ERRATA

THE CORRECTIONS BELOW ARE *INCLUDED*
IN THIS REVISED VERSION OF THE DOCUMENT

ERA14MA271
MAY 31, 2014
BEDFORD, MA

GROUP CHAIRMAN'S AIRCRAFT PERFORMANCE STUDY

This document supersedes the *Aircraft Performance Study* dated January 15, 2015. Subsequent to the publication of the January 15 *Study*, the time of the right brake pressure increase was adjusted from 21:40:08 to 21:40:10, based on a consideration of the 0.5 Hz sample rate of the data, and the consistency of the data with the recorded drop in longitudinal load factor. This adjustment required edits to several pages in the *Study*, as well as additional analysis of the training simulator test results.

Section D-VI (*Training Simulator Study*) now incorporates additional stopping distance calculations using the deceleration capability indicated by the simulator tests. These calculations are summarized in a new Table 9. The original Table 9 is now Table 10.

A new Section D-VII (*Alternative acceleration scenarios*) has been added, that presents an analysis of the acceleration of the airplane under two alternative engine power scenarios.

Table 4 has been edited to reflect the source of the CVR information in the "Full CVR transcript text" column. In addition, the "CAM-2 couldn't get (it manually any further)" CVR comment at 21:39:46.6 has been added to Tables 4 and 10 and to several Figures, in order to reflect the additions made in the Addendum to the CVR Group Chairman's Factual Report, dated July 13, 2015.

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

July 15, 2015

Aircraft Performance Study

by John O'Callaghan

ACCIDENT:

Location:	Bedford, MA
Date:	May 31, 2014
Time:	21:40 Eastern Daylight Time (EDT)
	01:40 Universal Coordinated Time (UTC) on June 1, 2014
Aircraft:	Gulfstream G-IV, registration N121JM
NTSB#:	ERA14MA271

TABLE OF CONTENTS

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

July 15, 2015

Aircraft Performance Study

by John O'Callaghan

A. ACCIDENT

Location:	Bedford, MA
Date:	May 31, 2014
Time:	21:40 Eastern Daylight Time (EDT)
	01:40 Universal Coordinated Time (UTC) on June 1, 2014[1]
Aircraft:	Gulfstream G-IV, registration N121JM
NTSB#:	ERA14MA271

B. GROUP

Chairman: John O'Callaghan
National Resource Specialist - Aircraft Performance
National Transportation Safety Board (NTSB)
490 L'Enfant Plaza E, SW
Washington, DC 20594

Members: N/A

C. HISTORY OF FLIGHT

On May 31, 2014, about 21:40 EDT, a Gulfstream Aerospace Corporation (GAC) G-IV, N121JM, operated by Arizin Ventures, LLC, crashed after a rejected takeoff and runway excursion at Laurence G. Hanscom Field (KBED), Bedford, Massachusetts. The two pilots, a flight attendant, and four passengers were fatally injured. The airplane was destroyed by impact forces and a postcrash fire. The personal flight, which was destined for Atlantic City International Airport (KACY), Atlantic City, New Jersey, was conducted under the provisions of *14 Code of Federal Regulations Part 91*. An instrument flight rules flight plan was filed. Night visual meteorological conditions prevailed at the time of the accident.

The objective of this *Aircraft Performance Study* is to determine and analyze the motion of the airplane and the physical forces that produce that motion. In particular, the *Study* attempts to define the airplane's position and orientation throughout the takeoff attempt, and determine the airplane's response to control inputs, external disturbances, and other factors that could affect its trajectory.

[1] EDT = UTC - 4 hours. Times in this *Performance Study* are based on the KBED Passive Multilateration (MLAT) time in EDT unless otherwise noted (see Section D-III).

The data the *Study* uses to determine and analyze the airplane motion includes but is not limited to the following:

- Wreckage location and condition.
- Ground scars / markings and damage to ground structures.
- Passive multilateration (MLAT) aircraft tracking data.
- Weight and balance information, including available payload and fuel weights.
- Flight Data Recorder (FDR) data.
- Cockpit Voice Recorder (CVR) information.
- Weather information.
- Output from computer programs and simulations that calculate aircraft performance.

This *Study* describes the results of using the data listed above in defining the position of N121JM relative to the KBED runway 11 threshold throughout the operation of the accident flight, and in particular during the takeoff attempt from runway 11. The *Study* introduces the airplane motion data collected during the investigation, describes the methods used to extract additional airplane motion information from the recorded data, and presents the results of these calculations.

The FDR data indicate that during the takeoff roll, the engine pressure ratios (EPRs) did not sustain the expected levels for either a full-thrust (MIN EPR[2]) takeoff, or a reduced thrust (FLEX EPR) takeoff. Furthermore, between the start of the takeoff roll and the end of the data, the elevator position slowly changed from -14° (i.e., 14° trailing-edge down (TED)) to -13°, and did not show any significant trailing-edge up (TEU) movement following the “rotate” call recorded on the CVR, as would be expected during a normal takeoff. Instead, following the “rotate” call, the CVR recorded several crew references to a “lock.” The FDR indicated that there was no “control check” conducted between the start of data recording for the accident flight (at about 21:31:20), and the end of the data.[3]

The pitch angle of the airplane did not change significantly during the attempted takeoff, and the three landing gear “squat” switches indicated the airplane stayed on the ground throughout the event.[4]

At 21:40:10, about 11 seconds after the “rotate” call, at a groundspeed of about 162 kt. and with about 1373 ft. of runway remaining, the left and right brake pressures started to rise. This increase in brake pressure appears to be the first action taken by the crew to reject the takeoff and bring the aircraft to a stop. At 21:40:14 (4 seconds after the brake pressure increase), the power levers were pulled back and the thrust reversers were deployed. The spoilers did not

[2] The terms "RATED EPR" and "MIN EPR" are interchangeable in GAC's GIV manuals and refer to the minimum EPR required to perform a maximum thrust takeoff.
[3] A “control check” is a pre-takeoff checklist item, wherein a pilot “sweeps” the cockpit flight controls (column, wheel, and rudder pedals) through their full range of motion, so as to verify the freedom and range of movement of the controls, and the appropriate response from the aerodynamic control surfaces. Reference 8 notes that “a review of the [Quick Access Recorder (QAR)] was performed to determine if pre-takeoff control checks were performed. The QAR contained 176 takeoff events including the accident takeoff. A control check was defined as stop-to-stop motion of the elevator, ailerons, and rudder at some point between the beginning of the FDR power cycle and takeoff. Out of the 176 takeoff events, two complete and 16 partial control checks were identified. The accident took place on takeoff number 176.” In addition to the pre-takeoff control check, the Airplane Flight Manual (AFM) calls for an elevator “freedom of motion check” at 60 kt. during the takeoff roll.
[4] At about 21:40:21, when the CVR recorded a “sound of impact,” the nose and left main gear squat switches indicated an “in air” status for 1 sample before returning to the “on ground” status.

deploy following the reduction in thrust, as would be expected on a normally configured airplane.

The airplane exited the runway onto the paved safety area at a groundspeed of about 151 kt., and exited the safety area onto grass at about 105 kt. The groundspeed at the "sound of impact" recorded by the CVR at 21:40:21 was about 97 kt.

This *Study* also presents an estimate of the braking friction developed by the airplane during the crew's attempt to reject the takeoff and bring the airplane to a stop, using FDR data, and airplane thrust and aerodynamic data provided by GAC. The calculation indicates that the brakes were providing the retarding force that would normally be expected on a dry, paved runway.

In addition, the *Study* presents the results of tests performed in a G-IV training simulator to determine the effects of rejecting the takeoff sooner in the takeoff roll. These tests indicate that the airplane could have been stopped on the paved surface if the crew had rejected the takeoff at the time that the first reference to a "lock" was made on the CVR.

Finally, the *Study* presents an analysis of the acceleration of the airplane under two alternative engine power scenarios: one with the EPRs set to about 1.4, and the other with the EPRs set to 1.7. The analysis indicates that even with the EPRs set to 1.4, the airplane could have achieved the takeoff rotation speed (V_R) of 127 kt. with about 3000 ft. of runway remaining.

The low engine EPR levels, relatively static elevator position, references to a "lock" on the CVR, and the lack of a "control sweep" prior to takeoff have prompted investigators to consider the possibility that the airplane gust lock (which prevents movement of the flight controls) was engaged during the attempted takeoff.[5] Furthermore, the lack of full spoiler deflection during the rejected takeoff (with only an approximately 2° spoiler movement instead) suggest that hydraulic power to the spoilers may have been interrupted at some point during the ground roll, allowing the spoilers to "float" up a bit under aerodynamic load, but preventing deployment. The fact that hydraulic power remained on for other systems (e.g., brakes and thrust reversers) suggests that the Flight Power Shutoff Valve (FPSOV) may have been activated during the event. Reference 13 includes a description of the gust lock system and its effects on the flight controls and throttle quadrant, and of the FPSOV and its effects on hydraulic power to the flight controls (including spoilers). Reference 13 also provides details regarding the examination of these systems on N121JM.

[5] In addition, the CVR recorded a crew reference to the "rudder limit light." Illumination of this light during the taxi is an additional indication of gust lock engagement (see Table 4 and Reference 13).

D. DETAILS OF THE INVESTIGATION

I. The Gulfstream G-IV Airplane

Figure 1 shows a 3-view image of the Gulfstream G-IV. Table 1 provides some dimensions of the airplane, as well as relevant mass properties for N121JM on the accident flight. The mass properties were computed using the weight and balance buildup shown in Table 2.

Item	Value
Reference dimensions (from Reference 1):	
Wing area	950.39 ft.^{2}
Wing span	77.83 ft.
Mean Aerodynamic Chord (MAC)	166.22 in. (13.85 ft.)
Mass properties for N121JM:	
Estimated ramp weight	58,906 pounds
Estimated ramp center of gravity (CG) position	33.8% MAC

Table 1. Dimensions of the Gulfstream G-IV airplane, and relevant mass properties for N121JM.

The empty weight and center of gravity (CG) position for N121JM shown in Table 2 was obtained from Reference 2. The fuel load of 14,000 lb. is listed in the flight plan filed for the flight (see Reference 3). The loading arm of the fuel (408.3 in.) was computed based on the loading diagram shown in Figure 2, which is taken from Reference 4, using a pitch angle (θ) of -1.5°. The weights of the pilot, co-pilot, Passenger 1, and baggage were provided by the Survival Factors Group Chairman. The passengers are identified by their seat numbers, as shown in Figure 3. The weights of Passengers 11 and 14 are estimates.[6]

---

[6] The weight and CG shown in Tables 1 and 2 were used in the calculation of the braking friction coefficient developed by the airplane during the rejected takeoff, described in Section D-V. Subsequent to this calculation, the Survival Factors Group Chairman provided updated weights for Passengers 11 and 14 (175 and 140 lb., respectively), though the seating location of these passengers are estimates, based on interviews and wreckage information. The updated passenger weights do not significantly affect the computed total weight of the airplane, or the friction coefficient analysis.

Item	Weight (lb.)	Arm (in.)	Moment (in.*lb.)	CG, %MAC
Basic operating 9/20/2013	44071.5	456.8	20130298.0	41.5
Actual Pilot	206.0	53.0	10918.0	
Actual Copilot	196.0	53.0	10388.0	
Actual Observer		79.0		
Actual basic operating	**43963.5**	**457.7**	**20120154.0**	**42.1**
Passenger 1	127.0	162.0	20574.0	
Passenger 2		179.0		
Passenger 3		200.0		
Passenger 4	170.0	208.0	35360.0	
Passenger 5	170.0	230.5	39185.0	
Passenger 6		264.0		
Passenger 7		264.0		
Passenger 8		330.5		
Passenger 9		330.5		
Passenger 10		363.0		
Passenger 11	170.0	375.0	63750.0	
Passenger 12		395.0		
Passenger 13		414.0		
Passenger 14	170.0	428.0	72760.0	
Baggage	135.0	593.0	80055.0	
Zero Fuel Weight	**44905.5**	**455.0**	**20431838.0**	**40.5**
Fuel	14000.0	408.3	5716668.2	12.4
Total Gross Weight	**58905.5**	**443.9**	**26148506.2**	**33.8**

Table 2. Weight and balance buildup for N121JM on accident flight.

II. Ground scars and markings

Surveys of the accident scene and survey coordinate systems

The recorded data described in Sections D-III and D-IV, and ground scars and markings on the runway and airport property, indicate that N121JM did not rotate for takeoff, but instead remained on the ground, overrunning the 7011 foot-long runway and 1020 foot-long paved safety area and onto grass. According to Reference 5,

> The airplane continued on the grass, struck approach lighting and a localizer antenna assembly, before coming to rest in a gully, on about runway heading, about 1,850 feet from the end of the runway. A postcrash fire consumed a majority of the airplane aft of the cockpit; however; all major portions of the airplane were accounted for at the accident site. The nose gear and left main landing gear separated during the accident sequence and were located on the grass area between the safety area and the gully.
>
> Tire marks consistent with braking were observed to begin about 1,300 feet from the end of runway 11. The tire marks continued for about another 1,000 feet through the paved runway safety area.

The Massachusetts State Police (MSP) assisted the NTSB with surveying the ground scars and markings left by the airplane, as well as the location of prominent wreckage items and airport property features.

The MSP provided the results of their survey to the NTSB as a data file for the *AutoCAD* computer program, and as images of the *AutoCAD* model printed to .pdf format. MSP also provided a legend to associate objects in the data file labeled with numbered flags with airplane parts or other items (such as tire marks). The objects in the *AutoCAD* file are located using a Cartesian coordinate system with x and y axes pointing east and north, respectively.

For the purposes of this *Study*, it is easiest to work in a coordinate system centered at the runway 11 threshold, and oriented with the x axis pointing down the center of the runway, and the y axis pointing towards the right edge of the runway (see Figure 4). The *AutoCAD* coordinates can be transformed into these "runway 11 coordinates" if the latitude and longitude of the origin, and the orientation relative to true north, of both the *AutoCAD* and runway 11 coordinate systems are known. The *AutoCAD* file does not contain the latitude and longitude of the origin of its coordinate system, though it can be observed that the *AutoCAD* axes are oriented east and north. However, the *AutoCAD* coordinates of the runway 29 threshold can be determined from the *AutoCAD* file, and the latitude and longitude of this point is known. Hence, the *AutoCAD* coordinates can be translated so that their origin is at the runway 29 threshold, and then the known latitude and longitude of this point can be used to transform all the *AutoCAD* coordinates into latitude and longitude. Then, the known latitude and longitude of the runway 11 threshold, and the known runway 11 heading, can be used to transform all the surveyed coordinates into the runway 11 coordinate system. In this *Study*, the runway 11 coordinate system will be used to describe the trajectory of the airplane and the location of surveyed items.

The latitude and longitude coordinates, and orientation relative to true North, of the runway 11 coordinate system are listed in Table 3, and depicted in Figure 4.[7]

KBED runway 11 coordinate system item	Value
Latitude of origin (threshold)	N 42° 28' 18.5654"
Longitude of origin (threshold)	W 071° 18' 01.2347"
Elevation of origin (threshold)	132.0 feet
x-axis bearing (runway heading)	97.13° (true)

Table 3. Origin and orientation KBED runway 11 coordinate system (from Reference 11).

Survey items of note

Selected items from the MSP survey are depicted in Figure 4. Figure 4 shows runway 11, the airplane trajectory recorded by the KBED Passive Multilateration system (MLAT, described in Section D-III) and computed from FDR data (as described in Section D-V), and ground scar evidence of the trajectory of the airplane in runway coordinates against a *Google Earth* satellite image background. The times and content of selected comments recorded by the Cockpit Voice Recorder (CVR) are also presented in Figure 4 at the airplane positions corresponding to the times at which the comments were recorded (the CVR data is described further in Section D-IV).

[7] 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.

The MSP survey items depicted in Figure 4 are the skid (tire) marks on the runway and paved safety area, the “furrows” in the ground created by the landing gear as the airplane departed the paved surface, and the final resting place of the main wreckage.

The right main gear skid marks start 5570 ft. from the runway threshold (1441 ft. from the runway end, and 2461 ft. from the end of the paved safety area), with the airplane about 12 ft. left of the runway centerline.[8] The left main gear skid marks start 5637 ft. from the threshold (1374 ft. from the runway end, and 2394 ft. from the end of the safety area), with the airplane about 13 ft. left of centerline. The skid marks cross the end of the runway (7011 ft. from the threshold) and onto the safety area with the airplane about 26 ft. left of centerline. The airplane’s maximum deviation to the left of the centerline, as indicated by the skid marks, is 29 ft., at about 7288 ft. from the threshold (743 ft. from the end of the safety area). The skid marks end about 7995 ft. from the threshold (36 ft. from the end of the safety area), with the airplane about 24 ft. left of centerline.

Three furrows created by the main and nose gear start about 8086 ft. from the threshold (55 ft. past the end of the safety area). The nose gear furrow is about 24 ft. to the left of centerline. The main gear furrows are about 42 ft. long, and the nose gear furrow is about 87 ft. long. The wings in the main wreckage came to rest about 8880 ft. from the threshold, or 1869 ft. past the runway end, and 849 ft. past the end of the safety area.

The last point recorded by the KBED MLAT is at 21:40:14.25, with the airplane 6761 ft. from the threshold (250 ft. from the runway end). The FDR data ends at 21:40:23.92; the airplane position determined from the data at this time is 8662 ft. from the threshold (1651 ft. from the runway end, and 631 ft. past the end of the safety area).

III. KBED Passive Multilateration (MLAT) data

Position data for N121JM was recorded by the Hanscom Field Passive Multilateration (KBED MLAT) system during the airplane’s taxi and attempted takeoff. This data was provided to the NTSB by Excelis, the company that supplied the MLAT system at KBED.

