National Transportation
Safety Board

Memorandum

Date: October 21, 2021

To: Heidi Kemner
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ERA21LA003 Investigator in Charge (IIC)

From: John O'Callaghan
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ERA21LA003 Aircraft Performance Specialist

Subject: Plots of radar data and performance estimates for ERA21LA003

References:
1. National Transportation Safety Board, Office of Aviation Safety, *Meteorology Specialist's Report, ERA21LA003,* November 18, 2020.
2. Daher Aerospace, *TBM 850 (TBM 700 N Version) Pilot's Operating Handbook*, Edition 1, June 22, 2007, Revision 14.

Heidi:

This memorandum transmits plots of flight path and airplane performance information for the Socata TBM 700 (N965DM) accident in Corfu, New York, on October 2, 2020 (ERA21LA003). The plots present radar data corresponding to N965DM recorded by the Rochester, New York (ROC) and Hamilton, Ontario (YHM) Airport Surveillance Radars (ASRs), and performance parameters computed from the radar data.

Description of radar data

I received ROC and YHM ASR data for the airplane from the NTSB Air Traffic Control specialist for this case. The data consists of:

- UTC time of each radar return, in hours, minutes, and seconds, at a frequency of 1 report every 4.5 to 5 seconds (0.22 – 0.20 Hz)
- Transponder beacon code associated with each return (secondary returns only)
- Transponder reported pressure altitude in hundreds of feet associated with each return (secondary returns only). The resolution of the altitude data in the radar file is ± 50 ft.
- Slant Range from the radar antenna to the return, in nm. The accuracy of this data is ±1/16 nm or about ± 380 ft.
- Azimuth relative to true north from the radar antenna to the return, in degrees. The accuracy of azimuth data is about ± 0.18º.

- The latitude and longitude of the return computed by the radar system data processing algorithms. These data are consistent with the latitude and longitude computed from the range and azimuth data recorded in the file.

To determine the latitude and longitude of radar returns from the range and azimuth data recorded by the radar (and to define the "uncertainty box" associated with each return), the geographic location of the radar antenna must be known. The coordinates of the ASR antennas are:

ROC ASR: 43° 07' 14.4" N latitude; 77° 39' 54.1" W longitude; elevation 599 feet
YHM ASR: 43° 10' 9.49" N latitude; 79° 55' 18.53" W longitude; elevation 814 feet

Presentation of the Radar Data

To calculate performance parameters from the radar data (such as ground speed and track angle), it is convenient to express the position of the airplane in rectangular Cartesian coordinates. The Cartesian coordinate system used in this analysis is centered at the ROC ASR and its axes extend east, north, and up from the center of the Earth. The range and azimuth data from the ROC and YHM ASRs are transformed into this coordinate system for plotting and performance calculations. The latitude and longitude coordinates of the ASR antennas are transformed into this coordinate system using the WGS84 ellipsoid model of the Earth. The range and azimuth data are used in this analysis (instead of the latitude and longitude positions recorded directly in the radar file) so that the uncertainty in the radar return east and north coordinates, resulting from the uncertainties in range and azimuth, can also be computed and plotted.

Figure 1 plots the last 4 minutes of the ROC and YHM ASR data in terms of nautical miles north and east of the ROC ASR. Figure 2 presents a detailed view of the end of the flight plotted in Figure 1, and also depicts primary radar returns (as opposed to secondary transponder returns) detected near the time and place of N965DM's final descent. Selected radio transmissions from N965DM, transcribed from an ATC audio recording and listed in Table 1, are also plotted in Figures 1 and 2 at the locations along N965DM's flight track at which they occurred. Note that only the highlighted transmissions in Table 1 are presented in the Figures.

The YHM returns plotted in Figures 1 and 2 are shifted 435 ft. east and 342 ft. north so as to be consistent with the positions recorded by the ROC ASR. In addition, the ROC data plotted in the Figures are smoothed with a running-average algorithm in order to reduce noise in the speeds and other performance parameters computed using these data. The unsmoothed ROC positions are depicted as the center of the uncertainty boxes associated with each radar return. Note that the smoothed positions lie within the uncertainty boxes, and that the positions during the final spiral dive are not smoothed at all.

The ROC and YHM pressure altitude data are plotted in Figure 3, along with a smoothed altitude through the ROC data that is used in the performance calculations. Selected radio transmissions from N965DM are depicted as vertical lines intersecting the x-axis at the times that they occurred.

Time (EDT)	Source	Content
11:40:26	N965DM	Buffalo Approach, TBM 965DM
11:40:29	ER	TBM 965DM Buffalo
11:40:33	N965DM	965DM I somehow lost comm with Center, but I'm landing at Buffalo, IFR flight plan
11:40:41	ER	OK TBM 965DM for now maintain flight level 280, yeah we've been trying to get a hold of you we're going to work it out with the Center and I'll get you lower here shortly
11:40:50	N965DM	OK sir and I'd like vectors for the ILS 23 please, 965DM
11:40:58	ER	TBM 965DM descend and maintain 8000, expect the ILS for runway 23
11:41:02	N965DM	8000, expect ILS 23
11:41:05	ER	And everything OK up there?
11:41:07	N965DM	Yes sir, I'm fine
11:41:09	ER	OK
11:41:09	N965DM	5DM
11:41:10	ER	5DM roger
11:41:59	ER	TBM 5DM I'm just going to lead you direct to the airport I wanna just bring him all the way back [?] around on the left downwind for the ILS
11:42:07	N965DM	Ah 965DM
11:43:51	ER	And TBM 5DM where are you headed?
11:44:00	ER	TBM 5DM Buffalo
11:44:03	Unknown	[abrupt vocalization that sounds like "hi" or "aye"]
11:44:07	ER	TBM 965DM stop your descent maintain 10000
11:44:17	ER	TBM 965DM Buffalo stop your descent level your wings maintain any altitude
11:44:30	ER	TBM 965DM Buffalo stop your descent
11:44:39	ER	TBM 965DM Buffalo
11:44:48	ER	TBM 965DM Buffalo
11:45:05	ER	TBM 965DM Buffalo stop your descent
11:45:19	ER	TBM 965DM Buffalo how do you hear
11:45:37	ER	TBM 965DM Buffalo
11:45:43	ER	TBM 5DM radar contact lost
11:46:12	ER	TBM 965DM Buffalo
11:47:04		[new controller in position]

