The Last 80 Seconds of Flight MP495 on Dec 21, 1992

DFDR and AIDS data analyzed in detail

3 August 2017

A. Cats

H. Horlings

Avio*Consult*

Independent Aircraft Expert and Consultant

Table of Contents

References

A – Analyse Ongeval Martinair DC-10-30F, MP495, Faro, 21 dec. 1992, Avio*Consult*, 17 dec. 2012. https://www.avioconsult.com/downloads-nl.htm.

B – Accident Investigation Report, DC-10-30F Martinair Holland NV, DGAC, No. 22/ACCID/GPI/92, 31-10-1994. Via: https://aviation-safety.net/database/record.php?id=19921221-0&lang=nl.

C – Aircraft Operations Manual DC-10, Martinair Holland NV, Volumes I – III.

D – Basic Instructions Martinair Holland NV, Flight Operations Manual.

E – Digital Flight Data Recorder Factual Report, NTSB Washington, DCA-92-RA-011, dated Feb. 11, 1993 (Required data plots are included in Attachments).

List of Figures

List of Tables

List of Attachments

Colophon

Please check this website for the most recent version of this analysis, in EN or NL languages.

Avio*Consult* is an independent aircraft expert and consultant. See also www.avioconsult.com.

Harry Horlings is Lt-Col ret. of the Royal Netherlands Air Force, Graduate Flight Test Engineer of the USAF Test Pilot School, Edwards Air Force Base, CA, USA (1985) and an experienced private pilot.

Aart Cats is Senior Inspector pilot flight operations / DC-10 Type Rating Examiner / Captain B-757, 767 (RLD, ret.).

The General Conditions deposited at the Chamber of Commerce applied during conducting this analysis.

1. Executive Summary

1.1. Preamble

1.1.1. Survivors and next of kin of the deceased passengers of the catastrophic accident with a Martinair DC-10, flight MP495, at the airport Faro in Portugal on December 21, 1992, asked Avio*Consult* to analyze the accident, the Portuguese Report of Accident (RoA) and the contribution of the Dutch Safety Board (DSB) to the Investigation Commission. The analysis was presented in ref. A. Although the last 80 seconds were also included, this period was not yet described in great detail, which is the purpose of this document, that is to be considered a supplement to ref. A. Included are data graphs out of the Digital Flight Data Recorder (DFDR) and Airborne Integrated Data System (AIDS) of the airplane to which will be referred to from the text; no other documents will be needed during reviewing this analysis. The documents referenced A – E on page 2 were used during the analysis.

1.2. Main Conclusions

1.2.1. Accurate analysis of the DFDR data revealed that the flight crew did conduct the approach to Faro airport neither in accordance with the published procedures by the Portuguese authorities, nor with the Basic Instructions Martinair (BIM) and the DC-10 Aircraft Operations Manual (AOM).
Both the Air Traffic Control (ATC) ground radar data in Annex 12 of the Report of Accident (RoA, Figure 1 on page 9), as well as the wind and heading analysis presented in this report prove that the final turn radius was too large, because the very strong and well-known crosswind was not taken into account by the pilot-flying (the copilot), that the aircraft did not return to the prescribed 111° VOR approach radial and that the aircraft cannot have flown on this approach radial, but approached the airport on a ground track of 117° (§ 2.1.1 and § 5.6.5).
ATC had informed MP495 during the final turn that the runway was flooded, resulting in a 5 kt crosswind limit. DFDR heading and airspeed data prove that the crosswind during the last 80 seconds of flight was near constant (20 kt) and exceeded the limits for landing at both a wet (15 kt) and a flooded runway (5 kt). Despite the large limits-exceeding crosswind, the crew continued the approach.
Altitude, airspeed and control input data recorded by the DFDR and AIDS prove that there were no large abnormal vertical deviations in the descent altitude profile. The deviations from a straight descent below 2000 ft were the result of the transition from the Vertical Speed mode of the autopilot to manual control with support of the Control Wheel Steering (CWS) mode of the autopilot below 600 ft. The rate of descent that was set in the autopilot might have been a little too high, or the headwind component larger than anticipated, because a 10-second level flight was required to intercept the visual PAPI glide path at 500 ft. This is not exceptional during a non-precision approach. Airport Faro was not equipped with an instrument landing system. It does not prove the occurrence of up- or downdrafts either.

1.2.2. This accident is a classic example of the fatal consequences of not applying the written and well-established procedures and protocols for a non-precision approach. The Approach and Landing Accident Reduction (ALAR) working Group of the Flight Safety Foundation already advises for many years to indeed apply the procedures during approaches, and more specifically to maintain the required approach radial and descent path, and a stabilized engine RPM to reduce the workload ('stabilized approach').
Below, all conclusions of this report are copied and grouped with references to the individual paragraphs within the analysis.

1.3. All Conclusions of This Analysis – Sectionalized

1.3.1. *Application of Procedures*

1.3.1.1. The CVR transcript proves that the airplane was not configured in-time for the approach and landing § 4.1.4). Landing gear extended, flaps and slats too late, approach speed not attained. The crew did not follow the prescribed procedures.

1.3.1.2. The required calls for approach safety at altitudes 500 ft and 50 ft were not given by the captain and flight engineer, and not by the pilot-flying, the copilot, either. In addition, other procedural and safety related calls were not given either. The cockpit crew did not adhere to the AOM-prescribed crew coordination procedures. (§ 5.6.1 and § 5.12.5).

1.3.2. *Approach Path*

1.3.2.1. Annex 12 of RoA (Figure 1) proves that MP495 did not end the final turn on the prescribed approach radial of 111° and did not return to it either (§ 4.1.2). This conclusion could be confirmed with a wind and heading analysis (§ 5.6).

1.3.2.2. The ATC radar data in RoA Annex 12 (Figure 1) shows that the radius of the final turn was too large because the known strong southerly wind was not taken into account by the pilot-flying; the airplane did not intercept, and was not steered back to the required 111° approach radial but approached the runway on a direct, near constant heading of 125° (§ 4.1.2 and § 5.6.8).

1.3.2.3. The DFDR data show that the heading did not change during the last 80 s of flight, with the exception of the small heading changes (yawing) due to (inappropriate) rudder inputs by the copilot. The wind and heading analysis proves that the wind during the last 80 s was a constant 190°/ 20 kt, as the captain read at 10 s before landing from the display of navigation computer. The wind and heading analysis above also proves that the airplane cannot have been on the 111° approach radial, but approached the airport at a ground course, a radial of 117° (§ 5.6).

1.3.2.4. The copilot already applied rudder inputs at 42 s, even before passing the 1 nm point (Figure 1), without any roll control inputs to prevent drift due to the crosswind, which is required to stay on the same (ground) course. This is not normal at that distance, and not if the airplane would have flown on the 111° approach radial either, not even under strong crosswind conditions. These control inputs were maintained during 27 s until after passing the 1 nm point, to about 0,5 nm in front of the runway threshold. This also proves that the airplane cannot have flown on the 111° approach radial, and did not make the 5° turn from the 111° approach radial to end on the extended runway centerline of 106° (§ 5.9 and § 5.7.1).
The captain did not intervene when the copilot applied rudder too early (§ 5.7.2).

1.3.2.5. The DFDR data do not show bank angle and heading changes for the transition from the 111° approach radial to the runway heading of 106° at 1 nm in front of the runway. This also proves that the airplane cannot have approached on the prescribed 111° approach radial (§ 5.9).

1.3.2.6. The DFDR and AIDS recorded control input and heading data do not show a heading change of 5° to the left at the 1 nm approach offset point (≈30 s) from the runway threshold. Bank angle and heading did not change. This is another indication that the airplane was not on the 111° approach radial or the extended runway centerline (§ 5.10.2).

