VIDEO-BASED FLIGHT-DATA RECONSRUCTION OF THE AMAZON PRIME AIR B767 ACCIDENT, TRINITY-BAY, USA, 2019

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PUBLICATIONS:

- ESASI CONFERENCE (05/2018)
- ISASI FORUM MAGAZINE (07/2016)
- ISASI CONFERENCE (08/2015)
- CHC – 10TH SAFETY & QUALITY SUMMIT (04/2014)
- EASA – FIFTH ROTORCRAFT SYMPOSIUM (12/2011)
- 67TH AMERICAN HELICOPTER SOCIETY (05/2011)
- CEAS – AIR AND SPACE CONFERENCE (10/2009)
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1. Introduction

The sole objective of an investigation into an aircraft accident or incident conducted under the provisions of Annex 13 shall be the prevention of accidents and incidents. The purpose of this paper is to encourage an additional investigation mean to the existing procedures, practices and techniques that can be used in aircraft accident investigations.

The investigation of air accidents is based on available data and information to determine the root cause. Flight recorder data, radar data and wreckage analysis can provide important information. However, in some air accidents, some if not all of these sources of information may not be available to investigators. In recent years, more and more video footages are available, either from witnesses, that recorded the accident situation with their mobile phones, or videos recorded by security cameras. This information can be used to reconstruct flight data, aircraft attitude, descent-rate and ground speed.

2. Thesis:

This paper represents the potential and the implementation of using video information to reconstruct the flight history and the flight path in detail. The consitency of the reconstructed information will be explained and how its been validated.

“Flight data that is reconstructed based on video information is applicable!”

3. The Methodology:

In the frame of the doctoral thesis of Dr. Bauer, the reconstruction methodology iwi® was developed in 2009, based on eyewitness reports in the field of aircraft accident investigation. The development has been based on the overview of existing applications and the existing problematic to recalculate a flight path and thus the flight history without flight recorder data (FDR) or radar information. The physiology and psychology of eyewitness have been evaluated, however the method can also process video information to approximate flight data.

The methodology has been applied already and successfully in several investigations, using video information in example such as :

- AS350 Mid-Air Accident, La Rioja, Argentina, BEA, 2015 [6]
- EC145 Accident, Hautes-Pyrénées, France, BEA-É, 2016 [5]
- Gazelle Mid-Air Accident, Carcès, France, BEA-É, 2018 [4]

The iwi method allows to approximate flight path as well as aircraft attitude and ground speed. The accuracy as the difference between the measurement and the part’s actual value, of the reconstructed data is influenced by multiple technical factors.

In order to reconstruct the elevation, the following factors must be considered and computed for the error calculation as the observed value versus the true value of a measurement:

- Δd_{xyGPS}: Video location accuracy (latitude and longitude) in meters
- Δd_{zGPS}: Video location accuracy (altitude) in meters
- Δd_{xyZPos}: Location accuracy of reference objects (latitude and longitude) in meters
- Δd_{zZPos}: Location accuracy of reference objects (altitude) in meters
- Ratio of the recorded object resolution in pixel and object size in meters

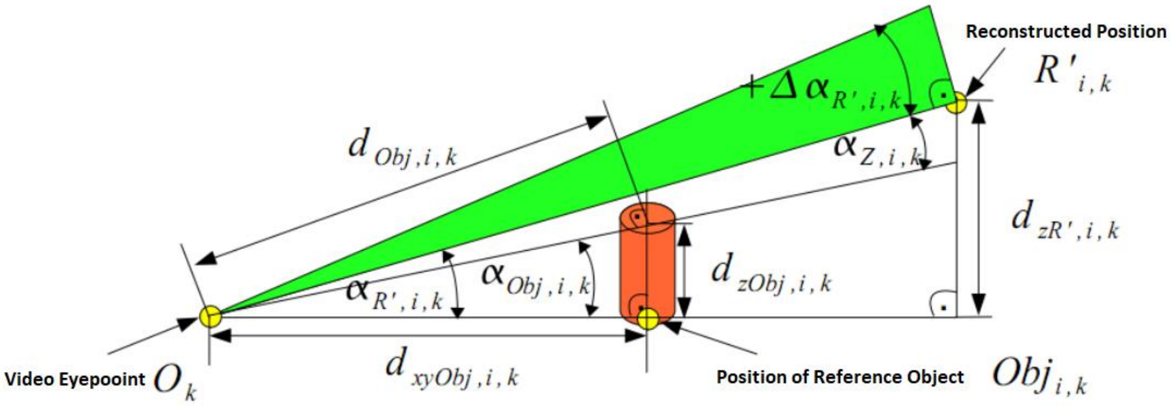

Figure 1: Angular deviation in elevation depending on reference object, eyepoint (left), position of reference object (middle) and observed object location (right) [1]

With reference to figure 1, the formula considers different errors. To place the video informationin in 3D, a reference object (Obj) as well as the observer (O) location are required. By knowing the positions of “O” and “Obj”, the minima and maxima altitude of the aircraft can be calculated by the formula below. The default error tunnel (green cone) is the result of an aproximated model, showing the possible area, where the altitude of the observed object was located. The error tunnel dimension is based on the known errors, such as the camera’s position accuracy, as well as the video resolution. Another influencing factor of the default tunnels size is the distance between the observer and the reference point, as a small miss-positioning of the observer resulting in a variation of the observed object’s height. The extend of the variation gets larger, the closer the reference object is relative to the position (latitude/longitue) to the observer.