Table 1. Selected communications between N965DM and the Buffalo Approach East Radar (ER) Air Traffic Control position, as transcribed by the author of this memo from a recorded audio file provided by the NTSB ATC specialist. Transmissions from N965DM highlighted in gray are also depicted in the Figures of this *Memorandum*. For brevity, the full verbalization of "November niner-six-five-delta-mike" is depicted as "N965DM."

Additional performance parameters computed from the smoothed radar data

The position of an airplane as a function of time defines its velocity and acceleration vectors. In coordinated flight, these vectors lie almost entirely in the plane defined by the airplane's longitudinal and vertical axes. Furthermore, any change in the *direction* of the velocity vector is produced by a change in the lift vector, either by increasing the magnitude of the lift (as in a pull-up), or by changing the direction of the lift (as in a banked turn). The lift vector also acts entirely in the aircraft's longitudinal-vertical plane, and is a function of the angle between the aircraft longitudinal axis and the velocity vector (the angle of attack, α). These facts allow the equations of motion to be simplified to the point that a solution for the airplane orientation can be found given additional information about the wind and the airplane.

The wind speed and direction, as well as the airplane weight and lift and drag coefficients as a function of α, are required to compute additional performance parameters such as the Euler angles (pitch, roll, and heading) and power required. In response to an NTSB request, Daher Aerospace provided flaps-up lift and drag coefficient data for the TBM 700.

The *Meteorology Specialist's Report* for this accident (Reference 1) presents winds aloft data for area of the accident at 12:00 EDT based on a High-Resolution Rapid Refresh (HRRR) model sounding (see Reference 1 for details). These winds aloft are plotted here in Figure 4, and are used in the performance calculations.

A weight of 5,765 lb. is used in the performance calculations. This value is based on the zero-fuel weight estimate you provided in your email dated 12/01/2020, an assumption of 301 gallons of fuel on the airplane at the start of the previous flight, and an estimated fuel burn of 1,168 lb. computed by the engine manufacturer[1] for the previous flight and the accident flight.

Results

The radar data and results of the performance calculations are presented in Figures 1-7. Figure 1 presents a birds-eye view of the last four minutes of the flight path of the airplane. Figure 2 presents a detailed view of the end of the flight plotted in Figure 1, and also depicts primary radar returns (as opposed to secondary transponder returns) detected near the time and place of N965DM's final descent.

Figure 3 presents the pressure altitude data recorded by the ROC and YHM ASRs, along with the results of smoothing the ROC data while respecting the ±50 ft. uncertainty bands in that data.

Figure 4 presents the winds aloft from the 12:00 EDT HRRR model sounding used to compute airspeed and other performance parameters from the ground speed derived from the smoothed ROC data.

Figure 5 presents the speed calculations based on the smoothed ROC data, including ground speed, true airspeed, and calibrated airspeed (the airspeed depicted on the airspeed indicator is calibrated airspeed plus any instrument error). The ground speed computed from the "raw" (unsmoothed) radar position data is also shown; note that this parameter exhibits unrealistic, noisy "spikes" resulting from uncertainty in the radar position. The ground speed computed from the smoothed data reduces this noise considerably, as intended. Likewise, the rate of climb based on the raw pressure altitude data is noisy compared to that based on the smoothed data.

Figure 6 presents the calculation of several flight angle parameters. The top plot presents pitch angle, flight path angle, and angle of attack; the middle plot presents the roll and drift angles; and the bottom plot presents the heading and track angles.

Figure 7 plots the longitudinal and normal load factors computed from the smoothed radar data, and the engine horsepower required. The horsepower calculation is noisy, even though it is based on the smoothed radar data. The curve fit through the horsepower calculation helps to filter out some of this noise.

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[1] Transmitted via an email titled "RE: N965DM - Weight and Balance - Fuel calculations," dated 12/21/20.

Conclusions

The data plotted in Figures 1-7 support the following observations regarding the accident flight:

The airplane appears to be cruising normally at 28,000 ft. and about 190 KCAS until about 11:41:17, when the pitch slowly decreases, over about 30 seconds, to about -10°, and the rate of descent increases to between 4,000 and 5,000 feet/minute. The airplane starts to pitch down and descend about 15 seconds after the pilot acknowledges an ATC instruction to descend and maintain 8,000 ft., and so this initial descent is likely intentional. The airplane stays on track during this descent until about 11:43:31, at which time the altitude has decreased to about 19,300 ft., and the airspeed has increased to about 270 KCAS (the maximum operating speed, per the Pilot's Operating Handbook (Reference 2)).

