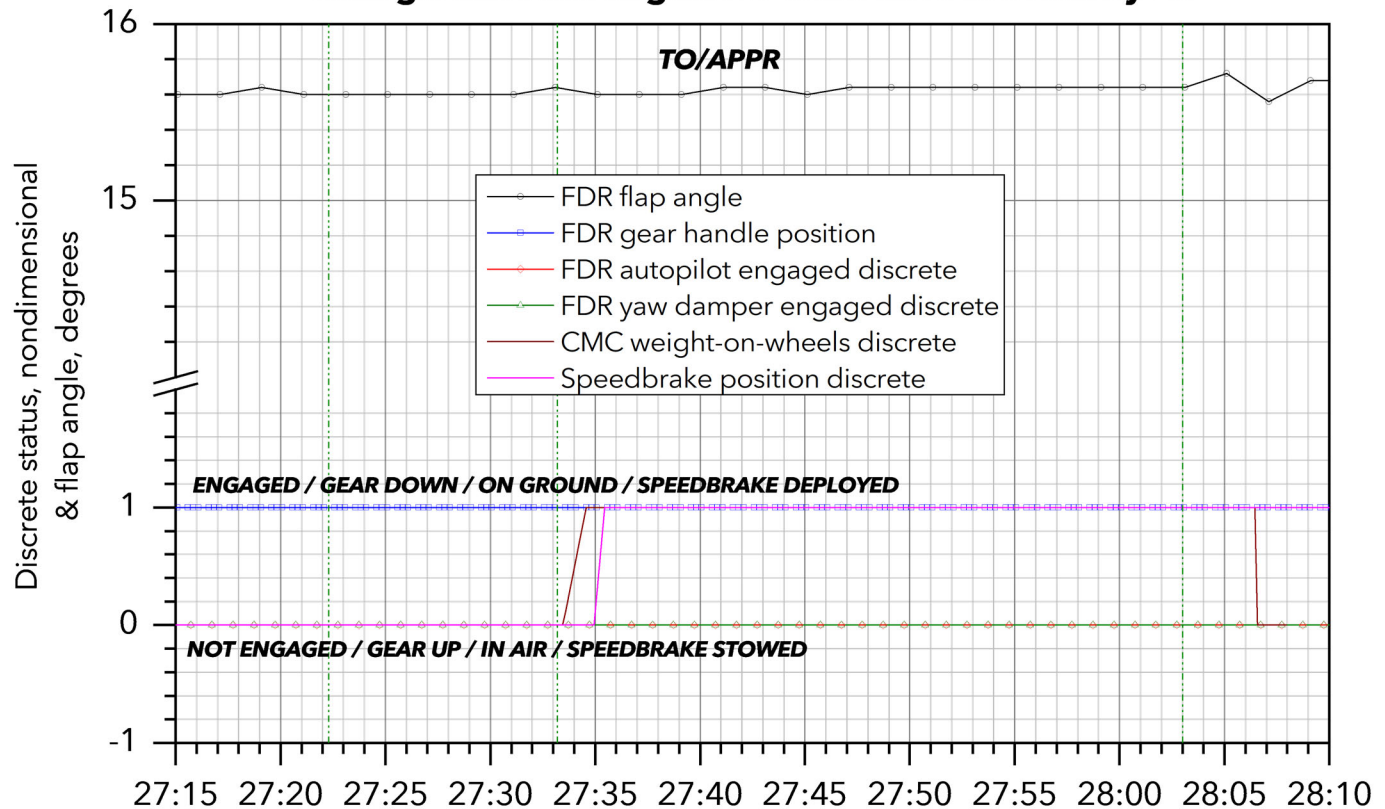


Figure 15b.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Braking performance parameters vs. time