Description of the KBED MLAT system and data

The Massachusetts Port Authority (Massport) uses the MLAT system at KBED to monitor flight operations at the airport, primarily for noise monitoring and abatement purposes. A paper describing Massport’s MLAT system (Reference 6) is available from the Massport website (Reference 7).

Reference 6 describes the MLAT system, and contrasts it with traditional radar, as follows:

> Since the 1940’s, air traffic controllers have relied on radar (Radio Detection And Ranging) for aircraft surveillance. Radar has been upgraded through the years, but is still relatively expensive and has limitations, including line-of-site only surveillance and accuracy decreases with distance. The terminal radar at Logan International Airport (BOS) is the closest to Hanscom Field (BED) and provides the best surveillance due to its proximity. While this radar has clear site lines to aircraft operating into and out of Logan, it cannot see the aircraft operating at BED nearly as well. The precision of the radar is reduced due to the distance from the Logan radar to Hanscom and the fact that the radar beam must travel over

[8] The airplane centerline is assumed to be 6.8 ft. inboard of the main gear skid marks (the main gear struts are 13.67 ft. apart).

the hills in Arlington, which causes a radar shadow that limits low-level coverage in the area around BED.

In order to increase the coverage and precision of the flight tracking in the areas around Logan and Hanscom for the noise and operations monitoring system (NOMS), Massport decided to install a state-of-the art passive multilateration (MLAT) system from Exelis Inc.(Rannoch) The multilateration system listens to the radio responses from aircraft and determines the aircraft's range by using a method known as Time Difference of Arrival (TDOA). Multilateration has the added benefit of being able to capture the aircraft's unique identification code from its transmitted signal, provided the aircraft is equipped with a modern mode S transponder found on all commercial aircraft and some private aircraft. The MLAT system is more accurate than radar, provides improved coverage, and has a higher update rate, providing one position report per second, compared to radar's one report per five seconds.

Recorded MLAT data

The recorded MLAT data provided to the NTSB includes the following parameters, at an average sampling interval of about 0.7 seconds:

- Identification code of the target (code "a0583d" corresponds to N121JM).
- UTC time of the MLAT return, in milliseconds from midnight.
- Latitude of the target, in decimal degrees.
- Longitude of the target, in decimal degrees.

The MLAT latitude and longitude data are transformed into the KBED runway 11 coordinates described in Section D-II, and presented in Figure 4. In Figure 4, the EDT times of the returns are labelled every 10 seconds during the taxi to the runway, and every 5 seconds during the attempted takeoff roll. Note that the last point recorded by the KBED MLAT is at 21:40:14.25; the last two time labels in Figure 4 are based on an extrapolation of the data beyond this time, which matches the airplane position computed from an integration of the FDR accelerometer data (this integration is described in Section D-V).

IV. Recorded flight data

FDR and CVR Data Description

The aircraft cockpit voice recorder (CVR) and flight data recorder (FDR) were recovered from the aircraft and sent to 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. The CVR readout results in a transcript of the CVR events, a partial list of which is shown in Table 4. The paraphrased version of the selected CVR events listed in Table 4 are also presented along with other information in various Figures throughout this *Study*. For the complete list of CVR events, see Reference 9.

KBED MLAT Time	Full CVR transcript text	Paraphrased text on plots
21:39:05.9	CAM [sound similar to power increase].	sound of power increase
21:39:21.1	CAM-2 it says rudder limit light is on.	reference to rudder limit light
21:39:33.7	CAM [sound similar to power increasing further].	sound of further power increase
21:39:45.5	CAM [sound similar to ground roll].	sound of ground roll
21:39:46.6	CAM-2 couldn't get (it manually any further).	couldn't get
21:39:51.3	CAM-1 eighty.	eighty knot call
21:39:57.5	CAM-1 V-1.	V-1 call
21:39:58.9	CAM-1 rotate.	rotate call
21:39:59.9	CAM-2 (steer) lock is on.	reference to lock being on
21:40:12.6	CAM-2 (steer) lock is on.	reference to lock being on
21:40:14.3	CAM-2 I can't stop it.	reference to stopping ability
21:40:16.2	HOT [sound of triple chime].	sound of triple chime
21:40:21.0	CAM [sound of impact].	sound of impact

Table 4. Full CVR transcript text corresponding to paraphrased text on plots in this *Study*.

Correlation of MLAT, FDR, and CVR Times

The KBED MLAT, the FDR, and the 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 the MLAT time introduced in Section D-III and used throughout this *Study*.

Time on the FDR is measured in terms of the Subframe Reference Number (SRN), with one SRN equivalent to one second of time. The relationship between MLAT time and FDR SRN is established by aligning the groundspeed and track angle from the FDR to equivalent parameters computed using the MLAT data.[9] This results in the following relationship:

(Seconds elapsed since midnight EDT, MLAT time) = (FDR SRN) – 70003 seconds [1]

Equivalently,

21:40:00 EDT MLAT time = 148,003 FDR SRN [2]

The relationship between the times of events recorded on the CVR and the MLAT reference time is determined by first establishing the conversion from CVR to FDR time, and then using the FDR to MLAT time conversion defined by Equation [1]. The correlation between the FDR and CVR times is described in Reference 9. The CVR transcript provided in Reference 9 uses the MLAT times.

Several of the plots in this *Study* portray selected CVR content at positions corresponding to the occurrence of the content on the CVR. For example, plots of data vs. time include CVR content overlaid on vertical lines that intersect the x axis of the plot at the times that the CVR content was recorded. The CVR content portrayed on the plots is not the verbatim CVR transcript text, but rather a paraphrase or short-hand code for this text. The full CVR transcript text associated with each paraphrase or code is shown in Table 4.

---

[9] This alignment can be verified by observing the excellent agreement between the airplane runway x-coordinates obtained from the MLAT data and from an integration of the FDR accelerometer and groundspeed data, as shown in the top plots of Figures 5 and 6.

V. Additional performance parameters computed using FDR data

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 errors[10] and must be corrected before being used in these calculations.

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 58,906 lb. and 33.8 %MAC, respectively.[11] Further details on the derivation of the equations and calculation methods used in this *Study* can be found in Appendix A of Reference 10.

The FDR corrections discussed in this Study attempt to remove the following errors:

- Accelerometer bias errors
- Small errors in recorded groundspeed and drift angle that result in a ground track that differs slightly from the track evidenced by the tire skid marks and furrows
- Unrealistic spikes in groundspeed and airspeed following the "sound of impact" recorded on the CVR at 21:40:21

The performance parameters derived from the corrected FDR data include:

- True airspeed
- Airplane positions and velocities from accelerometer integration that match MLAT data and tire skid mark / furrow evidence
- Braking friction coefficient developed during the rejected takeoff

The results of these corrections and derivations for the last 58 seconds of recorded data (corresponding to the airplane's motion down the runway) are presented in Figures 5 - 13.
True airspeed calculation

True airspeed equals the Mach number multiplied by the speed of sound; the speed of sound is a function of the static temperature. Static temperature is recorded on the FDR.

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).

Figures 5 and 6 show the results of the true airspeed calculation, compared with the indicated (calibrated) airspeed recorded by the FDR. Note that after the "sound of impact" recorded on the CVR at 21:40:21, the FDR calibrated airspeed exhibits unrealistic behavior (jumping from

[10] "Measurement error" in this context means the difference between the actual 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.
[11] See Table 1.

100 to 160 knots), likely as a result of disruptions to the pitot / static system. The true airspeed calculation, which uses the FDR calibrated airspeed as input, also exhibits the unrealistic behavior. Figures 5 and 6 also show the groundspeed recorded by the FDR, and the groundspeed computed from integration of the accelerometer data (this calculation is described below). As discussed further below, the FDR groundspeed also exhibits unrealistic behavior after the “sound of impact.” Prior to this point, the close match between the computed true airspeed and computed groundspeed confirms that the winds were calm at the time of the attempted takeoff (the KBED weather reported during a special weather observation at 21:58 EDT is shown in Table 5).

Parameter \ Report	KBED METAR 20:56 EDT	KBED SPECI 21:58 EDT	KBED METAR 22:56 EDT
Sky condition	Clear	Clear	Clear
Visibility	10 miles	10 miles	10 miles
Winds	Calm	Calm	Calm
Temperature / Dew Point	9.4°C / 4.4°C	7.8°C / 5.6°C	6.7°C / 5.6°C
Altimeter setting	30.27 “Hg	30.28 “Hg	30.29 “Hg

Table 5. Weather observations at KBED surrounding the time of the accident.

Accelerometer data corrections and integration

The MLAT data provides a relatively accurate measure of the airplane’s position, though unrealistic “noise” is apparent when speeds are computed by taking the time derivative of the position data (and a larger error in the MLAT position data is apparent in Figure 5a at time 21:40:12). The FDR groundspeed data is smooth, but exhibits unrealistic “spikes” after the “sound of impact” at 21:40:21, similar to those seen in the FDR calibrated airspeed data.

The FDR speed data can be corrected and verified by integrating the accelerations at the CG of the airplane. In general, the accelerometers that generate the FDR load factor data 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. [12] 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 positions determined from another source. In this case, the best results were obtained by integrating the accelerometer data in two segments: the acceleration and deceleration portions of the ground roll.

For the acceleration segment, the target positions are defined by the integration of the FDR groundspeed and track angle. The resulting accelerometer biases and constants of

[12] For details about the equations to be integrated and the bias correction technique described in this Study, see Appendix A of Ref. 10.

integration were then used to integrate the accelerometer data over the entire ground roll (both the acceleration and deceleration segments). This calculation resulted in a good match of the MLAT runway x-coordinate data (see Figures 5 and 6), though the resulting track did not pass over the surveyed tire skid marks and furrows.

A track that did pass over the tire track evidence was obtained by integrating the deceleration portion of the ground roll separately, using the same accelerometer biases as the original integration, but selecting different constants of integration at the start of the segment. The initial track angle of this segment was selected to make the integrated track match the tire skid marks and furrows as well as possible, while the initial groundspeed and rate of climb were selected to match the runway x-coordinate and altitude from the original integration of the entire ground roll. The “accelerometer integration” results shown in Figures 5 and 6 are the result of “splicing” together the first integration for the acceleration segment of the ground roll, and the second integration for the deceleration segment of the ground roll.

The accelerometer biases used during both the acceleration and deceleration segments are the same, but the constants of integration are slightly different. The start and stop times, accelerometer biases, and constants of integration (expressed as increments, or biases, on the FDR groundspeed, track, and rate of climb data at the start time for each segment) are listed in Table 6.

Item	Acceleration Segment	Deceleration Segment
Start time	21:39:38.05	21:40:09.80
End time	21:40:09.67	21:40:23.92
Speed bias, knots	-0.59	0.35
Track bias, degrees	-0.82	0.30
Rate of climb bias, feet/minute	18.89	0.
n_x bias, G’s	-0.002832	-0.002832
n_y bias, G’s	0.024577	0.024577
nlf bias, G’s	0.010871	0.010871

Table 6. Biases and constants of integration for the two accelerometer integration segments.

The FDR heading and track angle, and track angle resulting from the accelerometer integration, are shown in Figures 7 and 8.

Braking friction calculations

Figures 5 and 6 indicate that at about 21:40:10, at a groundspeed of about 162 kt. and about 5638 ft. from the runway threshold (with 1373 ft. of runway remaining), the left and right brake pressure rose from about 50-100 psi to about 800 psi.[13] This increase in brake pressure appears to be the first action taken by the crew to reject the takeoff and bring the aircraft to a stop. It is of interest to determine whether the braking performance of the airplane during this portion of the ground roll was as expected. A measure of the braking performance is the braking friction developed by the tires, which can be computed from the longitudinal load factor, engine power, and thrust reverser position data recorded on the FDR of the airplane,

[13] The brake pressures are recorded at a sample rate of 0.5 Hz (1 sample every 2 seconds), and indicate that the right wheel pressure started to rise sometime between 21:40:08 and 21:40:10. However, the longitudinal acceleration drops suddenly between 21:40:09.8 and 21:40:10.1, indicating that the time of brake application was very close to 21:40:10.

and knowledge of the airplane's aerodynamic and thrust characteristics. As described below, the results of such a calculation indicate that during the braking event, the airplane developed a wheel braking coefficient (μ_B) of about 0.55, which is consistent with the expected braking friction on a dry, paved runway.

Figure 9 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 9 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:

$$F_N = \mu_N N_N \quad [3]$$

$$F_M = \mu_B N_M \quad [4]$$

$$\sum F_x = W n_x + W_x = W(n_x - \sin\theta) \quad [5]$$

$$\sum F_z = W n_z + W_z = W(n_z + \cos\theta) \quad [6]$$

$$\sum M_y = 0 \quad [7]$$

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 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 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

Assuming the rolling friction on the nose gear (μ_N) is about 0.02, Equations [2]-[7] can be reduced to three equations for the three unknowns N_N, N_M, and μ_B. As is evident in Figure 9, 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 G-IV, were provided to the NTSB by GAC.

For the μ_B calculation, a constant angle of attack of -1.8°, and a runway slope of -0.1% (-0.06°, the slope reported in Reference 11) was assumed. As shown in Figures 5 and 6, at about 21:40:14, about 6685 ft. from the threshold (with 326 ft. of runway remaining), the left and right thrust reversers were deployed. Hence, the μ_B calculation must account for the thrust changing from forward to reverse thrust. Tables for forward and reverse thrust as a function of Mach number, pressure altitude and Engine Pressure Ratio (EPR) were provided by GAC; for the μ_B calculation, the net forward thrust for each engine is computed by linearly interpolating between the forward and reverse thrust tables, according to the Thrust Reverse Deployed (TRD) parameters[14] recorded on the FDR:

$$TNET_i = TFWD_i(1 - TRD_i) + TREV_i(TRD_i) \quad [8]$$

Where $TFWD_i$ is the forward thrust for engine *i* (at the current Mach number, altitude, and EPR for engine *i*), $TREV_i$ is the reverse thrust for engine *i,* and TRD_i is the TRD command for engine *i*.

The thrust calculation requires Mach number as an input, but the FDR airspeed data exhibits unrealistic spikes during the deceleration, that if used to compute Mach number would result in unrealistic spikes in Mach number, thrust, and the μ_B calculation. Consequently, the Mach number for the thrust calculation was computed based on the groundspeed from the accelerometer integration, and assuming calm winds (see Figures 10 and 11).

Figures 10 and 11 also show the results of the μ_B calculation, for two different assumptions for TRD_1 and TRD_2. The “A” solutions correspond to values of TRD_i that match those recorded on the FDR, but that result in an unrealistic spike in the μ_B calculation at 21:40:15.5, i.e., close to the time that the reversers are deployed. The spike can be removed by shifting the TRD parameters to show deployment about 1 second earlier, as shown in the “B” solutions.[15]

Figures 10 and 11 indicate that, prior to the brake pressure rising at 21:40:10, the μ_B was low (about 0.02 to 0.04), close to the 0.02 value assumed for rolling friction. During the period of high brake pressure, the μ_B ranged between 0.5 and 0.6, which is consistent with the braking performance expected from a dry, paved runway. Figure 12 plots μ_B data for a dry, paved runway vs. groundspeed, as specified in Reference 12, for a tire inflation pressure of 190 psi (the nominal main gear tire inflation pressure of the G-IV), and an anti-skid system efficiency of 80%.[16] The calculated μ_B from Figures 10 and 11 is also plotted in Figure 12 as a function of groundspeed, for comparison. Note that the oscillations in the μ_B calculation are bounded by the range of μ_B determined from Reference 12.

[14] These are different parameters than the “Thrust Reverser Command” parameters plotted in Figures 5 and 6.

[15] The TRD parameters are sampled at 1 Hz, so if the TRD status changes to “deployed” just after it is sampled, there can be up to (just short of) a 1-second delay before the change is reflected in the recorded data.

[16] 14 Code of Federal Regulations (CFR) Part 25.109, *Accelerate-stop distance*, specifies that for a wet runway, the maximum tire-to-ground braking coefficient of friction (μ_{MAX}) must be multiplied by an efficiency value of 0.80 for “fully modulating” anti-skid systems, unless the efficiency of the system is demonstrated to be greater. The same 80% efficiency is applied here to the μ_{MAX} specified by Reference 12 for a dry runway.

VI. Training simulator study

Overview

Investigators from the NTSB, Gulfstream, and the FAA performed a number of exercises in a Gulfstream GIV-SP[17] Level D training simulator in order to evaluate the effect of various pilot actions on the accelerate-stop distance of the airplane, for the loading and environmental conditions of the accident. In particular, the investigators sought to determine what effect spoiler deflection would have on the speed at which the airplane departed the runway and safety area (as shown in Figures 5 and 6, the spoilers did not deploy during the deceleration segment of the ground roll, though their positions increased from 0° to about 2° between 21:40:05 and 21:40:08). In addition, investigators sought to determine whether the airplane could be brought to rest on the runway or safety area if the rejected takeoff procedures outlined in the Airplane Flight Manual (AFM) had been applied shortly after the rotation speed, or at the point the CVR recorded the first reference to a "lock." The exercises indicated that:

- Full deployment of the spoilers at the time at which the power levers were pulled back in the accident would not have diminished the speed at which the airplane departed the runway significantly, but could have reduced the speed and kinetic energy at which the airplane departed the safety area.
- If the AFM rejected takeoff procedures had been followed even as late as the time that the first reference to a "lock" was made on the CVR, the airplane could have been brought to a stop on the runway.

Test conditions / scenarios

The simulator was set up at KBED runway 11 with the loading conditions shown in Table 1, and the atmospheric conditions shown in Table 5 (for the 21:58 SPECI). The takeoff speeds used in the simulator were based on these conditions and graphs in the Performance section of the G-IV AFM, as follows:

Takeoff decision speed (V_1): 120 kt.
Rotation speed (V_R): 127 kt.