The following formula is used with its derivations to calculate the elevation error based on the reconstructed distance to the object:

$$\sigma^2_{zObj} = 2 \cdot \Delta d^2_{zGPS} + \Delta d^2_{zZPos}$$

$$\sigma^2_{zObj} = \sigma^2_{xyObj} = 2 \cdot \Delta d^2_{zGPS} + \Delta d^2_{zZPos}$$

$$\Delta\alpha_{R\prime,i,k} = \sqrt{\left(\frac{\partial \alpha_{Obj,i,k}}{\partial d_{zObj,i,k}}\right)^2 \cdot \sigma^2_{zObj} + \left(\frac{\partial \alpha_{Obj,i,k}}{\partial d_{xyObj,i,k}}\right)^2 \cdot \sigma^2_{xyObj} + \Delta\alpha^2_Z + \Delta\alpha^2_{FotoObj,i,k}}$$

$$d_{z4,i,k} = \cos(\alpha_{R\prime,i,k}) \cdot \tan(\Delta\alpha_{R\prime,i,k}) \cdot d_{R\prime,i,k}$$

$$d_{z5,i,k} = \tan(\alpha_{R\prime,i,k} + \Delta\alpha_{R\prime,i,k}) \cdot \tan(\alpha_{R\prime,i,k}) \cdot d_{z4,i,k}$$

$$\Delta R'_{z,i,k} = |d_{z4,i,k}| + |d_{z5,i,k}|$$

In azimuth the following factors must be considered for error calculation:

- Video location accuracy (latitude and longitude) in meters
- Location accuracy of reference objects (latitude and longitude) in meters
- Ratio of the recorded object resolution in pixel and object size in meters

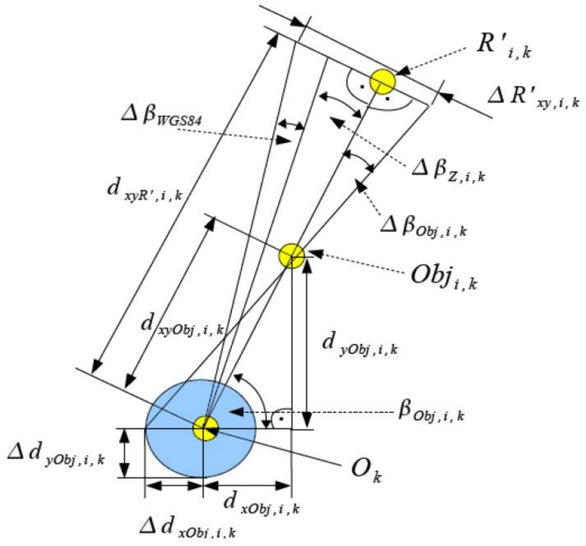

Figure 2: Geometry for calculating the error in azimuth, from witness / camera location via Obj (reference object) to reconstructed aircraft location (R) [1]

Figure 2 illustrates the formula for the calculation of the observed object's (R') position in latitude and longitude. The observer (O) requires here as well a reference point (Obj), which indicates the reference to the observed object's position. By knowing the exact position of "O" and "Obj", the exact position in longitude and latitude can be provided by the formula shown hereinafter.

The following formula is used with its derivations to calculate the azimuth error based on the reconstructed distance to the object:

$$\sigma_{xObj}^2 = \sigma_{yObj}^2 = 2 \cdot \Delta d_{xyGPS}^2$$

$$\Delta\beta_{Obj,i,k} = \sqrt{\left(\frac{\partial \beta_{Obj,i,k}}{\partial d_{yObj,i,k}}\right)^2 \cdot \sigma_{yObj}^2 + \left(\frac{\partial \beta_{Obj,i,k}}{\partial d_{xObj,i,k}}\right)^2 \cdot \sigma_{xObj}^2 + \Delta\beta_{FotoObj,i,k}^2}$$

$$\Delta R'_{xy,i,k} = \sqrt{(\tan(|\Delta\beta_{Obj,i,k}|) \cdot (d_{xyR',i,k} - d_{xyObj,i,k}))^2 + (\tan(|\Delta\beta_Z| + |\Delta\beta_{WGS84}|) \cdot d_{xyR',i,k})^2}$$

4. <u>The evaluation case:</u>

On February 23rd 2019 the Amazon Prime Air cargo aircraft was operated by the Atlas Air, flew from Miami to Houston, when during the arrival phase the Boeing 767-375BCF entered a rapid descent from 6,200 feet and impacted into a marshy bay area around 40 miles away from Houston's George Bush Int. Airport.