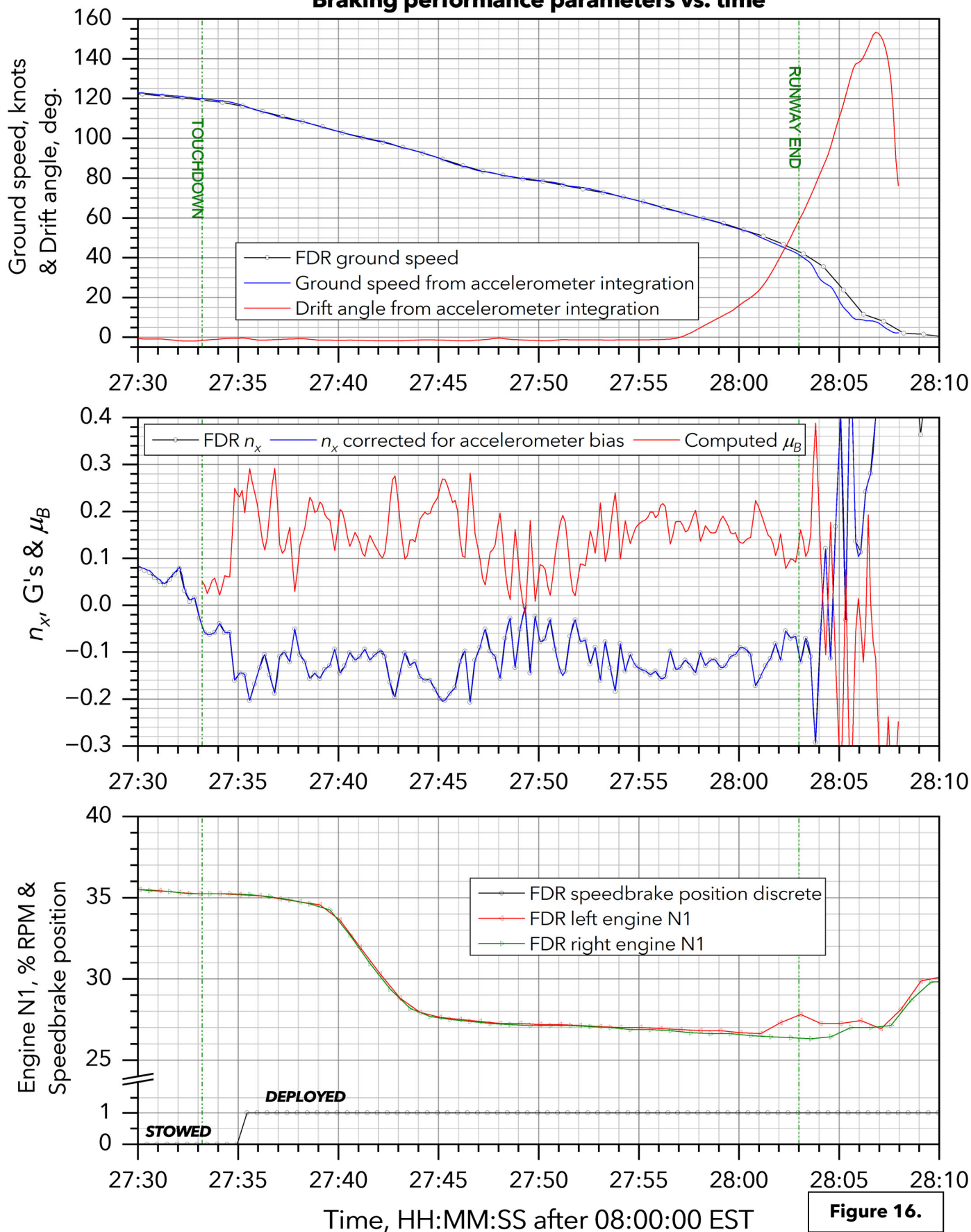


Figure 16.

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Braking performance parameters vs. distance