These speeds agree reasonably well with the FDR calibrated airspeed recorded at the times of the "V_1" and "rotate" callouts on the CVR, which are 119 and 125 kt., respectively. Figure 13 is the sea-level, flaps 20 "Takeoff Planning Chart" for "FLEX" (reduced thrust) takeoff performance, from Appendix A of the G-IV AFM.[18] According to the instructions in this Appendix, values in the table should not be interpolated; instead, "to ensure conservatism in airplane performance for takeoff conditions which fall between the given values … the next HIGHER weight, HIGHER ambient temperature, HIGHER airport pressure altitude and the next SHORTER field length" should be used. On this basis, the chart values for an OAT of 15°C and a gross weight of 60,000 lb. should be used, resulting in the following:

---

[17] With aircraft serial #1214, GAC began to incorporate Aircraft Service Change (ASC) 190, which included modifications that provided for improved braking capability and increased landing weight. Airplanes that incorporate ASC-190 (such as N121JM) are designated "Special Performance" or GIV-SP airplanes, as a marketing term or descriptor.

[18] The Appendix notes that "the use of FLEX Thrust reduces engine wear and maintenance and prolongs engine life by reducing the high turbine gas temperatures that occur during the use of full (MIN EPR) takeoff thrust … a second, important benefit is the reduction of sideline noise during the takeoff profile."

Full-thrust takeoff decision speed (V_1): 119 kt.
Full- thrust rotation speed (V_R): 127 kt.
Full-thrust EPR (MIN EPR): 1.70

These speeds agree well with the speeds determined using the graphs in the Performance Section of the AFM. Since KBED runway 11 is 7011 ft. long, Figure 13 indicates that a FLEX EPR as low as 1.59[19] can be used; for this case, the takeoff speeds would be:

FLEX takeoff decision speed (V_1): 125 kt.
FLEX takeoff rotation speed (V_R): 130 kt.
FLEX takeoff EPR (FLEX EPR): 1.59

These speeds do not match the FDR speeds at the times of the CVR callouts as closely as the “full-thrust” takeoff speeds match the FDR speeds. In addition, it should be noted that the EPR values from both engines recorded on the FDR are consistently below both the MIN EPR and FLEX EPR values specified above (see Figures 5 and 6), except for the brief peak at 21:39:46, where the EPRs momentarily reach 1.62.

For the simulator exercises, thrust was set to approximately match the initial 1.53 EPR shown in Figures 5 and 6 (following the brief 1.62 EPR peak). The starting point of the takeoff roll was determined by trial-and-error so that, when the brakes and thrust levers were operated so as to approximately match the FDR data, the simulated airplane departed the runway (7011 ft. from the threshold) and safety area[20] (8031 ft. from the threshold) at groundspeeds that were intended to match those determined from the accelerometer integration (151 and 105 kt., respectively). However, during the setup for the actual test, these speeds were mis-identified, and the target speeds used were 159 and 107 kts. In addition, a delay of 6 seconds between brake application and thrust reverser deployment was used, rather than 4 seconds.[21] This set of conditions was termed the “accident scenario.” For the “accident scenario,” the spoilers were prevented from operating by pulling the Flight Power Shutoff Valve (FPSOV) before starting the run, so as to match the spoiler data recorded on the FDR.

The investigators hoped to match the TED position of the elevators recorded on the FDR throughout the ground roll (commanding airplane nose-down) by engaging the gust lock in the simulator. However, the simulated gust lock did not have the intended effect, and so to match the elevator positions, the control column had to be held forward manually by the co-pilot. To reduce the control forces required and avoid overloading the control loader, the elevator trim was set more airplane-nose-down (i.e., elevator trim tab TEU) relative to the nominal takeoff position.

The effect of different operations of the brakes, power levers, and spoilers were determined by repeating the “accident” scenario, but with these systems operated differently. During the accident, the first indication of the crew’s intent to reject the takeoff and stop the airplane was the increase in brake pressure at 21:40:10; however, the power levers were not pulled back

---

[19] This is the lowest EPR value specified in Figure 13; however, the G-IV AFM states that “to ensure that takeoff configuration warnings are not inhibited, FLEX power settings must not reduce EPR below 1.56” (p. A-2).
[20] The safety area was not modelled in the simulator; instead, the ground continued as a flat surface past the end of the generic, 7011-ft. long runway.
[21] The effect of these errors and of slight variations in pilot technique and uncertainties / imprecision in determining the airplane speed and position during the simulation runs are discussed below.

and into reverse until 21:40:14, or about 4 seconds later (see Figure 5). Further, the spoilers did not come up after the power was reduced, as would be the case if they were properly armed, hydraulically powered, and functioning normally. For the simulator tests, an aborted takeoff "per AFM procedures" involved application of the brakes and reduction of thrust nearly simultaneously, with the spoilers deploying automatically with the reduction of thrust.

The alternative scenarios tested in the simulator included:

- The "accident scenario," but with the spoilers deploying when the power levers were pulled back;
- A rejected takeoff per AFM procedures, intended to be at the speed corresponding to the first reference to a "lock" on the CVR (129 kt.). However, during the test setup this speed was mis-identified as 140 kts.[22]
- A rejected takeoff per AFM procedures at V_R, plus pilot reaction time for the recognition of a locked control column;
- A rejected takeoff per AFM procedures at V_R, plus pilot reaction time for the recognition of a locked control column, but with the FPSOV pulled to disable the spoilers.

The various scenarios tested in the simulator are summarized in Table 7.

Scenario #	Description
1	Accident scenario: - Disable spoilers by pulling FPSOV - Co-pilot holds column forward to position elevators - Set EPR and initial position to match target runway and safety area exit speeds - At 157 knots, pilot flying applies full braking - 6 seconds after brake application, pilot flying commands full reverse thrust[23] - Bring aircraft to stop, maintaining runway centerline
2	Same as scenario # 1, except: - Do not pull FPSOV (spoilers armed, and deploy when power levers pulled back)
3	Perform rejected takeoff per AFM technique at first reference to "lock" on CVR.
4	Perform rejected takeoff per AFM technique at V_R + time required to recognize that control column will not move.
5	Same as scenario #4, but with FPSOV pulled to disable the spoilers.

Table 7. Training simulator test scenarios.

Test results

Data from the simulator tests was not recorded electronically. However, the following parameters of interest were noted, as applicable:

- The airspeed indicated when the airplane crossed the end of the runway (7011 ft. from the threshold).
- The airspeed indicated when the airplane crossed the end of the safety area (8031 ft. from the threshold).
- The distance from the threshold at which the airplane was brought to rest.

[22] The effect of this error is discussed below.
[23] After the simulator tests, the computed delay between brake application and thrust reverser deployment was adjusted from 6 to 4 seconds based on a review of the brake pressure data, considering the uncertainties associated with its sampling rate. The effect of this adjustment on the simulation results is discussed below.

The test results, and comparable FDR data, are shown in Table 8.

Case	Speed at end of runway (x = 7011 ft.)	Speed at end of safety area (x = 8031 ft.)	Distance from threshold (x coordinate) when stopped[24]
Accelerometer integration	151 kt.	105 kt.	n/a
Simulation scenario #1	159 kt. (approx.)	107 kt. (approx.)	10334 ft.[25]
Simulation scenario #2	152 kt. (run 1) 158 kt. (run 2)	90 kt. (run 1) 113 kt. (run 2)	Not recorded
Simulation scenario #3[26]	n/a	n/a	6683 ft.
Simulation scenario #4	n/a	n/a	6328 ft.
Simulation scenario #5	n/a	n/a	6890 ft.

Table 8. Training simulator test results.

It is difficult to use the results in Table 8 to determine, directly, how spoiler deflection at the time that the power levers were pulled back would have reduced the airplane's speed at the point it exited the runway (at x = 7011 ft.) and the safety area (at x = 8031 ft.). It is also difficult to use the results to determine (directly) how alternative stopping techniques would have affected the airplane's stopping point on the runway during the accident flight. This is because:

- The target speeds for the x = 7011 ft. and x = 8031 ft. points were mis-identified when setting up the test, and are different than those determined from the accelerometer integration;
- The delay between brake application and thrust reverser deployment used in Scenario 1, which affects the starting point of subsequent Scenarios, was 6 seconds instead of 4 seconds (the computed delay was revised from 6 to 4 seconds after the simulator tests had been run);
- There is uncertainty and imprecision involved in determining the airplane position and speed during the test, because of the need to determine these items by reading data from computer screens and aircraft instruments during the test;
- Slight variations in pilot technique can affect the speeds at the measured points.

The last two items likely account for the differences between the two Scenario 2 run results.

Nonetheless, the two Scenario 2 runs listed in Table 8 can be used to estimate the average deceleration of the airplane under the accident conditions, but with the spoilers deployed. This average deceleration can then be used to compute the expected stopping distance using the AFM rejected takeoff procedures for various scenarios. For a constant deceleration equal to gn_x,

$$V_2^{\,2} = V_1^{\,2} + 2gn_x(x_2 - x_1) \qquad [9]$$

[24] These distances are significantly longer than the required runway lengths specified in the AFM (see Figure 13) because the AFM assumes that the takeoff is rejected at V_1, with a 1 second delay for pilot reaction time.
[25] Once past the runway safety area, the simulator assumes a flat surface; hence this distance assumes the available runway length is unlimited.
[26] For Scenario 3, the rejected takeoff in the simulator was mistakenly initiated at 140 kt. rather than at the intended speed of 129 kt. The results for this Scenario are adjusted to account for this error in the discussion below.

Where:

x_1 = initial airplane x coordinate
x_2 = final airplane x coordinate
V_1 = speed at x_1
V_2 = speed at x_2

Using Equation [9] to compute the average n_x for the two Scenario 2 runs in Table 8, and averaging the two results, yields an n_x of -0.60 G's (compared to an average n_x of -0.51 G's computed using the speeds from the accelerometer integration, at the same x_1 and x_2 points).

Since the power levers were pulled back very close to the point where the airplane exited the runway (see Figure 6), the additional deceleration provided by the spoilers would not have changed the speed at that point significantly. However, the additional deceleration would have been beneficial during the time the airplane was traversing the safety area. Equation [9] can be used to determine the speed at the end of the safety area (at x = 8031 ft.), assuming the average n_x determined from the Scenario 2 runs, starting from the point where the FDR recorded the decrease in n_x from -0.15 G's to -0.55 G's (at 21:40:15.6, corresponding to the deployment of the thrust reversers).

Using time 21:40:15.6 as the initial point in Equation [9], x_1 = 7098 ft. and V_1 = 148 kt. With an n_x of -0.60 G's and an x_2 of 8031 ft., Equation [9] gives V_2 = 96 kt., the speed at which the airplane would exit the safety area with the spoilers deployed. This is 9 kt. slower than the speed determined from the accelerometer integration, and represents a 16% decrease in the airplane's kinetic energy at that point.

If a constant n_x of -0.60 G's is applied at 21:40:12.1, where x_1 = 6169 ft. and V_1 = 159 kt., then by Equation [9], V_2 = 0 at x_2 = 8031 ft. (the end of the safety area). Similarly, applying a constant n_x of -0.60 G's at 21:40:11.0 (where the actual n_x drops to -0.15 G's, corresponding to brake application), then V_2 = 0 at x_2 = 7802 ft., 229 ft. before the end of the safety area.

The average acceleration computed above can be used to correct the results for Scenario 3, which was improperly run in the simulator test because the takeoff was aborted at 140 kt. rather than at the intended 129 kt. The first reference to a "lock" on the CVR is at 21:39:59.9. Assuming that the pilot decides to take action to stop the airplane at this time, and assuming an additional two seconds to get the airplane configured and to achieve the average n_x during the stop, this n_x would be established at about 21:40:02. At this time, x_1 = 3594 ft. and V_1 = 137.0 kt. With an average n_x of -0.60 G's and a V_2 of 0 kt., Equation [9] gives x_2 = 4979 ft., 2032 ft. before the end of the runway. Using an average n_x of -0.51 G's (corresponding to the deceleration observed in the FDR data, with the spoilers stowed) results in x_2 = 5223 ft., 1788 ft. before the end of the runway.

If a constant n_x of -0.55 G's (the n_x recorded on the FDR after the thrust reversers were deployed) is applied at 21:40:11.2, where x_1 = 5932 ft. and V_1 = 161 kt., then by Equation [9], V_2 = 0 at x_2 = 8013 ft. (18 ft. before the end of the safety area).

For Scenarios 4 and 5, assuming a two-second pilot reaction time following the V_R call, plus an additional two seconds to configure the airplane, the average n_x would be established at the time of the V_R call plus 4 seconds, or at about 21:40:03, where x_1 = 3829 ft. and V_1 = 140.6 kt. With an average n_x of -0.60 G's and a V_2 of 0 kt., Equation [9] gives x_2 = 5288 ft., 1723 ft. before the end of the runway. Using an average n_x of -0.51 G's results in x_2 = 5545 ft., 1466 ft. before the end of the runway.

These computed results are summarized in Table 9.

Case	Speed at end of runway (x = 7011 ft.)	Speed at end of safety area (x = 8031 ft.)	Distance from threshold (x coordinate) when stopped
Simulation scenario #2	~151 kt.	96 kt.	n/a
Simulation scenario #3, average n_x = -0.60 G's	n/a	n/a	4979 ft. (2032 ft. remaining to end of runway)
Simulation scenario #3, average n_x = -0.51 G's	n/a	n/a	5223 (1788 ft. remaining to end of runway)
Simulation scenario #4, average n_x = -0.60 G's	n/a	n/a	5288 ft. (1723 ft. remaining to end of runway)
Simulation scenario #5, average n_x = -0.51 G's	n/a	n/a	5545 ft. (1466 ft. remaining to end of runway)
average n_x = -0.60 G's applied @ 21:40:11.0	104 kt.	n/a	7802 ft. (229 ft. remaining to end of safety area)
average n_x = -0.55 G's applied @ 21:40:11.2	112 kt.	n/a	8013 ft. (18 ft. remaining to end of safety area)
average n_x = -0.60 G's applied @ 21:40:12.1	118 kt.	0 kt.	8031 ft. (end of safety area)

Table 9. Stop distances computed using deceleration determined from simulation runs.

Note that the computed stop distances shown in Table 9 for Scenarios 3, 4, and 5 are significantly shorter than those shown in Table 8, which were determined in the training simulator, and are more consistent with the AFM field length requirements shown in Figure 13. The likely reason for the difference is that the initial conditions for the computations summarized in Table 9 are based on the actual airplane position and ground speed as determined from the FDR data, whereas the initial conditions for simulator runs are an estimate based on trying to match the FDR ground speed at the end of the runway and paved overrun. These estimates suffer from the errors and uncertainties listed above, and apparently place the initial condition further down the runway than is indicated by the FDR data. Nonetheless, the training simulator results are useful, since they indicate the deceleration that can be obtained using the AFM rejected-takeoff procedures.

Qualitatively, the results in Tables 8 and 9 are consistent in that they indicate that the airplane could have been stopped on the runway using the AFM rejected takeoff procedures shortly after the rotation speed, or at the point the CVR recorded the first reference to a "lock."

In summary, a conservative analysis of the simulator testing indicates that:

- Full deployment of the spoilers at the time at which the power levers were pulled back in the accident would not have diminished the speed at which the airplane departed the runway significantly, but could have reduced the speed at which the airplane departed the safety area by about 9 kt., corresponding to a 16% decrease in the airplane's kinetic energy at that point (simulation Scenario #2).

- If the takeoff is rejected per the AFM procedures at the first reference to a "lock" on the CVR (i.e., at 21:39:59.9, or 1 second after the "rotate" call), then the airplane can be brought to a stop on the runway with at least 300 ft. of runway remaining (or at least 1300 ft. remaining to the end of the paved safety area) (simulation Scenario #3).

- Even without the use of spoilers, if the takeoff is rejected per the AFM procedures following the V_R call, then the airplane can be brought to a stop on the paved surface, but with little or no runway remaining (though with about 1000 ft. of paved safety area remaining) (simulation Scenarios #4 and #5).

VII. Alternative acceleration scenarios

Overview

During the investigation, investigators became interested in the time and runway distance required to accelerate to the rotation speed (V_R) of 127 kts. with engine EPR settings different from those recorded on the FDR. Specifically, investigators sought to understand how the time and distance to 127 kts. would differ from those during the accident under the following scenarios:

1. An EPR maintained at the approximately 1.42 level observed in the FDR data between about 21:39:38 and 21:39:43; and
2. An EPR maintained at a 1.70 level, consistent with the EPR recorded on the FDR during previous takeoffs.

This section of the *Study* describes the method used to compute the thrust and acceleration associated with these alternative scenarios, and the resulting differences in time and distance required to accelerate to 127 kt.

Acceleration calculation method

The forces and moments on the airplane illustrated in Figure 9 and described by Equations [3] – [7] can be used to solve for the longitudinal load factor (n_x), if the thrust of the engines is known, and assuming rolling friction only on the main and nose gear tires. The acceleration of the airplane down the runway follows from the n_x and the following equation:

$$a_x = \frac{dV}{dt} = n_x g + g_x = n_x g - g\sin\theta = g(n_x - \sin\theta) \qquad [10]$$

Where $a_x = dV/dt$ is the rate of change of speed (acceleration) of the airplane.

As mentioned in Section D-V, the coefficient of friction (μ) for a rolling (unbraked) tire is assumed to be 0.02, and the aerodynamic and thrust characteristics of the G-IV were provided by GAC. This information can be used to program a simple computer simulation that, given EPR and an initial runway position and speed, computes thrust and a_x, and integrates a_x and V over time to obtain updated speeds and runway positions.