At this point, the airplane rolls right suddenly to about 35°, and the pitch angle starts steadily decreasing to about -47° while the roll angle also increases to almost 90°. The airspeed and rate of descent increase accordingly, with the airspeed reaching 350 KCAS and the rate of descent peaking at 28,400 ft./min. at 11:44:13 before decreasing to 6,800 ft./min. at the end of the data. These motions describe a spiral dive; the computed normal load factor increases to about 3.8 G's at 11:44:17, though the calculations become somewhat unreliable at this point because of the very dynamic situation and the sparse radar points available to define the path of the airplane in the dive. But it seems clear that the load factor is increasing to high levels while the airspeed is increasing far above the maximum operating speed, a combination that can overstress the airplane.

The horsepower calculation is noisy, but appears to be consistent with about 600 HP on the airplane until the airspeed reaches 270 KCAS, and decreasing thereafter. Large negative horsepower values (where valid) indicate more drag on the airplane than is being modeled; such drag might be generated by the propeller at idle power and extreme airspeeds. However, the horsepower calculation is so noisy (particularly when based on the few data points after 11:44:00) that the results must be considered unrealistic and inappropriate for drawing any conclusions.

The last known communication of the pilot with ATC was at 11:42:07, acknowledging the controller's intentions for vectoring the airplane towards the airport. This communication occurs 1 minute and 24 seconds before the sudden right roll that starts at about 11:43:31. The controller noticed the airplane's right turn and at 11:43:51 asked the pilot "where are you headed?" The pilot did not respond, and at 11:44:00 the controller again tried contacting the pilot. At 11:43:03 there is an abrupt, unintelligible transmission on the ATC recording from an unknown source that might be from the accident pilot. The controller tried contacting the pilot again numerous times between 11:44:07 and 11:46:12, with no response. The radar data ends at 11:44:31, at a pressure altitude of 4,600 ft.

Please let me know if you would like to discuss the contents of this memorandum further.

Regards,

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John O'Callaghan

ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020

Plan view of flight path

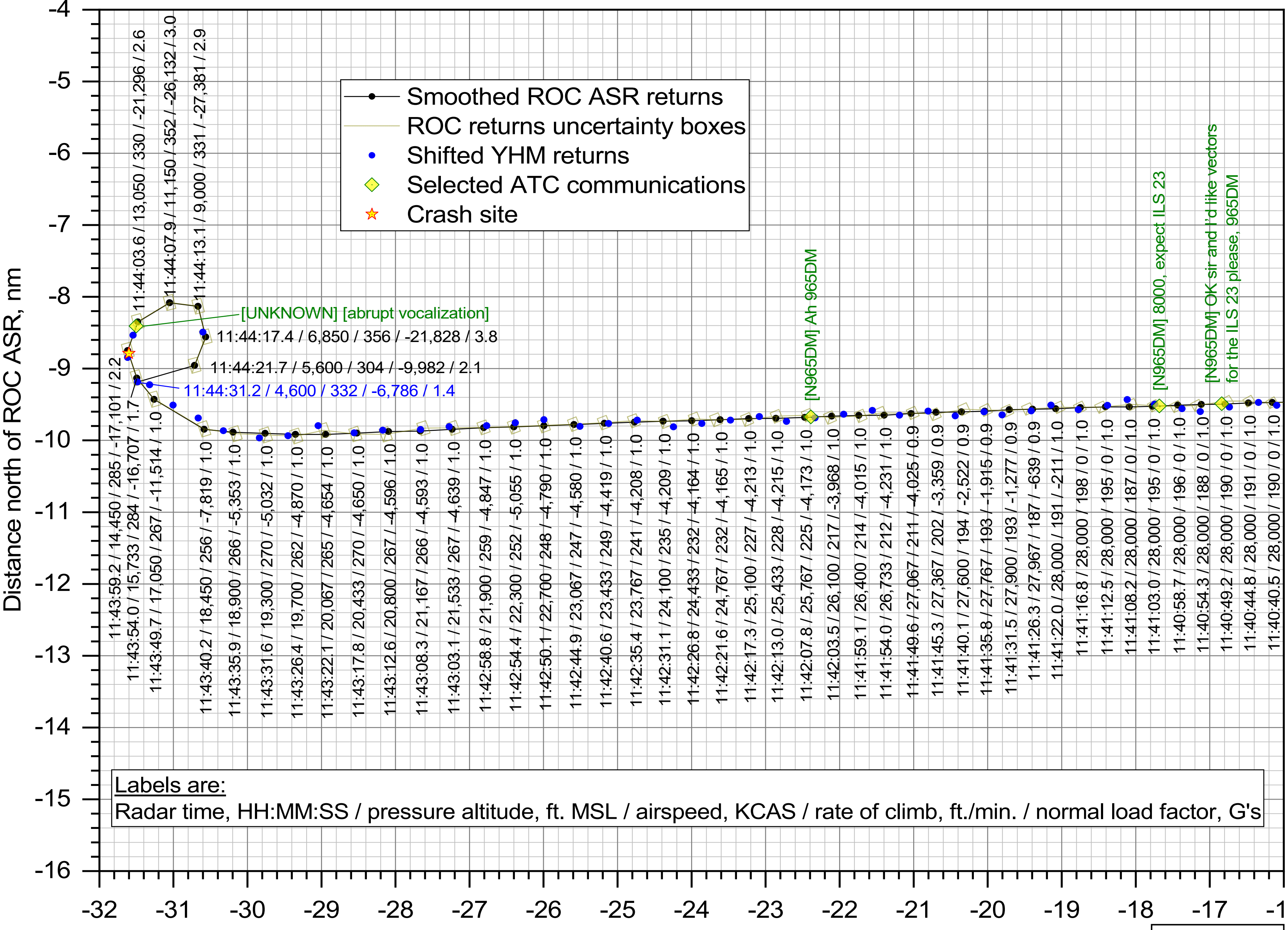

Figure 1.