1.3.2.7. At a distance of about 0.5 nm in front of the runway, the increase of the heading was not counteracted; the airplane obviously had to be displaced further to the right, to the middle of the runway. The conclusion is that the airplane flew left of the runway and definitely not above the (extended) centerline (§ 5.10.2).

1.3.2.8. At 13 s before landing, the copilot also applied rudder to the left to 90% of maximum pedal travel. This looks like an attempt to align the airplane with the runway to avoid a traversing landing, but the pilot allowed the bank angle to increase to 14° to the left, at 6 s, rather than attaining and maintaining a bank angle to the right to counteract the large crosswind from the right and avoid drifting to the left (away from the runway centerline). The airplane obviously needed to be displaced towards the runway centerline. Another indication that the airplane was not approaching at the extended runway centerline (§ 5.11.2).

1.3.2.9. At 7 s before landing, the pilot reduced the rudder control input from 90% left to zero, causing the heading to increase slowly, rather than decreasing the heading further which would be required to align the airplane with the runway. The bank angle also decreased from the left to 0°. The release of the rudder, and a bank angle that was kept at wings level, rather than to the right as would be required with the strong 20 kt crosswind from the right, prove that the airplane was not above the runway centerline, but obviously still had to get there from the left side (§ 5.12.1).

1.3.2.10. The heading change due to the large 90% rudder input from 13 s was 13°, but not adequate to reach the runway bearing of 106° from 125°. The rudder of the DC-10 is not designed for this yawing angle of 19°. If the airplane would have approached above the extended runway centerline, then the 13° heading change / rudder authority would have been sufficient, and the traversing landing could have been avoided. This also proves that the airplane did not approach the runway at the extended runway centerline, but under an angle from the left (§ 5.11.3).

1.3.2.11. The airplane landed with a crab angle of 11°, but in the direction of the runway; the left main landing gear touched down outside of the runway.
The bank angle, control inputs of rudder and ailerons and the heading during the last 1.5 s of flight also prove that the airplane was not, and was not being aligned for a landing under crosswind conditions (Figure 4 middle), which also is evidence that the airplane was not approaching above the center of the runway just before landing. Control inputs do not show any response to sudden wind changes (§ 5.13.6).

1.3.2.12. The 6° deviation from the 111° approach radial was three times larger than the AOM-approved maximum 2°. Hence, at 500 ft, the approach did not comply with the AOM and BIM requirements for a stabilized approach. This should have been a reason for an immediate go-around. The captain however, did not intervene to prevent and correct this navigation error, and did not order a go-around (§ 5.6.8).

1.3.3. *Flight Techniques*

1.3.3.1. At 13 s before landing, at an altitude of 150 ft, the copilot closed the throttles manually against the autothrottle, while this would normally occur from 50 ft. The RPM of the engines decreased further than the autothrottle would do. The too low RPM increased the spool-up time of the engines, preventing the thrust from increasing quickly enough for the initiated go-around at low altitude to be successful (§ 5.11.1).

1.3.3.2. The apparently not very experienced copilot not only pushed the roll and elevator controls inappropriately, with as result unnecessary variations in the flight path and engine RPMs, but also the right brake pedal. His right foot was not positioned correctly on the rudder pedal (§ 5.2.1).

1.3.3.3. The copilot proved not to be adequately proficient in the operation of the autopilot, directional control under crosswind conditions and the brake system of the DC-10 (§ 5.2.2).

1.3.3.4. Both the letter of the NTSB, that is included as attachment in the RoA, and the analysis in this report show that the copilot himself induced unnecessary motions of the airplane (Pilot Induced Motions) by continuously acting against the CWS mode of the autopilot, that tried hard to maintain the set flight path and now also had to act against these inappropriate control inputs with large control deflections. The pitch changes caused RPM changes of the engines as well.
The variations in flight path and engine RPM were caused by the copilot, not by outside disturbances. Again, the captain did not intervene (§ 5.8.1).

1.3.3.5. At 7 s before touchdown, the captain decided to take control of the airplane when the bank angle started to increase to the left (to 14°), following the large rudder input to the left. He increased the roll control input to the right, but did not call "*my controls*", and did not call "*go-around*" either when he increased the throttles to maximum. He did not push the go-around button of the flight management system to quickly configure the airplane systems for the go-around. All of this was not in accordance with the good principles of crew coordination and adequate operation of aircraft systems as prescribed in the AOM (§ 5.12.2).

1.3.3.6. Although the CWS mode of the autopilot disengaged itself because of conflicting roll control inputs by captain and copilot, DFDR data show no adverse effects on the controllability of the airplane (§ 5.12.4).

1.3.3.7. After the captain pushed the throttles forward for a go-around, the engine RPM could not increase fast enough to provide for go-around thrust and stay clear of the ground, because the copilot had manually closed the throttles to idle against the engaged autothrottle. The initiation of a go-around at this time is also an indication that the airplane did not approach on the runway centerline (§ 5.13).

1.3.3.8. Due to a malfunction in the ground spoiler system, the spoilers deployed within 1 s after touchdown, while the throttles were advanced for go-around, which made a go-around impossible because of the reduced wing lift.
In fact, the premature closure of the throttles (§ 5.11.1 and § 5.11.7) and the ground spoiler malfunction (§ 5.13.3) were contributing factors to the accident.

1.3.4. *Wind & Windshear*

1.3.4.1. The wind correction angle near the 8 nm point at the start of the final turn for landing (Figure 1) was 17°, indicating a very strong southerly wind (§ 4.1.1). Following the turn, at 6 nm, the captain said: "*wind is coming from the right, 30 kt, drift 12 degrees*" which he must have read on the display of the navigation computer (§ 4.1.2). The Air Traffic Controller reported a wind 150°/ 15 – 20 kt. Hence, the crew was aware of the strong winds during the approach. (§ 5.11.5).

1.3.4.2. Maintaining level flight for a number of seconds during the non-precision approach, being the only approach option, to airport Faro is quite normal and the consequence of the transition of the descent with a constant vertical speed, in the Vertical Speed mode of the autopilot, to the final approach flown manually supported by the CWS mode of the autopilot, while using the visual approach guidance of the PAPI.
This short level flight is definitely not caused by up- or downdrafts as concluded by the NLR and not refuted by the DSB.
The glidepath, indicated with the red and white PAPI lights, was reached just in time, just before reaching the Minimum Decision Altitude (MDA) of 400 ft at Faro.
NLR was obviously not aware of this AOM-published approach procedure. The pilots of

the Commission and the DSB must have been aware, but did not contradict the error of the NLR. Windshear, up- and/ or downdrafts cannot be confirmed following analysis of objective DFDR data and AOM approach procedures. (§ 5.5).

1.3.4.3. The visibility restriction at 240 ft altitude, below the MDA and at only 20 s before touchdown, should have led to an immediate go-around, also because the copilot as pilot-flying had not given the call "*Landing*" (§ 5.10.3).

1.3.4.4. DFDR data show no evidence of airplane motions due to external influences such as windshear, up- or downdrafts; there was light turbulence though. The NTSB also concluded that there was no windshear during the approach. The airplane motions recorded by the DFDR were not only caused by the light turbulence, but also by the copilot who acted against the autopilot frequently and inappropriately (§ 5.13.5).

1.3.4.5. Both the DFDR data and the direction of scratches and grooves on the runway after touchdown do not support the statement of a sideward displacement just prior to touchdown.
Indeed, crosswind limitations of the DC-10 and of the pilot-flying were exceeded for landing at a flooded runway. The actual crosswind requiring a wind correction angle of 11° at touchdown was even too high for landing on a wet runway. If the right landing gear would not have failed, the airplane would have suffered a runway excursion because of aquaplaning of the nose gear wheels while reducing speed with the current large crosswind and runway conditions, resulting in an accident as well. The crew infringed many landing procedures and limits as prescribed in their airplane and company manuals (§ 5.15).