The FDR EPR data plotted in Figure 5b indicates that between 21:39:48 and 21:40:14, the EPR steadily decayed from about 1.54 to 1.44, even though the PLA angles remained relatively constant. For this *Study*, it is assumed that if the PLA angles had remained constant at the positions that produced the EPR = 1.42 level between 21:39:38 and 21:39:43, then the EPR would similarly have steadily decayed from the 1.42 level as the airplane airspeed increased. To model this effect, the rate of decay of EPR with speed observed in the FDR data was applied in the simulation program.

For the EPR = 1.70 simulation, however, no EPR decay with speed was implemented, because the previous takeoffs (that all reached this EPR level) did not exhibit a decay in EPR with speed (see Reference 14).

Results

The results of the alternative acceleration scenarios are presented in Figures 14 and 15. The Figures show results for 3 takeoff scenarios:

- An approximate match of the accident scenario starting at about 21:39:48, where the FDR EPR had decreased to about 1.53 from its peak of 1.62, and then started a steady decay as the airplane accelerated (this is the "EPR_{REF} = 1.53" scenario);

- A simulation of the acceleration starting at 21:39:40.5, where the FDR EPR had stabilized at about 1.42, and incorporating the same decay in EPR with speed as observed in the FDR data (this is the "EPR_{REF} = 1.42" scenario);

- A simulation of the acceleration starting at about 21:39:47, the time where it is estimated that the EPR would have reached 1.70 had it continued to increase at the rate seen in the FDR data as the EPR approached its peak of 1.62. As mentioned above, there is no EPR decay with speed for this (the "EPR_{REF} = 1.70") scenario.

The bottom plot in Figure 14 indicates how the EPR decay as a function of speed (Mach number) was modeled (for the EPR_{REF} = 1.53 and 1.42 scenarios). The blue line shows that the model matches the FDR EPR data well for the period between 21:39:48 and 21:40:14, where EPR is decaying with speed. The red line indicates how the same rate of decay with speed is applied in the EPR_{REF} = 1.42 scenario. The brown line shows how EPR is constant at 1.70 for the EPR_{REF} = 1.70 scenario.

The top plot in Figure 14 shows the total thrust for the three scenarios that follows from the EPR modeling. The middle plot shows the resulting n_x for each scenario. Note that the EPR_{REF} = 1.53 n_x matches the FDR n_x well, thereby validating the method as a means of evaluating the other acceleration scenarios. Note that the initial n_x for the EPR_{REF} = 1.42 scenario also matches the FDR n_x well, when the FDR EPR is at about the 1.42 level. The brown line shows the substantially higher n_x resulting from the EPR_{REF} = 1.70 scenario.

Figure 15 shows the increase in groundspeed for the three scenarios both as a function of time and as a function of distance from the runway threshold. Note that the EPR_{REF} = 1.53 scenario (blue line) matches the FDR-based data (black line) well, again validating the method. (The small but growing differences between the blue and black lines is most likely the result of small differences between the actual and simulated airplane thrust and acceleration, which result in growing differences in speed and distance over time.)

The red line in Figure 15 shows that with the reduced thrust resulting from the EPR_{REF} = 1.42 scenario, to reach the V_R of 127 kt. the airplane would have needed to accelerate for 7.4 more seconds and 1170 more feet of runway than in the accident scenario, and would have reached V_R about 4100 ft. from the runway threshold, with about 3010 ft. of runway remaining.

The brown line in Figure 15 shows that with the increased thrust resulting from the EPR_{REF} = 1.70 scenario, the airplane would have reached the V_R of 127 kt. 4 seconds and 676 ft. of runway sooner than in the accident scenario.

E. CONCLUSIONS

The accident scene, MLAT, FDR, CVR, and simulation data presented in this *Study* are consistent with the sequence of events summarized in Table 10, concerning the motion of N121JM during its attempted takeoff from runway 11 at KBED:

Event	Time (EDT)	Ground-speed, kt.	x runway coordinate, ft.	Distance to runway end, ft.	Distance to safety area end, ft.
N121JM starts taxi towards runway 11	21:33:00	4	n/a	n/a	n/a
N121JM turns onto runway 11	21:39:20	4	96	6915	7935
Brakes released & power increased	21:39:34	8.8	200	6811	7831
“Couldn’t get” comment on CVR	21:39:46.6	65	898	6113	7133
80 knot call on CVR	21:39:51.3	90.0	1516	5495	6515
V1 call on CVR	21:39:57.5	118.7	2612	4399	5419
Rotate call on CVR	21:39:58.9	124.5	2899	4112	5132
First reference to “lock” on CVR	21:39:59.9	128.6	3113	3898	4918
Spoiler positions start to increase from 0° to about 2°	21:40:05.7	149.6	4479	2532	3552
Brake pressures start to rise	21:40:10.0	162.2	5638	1373	2393
Peak groundspeed	21:40:10.3	162.3	5694	1317	2337
n_x decreases to -0.15 G’s	21:40:11.0	161.2	5885	1126	2146
Last reference to “lock” on CVR	21:40:12.6	157.4	6315	696	1716
PLAs[27] start to move from 20° to -20°	21:40:14.0	155.6	6685	326	1346
Reference to stopping ability on CVR	21:40:14.3	154.7	6763	248	1268
Airplane exits runway onto safety area	21:40:15.3	150.9	7011	0	1020
Both thrust reversers discretes on FDR show “DEPLOY”	21:40:15.5	149.2	7072	-61	959
n_x decreases to -0.55 G’s	21:40:15.6	148.2	7098	-87	933
Sound of triple chime on CVR	21:40:16.2	142.3	7245	-234	786
Airplane exits safety area onto grass	21:40:20.0	104.8	8031	-1020	0
Sound of impact on CVR	21:40:21.0	97.3	8206	-1195	-175
End of FDR data	21:40:23.9	90.2	8662	-1651	-631
Surveyed main wreckage location	n/a	0	8880	-1869	-849

Table 10. Sequence of events during N121JM’s attempted takeoff from KBED runway 11. Ground speed and runway x coordinate data are from the accelerometer integration described in Section D-V.

As noted previously, the FDR data indicate that during the takeoff roll, the engine EPRs did not sustain the expected levels for either a full-thrust (MIN EPR) takeoff, or a reduced thrust (FLEX EPR) takeoff. Furthermore, between the start of the takeoff roll and the end of the data, the elevator position slowly changed from -14° (i.e., 14° TED) to -13°, and did not show any significant TEU movement following the “rotate” call recorded on the CVR, as would be

[27] Power Lever Angles (PLAs).

expected during a normal takeoff (see Figures 5 and 6). Instead, following the “rotate” call, the CVR recorded several crew references to a “lock.” The FDR indicated that there was no “control check” conducted between the start of data recording for the accident flight, and the end of the data.

The pitch angle of the airplane did not change significantly during the attempted takeoff, and the three landing gear “squat” switches indicated the airplane stayed on the ground throughout the event.

At 21:40:10, about 11 seconds after the “rotate” call, at a groundspeed of about 162 kt. and with about 1373 ft. of runway remaining, the left and right brake pressures started to rise. This increase in brake pressure appears to be the first action taken by the crew to reject the takeoff and bring the aircraft to a stop. At 21:40:14 (4 seconds after the brake pressure increase), the power levers were pulled back and the thrust reversers were deployed. The spoilers did not deploy following the reduction in thrust, as would be expected on a normally configured airplane.

The airplane exited the runway onto the paved safety area at a groundspeed of about 151 kt., and exited the safety area onto grass at about 105 kt. The groundspeed at the “sound of impact” recorded by the CVR at 21:40:21 was about 97 kt. The airplane came to rest about 8880 ft. from the runway threshold, or 1869 ft. past the runway end, and 849 ft. past the end of the safety area.

The estimate of the braking friction developed by the airplane during the crew’s attempt to reject the takeoff indicates that the brakes were providing the retarding force that would normally be expected on a dry, paved runway (see Figure 12).

The results of tests performed in a GIV-SP training simulator to determine the effects of rejecting the takeoff sooner in the takeoff roll indicate that the airplane could have been stopped on the paved surface if the crew had rejected the takeoff at (or before) the time that the first reference to a “lock” was made on the CVR. The tests also indicated that full deployment of the spoilers at the time at which the power levers were pulled back in the accident would not have diminished the speed at which the airplane departed the runway significantly, but could have reduced the speed at which the airplane departed the safety area by about 9 kt., corresponding to a 16% decrease in the airplane’s kinetic energy at that point.

Calculations of the acceleration of the airplane under alternative EPR-level scenarios indicate that with the reduced thrust resulting from the EPR_{REF} = 1.42 scenario, to reach the V_R of 127 kt. the airplane would have needed to accelerate for 7.4 more seconds and 1170 more feet of runway than in the accident scenario, and would have reached V_R about 4100 ft. from the runway threshold, with about 3010 ft. of runway remaining. With the increased thrust resulting from the EPR_{REF} = 1.70 scenario, the airplane would have reached the V_R of 127 kt. 4 seconds and 676 ft. of runway sooner than in the accident scenario.

John O’Callaghan
National Resource Specialist – Aircraft Performance
Office of Research and Engineering

F. REFERENCES

1. Gulfstream Aerospace Corporation (GAC), *General Arrangement GIV*, GAC drawing # 1159-40001, Revision A, June 29, 2006 (GAC proprietary document).

2. Repair Station FAA CRS GR4R216M, *Gulfstream Aerospace GIV/G400/G300 Weight & Balance Manual Aircraft Basic Weight, Serial # 1399,* dated 9/20/2013, page 3.

3. National Transportation Safety Board, Office of Aviation Safety, *Operations Group Chairman's Factual Report, Gulfstream G-IV, registration N121JM, Bedford, MA, May 31, 2014.* NTSB Accident Number ERA14MA271 (Washington, DC: NTSB, February 12, 2015). (Contact NTSB at pubinq@ntsb.gov).

4. Gulfstream Aerospace Corporation, *Gulfstream IV Estimated Aerodynamic Characteristics,* Report No. A/P-ER-86-015, dated August 22, 1986 (GAC proprietary document).

5. National Transportation Safety Board, *Preliminary Report – Aviation, Gulfstream G-IV, registration N121JM, Bedford, MA, May 31, 2014.* Available on the NTSB website at *http://www.ntsb.gov/_layouts/ntsb.aviation/GeneratePDF.aspx?id=ERA14MA271&rpt=p* (accessed 12/17/2014).

6. Massachusetts Port Authority, paper describing the Passive Multilateration System at Hanscom Field. Accessible at http://www.massport.com/media/7497/SurveillanceRadar.pdf (accessed 12/19/2014).

7. Massachusetts Port Authority, *How flight operations at Hanscom affect airport noise,* website http://www.massport.com/hanscom-field/overview/airport-activity-monitor/flight-operations/ (accessed 12/19/2014).

8. National Transportation Safety Board, Office of Research and Engineering, *Flight Data Recorder Specialist's Factual Report, Gulfstream G-IV, registration N121JM, Bedford, MA, May 31, 2014. NTSB Accident Number ERA14MA271* (Washington, DC: NTSB, August 26, 2014). (Contact NTSB at pubinq@ntsb.gov).

9. National Transportation Safety Board, Office of Research and Engineering, *Cockpit Voice Recorder Specialist's Factual Report, Gulfstream G-IV, registration N121JM, Bedford, MA, May 31, 2014. NTSB Accident Number ERA14MA271* (Washington, DC: NTSB, March, 2015). (Contact NTSB at pubinq@ntsb.gov).

10. National Transportation Safety Board, Office of Research and Engineering, *Group Chairman's Aircraft Performance Study, American Airlines Flight 587, Airbus A300B4-605R, Belle Harbor, New York, November 12, 2001*, NTSB Accident Number DCA02MA001, Docket Item 188 (Washington, DC: NTSB, October 10, 2002). (Contact NTSB at pubinq@ntsb.gov).

11. Federal Aviation Administration, *Airport Details for KBED – ACTIVE, Laurence G Hanscom Fld, Bedford*, Report Date 09/12/2014. Accessible at: http://webdatasheet.faa.gov/Home/findAndOpenPDF/83c770bc-7472-4b11-b50c-c7f3c56f9ee2

12. Engineering Sciences Data Unit, *Frictional and retarding forces on aircraft tyres: Part II: estimation of braking force (friction data updated – 1981).* Engineering Sciences Data Item Number 71026, approved for issue October 1971. Sponsored by the Royal Aeronautical Society.

13. National Transportation Safety Board, Office of Aviation Safety, *Systems & Certification Group Chairman's Factual Report, Gulfstream G-IV, registration N121JM, Bedford, MA, May 31, 2014.* NTSB Accident Number ERA14MA271 (Washington, DC: NTSB, February 27, 2015). (Contact NTSB at pubinq@ntsb.gov).

14. National Transportation Safety Board, Office of Research and Engineering, *Flight Data Recorder Specialist's Factual Report – Addendum 2, Gulfstream G-IV, registration N121JM, Bedford, MA, May 31, 2014. NTSB Accident Number ERA14MA271* (Washington, DC: NTSB, April 20, 2015). (Contact NTSB at pubinq@ntsb.gov).

G. GLOSSARY OF SYMBOLS AND ACRONYMS

English characters

AFM	Airplane Flight Manual
CG	Center of Gravity
CVR	Cockpit Voice Recorder
EDT	Eastern Daylight Time
EPR	Engine Pressure Ratio
F_M	Braking friction force on main gear
F_N	Rolling friction force on nose gear
F_x	Force along body longitudinal axis
F_z	Force along body vertical axis
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FPSOV	Flight Power Shutoff Valve
g	Acceleration due to gravity (32.17 ft/s^2)
GAC	Gulfstream Aerospace Corporation
KACY	Atlantic City International Airport, Atlantic City, New Jersey
KBED	Laurence G. Hanscom Field, Bedford, Massachusetts
M_y	Pitching moment about body lateral axis
MAC	Mean Aerodynamic Chord
MLAT	Passive Multilateration surveillance system at KBED
MSP	Massachusetts State Police
nlf	Normal load factor = $-n_z$
n_x	Body-axis longitudinal load factor, G's
n_y	Body-axis lateral load factor, G's
n_z	Body-axis vertical load factor, G's
NTSB	National Transportation Safety Board
S	Wing area
SRN	Subframe Reference Number
TED	Trailing-edge down
TEU	Trailing-edge up
$TNET_i$	Net forward thrust, engine i
$TNET_i$	Forward thrust at given Mach number, EPR, and altitude, engine i
$TREV_i$	Reverse thrust at given Mach number, EPR, and altitude, engine i
TRD_i	Thrust Reverse Deployed parameter for engine i
UTC	Universal Coordinated Time
V	Groundspeed
V_1	Takeoff decision speed, or initial groundspeed (depends on context)
V_R	Takeoff rotation speed
w	Velocity component along z-body axis
W	Airplane weight = mg
x	x-coordinate (axis system dependent on context)
y	y-coordinate (axis system dependent on context)
z	z-coordinate (axis system dependent on context)

Greek characters

α	Angle of attack
μ_B	Coefficient of braking friction on main gear
μ_N	Coefficient of rolling friction on nose gear
γ	Flight path angle
θ	Pitch angle
ψ	Heading or track angle (magnetic or true dependent on context)

FIGURES

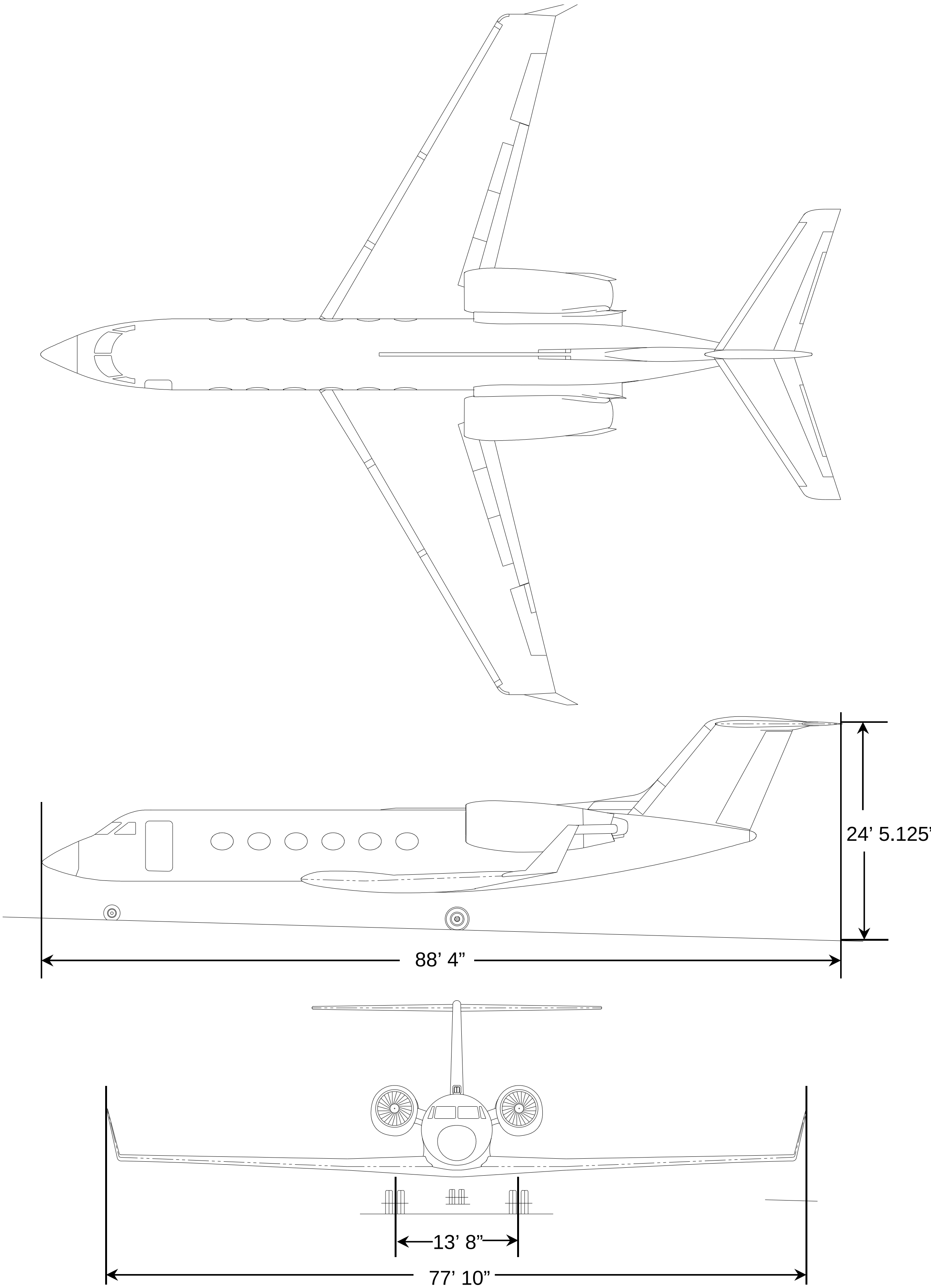


Figure 1: 3-view of the Gulfstream G-IV airplane (from Ref. 1).