Figure 3: Aerial view main debris field looking northwest [3]

Two security cameras captured the last five seconds of the aircraft in a steep, generally wings-level attitude until impact with the swamp. On own interest, the iwi® methodology was applied to validate the latest methodology developments, reconstructing flight path, aircraft attitude and ground speed based on the available video information. The results were shared with the NTSB before the black box [2] could be recovered.

5. Flight Data Reconstruction and Data Comparison

Two video recordings were available from two different locations [7] [8]. They were used to create a panoramic images with aircraft positions and video time stamps. The video distortion was corrected using the dedicated lens correction profile.

The resolution of the video influences the data reconstruction accuracy, as well as the precision of the time stamp information. Video frames at every second were selected to ensure maximum accuracy. The security camera recording frequency was approx. one frame per second.

Figure 4: Surveillance Camera Video [7]

Figure 5: Surveillance Camera Video [8]

Figure 6: Camera location shown in Google Earth [7][8]

The GPS location of both cameras were identified as shown in figure 6, using Google Street View, as well as the location of reference objects like buildings and trees, as shown in the video. The location accuracy was defined with +/- 16 feet in latitude/longitude and altitude. The reference objects were used to place the image information within the 3D environment. All data collected were imported into the reconstruction software called „Immersive Witness Analyzer“, which sets all lines of sight considering reference objects. The software estimates the reconstructed flight path considering potential error information using the specified and decribed formulas.

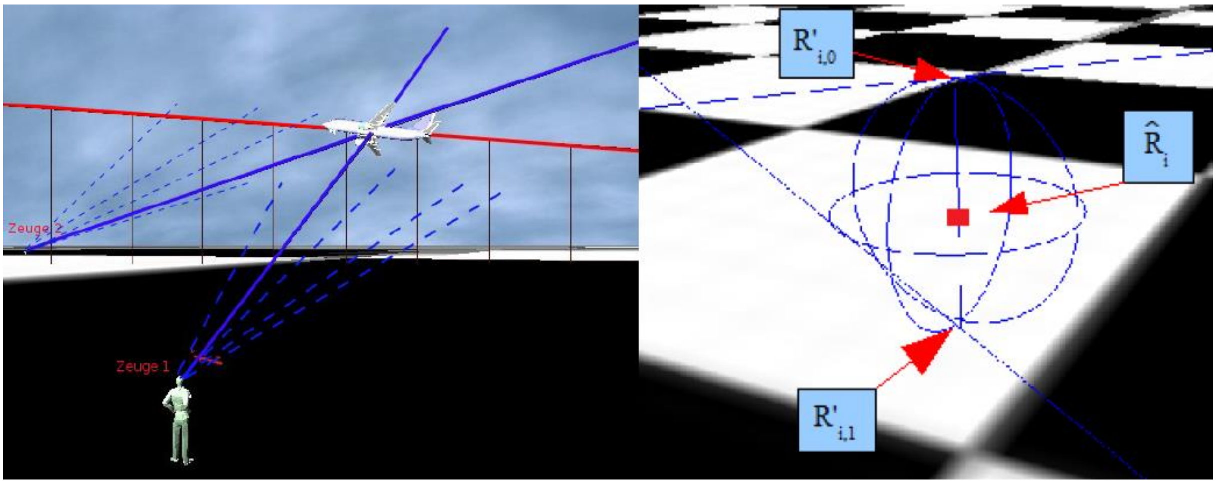

Figure 7: Lines of sight of witness statement (left) and reconstructed location with error (right) [1]

To estimate the aircraft’s attitude at different locations along the flight path, a 3D model of a B767 is placed and adjusted with respect to the video image frame rate.

The left image in figure 7 shows the lines of sight from the perspectives of two security cameras. The intersection of both lines approximates the position of one position of the observed object as shown in the rigth image. In this case the B767’s position (intersection of both lines of sight) was located, considering the potential errors.

Figure 8: Single frame of video [7] showing the B767 begind trees (left) and with overlay of 3D object (right)

The images in figure 8 show one single frame of the video [7]. The left image shows the outline of the aircraft behind trees. To determine the attitude of the aicraft, a 3D model of a B767 is placed in the 3D software application at the reconstructed position and the attitudes of the aicraft like heading, pitch and roll are adjusted until the objects fits best to the outline in the image. The accuracy for attitude reconstruction depends on the resolution of the frame. However the potential error can be up to +/- 10° based on experience.

Figure 9: Attitue Error +/-10° visualized (red/green), Heading (left), Pitch (middle), Roll (right)

To better explain the reason for the experienced size of the error in attitude, figure 9 shows the visual differences. The modified values for +/-10° are visualized in red and green and overlayed. Based on the experience of several reconstructions and video data, a good fit could be determined within the maximum error of +/-10° for all three axis.