1.3.5. *Approach and Descent Speeds*

1.3.5.1. The approach speed set in the ATS window (139 kt) was 5 kt too low and not in accordance with the AOM. The lower speed reduced the safety margin and the maneuverability of the airplane. The approach speed should have been 144 kt (§ 2.4.2).

1.3.5.2. The approach speed that was selected 5 kt too low, decreased further, even below the threshold speed before reaching 50 ft altitude, after the throttles were closed too early, the pitch angle increased and the rudder input increased the sideslip, hence the drag (§ 5.11.1).

1.3.5.3. The rate of descent during the last 7 s of flight was less than the maximum rate of descent for which the landing gear was designed. In addition, the landing weight was 16% lower than the design landing weight. The failure of the landing gear was not caused by the higher than normal rate of descent.
The right landing gear could have failed because the brakes were already actuated during touchdown causing the brake pressure to energize the brakes at wheel spin-up even before the nose gear was firmly on the ground. This developed forces that, in combination with the additional forces due to the crabbed landing, increased the limits of the landing gear and/ or of the fuse pin (§ 5.14).

1.3.5.4. If the touchdown would have been successful, the airplane would also have vacated the runway on the right side because the crosswind (20 kt) exceeded the limit (5 kt) for the flooded runway, and even for a wet runway (15 kt). The reduced friction of the nose gear wheels on the runway surface (like aquaplaning) would not be able to counteract the weathercock effect of the large vertical tail at decreasing taxi-speeds, which is one of the reasons for crosswind limits to exist (§ 5.6.4 and § 5.13.7).

2. General information

2.1. Preamble

2.1.1. This analysis is a supplement to the analysis of the accident, ref. A, but describes the last 80 seconds (symbol s) of flight MP495 on Dec. 21, 1992 in greater detail; it is in fact a stand-alone document. The used graphs and data plots with DFDR and AIDS data of Annexes 15 and 9 of the Report of the Portuguese Accident Investigation Committee (RoA, ref. B) are included in five attachments. Attachments 6 and 7 present a simplified overview of the many variables and of the effect of the control inputs on airplane motions during the last phase of the flight.

2.1.2. Annex 12 of the RoA presents the approach chart of runway 11 of Faro airport and the ground path of the airplane during the approach in accordance with ATC ground radar data. This path was copied into Figure 1 below. Some experts expressed doubts about this path, especially of the final approach from 7 nm inbound. Therefore, this path will be analyzed using heading and wind data.
Below, first some general information on relevant flying qualities and the available approach aids at Faro airport and their intended use, explanation of approaches without and with crosswinds, followed by the analysis of the last 80 s of flight MP495.

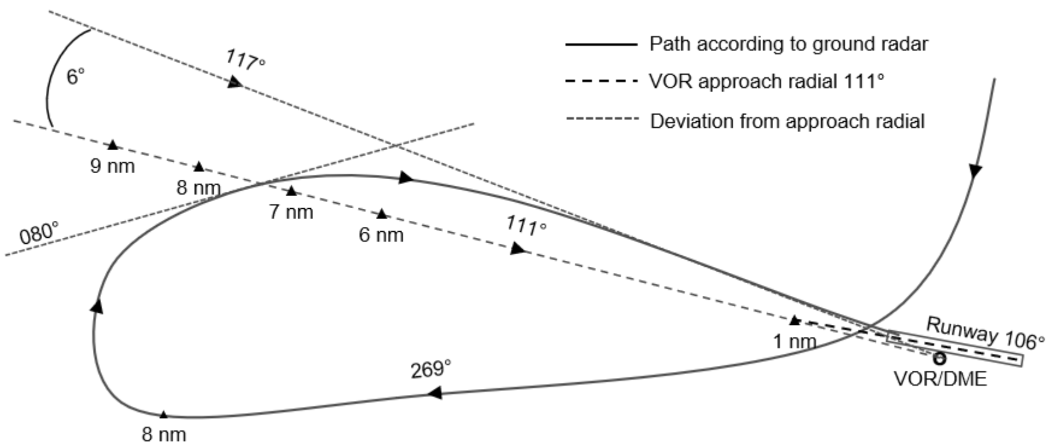
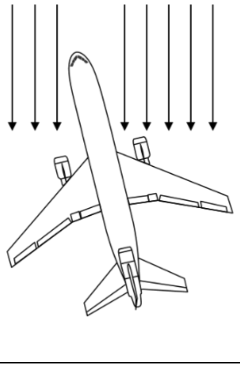


Figure 1. Approach to airport Faro according to Portuguese ATC radar.
Source: Approach chart, Annex 12 Portuguese Report of Accident.

2.2. Motions of an airplane

2.2.1. Motions of an airplane can be described about three body axes through the center of gravity: the longitudinal, lateral and vertical axes. Motions in all axes influence each other, and are defined during the design process of the airplane with so-called stability derivatives in the equations of motion. One of them describes the rolling moment that is the consequence of yawing, the motion about the vertical axis. When the rudder is actuated, the airplane yaws, and the airspeed of the outer wing increases a little, and there with its wing lift. The opposite is the case with the inner wing. As shown in the adjacent figure, during maintaining rudder input, the frontal area of the aft pointing wing (here the left wing) is smaller than of the other wing, resulting in asymmetrical wing lift distribution and hence, an increased rolling moment as well.



Another derivative describes the yawing due to roll control input (adverse yaw) caused by the difference in drag of the up and down going ailerons on the wings.
Not only the (magnitude of the) control deflections themselves have influence, also the roll rate and yaw damping. During manual flight, the pilot has to counteract the adverse motions, if these are not wanted, using the control wheel and rudder pedals. Not only small control-induced changes of an equilibrium about each of the body axes result in motions, but also atmospheric disturbances. An airplane however, is designed to return to the equilibrium of before the disturbance, without pilot intervention. Experimental and certification flight tests are conducted to determine the longitudinal, lateral and directional static and dynamic stability prior to commitment to service.

2.3. Autopilot & autothrottle

2.3.1. **The autopilot** (AP) and the auto throttle system (ATS) are controlled from a control panel that is located in between both pilots on the glare shield. Figure 2 below presents part of the control panel and some explanatory notes.
During the non-precision approach to Faro airport, both systems had to be used in accordance with the Aircraft Operations Manual – AOM (ref. C); the autopilot in the Vertical Speed Command mode until the runway/approach lights can be used as reference for line-up and glide path, down to a minimum height of 500 ft above terrain and thereafter in Control Wheel Steering (CWS). The ATS had to be engaged during the whole approach until touchdown. The Vertical Speed mode will be explained in a paragraph below.

2.3.2. CWS is a mode of the autopilot in which the autopilot maintains the pitch and roll attitude as set by the pilot, despite of external disturbances. CWS does not use inputs from for instance the navigation system, but only from control force transducers in both the control wheels and columns of captain and copilot, for roll and pitch control respectively (1 – 5 kg in roll, 1 – 11 kg in pitch).
In case the attitude of the airplane deviates from the attitude that the pilot wants, he just applies a small control force on the controls (with thumb and index finger) until the required attitude is attained, and then releases the controls. CWS maintains the attitude by controlling the ailerons and elevator, whatever the external circumstances, such as turbulence or other outside disturbances. When no control forces are applied, CWS maintains the attitude. The pilot inputs are added to the inputs of the other sensors of the autopilot system. The roll and elevator controls move with the CWS-operated control surfaces to provide a tactile feedback to the pilot. CWS is manual control with support from the autopilot for roll and pitch control (AOM 2.3.1 – 03).
The rudder is not controlled by CWS, but by a yaw damper, providing directional stability, unless overruled by the pilot via the rudder pedals.