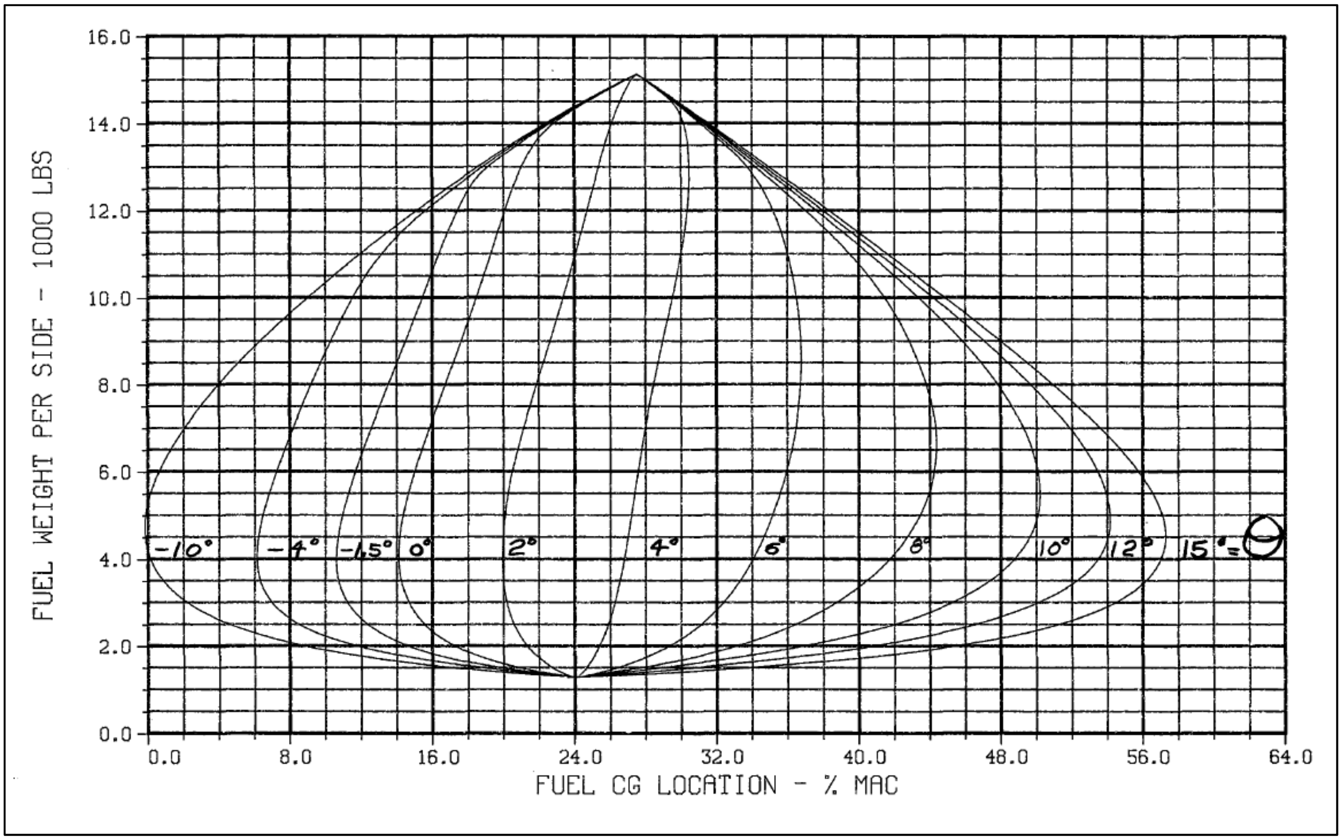


Figure 2. Fuel loading diagram from Reference 4.

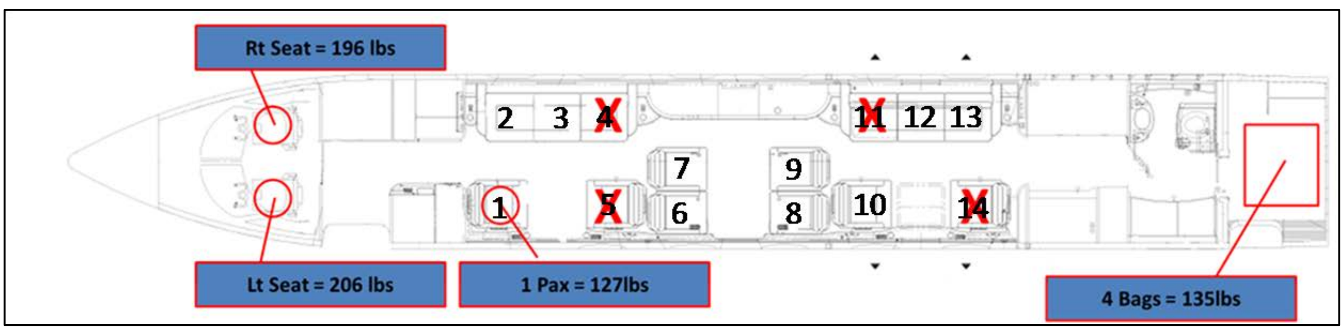


Figure 3. Seating diagram.

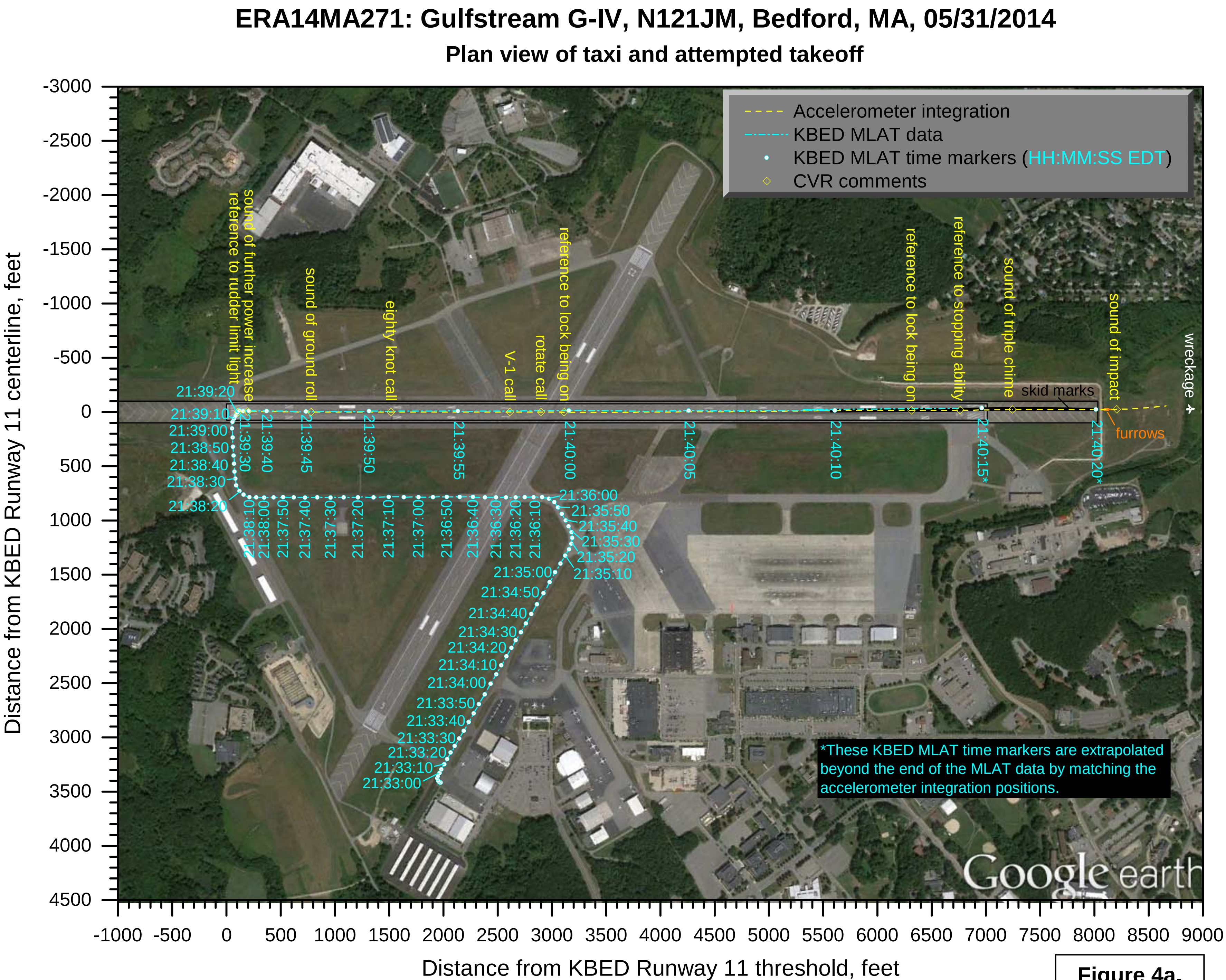

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
Plan view of taxi and attempted takeoff
Accelerometer integration
KBED MLAT data
KBED MLAT time markers (HH:MM:SS EDT)
CVR comments
reference to rudder limit light
sound of further power increase
sound of ground roll
eighty knot call
V-1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
sound of impact
skid marks
furrows
wreckage
*These KBED MLAT time markers are extrapolated beyond the end of the MLAT data by matching the accelerometer integration positions.
Distance from KBED Runway 11 centerline, feet
Distance from KBED Runway 11 threshold, feet
Google earth

Figure 4a.

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014

Plan view of taxi and attempted takeoff (detail)

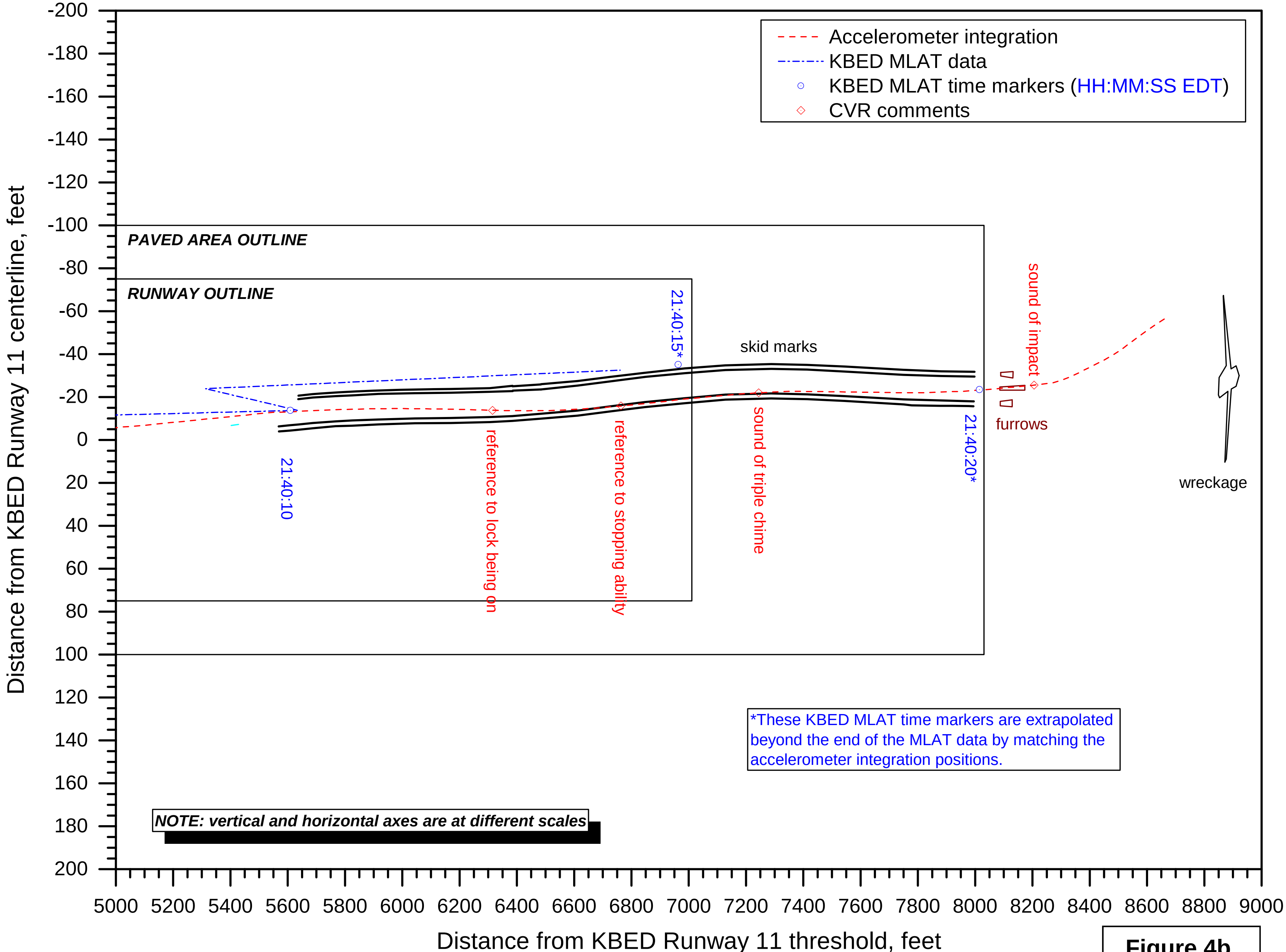


Figure 4b.

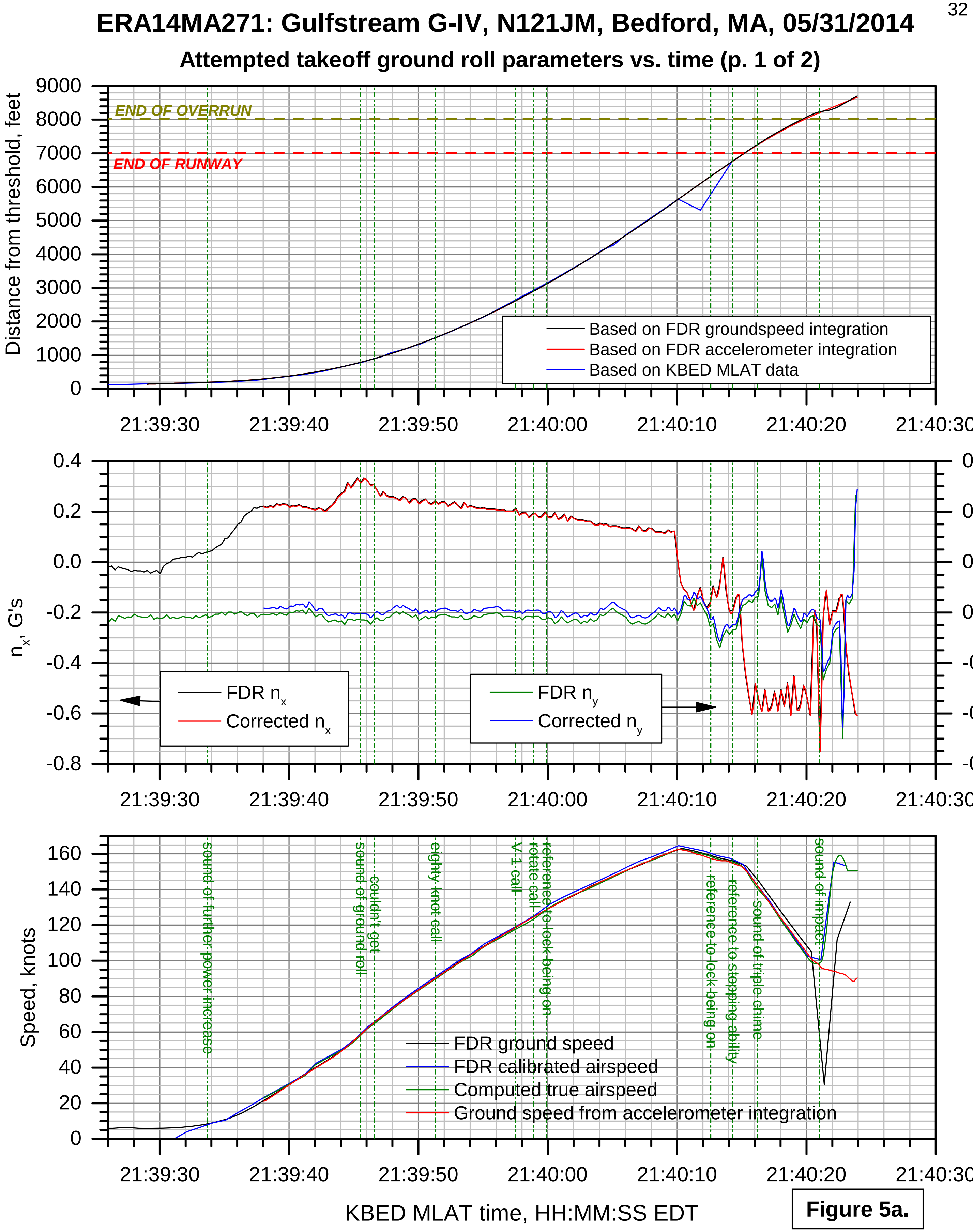

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
Attempted takeoff ground roll parameters vs. time (p. 1 of 2)
Distance from threshold, feet
END OF OVERRUN
END OF RUNWAY
Based on FDR groundspeed integration
Based on FDR accelerometer integration
Based on KBED MLAT data
nx, G's
ny, G's
FDR nx
Corrected nx
FDR ny
Corrected ny
Speed, knots
sound of further power increase
sound of ground roll
couldn't get
eighty knot call
V 1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
sound of impact
FDR ground speed
FDR calibrated airspeed
Computed true airspeed
Ground speed from accelerometer integration
KBED MLAT time, HH:MM:SS EDT

Figure 5a.