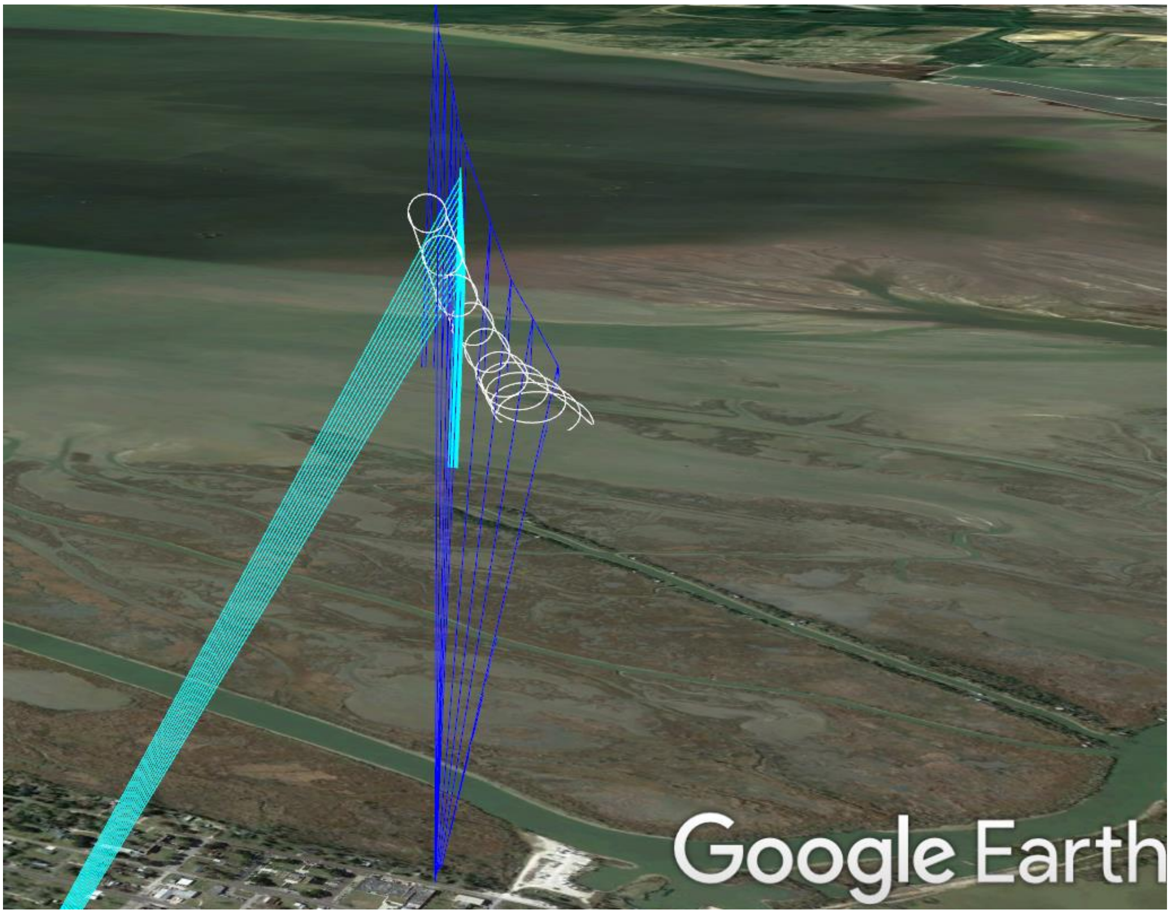

Figure 10: Reconstructed flight path

Figure 10 illustrates the reconstructed flight path with error tunnel (white circles) and shows the line of sight from the first observing camera (light blue) and second observing camera (dark blue).

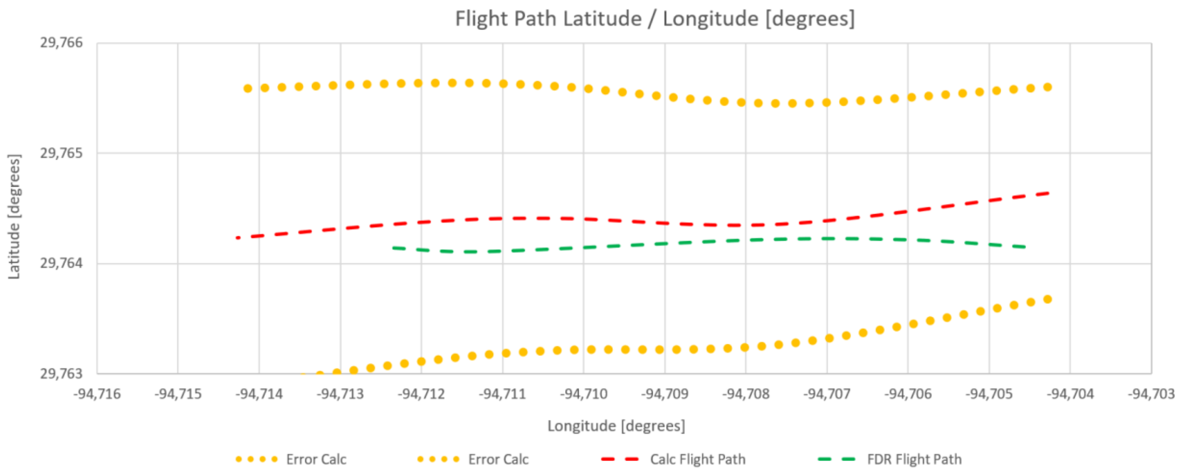

Figure 11: Reconstructed flight path (red), FDR flight path (green) and error tunnel (yellow)

The reconstructed flight path was compared to the original FDR data (shown in figure 12), that was recovered from the B767 wreckage. Figure 11 shows in latitude and longitude the flight path that could be reconstructed in red. The original flight path (green) is close to the reconstructed path (red) and within the error tunnel (yellow).