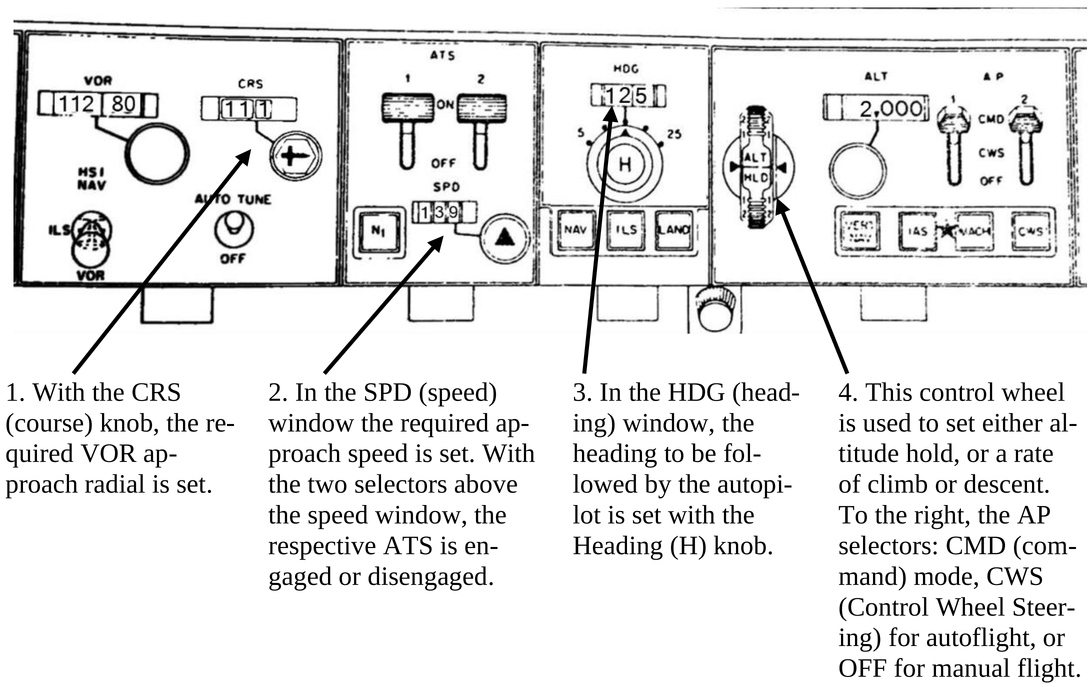


Figure 2. Control panel of autopilot and autothrottle out of AOM Volume 1.

2.3.3. **The Autothrottle**/ speed control system (AT/SC) provides automatic throttle positioning, speed control indications and stall protection & warning from takeoff to landing. The speed selected on the ATS panel (Figure 2 above, item 2) is the reference speed for the AT computer. Manual override of the autothrottle is possible at all time.
The retard mode engages when the airplane descends below 50 ft radio altitude; the throttles retard at a programmed rate. After main gear wheel spin-up, fast retard to idle stop.
Not only the airspeed is fed back to the autothrottle computer, also the position of the elevator. As soon as either the pilot or the autopilot increase the pitch angle of the airplane, the engaged autothrottle responds by increasing the throttles to prevent the airspeed from decreasing too much, taking into account the spool-up time of the large turbofan engines. This AT response can be observed a few times in the DFDR RPM data during the last 80 s of flight (Attachment 1).

2.4. Approach speed

2.4.1. The required airspeed during the final approach to an airport, during the last 6 nm while descending from 2000 ft, depends on a number of factors, like flap position, wind condition and airplane weight, and are determined in the AOM § 3.3.5. The basis is the threshold speed, the airspeed that is required during passing the runway threshold at an altitude of approximately 50 ft. The threshold speed is always 1.3 times the stall speed (Vs) for the actual landing weight (161,400 kg) and flap setting 50°, and was 1.3 * 107 = 139 kt.
The final approach speed must, in accordance with AOM 3.3.5 – 01, be the threshold speed plus a wind correction factor. This wind correction factor is presented in a table in AOM 3.3.5 – 03, which is included below (Table 1).
Hence, the minimum wind correction factor is 5 kt, meaning that the approach speed

should always be at least 5 kt higher than the threshold speed. A higher airspeed provides a larger safety margin and improved maneuverability.

03 WIND CORRECTION FACTOR (WCF)

WIND	AUTOLAND	MANUAL LANDING ATS ON			MANUAL LANDING ATS OFF		
			min	max		min	max
STEADY STATE	5 kt	1/2 of the wind above 20 kt	5 kt	20 kt	1/2 of the wind above 20 kt	5 kt	20 kt
GUST	5 kt	all of the gust above 5 kt	0 kt	15 kt	all of the gust	0 kt	20 kt

NOTE: - If both steady state and gust require a WCF, the greater will prevail.
- During gusty wind conditions, the ATS will add up to a maximum of 5 kt to the ATS reference speed. Without ATS the additive is not available.

SIGNIFICANT PERFORMANCE DECREASING WINDSHEAR	ATS ON or OFF	min 15 kt	max 20 kt

The maximum amount of the WCF may be governed by:
- Landing distance available.
- Flap Placard Speed in case of 50/LAND.

Keep in mind the additive of maximum 5 knots during gusty wind conditions.

Table 1. Wind Correction Factor data in AOM 3.3.5 – 03.

2.4.2. The wind used for planning the landing, that was recorded on the Landing Data Card (RoA Annex 3), was 140°/ 14 kt; this wind was not in agreement with the METAR and TAF on page 35 of the RoA. There were no reports yet on wind gusts and the steady wind was not higher than 20 kt. Hence, the minimum, the standard minimum increment of 5 kt would apply to MP495 (circled with a solid line in Table 1).
The approach speed of MP495 should have been 139 + 5 = 144 kt, but 139 kt was inserted as reference speed in the ATS speed window (Figure 2, item 2), and with a bug on the airspeed indicators of both the captain and the copilot (RoA § 1.12.9.10); hence, the reference speed set in the ATS was 5 kt too low.
In an ATC radio call with the clearance for landing (at 07:32:15 UTC), wind gusts were reported (150°/ 15 – 20 kt), but since the gusts were only 20 – 15 = 5 kt, the wind correction factor did not change, and the approach speed still had to be 144 kt, as the GUST line in Table 1 above shows.

2.4.3. In the NOTE and in the last line in Table 1 above, the additive is mentioned that the ATS automatically adds to the selected approach speed during gusty wind conditions, i.e. when turbulence is detected, to increase the safety margin. These speed increments are visible in the airspeed data of the DFDR (Attachment 1, from ②). The very last line of Table 1 even reminds the pilots of keeping in mind that the ATS increases the airspeed during gusty wind conditions with max. 5 kt, hence that the airspeed (and therewith the engine RPM, can vary during gusty wind conditions.
In addition, a selected approach speed equal to the threshold speed is not a safe approach speed due to the (too) small safety margin above the stall speed. As the AOM prescribes (Table 1), the approach speed always needs to be at least 5 kt higher than the threshold speed. A lower airspeed reduces the control power of the control surfaces reducing the maneuverability in gusty wind conditions.
DFDR data (Attachment 1) shows that the airspeed at 70 s before landing was 139 kt, being the threshold speed; hence too low. Following stronger gusts, during which the ATS increased the airspeed, the approach speed decreased to 139 kt when the gust intensity was lower; 139 kt is too low an approach speed without gusts and at the onset of gusts, as the correct interpretation of Table 1 of the AOM proves.