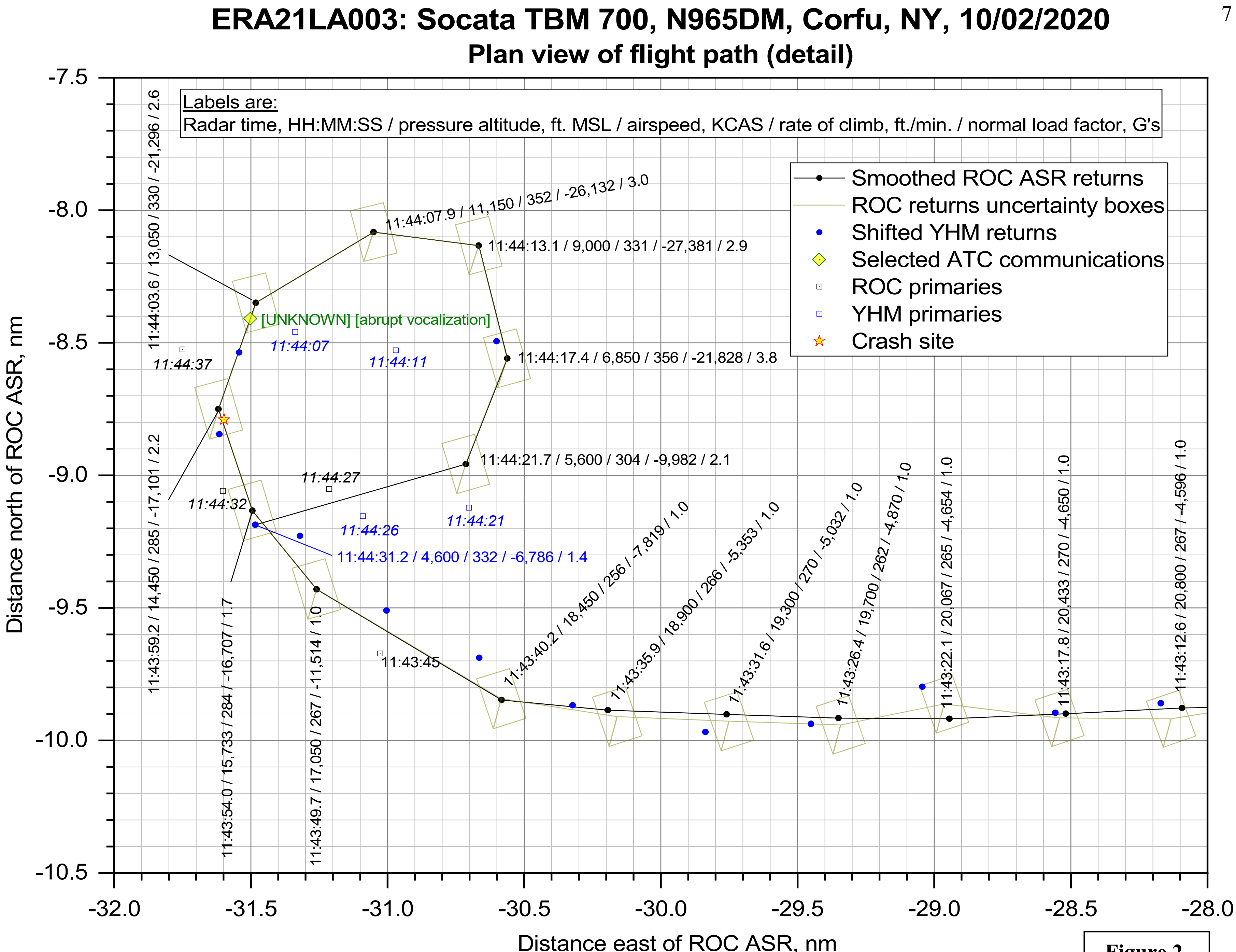
ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020
Plan view of flight path (detail)
Labels are:
Radar time, HH:MM:SS / pressure altitude, ft. MSL / airspeed, KCAS / rate of climb, ft./min. / normal load factor, G's
Smoothed ROC ASR returns
ROC returns uncertainty boxes
Shifted YHM returns
Selected ATC communications
ROC primaries
YHM primaries
Crash site
11:44:07.9 / 11,150 / 352 / -26,132 / 3.0
11:44:13.1 / 9,000 / 331 / -27,381 / 2.9
11:44:17.4 / 6,850 / 356 / -21,828 / 3.8
11:44:21.7 / 5,600 / 304 / -9,982 / 2.1
11:44:31.2 / 4,600 / 332 / -6,786 / 1.4
11:44:03.6 / 13,050 / 330 / -21,296 / 2.6
11:43:59.2 / 14,450 / 285 / -17,101 / 2.2
11:43:54.0 / 15,733 / 284 / -16,707 / 1.7
11:43:49.7 / 17,050 / 267 / -11,514 / 1.0
11:43:40.2 / 18,450 / 256 / -7,819 / 1.0
11:43:35.9 / 18,900 / 266 / -5,353 / 1.0
11:43:31.6 / 19,300 / 270 / -5,032 / 1.0
11:43:26.4 / 19,700 / 262 / -4,870 / 1.0
11:43:22.1 / 20,067 / 265 / -4,654 / 1.0
11:43:17.8 / 20,433 / 270 / -4,650 / 1.0
11:43:12.6 / 20,800 / 267 / -4,596 / 1.0
[UNKNOWN] [abrupt vocalization]
11:44:37
11:44:07
11:44:11
11:44:27
11:44:32
11:44:26
11:44:21
11:43:45
Distance north of ROC ASR, nm
Distance east of ROC ASR, nm
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-32.0
-31.5
-31.0
-30.5
-30.0
-29.5
-29.0
-28.5
-28.0

Figure 2.