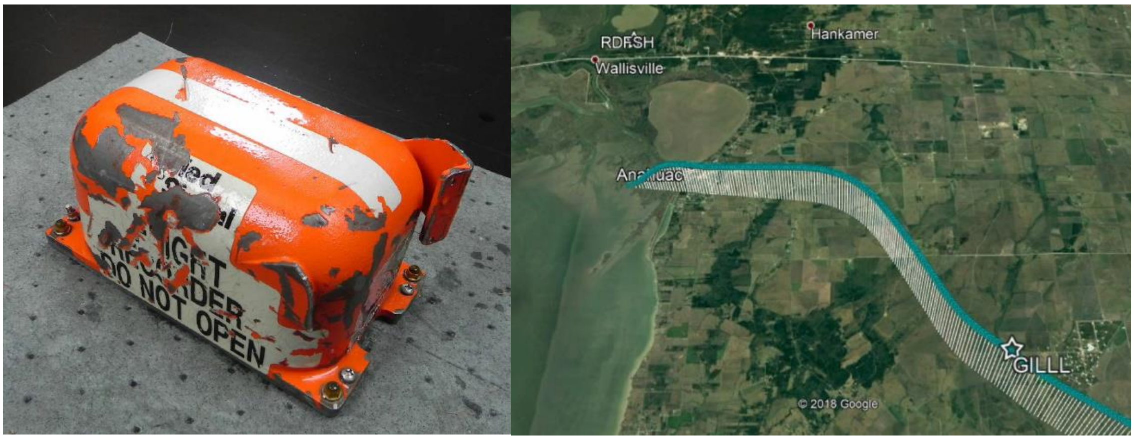

Figure 12: Recovered blackbox (left) and ADS-B flight path data (right) [3]

To better compare the difference between both, the extrapolated flight path from the video method and the recorded flight path from the FDR, the distance was calculated in feet and shown along the time in figure 13. The blue solid line describes the difference in latitude and longitude in feets between the reconstructed position and the recorded FDR data. The graph with dotted blue line shows the maximum possible distance, known as error tunnel based on the formulas. The achieved accuracy of the reconstructed flight path was in a range between 50 and 150 feet, finally within the error tunnel.

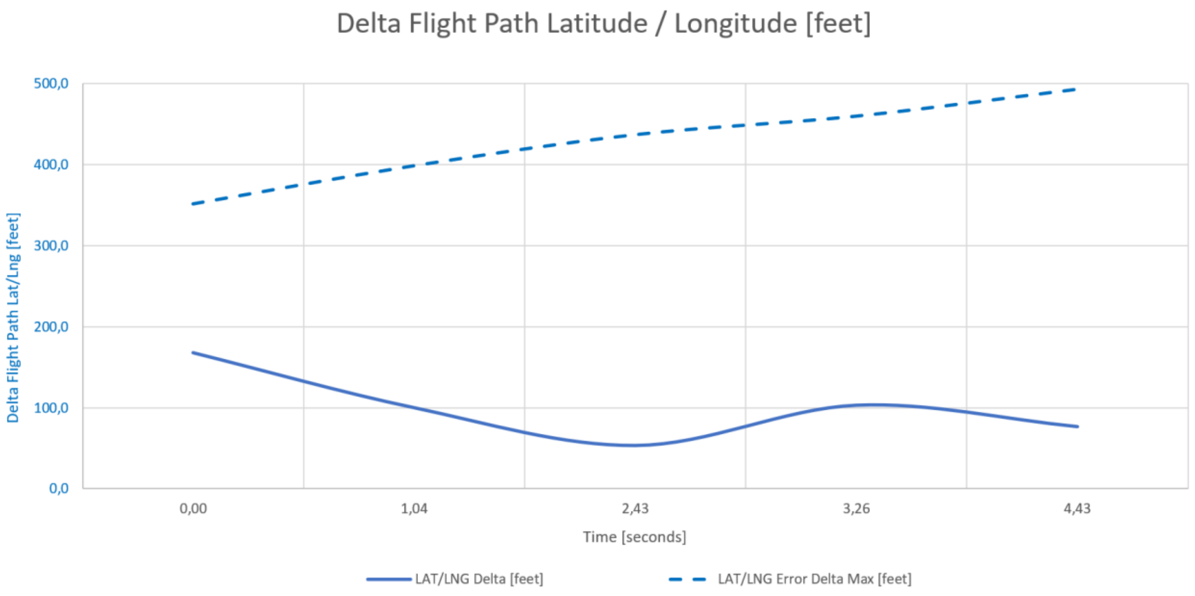

Figure 13: Distance in feets between reconstructed and recorded FDR (blue) and error tunnel (blue dotted)

Figure 14 shows the reconstructed altitude (red) of the airplane and the recorded FDR altitude data (green). The reconstructed altitude is within the error tunnel shown in yellow, with the exception of the beginning from 0.0 to 0.25 seconds, when the aircraft was shown only partially in the first frame. This may have resulted in a larger error in the early portion of the calculation. Finally the difference in calculated verses FDR recorded altitude was between 32.7 and 171.9 feet.