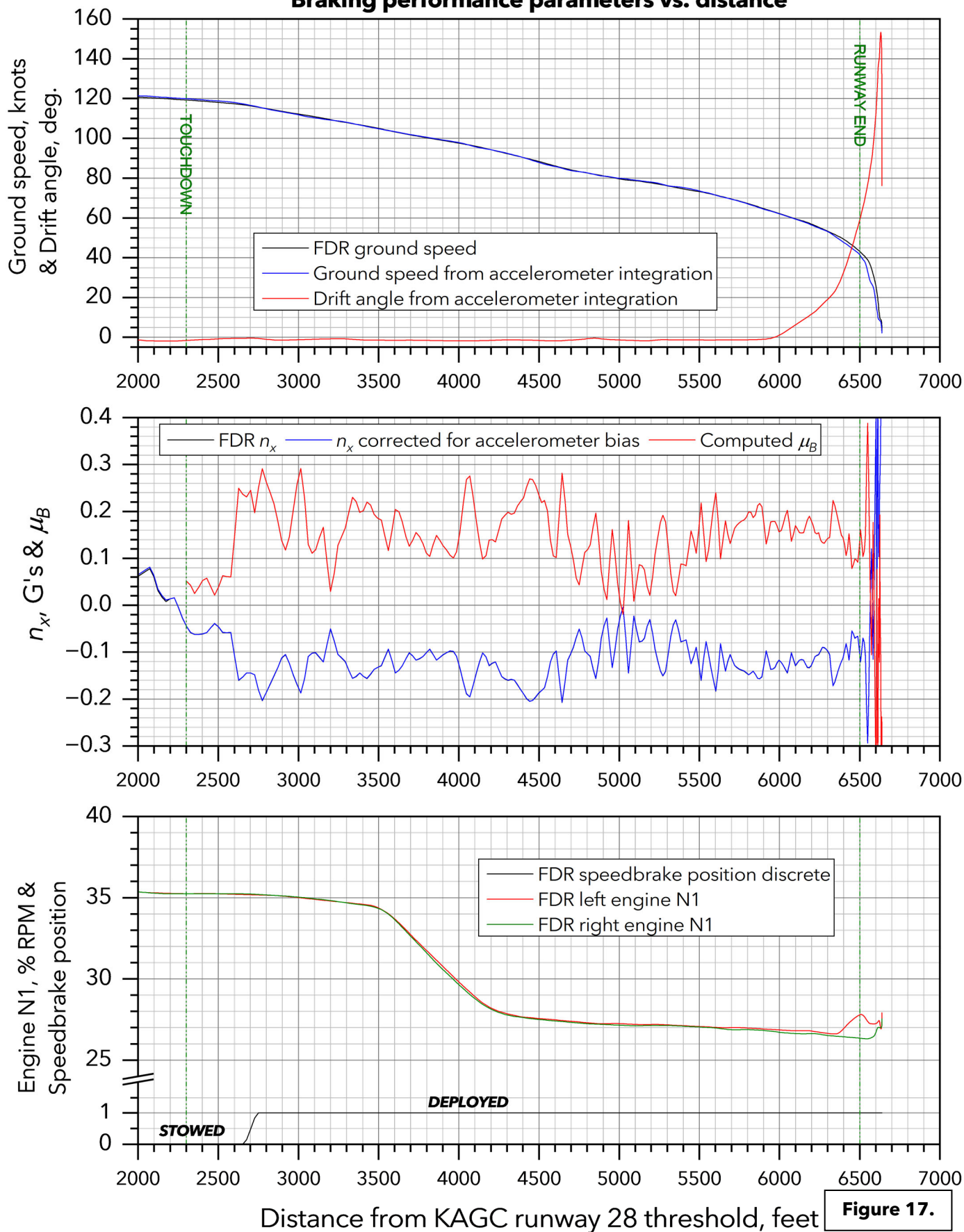


Figure 17.