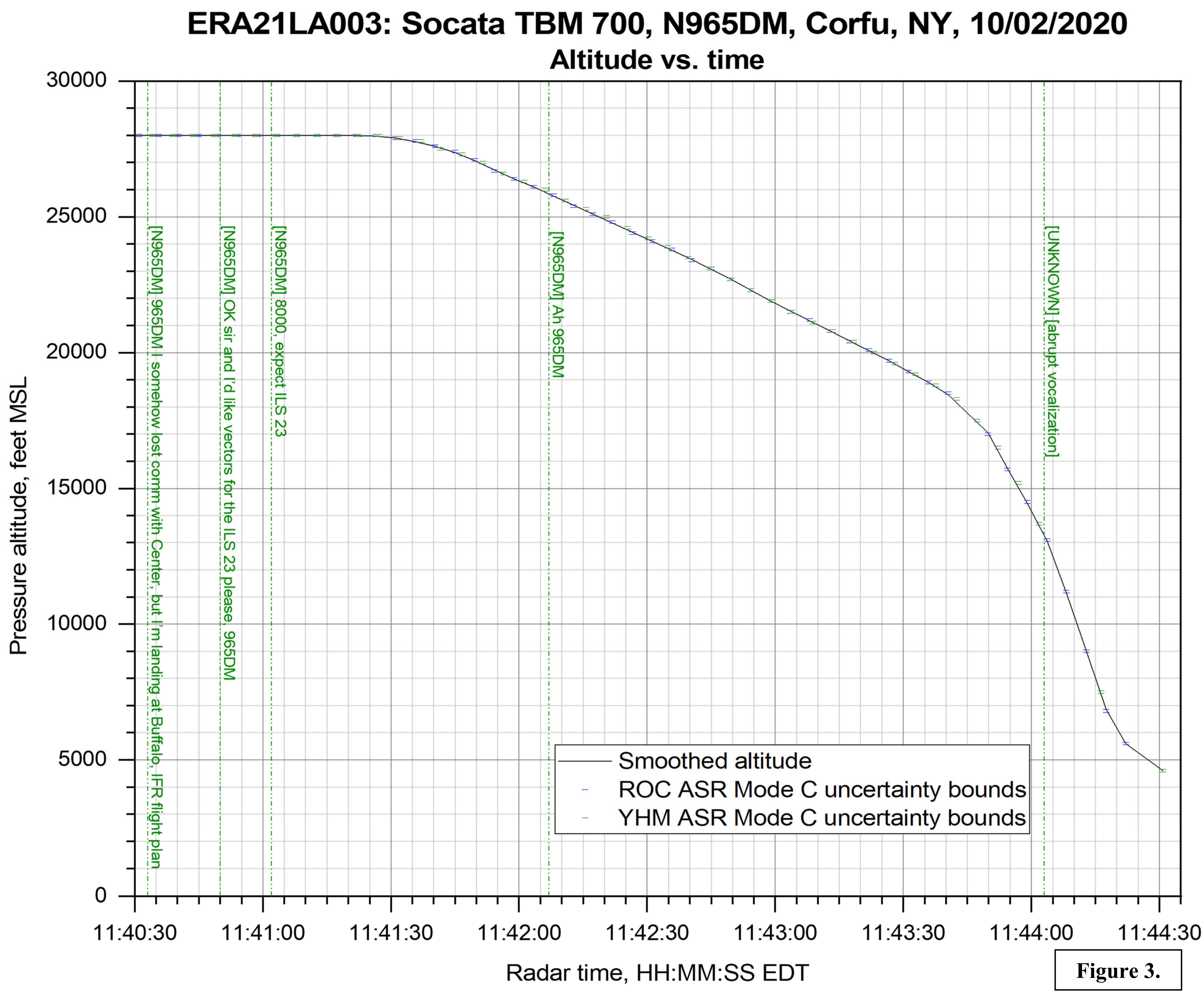
ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020
Altitude vs. time
Pressure altitude, feet MSL
Radar time, HH:MM:SS EDT
30000
25000
20000
15000
10000
5000
0
11:40:30
11:41:00
11:41:30
11:42:00
11:42:30
11:43:00
11:43:30
11:44:00
11:44:30
[N965DM] 965DM I somehow lost comm with Center, but I'm landing at Buffalo, IFR flight plan
[N965DM] OK sir and I'd like vectors for the ILS 23 please. 965DM
[N965DM] 8000, expect ILS 23
[N965DM] Ah 965DM
[UNKNOWN] [abrupt vocalization]
Smoothed altitude
ROC ASR Mode C uncertainty bounds
YHM ASR Mode C uncertainty bounds

Figure 3.