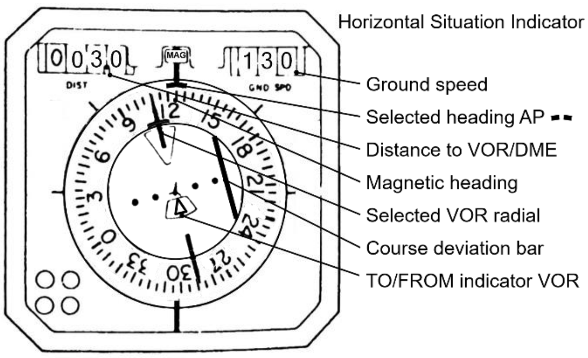
During the gusts, as shown by the normal g data (Attachment 1, from ①), the airspeed was frequently increased by ATS with 5 kt to an approach speed of 144 kt, while the approach speed during 5 kt gusts really had to be 144 kt + gust additive of 5 kt = 149 kt.
The airspeed also changes when the pitch attitude is decreased or increased by the pilot or autopilot, as is shown by Attachment 1 ④, ② and thereafter (§ 2.3.3).

2.4.4. Halfway Table 1 is also noted the required airspeed increment of minimum 15 kt in case of a significant performance decreasing windshear. This increment was not applied by the pilots, so it can be assumed that there was no windshear, otherwise they would have increased the airspeed for sure, because a higher airspeed prevents the loss of control in windshears, increases the controllability and the wing lift for the airplane to react better and faster to pilot control inputs.

2.5. Lateral approach guidance

2.5.1. Faro airport was equipped with minimal approach aids. For lateral guidance, a VOR/DME beacon at the airport had to be used. A VOR is the radio frequency equivalent of a coastal light house that sweeps a light bundle around with a constant RPM. When passing through the North, a 'flash' is generated that is visible all around the beacon. By measuring the time between this flash and the moment the light bundle 'hits' the airplane, the angle from the beacon to the airplane can be calculated.
With the DME, the distance from the VOR/ DME beacon is determined. By combining these data, the position of the airplane relative to the beacon can be determined quite accurately, and can be used for approach purposes, by selecting an approach radial on the VOR/ DME receiver. A VOR/DME approach is a so-called non-precision approach (AOM 3.3.5 - 08).

2.5.2. On the instrument panel in the cockpit, a Horizontal Situation Indicator (HSI) is installed that, besides the magnetic heading and other data, also can indicate both the course deviation from the pilot-selected VOR approach radial to or from the VOR/ DME and the distance (DIST).



This makes it possible to exactly follow a course (over the ground) selected with the CRS knob on the VHF navigation control panel (Figure 2, item 1). The course deviation bar of the HSI indicates exactly how many degrees the airplane deviates from the selected approach radial, and to which side the pilot must fly to intercept the radial ("follow the needle").
The maximum allowed deviation during the approach is 2°, one dot on the scale under the course deviation bar. In most airplanes, the VOR/DME can be coupled to the autopilot, but in the Martinair DC-10, the pilot had to enter the required heading to intercept and maintain the course (Figure 2, item 3). The pilot also had to compensate for the drift due to the crosswind, by increasing or decreasing the heading as required; more about this in § 3.2 below).
The HSI shown in the figure above indicates that the pilot needs to increase the heading with 30° to the right to intercept the selected 111° approach radial.
When the course deviation needle is in the middle, the angle between the magnetic heading and the selected VOR radial is the drift angle, the wind correction angle.

Hence, the HSI also provides a good indication of the crosswind, provided it is correctly set and used.

2.5.3. Because the VOR/ DME is positioned 240 m south of, and near halfway the runway, the inbound track is offset 5° from the runway bearing 106° and intercepts the extended runway centerline at 1 nm from the threshold of runway 11 (Figure 1 and Figure 4 below). At that point, the pilot must adjust the course 5° to the left to intercept and maintain the extended runway centerline, while also maintaining the wind correction angle.

As soon as the runway is in sight during the approach, the pilot can continue 'visual', rather than using the HSI.

2.6. Vertical approach guidance

2.6.1. For vertical guidance, a Precise Approach Path Indicator (PAPI) system was installed on the left and right sides of the approach end of the runway, as shown in the insert in the figure below. The four lights of a PAPI indicate the required glide path (≈ 3°), but are not visible from distances greater than 6 nm, or because of a cloud cover. Therefore, the AOM (§ 3.3.5 - 08) of Martinair prescribes that for a non-precision (VOR/ DME) approach, the first part of the descent, from 2000 ft at a distance of 6.5 nm, must be conducted using the vertical speed mode of the autopilot (Figure 2, item 4). At initiation of the descent, a fixed vertical speed is set in the autopilot on the pitch guidance control panel (Figure 2, item 4) that varies with the ground speed, but usually is 750 ft/min, for "Intercepting a 3° visual glide path" – AOM 3.3.5 – 09). This vertical speed is selected such that the airplane would descent to a point in front of the runway, as indicated in Figure 3 below.
Below 500 ft, the approach must be continued with the autopilot in the CWS mode. This mode was briefly explained in § 2.3.2 above.

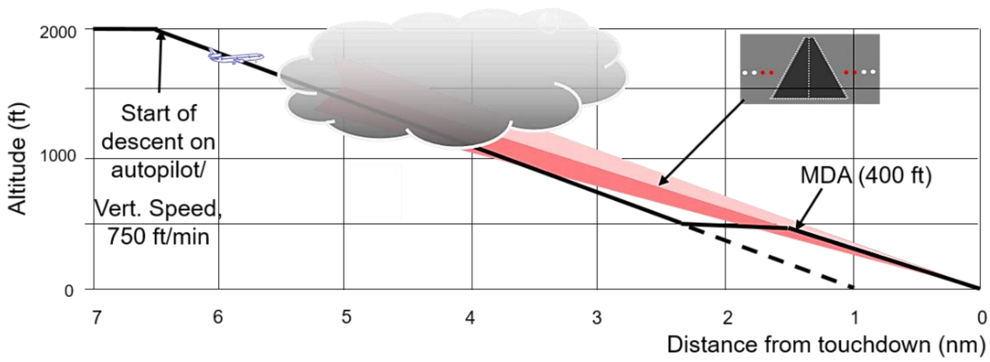


Figure 3. VOR/DME Approach for 125 kt ground speed. Initially, a vertical speed of 750 ft/min set on Autopilot. Continued on CWS as soon as PAPI is visible.

2.6.2. During the descent from 2000 ft, the autopilot maintains the preset constant vertical speed by adjusting the pitch angle, and continues to do so, whatever outside disturbances, until the pilot disengages the Vertical Speed mode of the autopilot, which is the case before reaching 500 ft, in any case above the Minimum Decision Altitude (MDA), that was 400 ft at Faro. Normally, this occurs when the runway and the individual lights of the PAPI vertical approach guidance become visible, and the PAPI glideslope can be intercepted from below (Figure 3 above).
If the autothrottle is engaged, which is normally the case, then this system maintains the selected airspeed by increasing or decreasing the throttles. As explained in § 2.4,

the ATS increases the airspeed with 5 kt when gusts are detected, which of course has influence on the generated wing lift and therewith on the rate of descent, changing the glidepath. The autopilot in-turn changes the pitch angle to maintain the set rate of descent (vertical speed). Hence, the pitch attitude changes with the ATS/ engine RPM changes that occur when crossing a gusty/ turbulent area, as DFDR data shows (Attachment 1). These pitch and RPM changes are not a sign of instability, but the consequence of using automated systems that act to and protect against the adverse effects of gusts during the approach.

2.6.3. The first part of a non-precision VOR/ DME approach with the autopilot in the Vertical Speed command mode is always a bit steeper than the second part under manual control using the visual PAPI. During the transition between the modes, it might be necessary to maintain level flight for a while to intercept the PAPI glide path as shown in Figure 3 above. This may not be explained as crossing an area with up- and downdrafts, because it is normal during a non-precision approach.

