Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Engineering Note

Analyzing the Descending Flight of the Germanwings A320 4U9525 on 2015-03-24, from 10:32 to 10:41

Faculty of Engineering and Computer Science

Automotive and Aeronautical Engineering

Aircraft Design and Systems Group (AERO)

Prof. Dr.-Ing. Dieter Scholz, MSME

Date, Time
2015-03-26, 10:00

Reply to
Dieter Scholz

Phone
+49.40.42875.8825

Fax
+49.40.42875.8829

E-Mail
info@ProfScholz.de

Internet
http://www.ProfScholz.de

Address
HAW Hamburg
Fahrzeugtechnik und Flugzeugbau
Berliner Tor 9
20099 Hamburg

Internet
http://AERO.ProfScholz.de

Abstract
This Engineering Note provides the summary of an analysis of the descending flight of the Germanwings A320 4U9525 on 2015-03-24 which ended in a tragic crash in which the aircraft and all on board where lost. The analysis starts with a collection of data publicly available on 2015-03-25 – especially the detailed data of time, altitude, ground speed, and vertical speed from flightradar24.com. The analysis takes into account simple flight performance and aerodynamic calculations and considers the functioning of the aircraft systems: Flight Control, Autopilot, and Autothrust and their dependencies. Results are interpreted in which a 9 minute long descending flight is described. The – by far – most likely explanation is followed in detail. It results in the observation that the A320 flew in the descending flight on its own down until impact. The aircraft did what it would do, when no one interferes with additional commands.

Introduction
Some hints were given by Germanwings and the BEA (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile). The BEA is the French authority responsible for safety investigations into accidents or incidents in civil aviation. Data has been collected by the press. Also the English Wikipedia (http://en.wikipedia.org/wiki/Germanwings_Flight_9525) has collected data suitable for further calculations.

The BEA is guiding the investigation, but has not revealed more details as this Engineering Note is written. The cockpit voice recorder was found and analyzed, but no details about it are in the public domain.

The interpretation uses the method called Occam's Razor. "The principle states that among competing hypotheses that predict equally well, the one with the fewest assumptions should be selected."
(http://en.wikipedia.org/wiki/Occam%27s_razor)

Collection of Data, Flight Performance Calculation, Aircraft System Considerations, Time Line, and Interpretation
The most detailed data at this time comes from flightradar24.com. It is a CSV-file that can be read e.g. with Excel. It consists of 7908 line of data. Each line represents data at one point in time from take-off to impact. The data shows some scatter. Irritating is that the lines are originally not in chronological order.

The first line is from 08:48:57 UTC and the last line is from 10:49:36 UTC. MEZ is one hour ahead of UTC. In every second about two datasets got recorded. Occasionally gaps of 4 s exist between recordings. For the simplified flight performance evaluation very few data sets are sufficient (Table 1).

Table 1: Selected data from FlightRadar24.com for further calculation.

time in UTC	altitude_feet	ground_speed	vspeed
09:27:02Z.260	37900	445	192
09:32:03Z.612	35900	472	-3584
09:35:31Z.654	22625	492	-4800
09:36:30Z.092	19475	468	-3776
09:40:36Z.794	6800	378	-3520

- altitude is measured in ft
- ground speed in kt
- vertical speed in ft/min

A good visualization of the data from FlightRadar24 can be found on http://de.tinypic.com/view.php?pic=2poz8sl&s=8#.VRPKWcmYD40, a platform for picture and video sharing (Figure 1).