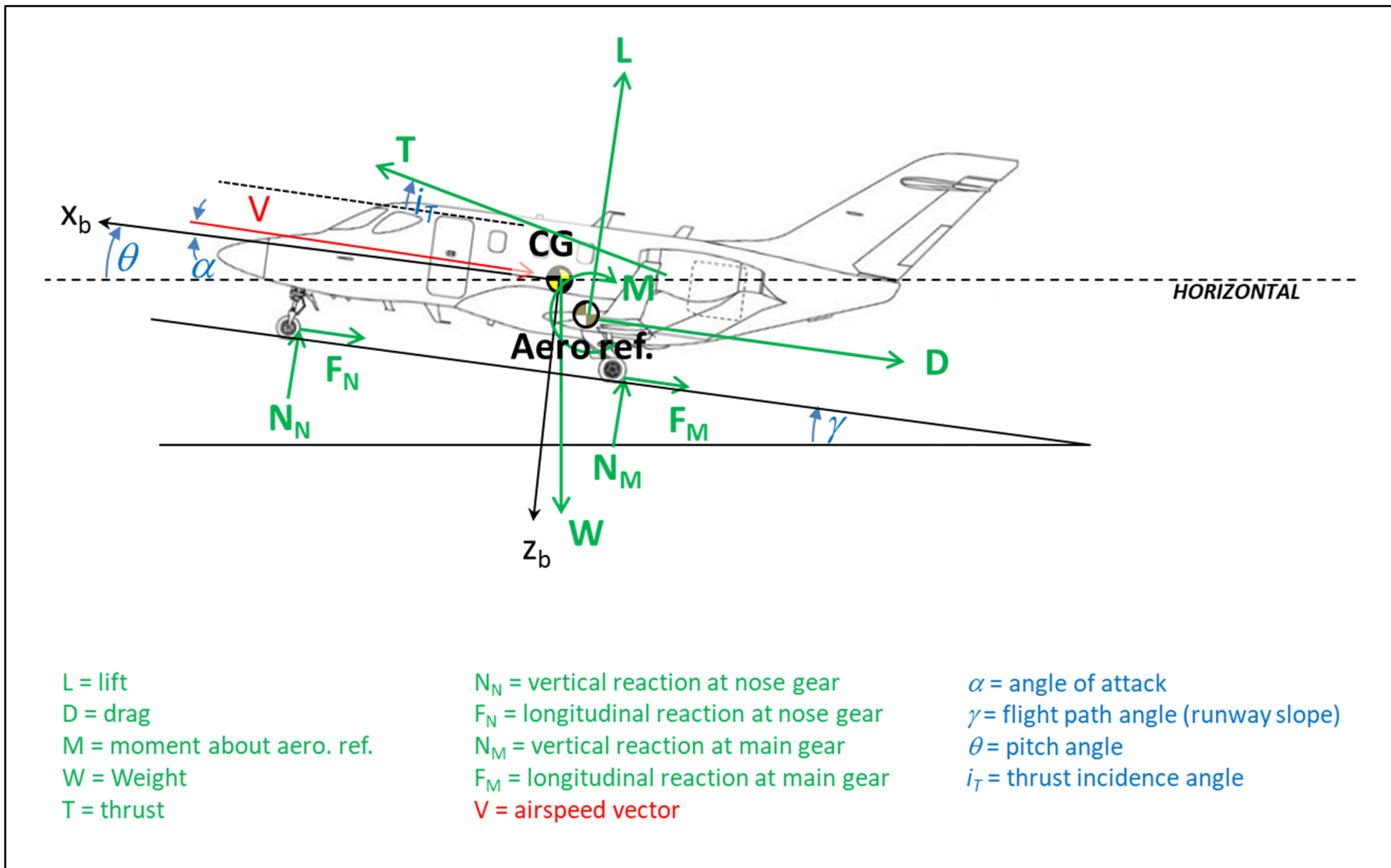


Figure 18. Free body diagram of forces on an airplane during the ground roll.

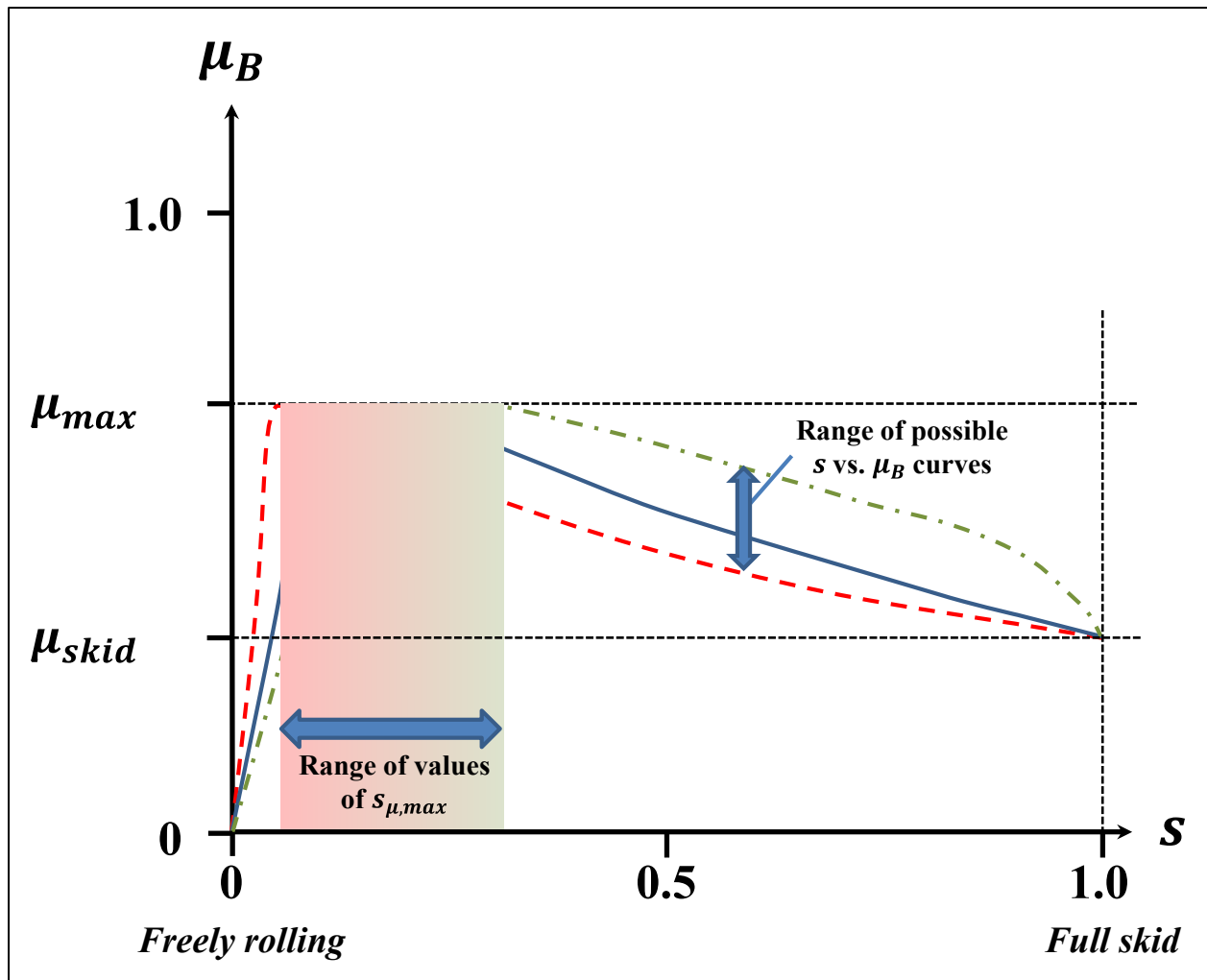


Figure 19. Effect of slip ratio s on the wheel braking friction coefficient μ_B (adapted from Reference 14).