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014

Attempted takeoff ground roll parameters vs. time (p. 2 of 2)

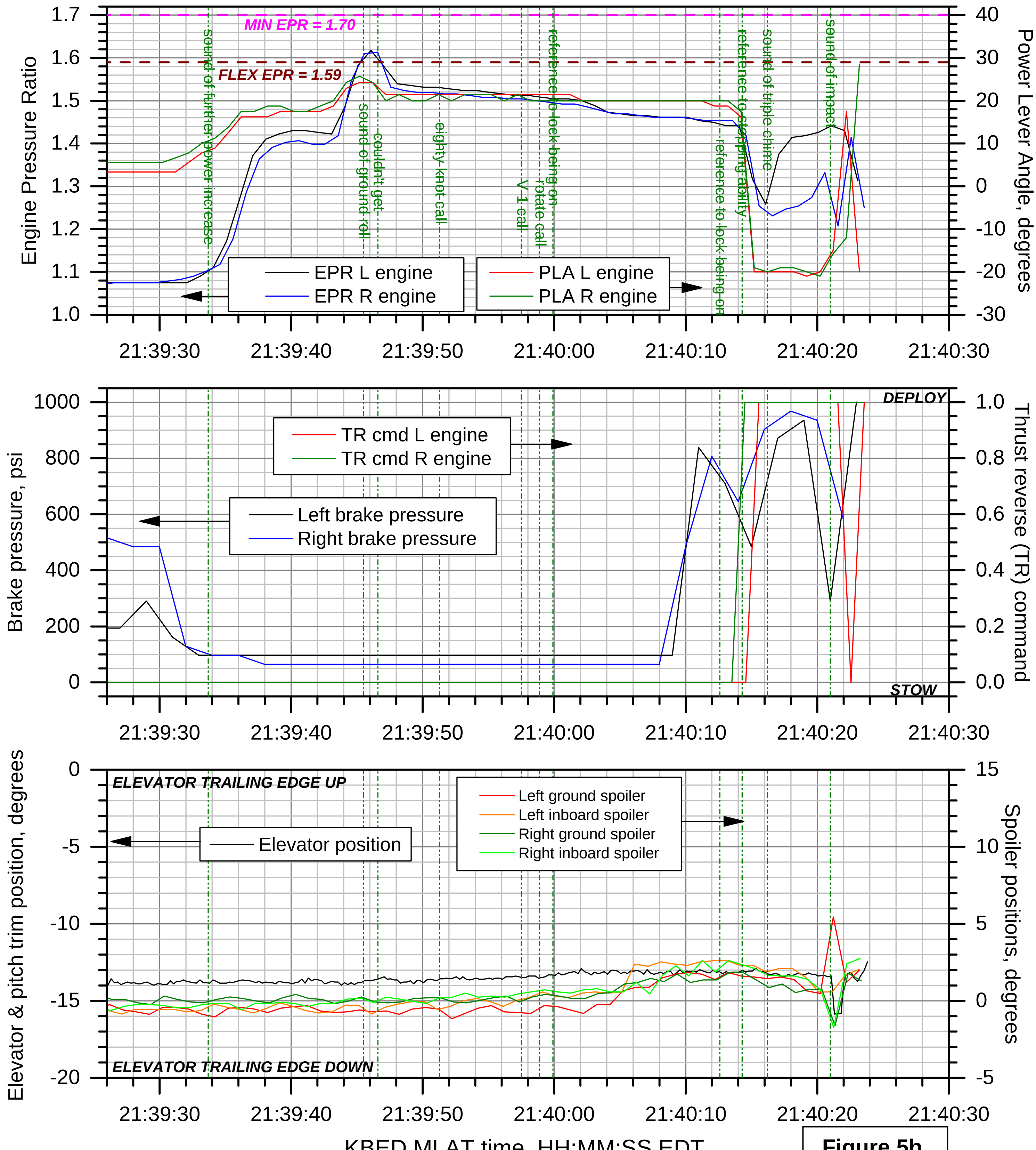


Figure 5b.

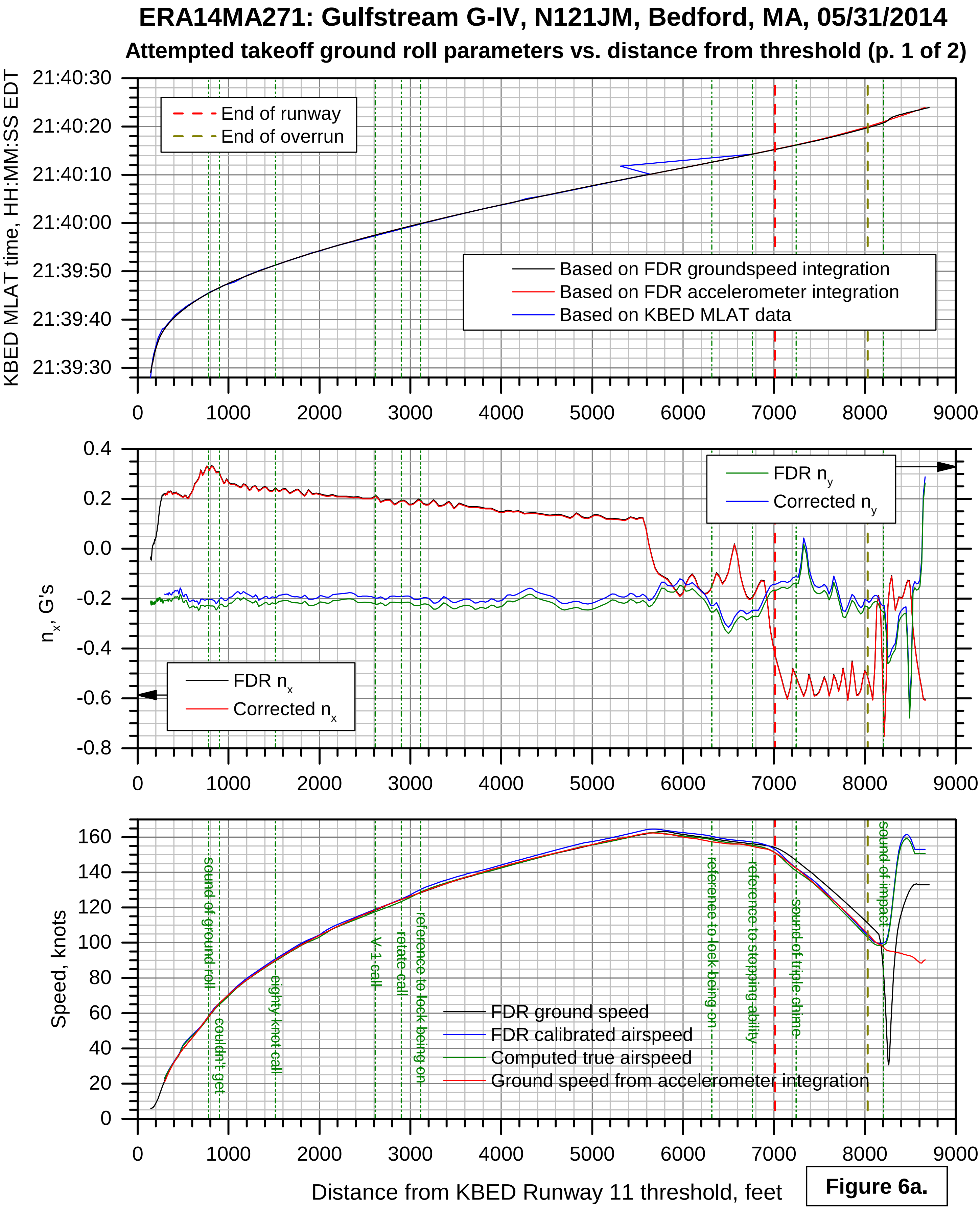

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
Attempted takeoff ground roll parameters vs. distance from threshold (p. 1 of 2)
KBED MLAT time, HH:MM:SS EDT
End of runway
End of overrun
Based on FDR groundspeed integration
Based on FDR accelerometer integration
Based on KBED MLAT data
n_x, G's
n_y, G's
FDR n_y
Corrected n_y
FDR n_x
Corrected n_x
Speed, knots
sound of ground roll
couldn't get
eighty knot call
V 1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
sound of impact
FDR ground speed
FDR calibrated airspeed
Computed true airspeed
Ground speed from accelerometer integration
Distance from KBED Runway 11 threshold, feet

Figure 6a.

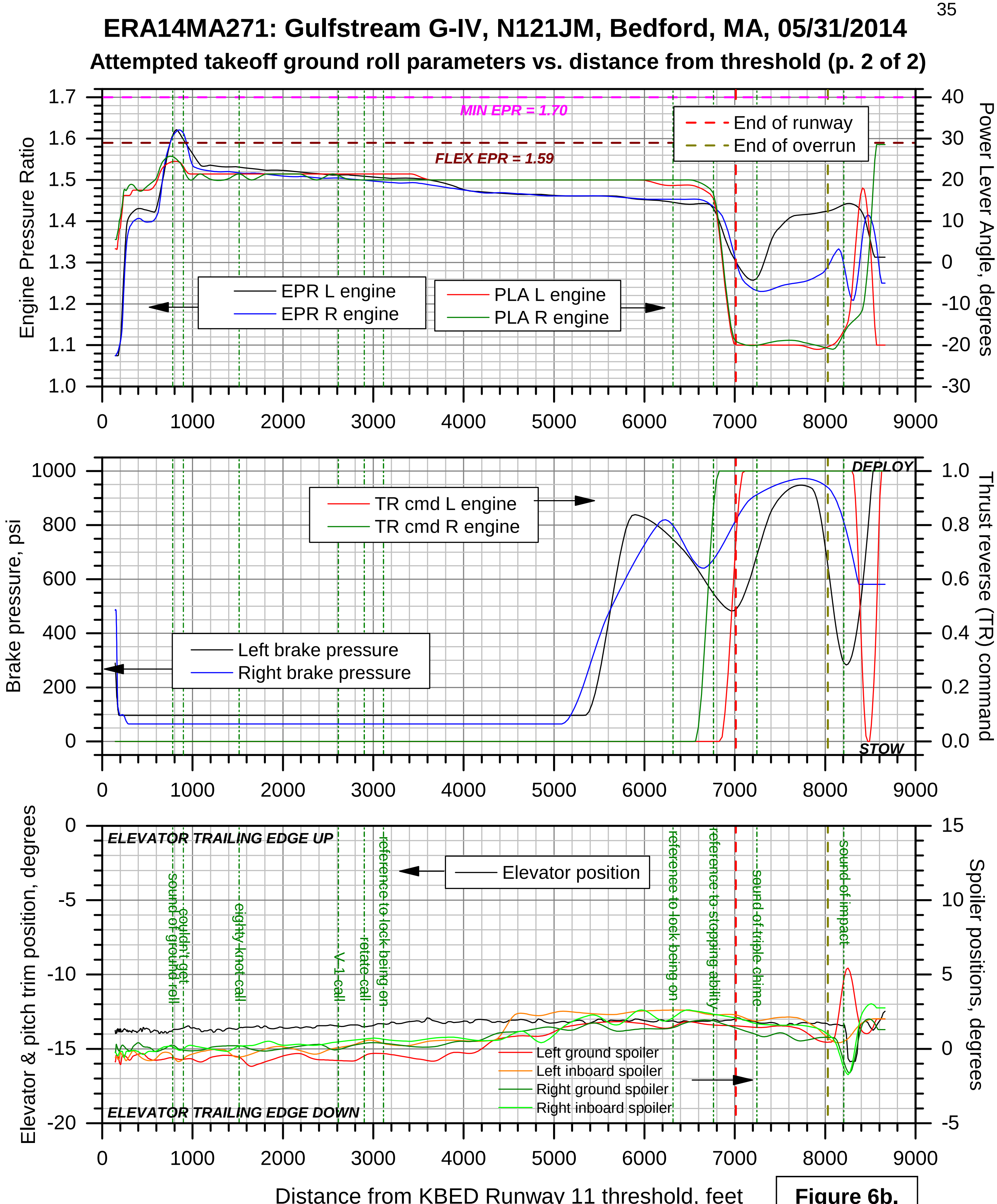

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
Attempted takeoff ground roll parameters vs. distance from threshold (p. 2 of 2)
Engine Pressure Ratio
Power Lever Angle, degrees
MIN EPR = 1.70
FLEX EPR = 1.59
End of runway
End of overrun
EPR L engine
EPR R engine
PLA L engine
PLA R engine
Brake pressure, psi
Thrust reverse (TR) command
DEPLOY
STOW
TR cmd L engine
TR cmd R engine
Left brake pressure
Right brake pressure
Elevator & pitch trim position, degrees
Spoiler positions, degrees
ELEVATOR TRAILING EDGE UP
ELEVATOR TRAILING EDGE DOWN
Elevator position
Left ground spoiler
Left inboard spoiler
Right ground spoiler
Right inboard spoiler
sound of ground roll
couldn't get
eighty knot call
V-1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
sound of impact
Distance from KBED Runway 11 threshold, feet

Figure 6b.

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014

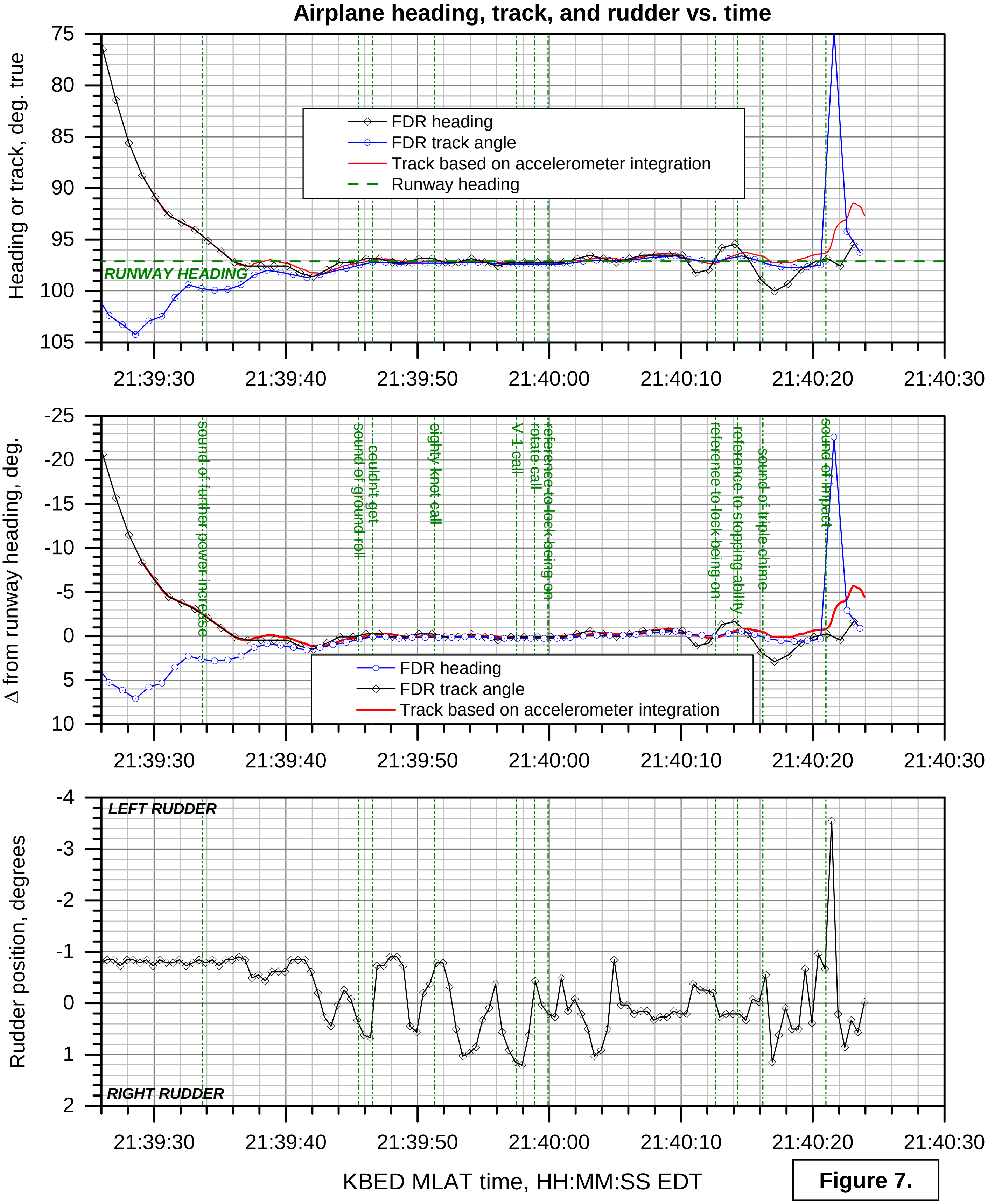


Figure 7.