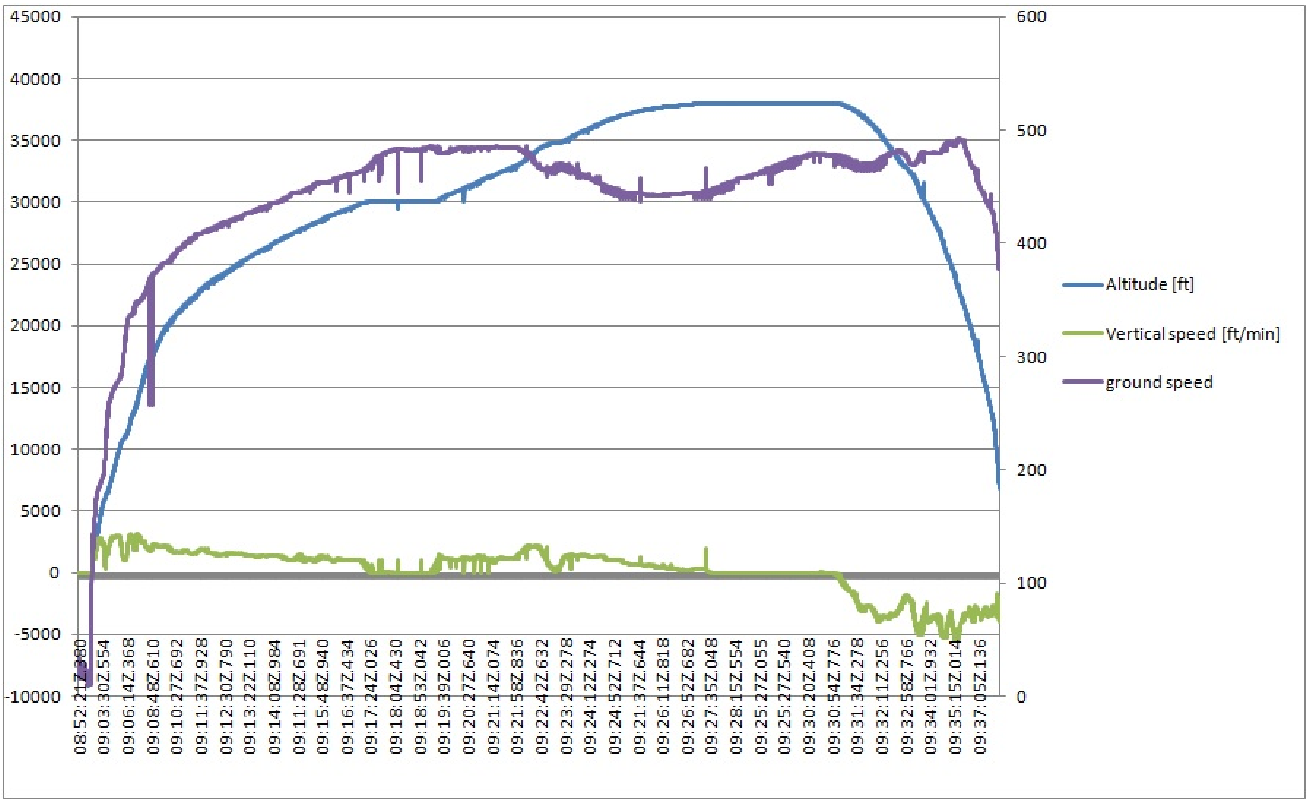

Figure 1: Data from FlightRadar24 as plotted and stored on http://de.tinypic.com (author is unknown)

Flight performance calculations have been done in a separate Excel table. This file can be found at http;//www.haw-hamburg.de/pers/Scholz/materialFM1/Germanwings_4U9525.xls
That file is briefly documented for readers with an aeronautical engineering background and the author himself. Only at a later time the calculations may be written in text form.

At 10:27
the aircraft reached cruise altitude recorded with 37900 ft. This was also reported as FL380 (38000 ft). As FlightRadar24 uses altitude and on 2015-03-24 seal level pressure in Marseille was 1007 hPa even an altitude of 37820 ft would make sense. For the performance calculation this is without importance. Altitude variation is what matters more.

At 10:31
the vertical speed gets negative. The aircraft starts to descend.

At 10:32
the descending flight can be considered started – also looking at the altitude recording. The reason for this is unknown today.

For flight performance calculations true airspeed is important and can only be determined if wind speed is known. Weather charts from 14 hours after the flight suggest that the flight may have met a head wind. There was a zone with wind speeds of 90 kt from north east. This weather was present however, much further over the west of France. In accordance to this, calculations indicate that about zero wind speed was more likely for the flight. This means that ground speed can be set equal to true airspeed.

Due to the descending flight, speed increases. At lower altitude the speed of sound is increased. This would reduce Mach number if speed stayed constant, but with increasing speed we face a situation in which Mach number is now high and variable around Mach 0.82.

Mach 0.82 is the Mach number of maximum operation (MMO) and the speed in the A320 flight control laws where High Speed Protection sets in. A slight nose up command is introduced (due to an added load factor command) by the Fly-by-Wire system and the autopilot disengages. If autothrust is still engaged it will manage thrust such that the current target **speed** [1] (A319/A320/A321 Flight deck and systems briefing for pilots, STL 945.7136/97, Sept.1998) is maintained. This speed is 445 kt and is equivalent to Mach 0.78 (the typical cruise Mach number) in FL 380 as indicated by the data when the aircraft reached cruise altitude. Flying at Mach 0.82 with a target equivalent to 0.78 means that autothrust throttles back eventually to flight idle. With autothrust disengaged pilots would most probably do the same and cut back on thrust when the aircraft gets into a high speed situation. So, no matter what the situation was (autothrust engaged or disengaged with pilots operating) we would see probably the same outcome at this point. The combination of autopilot disengaged and with pilots not pulling back on the thrust levers is not a possible explanation, because with such an energy situation (cruise thrust) the aircraft would not descent as it did.