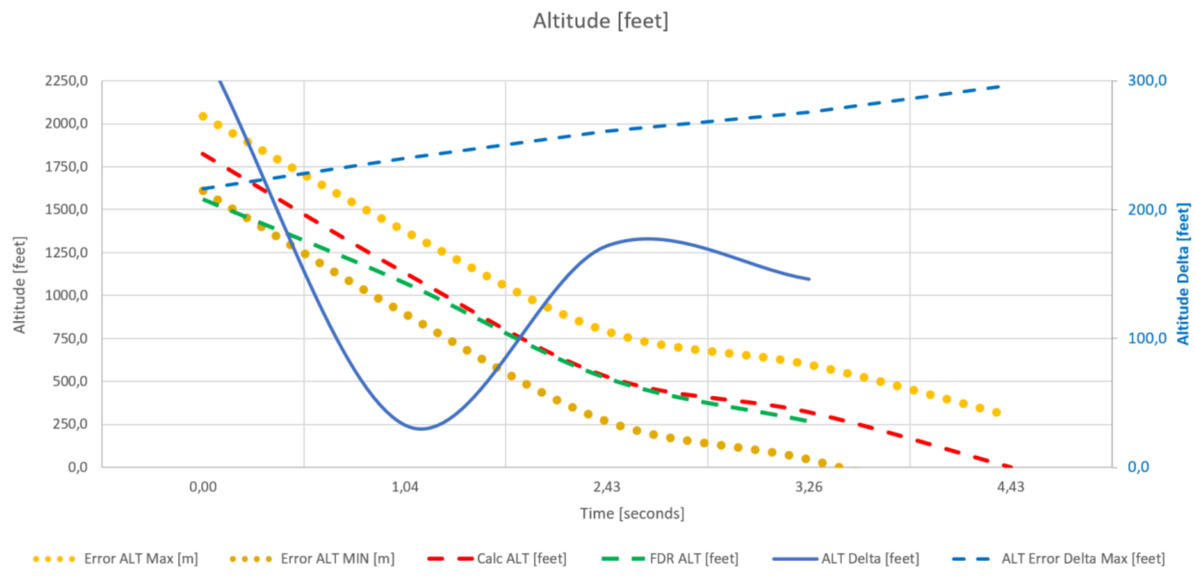

Figure 14: Reconstructed altitude (red), FDR altitude (green), error tunnel (yellow, blue dotted) and difference (blue)

Since the video could be synchronized with the time base, using the video frame time-stamps, a reconstruction of the ground speed and descent rate was possible.

Based on the calculated decent rate (red) in feet/min, figure 16 shows the aircraft reduced its descent rate from -39.800 feet/min to -15.000 feet/min. The recorded FDR data showed, the B767 reduced its decend rate from -28.000 feet/min to -18.240 feet/min within 2 seconds. The difference between the reconstructed data and recorded FDR data showed in the beginning a quite large difference up to 10.000 feet/min. This was possibly due to fact, that the aircraft was only partially visible in the video and that the recording rate of the security camera was relatively low one frame per second, as shown in figure 15.

Figure 15: First frame of video showing aircaft only partially [7]

Figure 16 shows, that within the time intervall from 2.4 to 3.2 seconds, the error is relatively low with +/- 3000 feet/min. At 2.75 seconds, the reconstruction and FDR values show the same result of -26.000 feet/min.

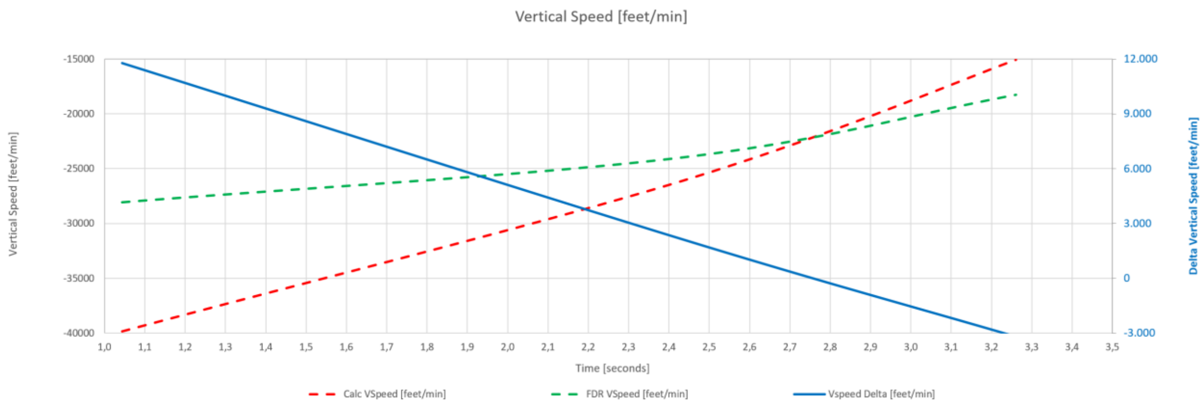

Figure 16: Calculated vertical speed (red), recorded FDR vertical speed (green) and difference value (blue)