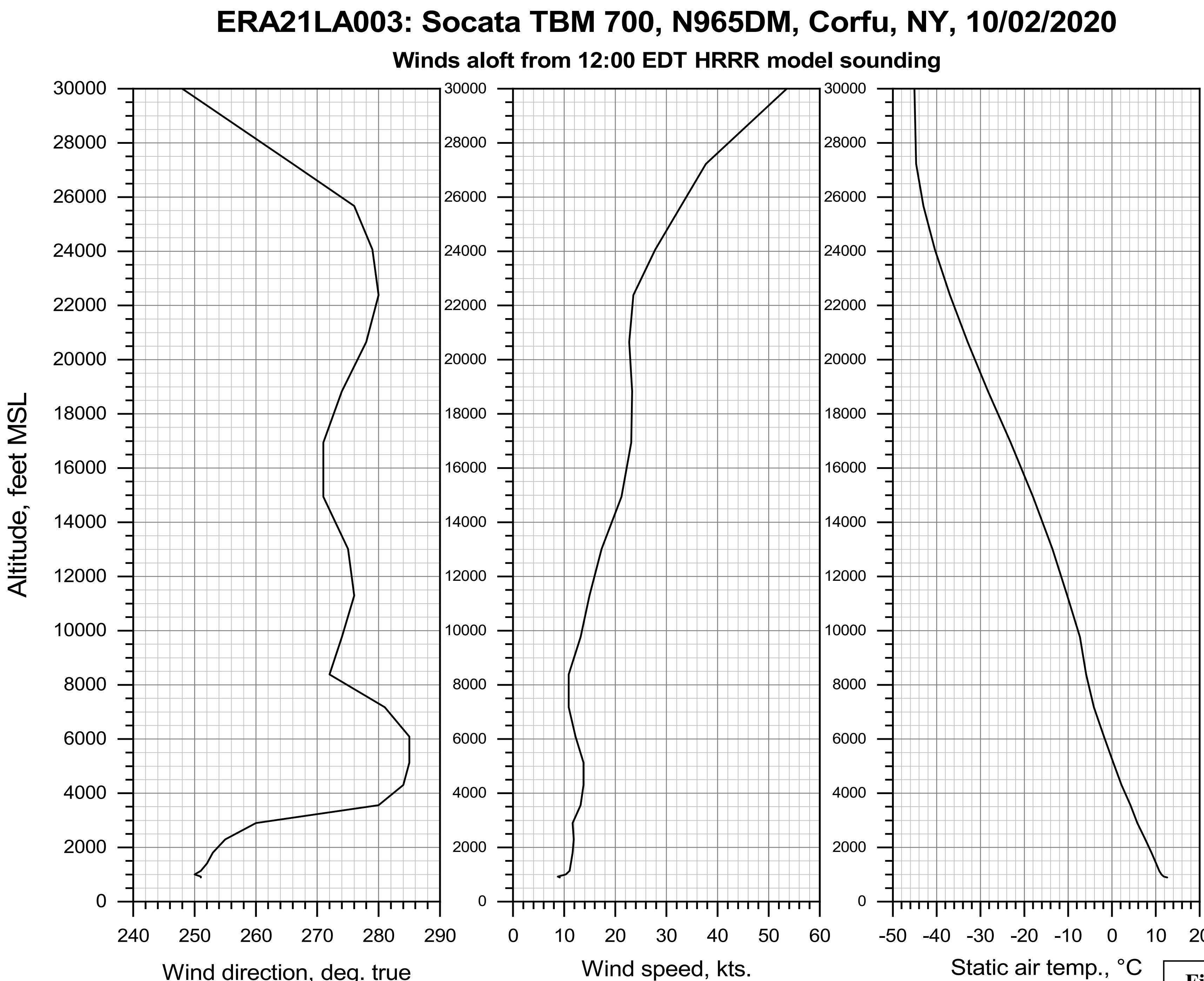
ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020
Winds aloft from 12:00 EDT HRRR model sounding
Altitude, feet MSL
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
26000
28000
30000
240 250 260 270 280 290
Wind direction, deg. true
0 10 20 30 40 50 60
Wind speed, kts.
-50 -40 -30 -20 -10 0 10 20
Static air temp., °C

Figure 4.

ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020

Altitude vs. time

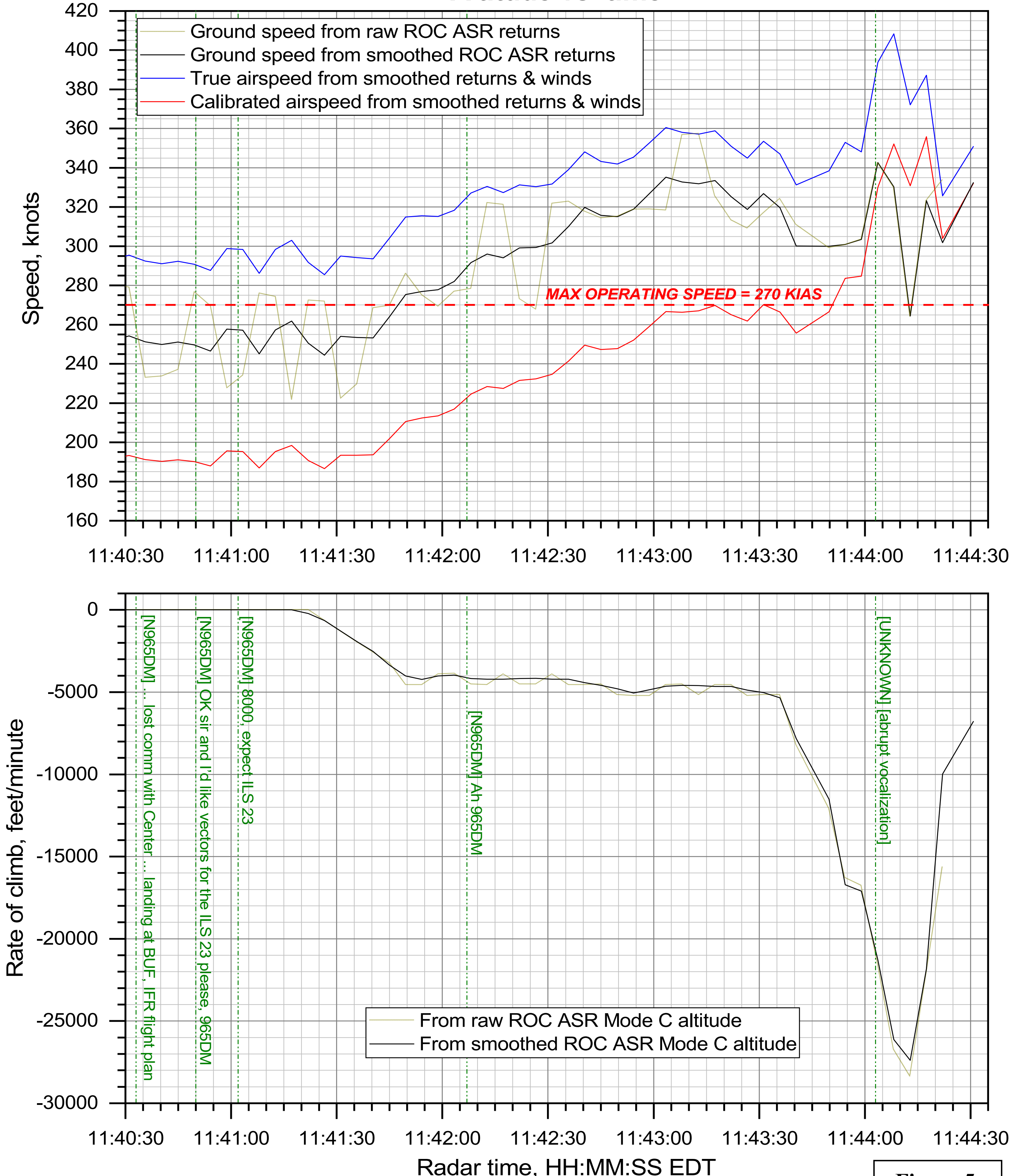

Figure 5.

ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020

Euler angles vs. time

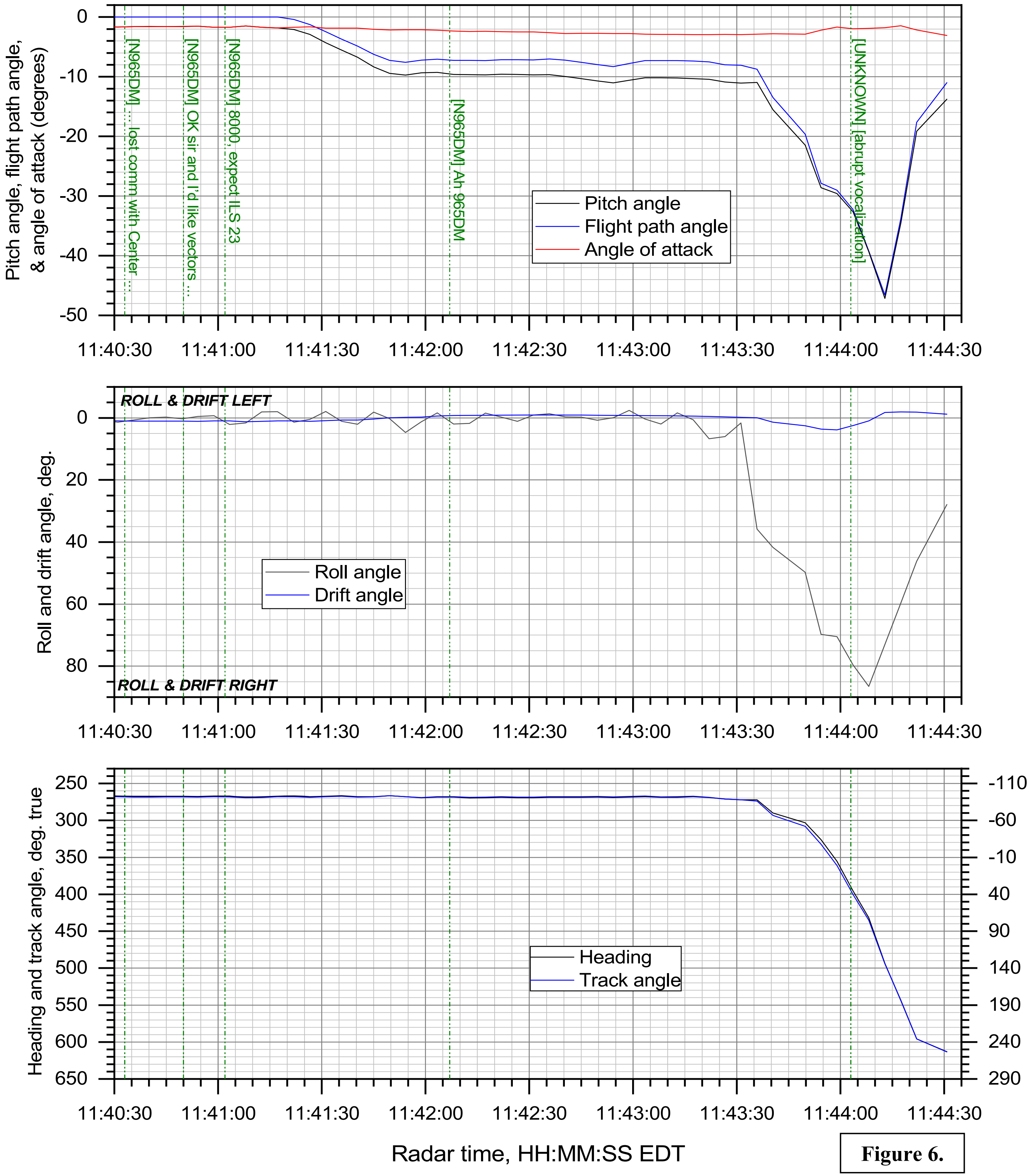

Figure 6.

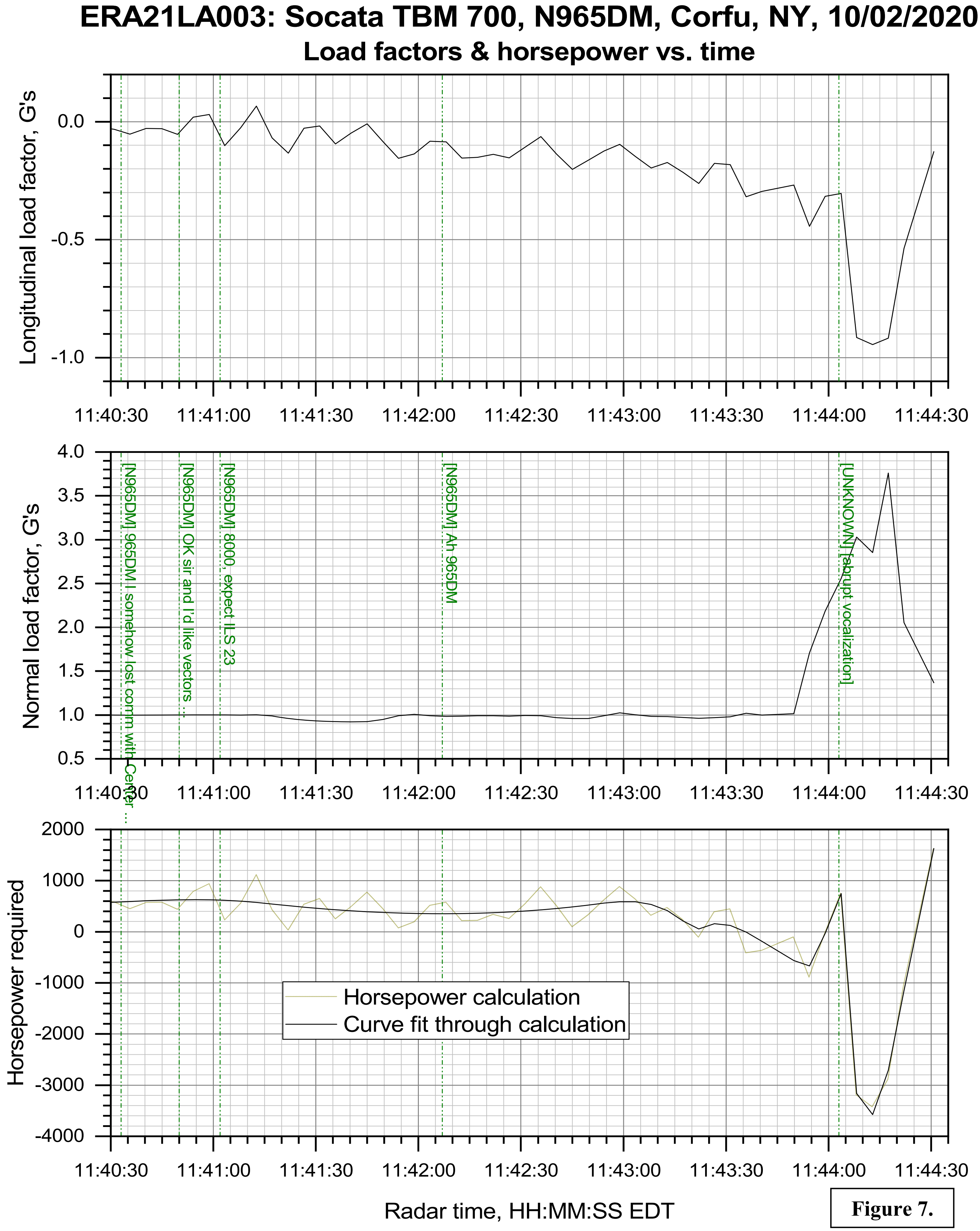
ERA21LA003: Socata TBM 700, N965DM, Corfu, NY, 10/02/2020
Load factors & horsepower vs. time
Longitudinal load factor, G's
0.0
-0.5
-1.0
11:40:30
11:41:00
11:41:30
11:42:00
11:42:30
11:43:00
11:43:30
11:44:00
11:44:30
Normal load factor, G's
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
[N965DM] 965DM I somehow lost comm with Center ...
[N965DM] OK sir and I'd like vectors ...
[N965DM] 8000, expect ILS 23
[N965DM] Ah 965DM
[UNKNOWN] [abrupt vocalization]
Horsepower required
2000
1000
0
-1000
-2000
-3000
-4000
Horsepower calculation
Curve fit through calculation
Radar time, HH:MM:SS EDT

Figure 7.