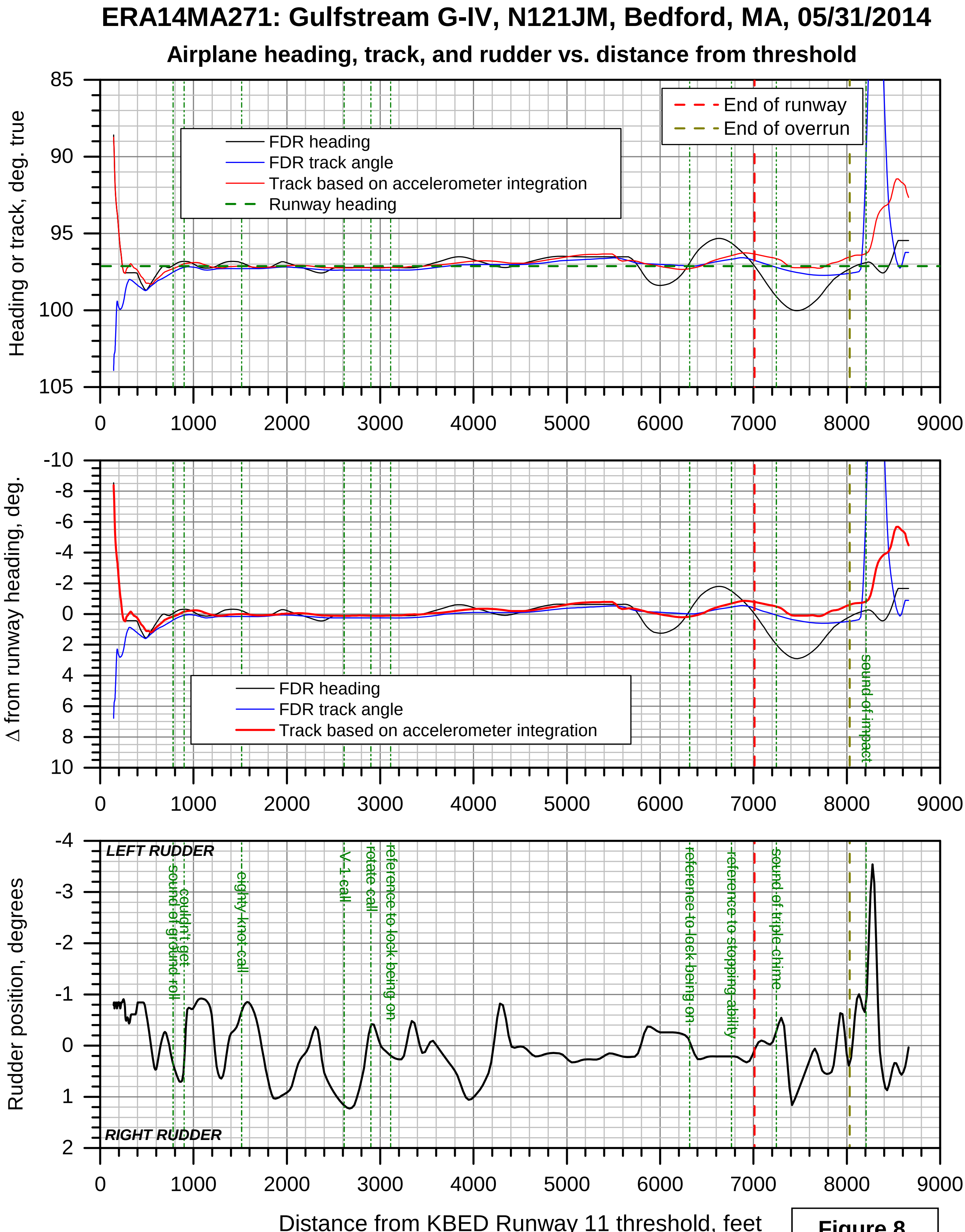

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
Airplane heading, track, and rudder vs. distance from threshold
Heading or track, deg. true
FDR heading
FDR track angle
Track based on accelerometer integration
Runway heading
End of runway
End of overrun
Δ from runway heading, deg.
sound of impact
Rudder position, degrees
LEFT RUDDER
RIGHT RUDDER
sound of ground roll
couldn't get
eighty knot call
V-1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
Distance from KBED Runway 11 threshold, feet

Figure 8.

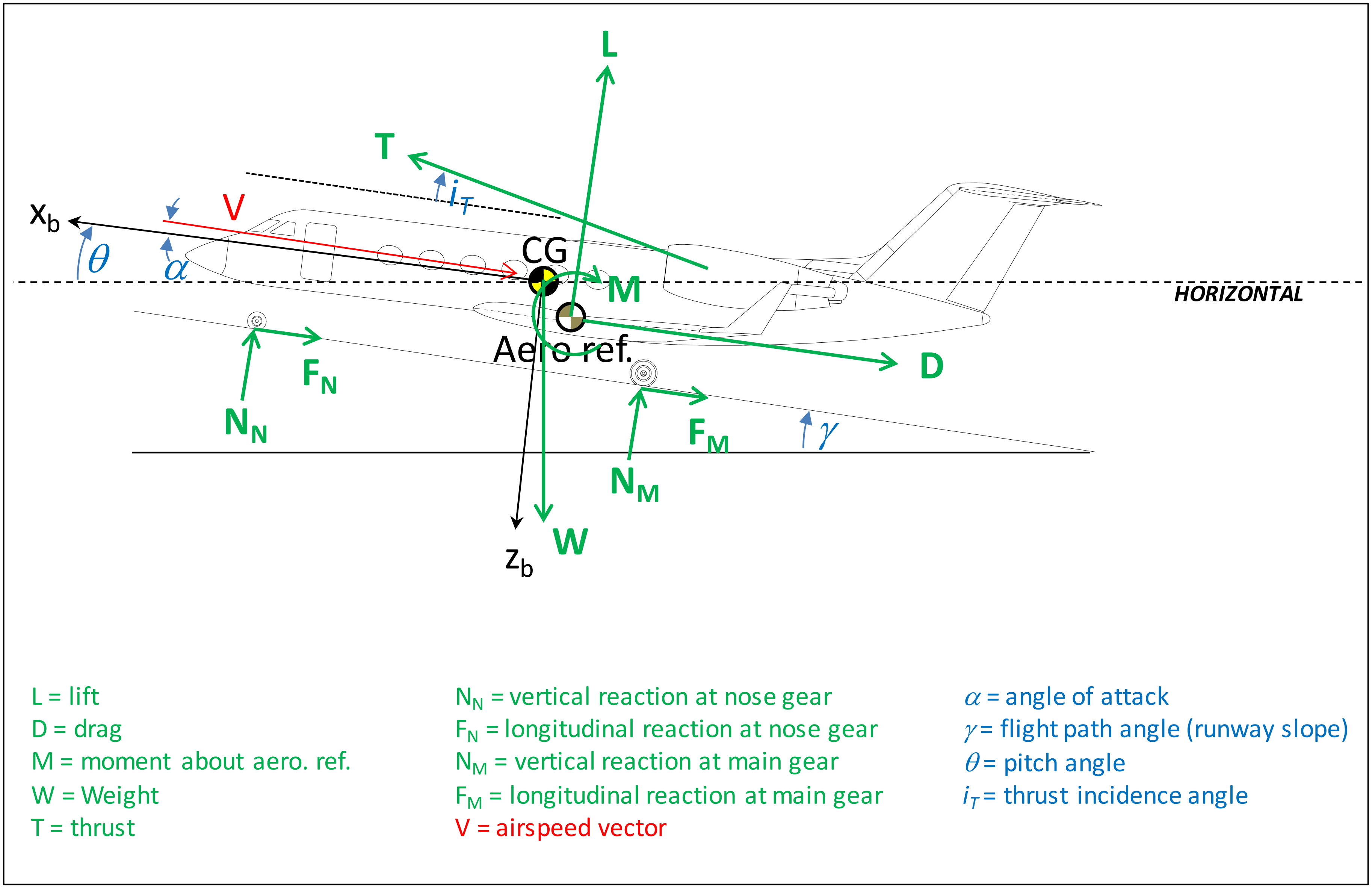


Figure 9. Free body diagram of forces on airplane during ground roll.

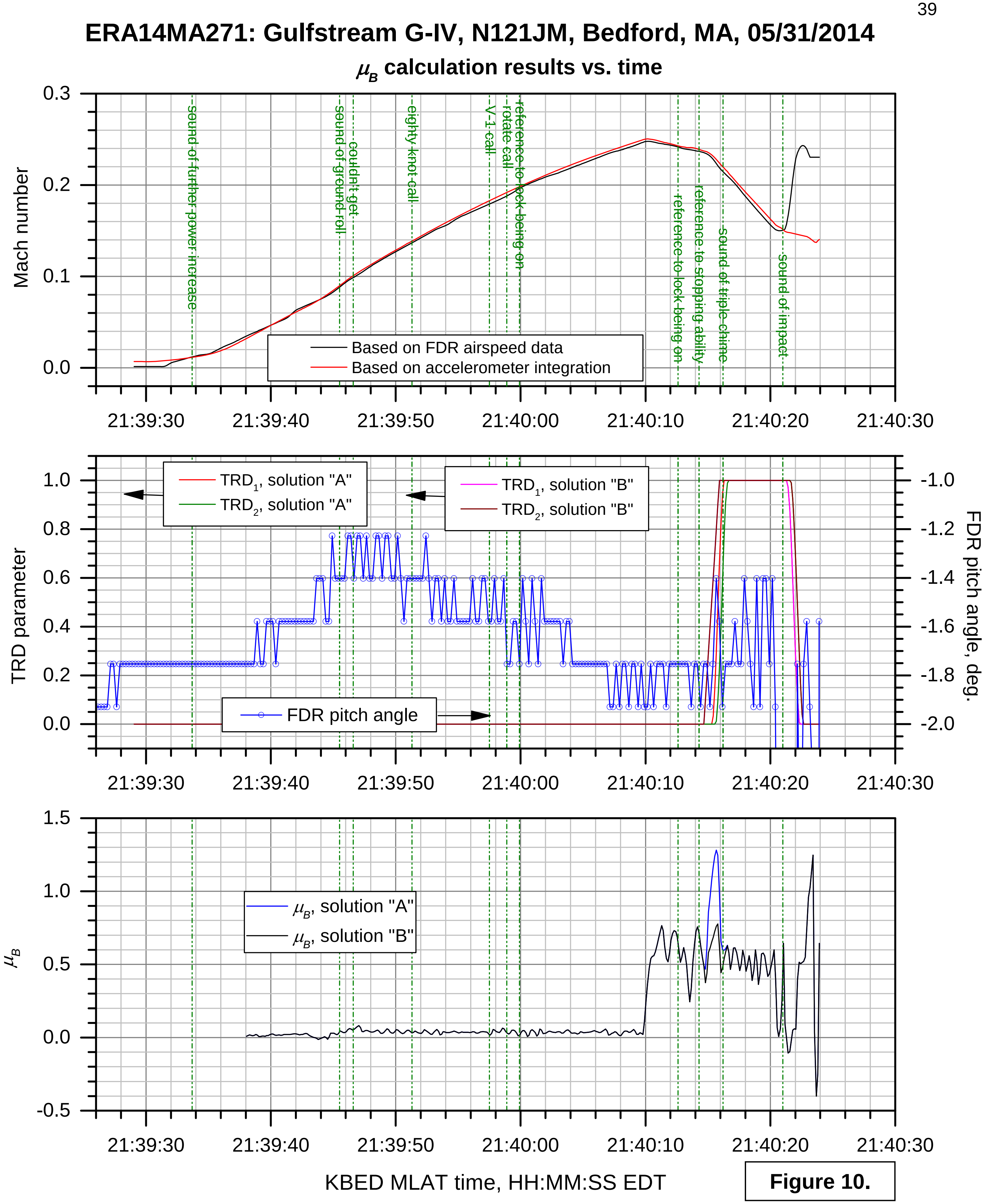
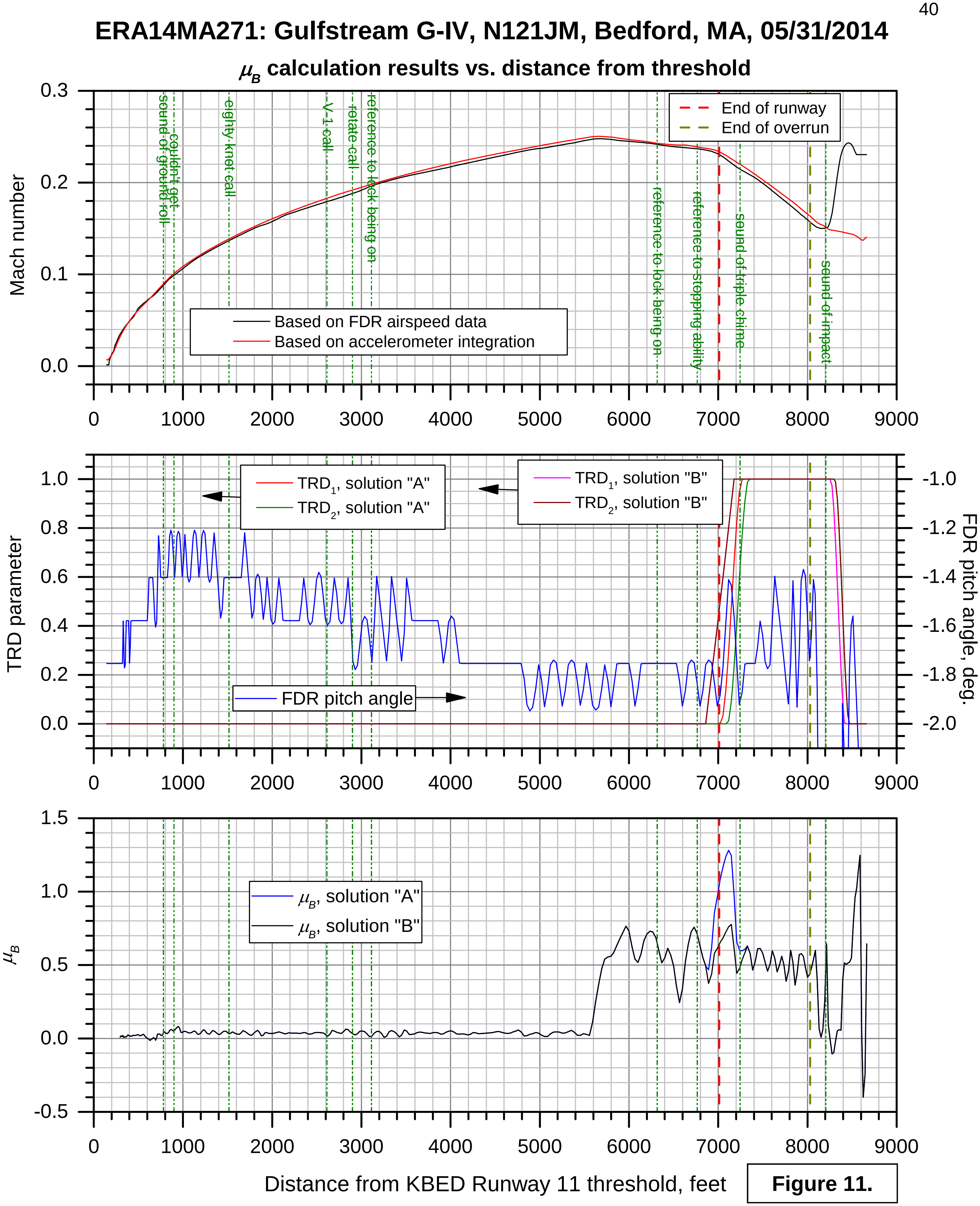

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
μ_B calculation results vs. time
Mach number
sound of further power increase
sound of ground roll
couldn't get
eighty knot call
V-1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
sound of impact
Based on FDR airspeed data
Based on accelerometer integration
TRD parameter
FDR pitch angle, deg.
TRD_1, solution "A"
TRD_2, solution "A"
TRD_1, solution "B"
TRD_2, solution "B"
FDR pitch angle
μ_B
μ_B, solution "A"
μ_B, solution "B"
21:39:30
21:39:40
21:39:50
21:40:00
21:40:10
21:40:20
21:40:30
KBED MLAT time, HH:MM:SS EDT

Figure 10.



ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
μ_B calculation results vs. distance from threshold
Mach number
sound-of-ground-roll
couldn't get
eighty knot call
V-1 call
rotate call
reference to lock being on
reference to lock being on
reference to stopping ability
sound of triple chime
sound of impact
End of runway
End of overrun
Based on FDR airspeed data
Based on accelerometer integration
TRD parameter
FDR pitch angle, deg.
TRD1, solution "A"
TRD2, solution "A"
TRD1, solution "B"
TRD2, solution "B"
FDR pitch angle
μ_B
μ_B, solution "A"
μ_B, solution "B"
Distance from KBED Runway 11 threshold, feet

Figure 11.