In figure 17 the reconstructed ground speed is shown in red. Similar to the calculation for vertical speed, the error is quite high in the beginning of the video recording compared to the recorded FDR ground speed data. The calculacted ground speed from the video analysis is far too high compared to the recorded FDR values for ground speed which ranged from 320 kts to 407 kts. This accounts for the same reason as explained for vertical speed.

However, the accuracy is quite good, as it shows a difference of less than 50kts between 2.5 and 4.5 seconds.

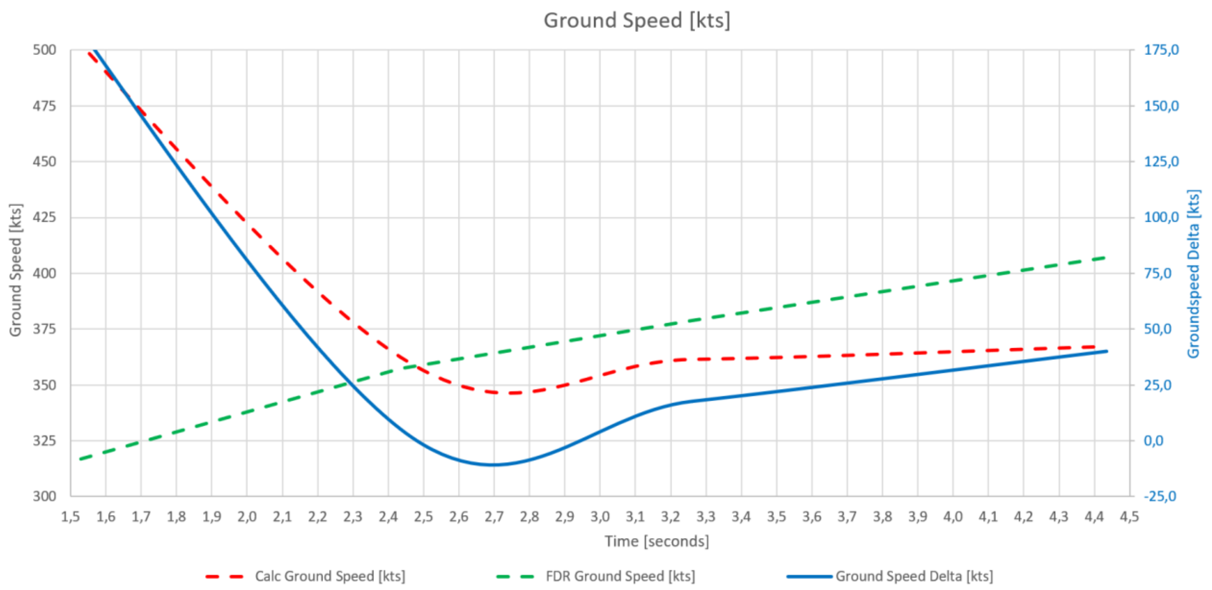

Figure 17: Calculated ground speed (red), FDR ground speed (green) and difference value (blue)

Figure 18 and 19 show the reconstructed attitude data for heading (yellow), roll (blue) and pitch (green). The calculated data is shown as dotted lines. The heading, pitch and roll values fit very well with an offset of less than +/- 10 degrees.