At 10:35:30
Maximum speed is reached with 492 kt. Wikipedia reports 515 kt referring to Figure 1, but this is not supported by Figure 1 as quoted by Wikipedia. Due to the lower altitude this is still equal to Mach 0.82 (and not more because speed of sound increased). The aircraft is still operating at the onset of High Speed Protection. As the altitude is now below 31000 ft the logic changes from limiting Mach number at MMO = 0.82 to limiting VMO = 481 kt TAS.

Even with autopilot disengaged, the Airbus A320 continues to fly straight. The Normal Law is a load factor demand law. It is like directing the aircraft to a point on the sky a little above the horizon, on the horizon, or below the horizon, and the aircraft will fly straight to this point. Gusts that may change the aircraft attitude cause a load factor which is automatically corrected by the Fly-by-Wire flight control system (although no autopilot is engaged). Without touching the side stick, the pilot commands "no load factor" which means the aircraft controls all disturbances such that the aircraft continues to fly straight. The flight path (the flight path angle) however follows the energy situation and the aerodynamics. Even if the pilot

[1] This needs to be verified. It is to be checked, if the autothrust system has also a target **speed** if the aircraft flies above 31000 ft based on **Mach number**.

would have initially pointed the aircraft nose higher with respect to the horizon, the aircraft must sink (because the autothrust so far went to idle thrust). The flight path is quite steep, because the aircraft does not fly at an optimum speed. The lift coefficient is too low (C_L = 0.25) for an aerodynamically optimum (shallow) gliding flight. The low lift coefficient is due to the high speed initially when the aircraft was still at high altitudes. As the aircraft comes down and slows down the low lift coefficient is due to the higher air density.

Interesting is the comparison between
a) the glide angle as determined from vertical speed and forward speed and further the glide ratio L/D assuming there is no thrust and
b) the glide ratio L/D calculated from aerodynamic considerations.

The aircraft shows an L/D = 16.4 when it reached cruise altitude. This is not much lower than the maximum L/D of the aircraft (this is a secret, but known to be in the order of 18 to 19). During the aerodynamically non-optimum descent an L/D of (on average) 14.1 could be measured from the flight data. This compares with the aerodynamic calculation showing an average L/D during descent of only 12.3. The measured L/D can be higher, because of the idle thrust acting as if it would reduce drag and as such making the impression of a higher L/D.

The L/D comparison also shows: Although the descent seems to be steeper than pilots are normally used to (when they maintain near optimum conditions), the descent was a normal reaction of the aircraft under given conditions. Thrust was most probably flight idle thrust. Of course also other combinations of spoiler deployment combined with exact the right thrust to compensate these additional aerodynamic spoiler losses would be possible, but based on Occam's Razor this is far fetched and not a viable explanation of events.

At 10:36:30
the airspeed is well below VMO and even more so (due to low altitude and high speed of sound) well below MMO. The autopilot could be engaged again by the pilots, but it is not. Autothrust still does not set in because the speed is 468 kt still higher than the target speed set for the autothrust system.

At 10:41
recording of flight data ends here. The aircraft still continues a little further until impact in its descending flight with speed decreasing now even below the target speed of the autothrust system.

Summary
Flight data can not explain what happened initially. What <u>can</u> be put into a logical sequence with a high degree of probability based on facts combined with the knowledge from aircraft performance, aerodynamics, and aircraft systems of the A320 is a plausible description of the descending flight.

Something (today still unknown) caused 4U9525 to descent. All the rest is the automatic reaction of a properly functioning Airbus A320 to these initial conditions: The aircraft is disengaging the autopilot automatically at a Mach number of 0.82 as a consequence of High Speed Protection and follows a subsequent descending flight in manual mode (with normal Fly-by-Wire flight control laws) and idle thrust. The pilots probably do neither touching the side sticks nor the thrust levers. At least, it does not need any pilot intervention to explain the cause of the last 9 minutes of the flight and the final tragic effect.