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Achieved vs. modeled wheel braking friction coefficient (μ_B)

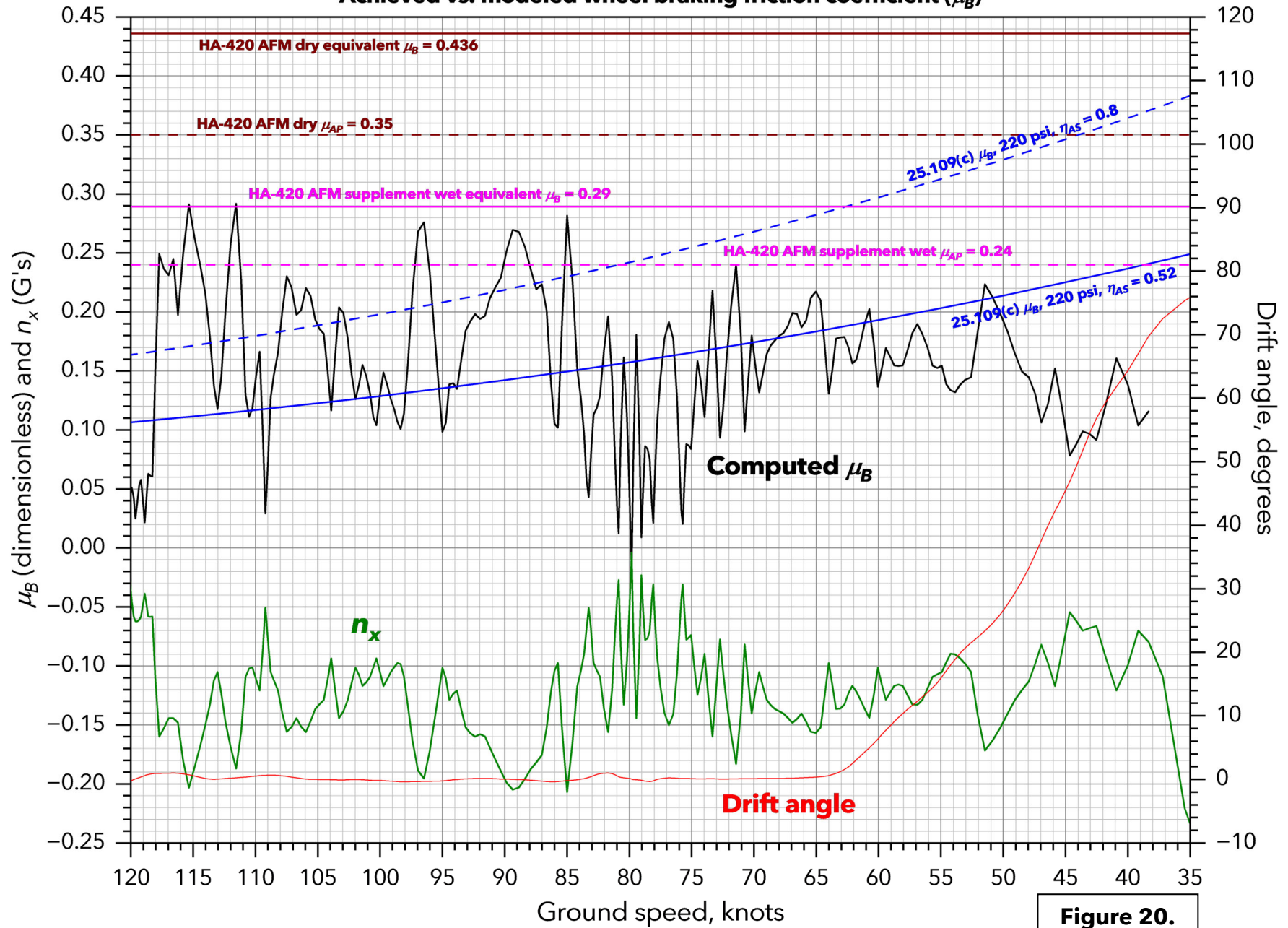


Figure 20.