2.6.4. The engines RPM and the pitch attitude do change in case of turbulence and changing weather conditions and outside influences. But this is not the only cause. The pilot has, even with an engaged autopilot, also control on the glide path by applying control forces on the controls. That he did interfere with the autopilot control will become clear in this analysis.
One of the requirements for a stable approach (BIM 3.4.4 – 06) is also that the engine RPM needs to be stabilized. When the ATS varies the engine RPM too much, the pilot should disengage the ATS and set a stable RPM to maintain the glidepath.

3. A 'short final' at Faro

In Figure 4 below, three approaches are presented; on the left, an approach to Faro without crosswind, in the middle with crosswind as should be flown, and on the right side the approach as flown by MP495 as documented by ATC-radar data (Figure 1) and analyzed in § 5 below. These three approaches will be explained for information purposes.

3.1. Approach and landing without crosswind

3.1.1. When no crosswind component is present, then the heading of the airplane during the approach on the 111° approach radial is also 111° (Figure 4 below left; see also Figure 1).
At 1 nm in front of the runway, a 5° course correction to the left is required to establish on the extended runway centerline. This correction is required because the VOR/DME is located south of the runway (refer to § 2.5.3). Following the offset correction, the landing can be accomplished without further directional and lateral corrections.

3.2. Approach and landing with crosswind

3.2.1. During an approach when a crosswind is present, a wind correction angle is required to prevent the airplane from drifting away from the 111° approach radial and from the extended runway centerline. This is shown in Figure 4 below, center. The wind correction angle depends on the magnitude of the crosswind component. As an example, with a 90° crosswind component of 15 kt and an airspeed of 139 kt, the wind correction angle is 6° ($\sin^{-1}$ (15/139); when the crosswind component is 30 kt, being the maximum approved for a DC-10 on a dry runway (AOM § 3.7.1 – 06), the angle is 12°.
In crosswind conditions, the small offset correction of 5° is also required to establish

on the extended runway centerline. Thereafter, a wind correction angle remains required to maintain the extended runway centerline.

3.2.2. Prior to touchdown, the longitudinal axis of the airplane needs to be brought in line

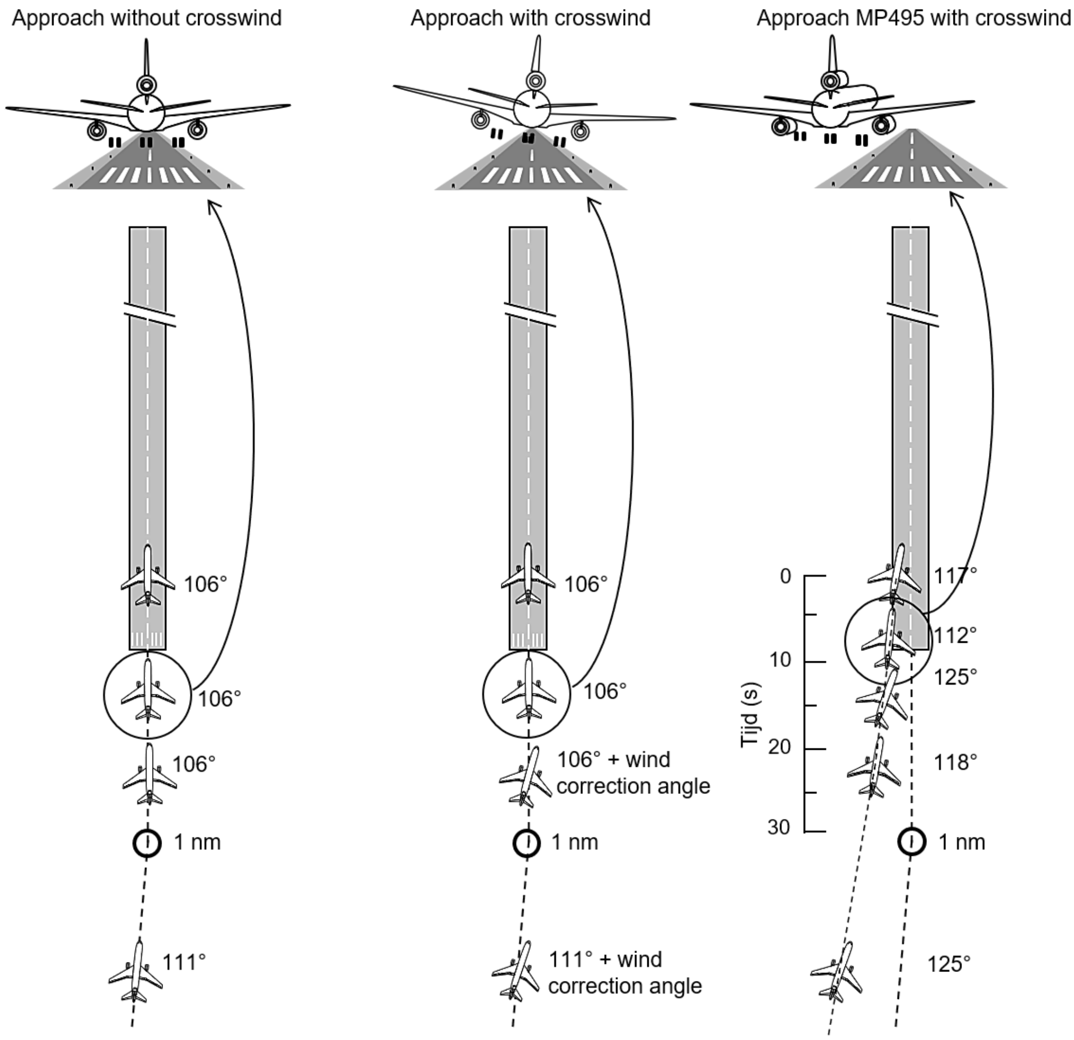


Figure 4. Approach and landing without and with crosswind, and of MP495 at Faro (not to scale). Magnetic heading is shown next to the airplanes.

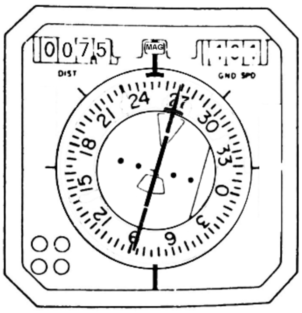
with the runway by applying rudder to avoid a traversing landing, which is not approved for a DC-10; aligning prevents large lateral forces on the landing gears. While applying rudder, a small bank angle needs to be attained and maintained into the wind to avoid drifting away from the runway centerline. This landing technique is not difficult, but the pilot needs to be proficient. The copilot, who was the pilot flying, had experience in crosswinds up to 15 kt, as was reported to the Commission. With the bank angle required for the maximum approved crosswind, wing parts or engine nacelles do not yet strike the runway surface during landing.

3.3. Approach and landing MP495 with crosswind

3.3.1. The last part of the approach of MP495 is shown in Figure 3, right side, as presented in RoA Annex 12. The analysis in § 5 below confirms this approach following a thorough analysis of the heading, control inputs and airplane motions.

4. The beginning of the final approach of flight MP495

4.1.1. The non-precision VOR/ DME approach to runway 11 of Faro airport had, as confirmed by ATC, to be flown in accordance with the published procedures (RoA Annex 12, refer to Figure 1).
MP495 approached the airport from the North to the VOR/DME at the airport. A DC-10 is a cat. C/D airplane (fast and big) that, after crossing overhead at 4000 ft, had to fly outbound on the 269° radial while descending to 2000 ft altitude at a distance of 8 nm from the VOR/ DME. At 8 nm, a right turn is to be initiated to establish on the 111° approach radial to the VOR/DME.