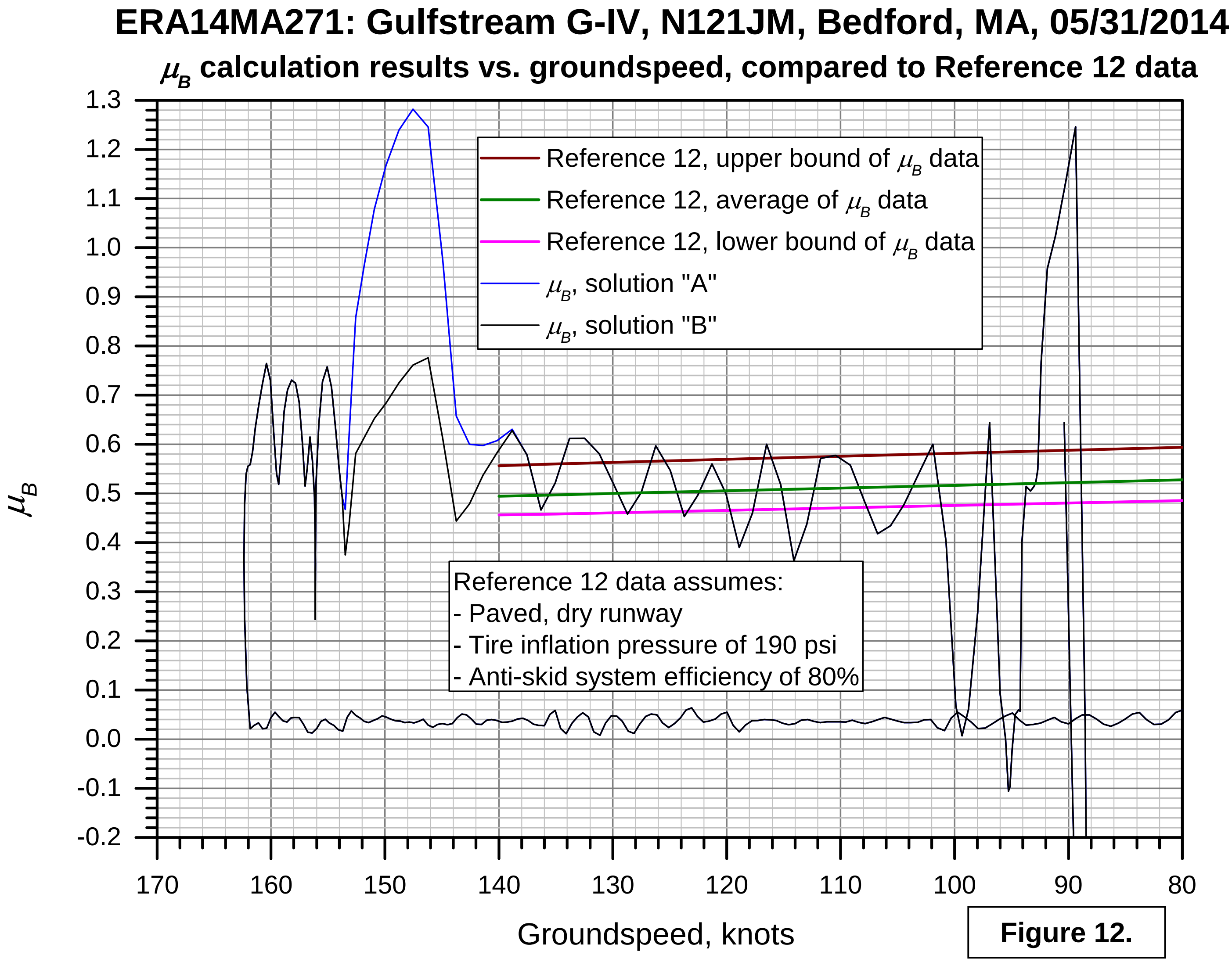

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
μ_B calculation results vs. groundspeed, compared to Reference 12 data
Reference 12, upper bound of μ_B data
Reference 12, average of μ_B data
Reference 12, lower bound of μ_B data
μ_B, solution "A"
μ_B, solution "B"
Reference 12 data assumes:
- Paved, dry runway
- Tire inflation pressure of 190 psi
- Anti-skid system efficiency of 80%
μ_B
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
170
160
150
140
130
120
110
100
90
80
Groundspeed, knots

Figure 12.

GULFSTREAM AEROSPACE

GIV AIRPLANE FLIGHT MANUAL

FLEX EPR
SPECIAL PERFORMANCE
APPENDIX A

TAKEOFF PLANNING CHART

GIV-SP **AIRPORT PRESSURE ALTITUDE = SEA LEVEL** **TAKEOFF FLAP 20°**

74,600 LB MTOGW	OAT (°C)	50	45	40	35	30	25	20	15	5	-5	-15
	OAT (°F)	122	113	104	95	86	77	68	59	41	23	5
	RATED EPR	1.59	1.62	1.64	1.67	1.70	1.70	1.70	1.70	1.69	1.69	1.69
-- 60,000 LB --												
V_{FS} = 155 KCAS	FLD LNGTH	4,850	4,530	4,250	4,000	3,770	3,710	3,660	3,600	3,510	3,390	3,280
V_{SE} = 161 KCAS	V_1 KCAS	125	123	122	120	119	119	119	119	120	120	120
V_{REF} = 142 KCAS	V_R KCAS	130	129	129	128	127	127	127	127	127	127	127
MAX TEMP = 50°C	V_2 KCAS	135	135	135	135	135	135	135	135	135	135	135
-- 58,000 LB --												
V_{FS} = 152 KCAS	FLD LNGTH	4,590	4,300	4,030	3,790	3,600	3,540	3,490	3,440	3,340	3,230	3,120
V_{SE} = 158 KCAS	V_1 KCAS	123	121	120	118	117	117	117	117	118	118	118
V_{REF} = 140 KCAS	V_R KCAS	128	128	127	126	126	126	126	126	126	126	126
MAX TEMP = 50°C	V_2 KCAS	133	133	133	133	133	133	133	133	133	133	133
-- 56,000 LB --												
V_{FS} = 150 KCAS	FLD LNGTH	4,340	4,070	3,820	3,650	3,540	3,480	3,430	3,380	3,280	3,180	3,070
V_{SE} = 156 KCAS	V_1 KCAS	121	119	118	117	118	118	118	118	118	118	118
V_{REF} = 137 KCAS	V_R KCAS	127	126	125	124	124	124	124	124	124	124	124
MAX TEMP = 50°C	V_2 KCAS	132	132	132	132	132	132	132	132	132	132	132
-- 54,000 LB --												
V_{FS} = 147 KCAS	FLD LNGTH	4,150	3,890	3,700	3,580	3,480	3,430	3,370	3,320	3,230	3,120	3,020
V_{SE} = 153 KCAS	V_1 KCAS	119	118	117	117	118	118	118	118	118	118	118
V_{REF} = 135 KCAS	V_R KCAS	125	125	124	123	123	123	123	123	123	123	123
MAX TEMP = 50°C	V_2 KCAS	131	131	131	131	131	131	131	131	131	131	131
-- 52,000 LB --												
V_{FS} = 144 KCAS	FLD LNGTH	4,010	3,760	3,630	3,520	3,420	3,370	3,320	3,270	3,170	3,070	2,970
V_{SE} = 150 KCAS	V_1 KCAS	118	117	117	118	118	118	118	118	118	118	119
V_{REF} = 132 KCAS	V_R KCAS	125	124	124	123	122	122	122	122	122	122	122
MAX TEMP = 50°C	V_2 KCAS	131	131	131	131	131	131	131	131	131	131	131
-- 50,000 LB --												
V_{FS} = 142 KCAS	FLD LNGTH	3,860	3,670	3,560	3,450	3,360	3,310	3,260	3,210	3,120	3,020	2,920
V_{SE} = 147 KCAS	V_1 KCAS	118	117	117	118	118	118	118	118	119	119	119
V_{REF} = 130 KCAS	V_R KCAS	125	124	123	122	122	122	122	122	122	122	122
MAX TEMP = 50°C	V_2 KCAS	131	131	131	131	131	131	131	131	131	131	131
-- 48,000 LB --												
V_{FS} = 139 KCAS	FLD LNGTH	3,720	3,600	3,490	3,390	3,300	3,250	3,200	3,150	3,060	2,970	2,870
V_{SE} = 144 KCAS	V_1 KCAS	117	117	118	118	119	119	119	119	119	119	119
V_{REF} = 127 KCAS	V_R KCAS	124	124	123	122	121	121	121	121	121	121	121
MAX TEMP = 50°C	V_2 KCAS	131	131	131	131	131	131	131	131	131	131	131
-- 46,000 LB --												
V_{FS} = 136 KCAS	FLD LNGTH	3,640	3,530	3,420	3,330	3,240	3,190	3,140	3,100	3,010	2,910	2,820
V_{SE} = 141 KCAS	V_1 KCAS	117	118	118	119	119	119	119	119	119	119	120
V_{REF} = 124 KCAS	V_R KCAS	124	123	122	122	121	121	121	121	121	121	121
MAX TEMP = 50°C	V_2 KCAS	131	131	131	131	131	131	131	131	131	131	131

CAUTION: DO NOT REDUCE TAKEOFF EPR BY MORE THAN .15 OR BELOW A MINIMUM VALUE OF 1.56.

NOTES:

HEADWIND: Increase available field length 2% for each 5 knots (up to 40 knots).
TAILWIND: Decrease available field length 11% for each 5 knots (up to 10 knots).
UPHILL SLOPE: Decrease available field length 20% for each 1% (up to 2%).
DOWNHILL SLOPE: No adjustments required (up to 2%).
GROUND SPOILERS INOP: Decrease available field length 800 feet.

Figure 13.

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014

1.53 & 1.42 EPR takeoff roll comparisons (p. 1 of 2)

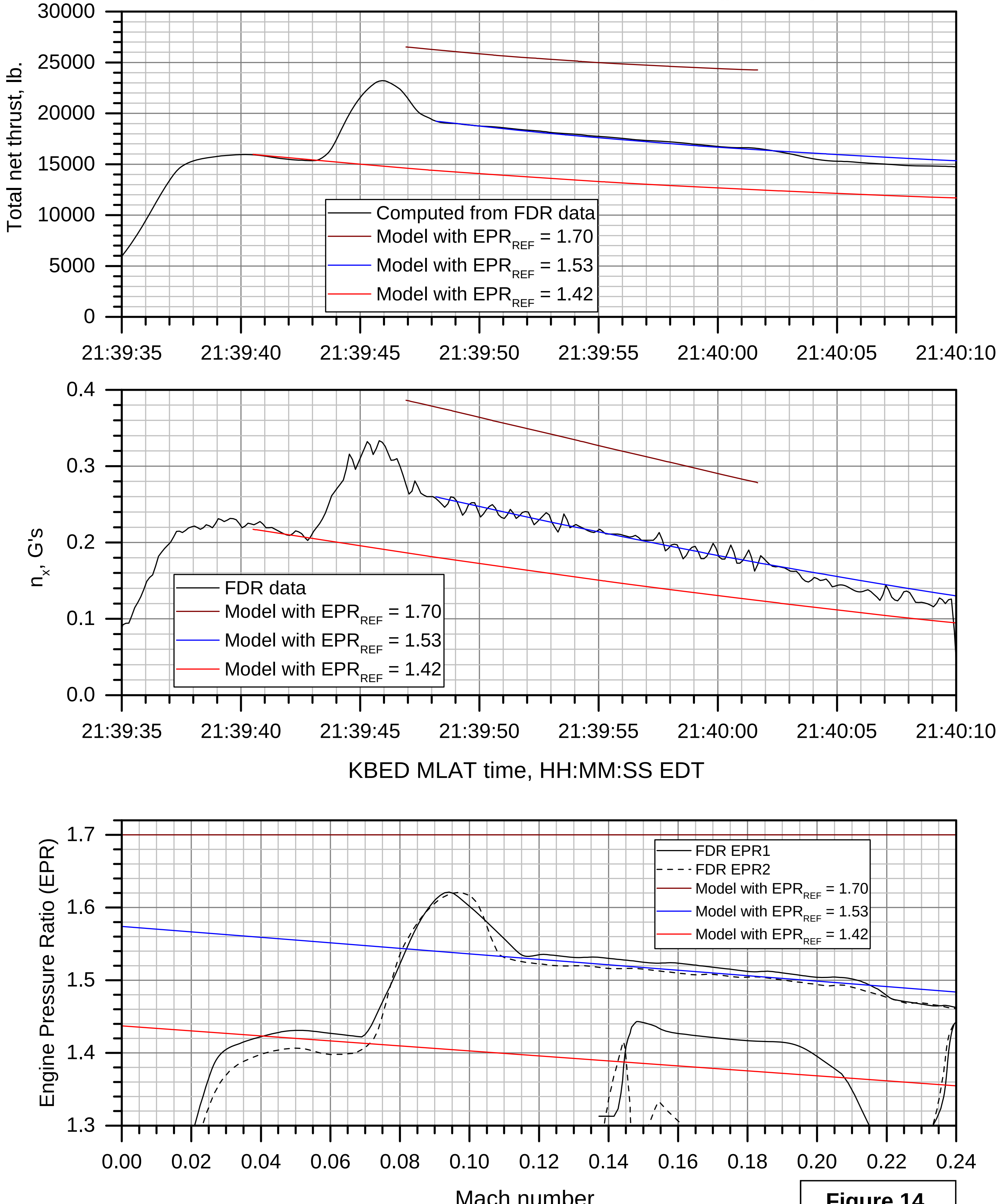


Figure 14.

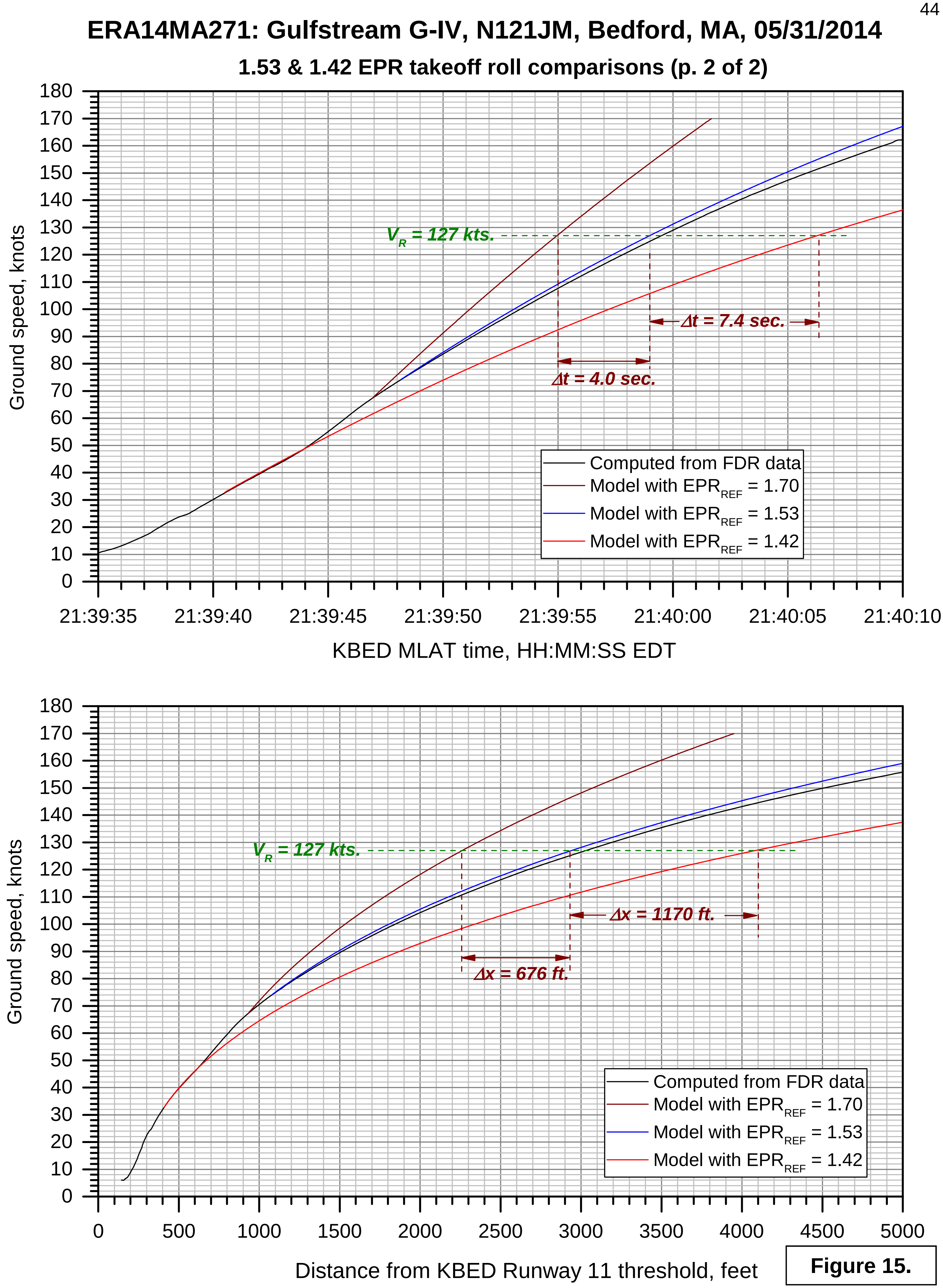

ERA14MA271: Gulfstream G-IV, N121JM, Bedford, MA, 05/31/2014
1.53 & 1.42 EPR takeoff roll comparisons (p. 2 of 2)
Ground speed, knots
VR = 127 kts.
Δt = 7.4 sec.
Δt = 4.0 sec.
Computed from FDR data
Model with EPRREF = 1.70
Model with EPRREF = 1.53
Model with EPRREF = 1.42
21:39:35
21:39:40
21:39:45
21:39:50
21:39:55
21:40:00
21:40:05
21:40:10
KBED MLAT time, HH:MM:SS EDT
Ground speed, knots
VR = 127 kts.
Δx = 1170 ft.
Δx = 676 ft.
Computed from FDR data
Model with EPRREF = 1.70
Model with EPRREF = 1.53
Model with EPRREF = 1.42
Distance from KBED Runway 11 threshold, feet

Figure 15.