Figure 21: Runway Surface Condition-Pilot Reported Braking Action–Wheel Braking Coefficient Correlation Matrix, from AC 25-32

Runway Condition Code	Runway Surface Condition Description	Pilot-Reported Braking Action	Wheel Braking Coefficient
6	Dry	–	90% of certified value used to comply with § 25.125 ¹ .
5	- Frost - Wet (includes damp and 1/8" (3 mm) depth or less of water) 1/8" (3 mm) depth or less of: - Slush - Dry snow - Wet snow	Good	Per method defined in § 25.109(c).
4	-15 °C and colder outside air temperature: Compacted snow	Good to Medium ²	0.20 ³
3	- Wet ("Slippery When Wet" runway) - Dry snow or wet snow (any depth) over compacted snow Greater than 1/8" (3 mm) depth of: - Dry snow - Wet snow Warmer than -15 °C outside air temperature: - Compacted snow	Medium ²	0.16 ³
2	Greater than 1/8" (3 mm) depth of: - Water - Slush	Medium ² to Poor	(1) For speeds below 85% of the hydroplaning speed ⁴ : 50% of the wheel braking coefficient determined in accordance with § 25.109(c), but no greater than 0.16 ³ ; and (2) For speeds at 85% of the hydroplaning speed ⁴ and above: 0.05 ³ .
1	Ice	Poor	0.08 ³
0	- Wet ice - Water on top of compacted snow - Dry snow or wet snow over ice	Nil	Not applicable. (No operations in Nil conditions.)

¹ 100% of the wheel braking coefficient used to comply with § 25.125 may be used if the testing from which that braking coefficient was derived was conducted on portions of runways containing operationally representative amounts of rubber contamination and paint stripes.

² The braking action term "FAIR" is in the process of being changed to "MEDIUM" throughout the FAA. Until an official change is published, the term "FAIR" may be used.

³ These wheel braking coefficients assume a fully modulating anti-skid system. For quasi-modulating systems, multiply the listed braking coefficient by 0.625. For on-off systems, multiply the listed braking coefficient by 0.375. (See AC 25-7C to determine the classification of an anti-skid system.) Airplanes without anti-skid systems will need to be addressed separately on a case-by-case basis.

⁴ The hydroplaning speed, V_P , may be estimated by the equation $V_P = 9\sqrt{P}$, where V_P is the ground speed in knots and P is the tire pressure in lb/in

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Speed vs. distance from accident data & simulations with different μ_B