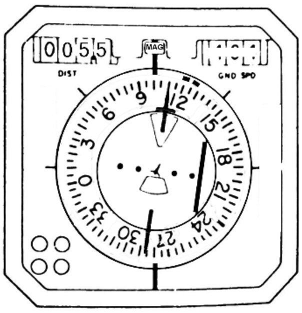


The ATC radar plot in Figure 1 shows that the outbound track was flown quite accurately. DFDR data show that close to the 8 nm point, the airspeed was 170 kt and the heading 252°, proving that a considerable wind correction angle was required at that point (269° – 252° = 17°) to compensate for the crosswind component, that must have been approximately 50 kt (170 · sin 17°). A strong wind of which the pilots must have been aware, because they had to manually set the required heading (252°) in the autopilot heading window rather than the outbound radial (269°) (refer to § 2.5.2). The drift/ wind correction angle was clearly visible, as shown in the adjacent figure. The wind at 8 nm was strong, may be because a thunderstorm was close by.

4.1.2. At the 8 nm point (Figure 1), the course (CRS) knob of the VOR panel needs to be turned from 269° to the approach radial 111°. The required heading, including a correction for the crosswind, needs to be set in the autopilot (Figure 2 item 3). The captain offered this setting, but the copilot, the pilot flying who also operates the autopilot heading control knob, asked for 080°, obviously to intercept the 111° radial under an angle of 30°. Intercepting a VOR radial this way is normal during enroute navigation, but not while in a VOR/ DME approach with a large crosswind from the south that would enlarge the turn radius. The copilot did obviously not take this into account. Figure 1 shows that the autopilot steered the airplane, despite the strong southerly wind, exactly to the 080° heading, but also that the correction to the 111° radial was initiated way too late. The copilot obviously did neither adjust the autopilot heading in time to establish on the 111° radial, nor returned to the radial following the overshoot, despite the fact that the captain advised a heading of 123°. At the same time, the captain also said: "*wind is coming from the right, 30 kt, drift 12 degrees*". The wind at that point, 6 nm in front of the runway, was higher than the crosswind limits for both a flooded and a wet runway, 5 kt resp. 15 kt. ATC had already reported to MP495 that the runway was flooded.

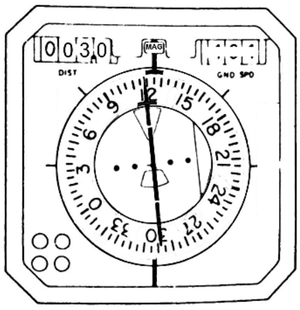
4.1.3. In crosswind conditions, the pilot has to apply a wind correction angle. With a crosswind from the right, the heading during the non-precision approach to Faro therefore needs to be larger than the course of approach radial 111°. The airplane approaches the runway with a drift angle; the nose does not point to the runway but, in this case with a southerly wind, to the right. The VOR pointer on the HSI points to the left and shows the drift/ wind correction angle. Refer to § 3 for a brief explanation of approaches without and with crosswind.

4.1.4. At 7 nm, the airplane not only had to be established on the approach radial, but also be configured for landing, i.e. the landing gear is down (at 9 nm), the flaps and slats are selected (at 8 nm) and the airspeed is the required approach speed (§ 2.3.3 above and AOM 3.3.5 – 06). The CVR transcript proves that the airplane was configured for



landing too late. At 7.5 nm, the vertical speed should be set in the autopilot, such that the descent indeed begins at 7 nm. The descent will be further analyzed in § 5 below.
At 5.5 nm, the display of the HSI could have been as shown in the adjacent figure. The heading set on the autopilot is 125°, the approach radial is set to 111° and the magnetic heading at this instant is 100°. The course deviation bar is maximal right to indicate that the heading needs to be increased (to 111° + 30° = 141°) for intercepting the 111° approach radial at an angle of 30°. This did not happen.

4.1.5. Both the ATC radar data in Figure 1 and the analysis in § 5 below prove that no course correction was applied to return to the 111° approach radial, while this is required for the approach to be stabilized, as required in BIM 3.4.4 – 06 and AOM 3.3.5 – 11. The angle between the airplane position and the approach radial at 500 ft altitude may not exceed 2° (1 dot), but was for MP495 even 6° that cannot even be displayed on the HSI. The course deviation bar must have been all the way to the right side as shown in the figure in the next paragraph. The pilot cannot only set the required approach radial on the VHF NAV Control Panel (Figure 2, item 1), but also adjust the course (CRS) knob until the course deviation bar of the HSI is in the middle, to be able to navigate direct to the VOR/ DME from the current airplane position.



This could have happened with MP495, because the ATC radar data in Figure 1 on page 9 shows a near constant (too) large deviation (6°) from the prescribed approach radial, in which case 117° would have been set as direct to radial. At 3 nm, the HSI indications would have been as shown in the adjacent figure. The heading was 125° (DFDR data), the approach radial set to 117°. This angle was measured in the radar plot in Annex 12 of the RoA, that is copied in Figure 1.

4.1.6. **Sub conclusions**

4.1.6.1. The wind correction angle near the 8 nm point at the start of the final turn for landing (Figure 1) was 17°, indicating a very strong southerly wind (§ 4.1.1). Following the turn, at 6 nm, the captain said: "*wind is coming from the right, 30 kt, drift 12 degrees*" which he must have read on the display of the navigation computer (§ 4.1.2). Hence, the crew was aware of the strong winds at the beginning of the approach.

4.1.6.2. Annex 12 of RoA (Figure 1) proves that MP495 did not end the final turn on the prescribed approach radial of 111° and did not return to it either (§ 4.1.2). This conclusion could be confirmed with a wind and heading analysis (§ 5.6).

4.1.6.3. The CVR transcript proves that the airplane was not configured in-time for the approach and landing.

4.1.6.4. In § 2.4, the approach speed was explained and concluded that the approach speed set in the ATS window (139 kt) was too low and not in accordance with the AOM. The lower speed reduced the safety margin and the maneuverability of the airplane. The approach speed should have been 144 kt (§ 2.4.2).

5. Analysis of the last 80 seconds of flight MP495

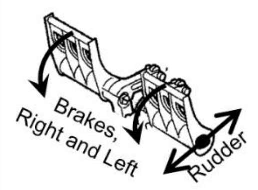
5.1. Analysis by elimination

5.1.1. The starting point for the detailed analysis is 80 s before landing, because the NTSB provided DFDR data is presented in graphs from that moment. The AIDS graphs already start at 110 s before landing. The altitude, the control inputs, the motions of the control surfaces, the accelerations (g) in the three body axes, the attitude of the airplane and the RPM of the three engines are documented in the DFDR and AIDS data, and are provided in Annexes 15 and 9 in the RoA. Five of the graphs of these annexes are included in Attachments 1 through 5.

5.1.2. The attachments are provided with a timeline in seconds before landing, to which is referred to in the paragraphs below. Where useful, numbers (like ① or (22)) are used for easy reference to the discussed events in the graphs of the attachments.
The DFDR and AIDS did not record the exact (lateral) positions of the airplane during the approach; i.e. if any, these data were not made available. Therefore, only the ATC-radar data could be used (Figure 1), that shows the approach path of the airplane. These low altitude radar data might not be very accurate though, because the ATC radar was located near Lisbon, at a distance of approximately 108 nm. The horizon of this radar would then be 7700 ft above Faro. A radar horizon in nm (due to the curvature of the earth) is 1.23 times the square root of the altitude in feet. MP495 flew the last 80 s below 1000 ft, hence below the ATC radar horizon. Because of this, the doubts that were already mentioned in § 2.1.2 and the opinion of other experts that the airplane did indeed approach on the 111° approach radial and flew the last mile above the extended runway centerline, the radar data should not be used for analyzing the final approach. The path of the airplane in this analysis is analyzed through elimination of options using the available, relevant and – above all – objective DFDR and AIDS data mentioned above. These data can be used to accurately and effectively analyze and describe the approach path. This analysis is presented below.