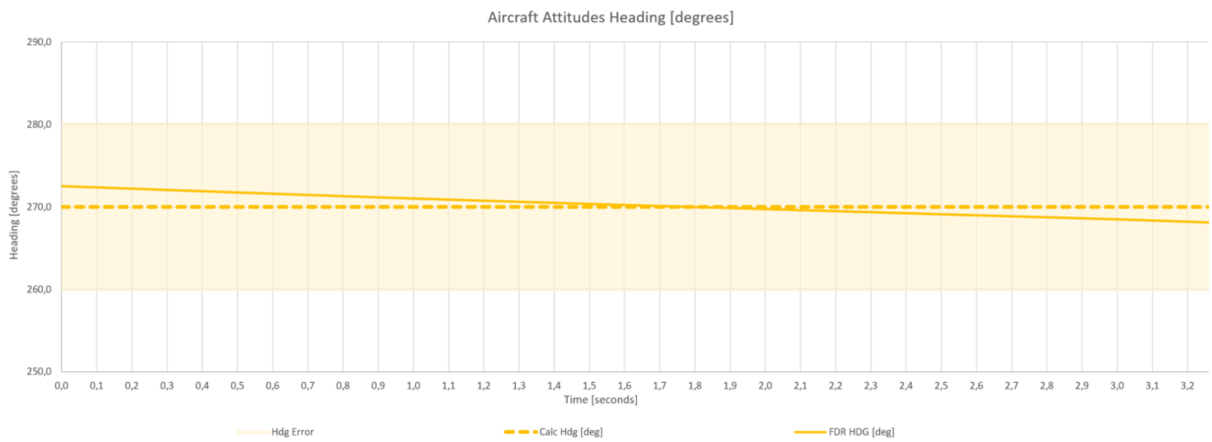

Figure 18: Reconstructed heading attitude (dotted lines) and recorded FDR heading (full line)

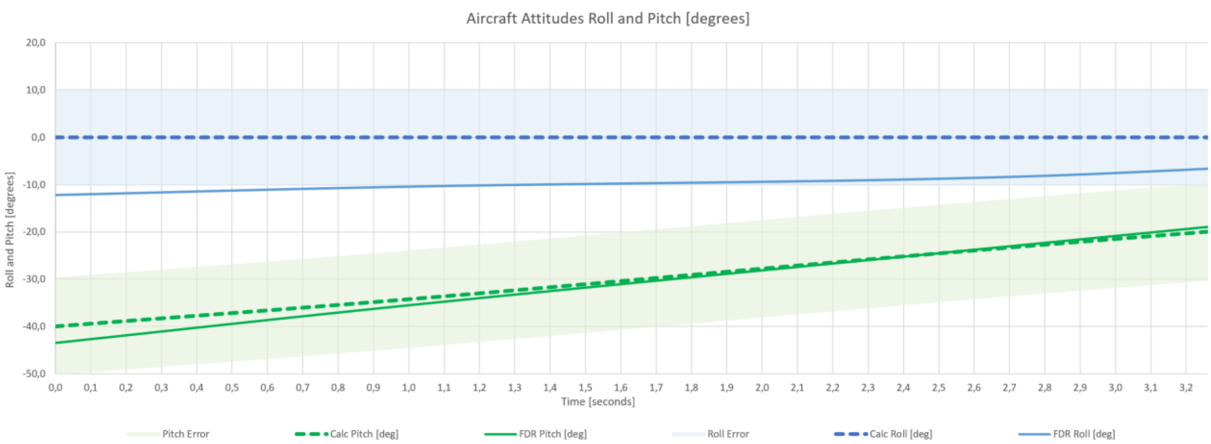

Figure 19: Reconstructed pitch / roll data (dotted lines) and recorded FDR data (full lines)

6. Conclusion

"Flight data that is reconstructed based on video information is applicable!"

The reconstruction of flight data based on video information is capable and the data is applicable. The accuracy of the reconstructed data depends on the location accuracy of the video source position and reference objects, as well as on the frame rate of the video and its resolution. Further the attitude data could be reconstructed very well within the experienced accuracy.

The more video sources that are avialable, the better the approximated positions can be calculated and cross checked.

In parallel to the increase of digital data, more and more video footage is available. The capability of this method can support to reconstruct data, based on video information, but also the combination of recorded data and video information can provide additional important details.

7. List of references:

[1]: University of Darmstadt, Marcus Bauer, Flightpath reconstruction based on witness information using Virtual-Reality technology, Darmstadt, Germany, https://tuprints.ulb.tu-darmstadt.de/1894/2/thesis_bauer_V2_3_finaldruck.pdf , April 2009.

[2]: NTSB, NTSB Laboratory Completes Initial Review of Cockpit Voice Recorder, Recovers Flight Data Recorder, https://www.ntsb.gov/news/press-releases/Pages/mr20190305.aspx, March 2019

[3]: NTSB, Interim report of Atlas Air #3591 crashed into Trinity Bay, https://www.ntsb.gov/investigations/Pages/DCA19MA086.aspx, December 2019

[4]: BEA-É, RAPPORT D'ENQUÊTE DE SÉCURITÉ T-2018-02-A, https://www.defense.gouv.fr/content/download/551240/9390700/Rapport%20d%27enqu%C3%AAte%20de%20s%C3%A9curit%C3%A9%20T-2018-02-A.pdf, February 2018

[5]: BEA-É, RAPPORT D'ENQUÊTE DE SÉCURITÉ BEAD-air-G-2016-008-A, https://www.defense.gouv.fr/content/download/516647/8689246/Rapport%20G-2016-008-A.pdf, May 2016

[6]: IWI, Immersive Witness Interview Report – AS350 Accident, http://www.iwiation.com/download/IWI_Report_Argentina_AS350_09March2015_MBauer_v1_2.pdf, July 2015

[7]: YouTube, Video shows cargo plane crash into Trinity Bay, https://www.youtube.com/watch?v=KhG97hHTv2A, March 2019

[8]: YouTube, New video shows plane´s final moments, https://www.youtube.com/watch?v=OIlnz3CTkfE, February 2019