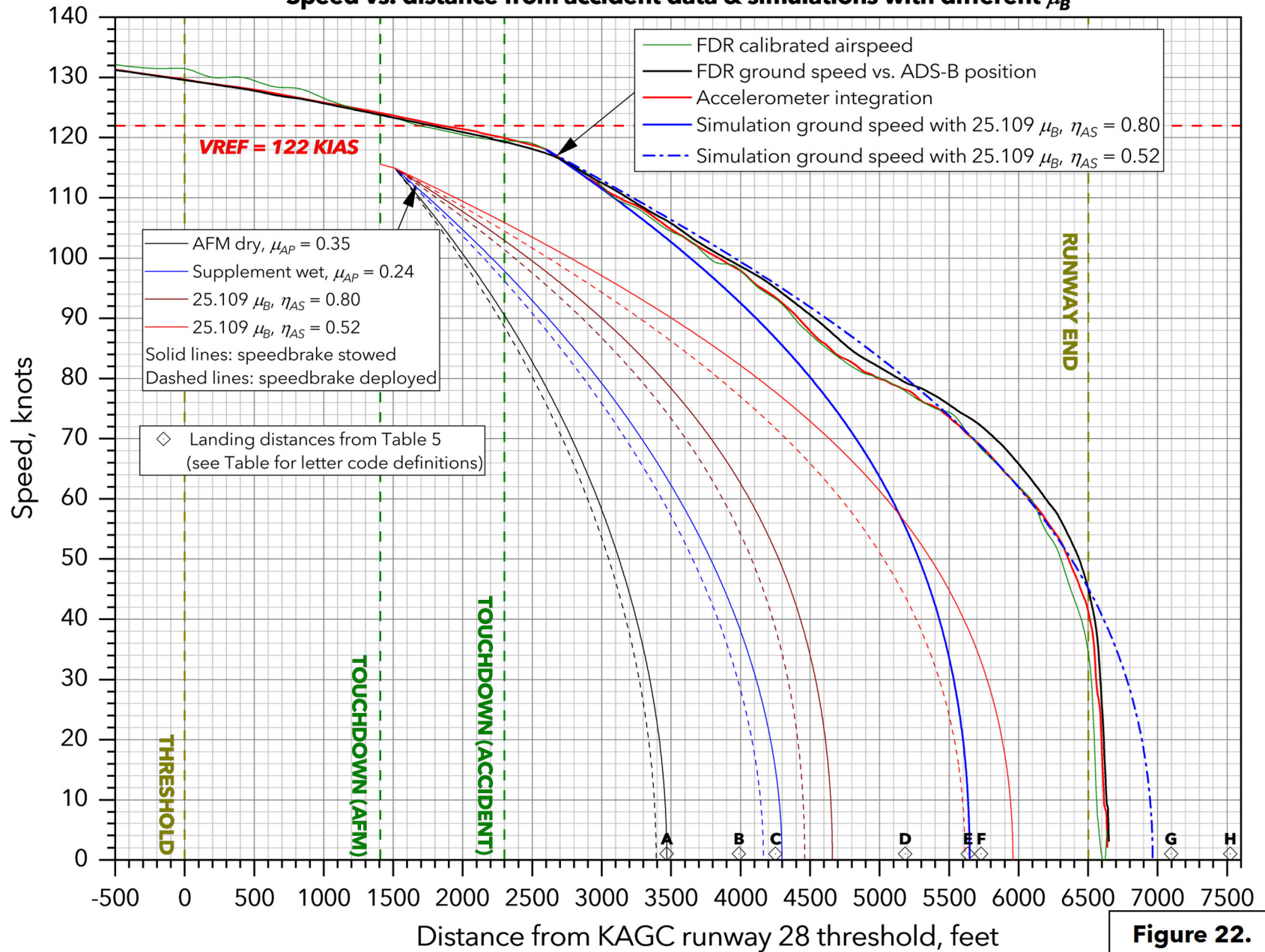


Figure 22.

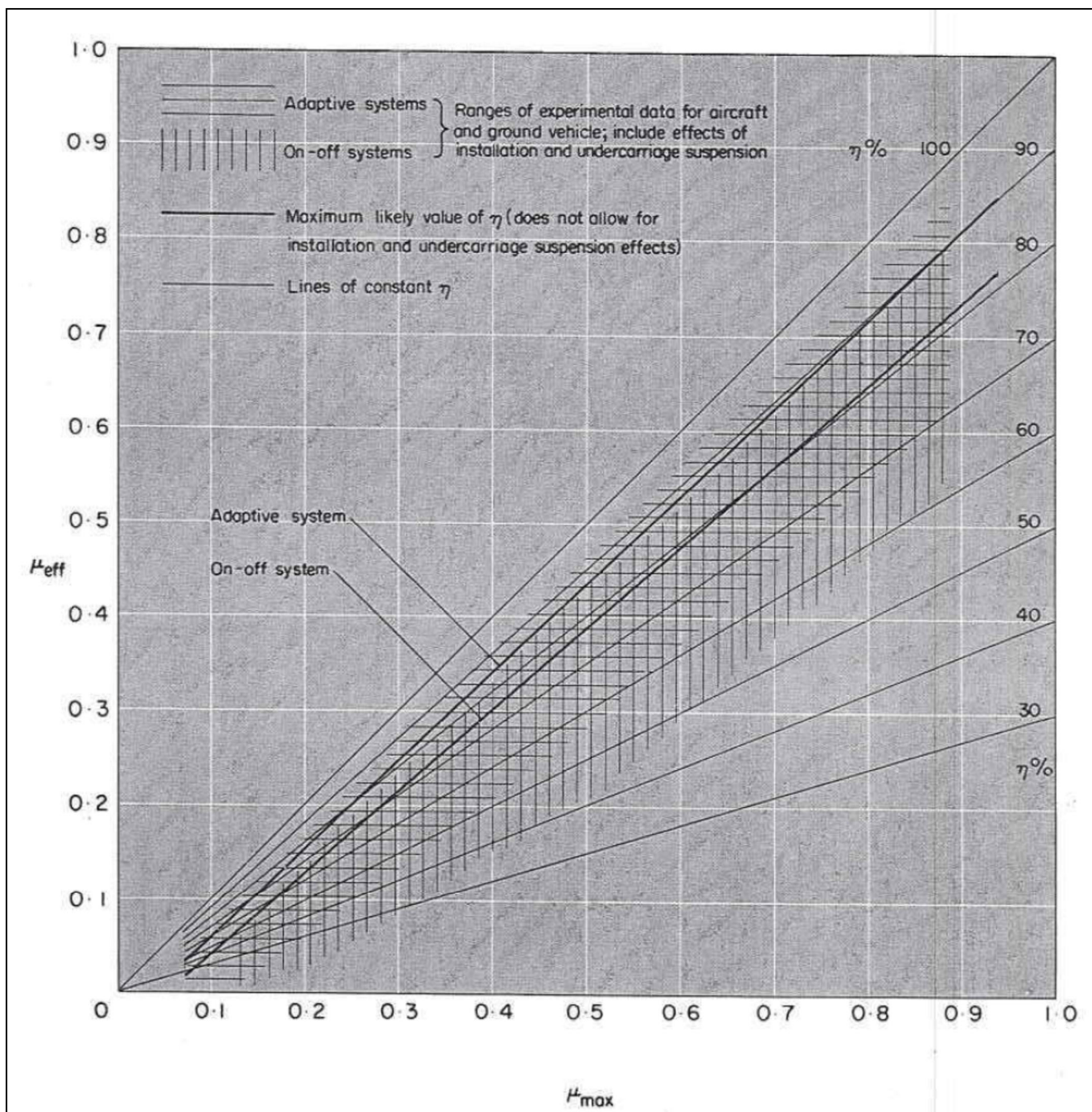


Figure 23. Brake system anti-skid efficiency (η_{AS}), from ESDU 71026 (Reference 14).

ERA22LA150: HondaJet HA-420, N903JT, Pittsburgh, PA, 03/09/2022

Flight test "wet/broken runway" braking performance

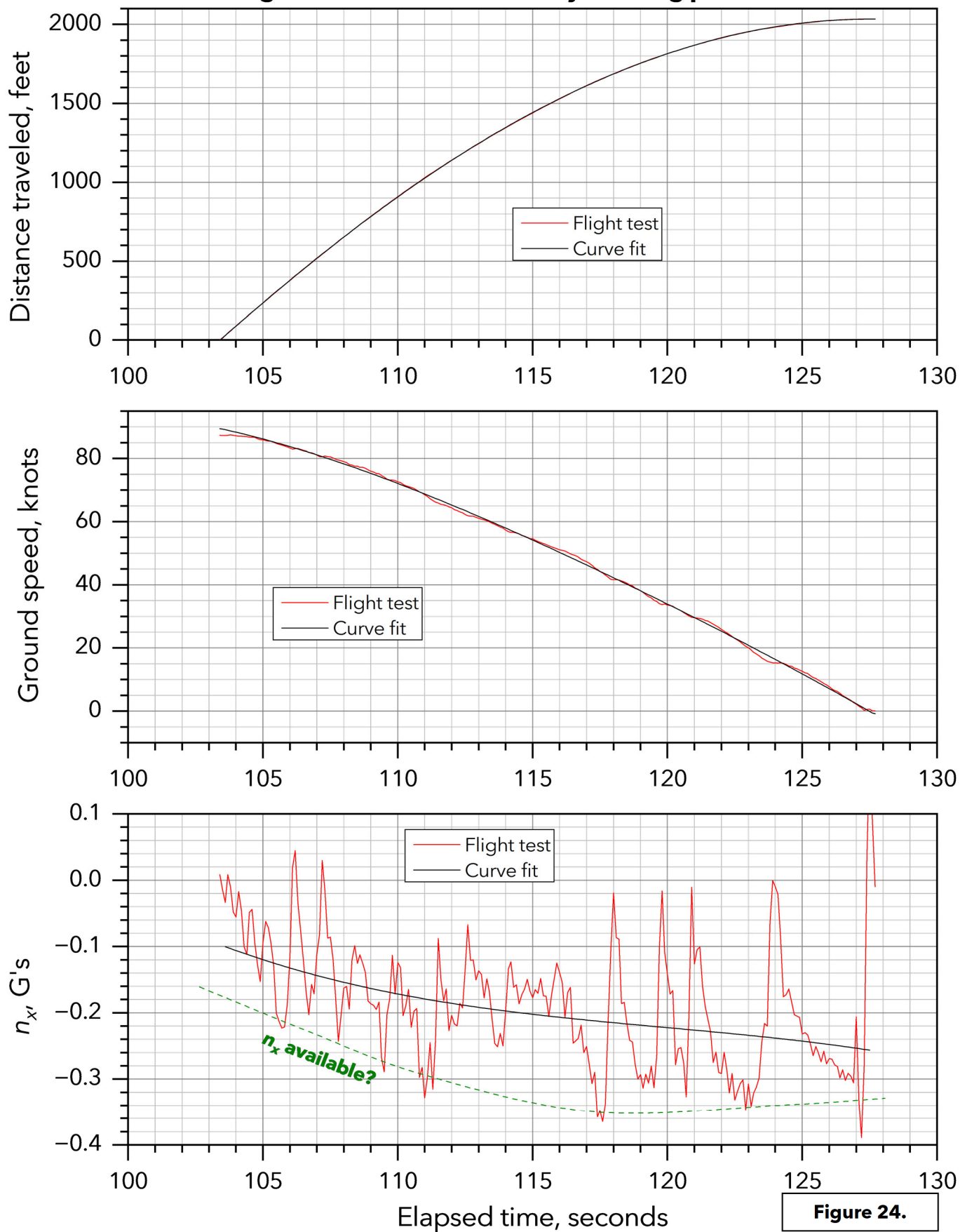


Figure 24.