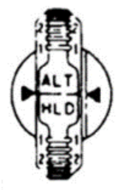
5.2. From 80 seconds before landing

5.2.1. **At 80 s** before landing, the altitude was approximately 950 ft (Attachment 1). The autopilot was, from the beginning of the descent at 2000 ft, set at a rate of descent of 750 ft/min (§ 2.6.1); the autothrottles controlled the engines to maintain the set approach speed of 139 kt (§ 2.4). AIDS-data (Attachment 3 ①) show that the copilot

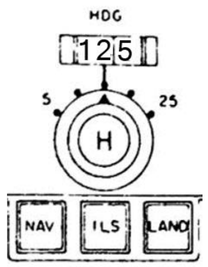


continuously pushed the right brake pedal with his toes, initially up to 6%. This is usually not done, because the heels are normally placed on the cockpit floor to only operate the rudder pedals if required. Applying rudder pedal in-flight is not required, because the yaw damper normally maintains directional stability and controls the rudder to counteract disturbances about the vertical body axis. In a DC-10, the brake pedals may only be pushed when the nose gear wheels are firmly on the ground after landing (AOM 3.3.5 – 15). Hence, the copilot did not position his right foot correctly on the rudder pedal and pushed the right brake pedal during the remainder of the flight, even up to 90 %, and must also have activated the brakes during touchdown, because under crosswind conditions, when rudder is applied, a pilot cannot shift his feet up or down the pedals. Applying brakes during touchdown leads to application of the brakes at main wheel spin-up, and before the nose gear is firmly on the ground. The early application of the brakes would contribute to the failure of the right main landing gear (§ 5.14.2).

5.2.2. The AIDS control column pitch force graph in Attachment 4 ① also shows that the copilot at that time pushed the elevator control up to 1,5 kg[1], in fact against the autopilot that was engaged to control the descent. A little pressure is normal, because the hands are loosely resting on the controls, also when the autopilot is engaged (during the approach); the control wheel and column move with the control surfaces as tactile feedback of the autopilot to the (human) pilot-flying (§ 2.6.1).



If the copilot had to change the descent for some reason, then he should have used the vertical speed wheel on the pitch guidance control panel (Figure 2, item 4 and adjacent figure). By pushing and pulling the controls, he disrupted control by the autopilot and caused unnecessary up and down going airplane motions, because the engaged autopilot tries to maintain the set rate of descent. In addition, pulling and pushing the elevator control causes the ATS to respond immediately by adjusting the engine RPM, leading to changes in airspeed and, in turn, also to changes in the flight path (§ 2.3.3).
At 65 s for instance (Attachment 4 ②), the autopilot applied opposite control input; the motions became fiercer because of the onset of turbulence.
From 110 s before landing, as AIDS data show (Attachment 5 ①), the copilot was also moving the control wheel, first to the left and from 80 s also to the right. These control inputs were not necessary, even unwanted because the autopilot also controlled the bank angle, and there with the heading, the direction of the airplane. If the autopilot is engaged in the command mode, then the pilot should only enter the required heading changes using the heading control knob (H, Figure 2, item 3 and adjacent figure) of the autopilot and not by using the control wheel. The inappropriate operation of the roll control, when the autopilot was engaged, also caused unnecessary motions, leading to a false impression of instability.



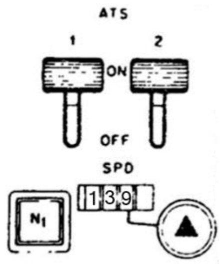
5.2.3. **Sub conclusions**

5.2.3.1. The apparently not very experienced copilot not only pushed the roll and elevator controls inappropriately, with as result unnecessary variations in the flight path and engine RPMs, but also the right brake pedal. His right foot was not positioned correctly on the rudder pedal.

5.2.3.2. The copilot proved not to be adequately proficient in the operation of the autopilot, directional control under crosswind conditions and the brake system of the DC-10.

5.3. From 70 seconds before landing

5.3.1. **From 70 s** before landing, light turbulence (to ICAO definition, ≤ 0,5 g; Attachment 1 ①) was experienced. Again, the copilot pushed the control column against the autopilot (Attachment 4 ②) causing the pitch attitude to change from 4° to 0° in 8 s (Attachment 1 ④. The airspeed increased to 150 kt (Attachment 1 ②) and the rate of descent also increased (altitude graph in Attachment 4 ③). The autothrottle reacted immediately to the elevator control input (§ 2.3.3) and to the increased speed by reducing the engine RPM (Attachment 1 ③) and therewith prevent a large increase in airspeed above the set approach



[1] Forces in the metric system are normally expressed in Newton, but in AIDS graphs in kg.

speed on the ATS panel plus the 5 kt increment due to the onset of light turbulence (above the threshold value, § 2.4.3).

5.4. From 60 seconds before landing

5.4.1. **At 60 s,** even before the vertical speed command mode of the autopilot was disengaged and CWS engaged, the copilot again pulled the elevator control column (Attachment 4 ④ and Figure 5 below), causing both the pitch attitude to maintain 0° for approximately 8 s (Attachment 1 ④) and the airspeed to decrease to the preset 139 kt (Attachment 1 ⑤). The turbulence had deceased below the threshold as well, hence the ATS did not add the 5 kt gust increment anymore.
The autothrottle responded to the decrease of airspeed and turbulence by increasing the engine RPM (Attachment 1 ⑥). The airspeed increased again (Attachment 1 ⑦), after which the RPM of the engines decreased when 144 kt was reached, being the 139 kt approach speed plus the (automatic) 5 kt gust increase by the autothrottle (§ 2.4.3).

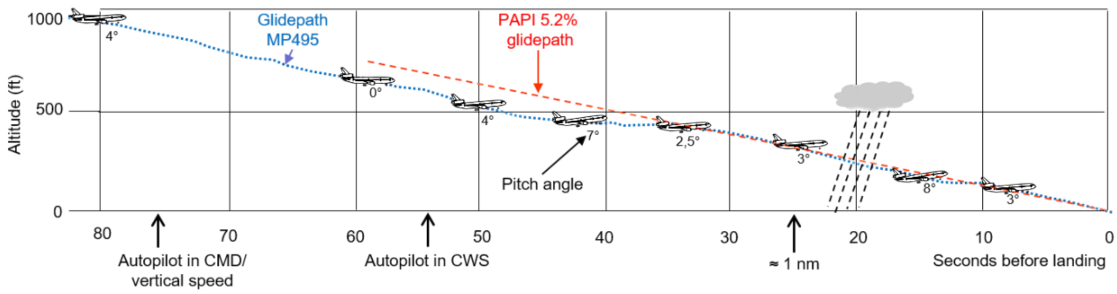


Figure 5. Vertical profile approach MP495, initially in Vertical Speed command mode, from 54 s in CWS. DFDR data.

5.5. From 54 seconds before landing

5.5.1. **At 54 s,** at an altitude of approximately 550 ft, the Vertical Speed mode of the autopilot was disengaged after which the flight continued on CWS, in accordance with the AOM. The airplane had already descended below the PAPI indicated glide slope of 5.2% (≈ 3%), as DFDR data in Figure 5 above shows and which is normal; see also Figure 3. If the runway and/ or the PAPI lights are not visible from greater distances because of clouds or precipitation, then the autopilot continues to be used to maintain the set vertical speed until the pilot sees the runway and the PAPI lights, assumes manual control and adjusts the glide path by maintaining level flight until two red and two white PAPI lights are visible (§ 2.6.1 and Figure 3). At 400 ft, the Minimum Decision Altitude (MDA), the pilots must see the runway and be established on the PAPI glide path, otherwise a go-around is to be initiated. The copilot was just in-time with adjusting the glide path.

5.5.2. The DFDR data shows that from 52 s the elevator control input caused the pitch angle to increase from 0° in 10 s time, with a small variation (Attachment 1 ⑧ and Figure 5). At that instant, the copilot obviously saw both the runway and more red than white PAPI lights and realized that he was below the PAPI glide path (Figure 3 and Figure 5 above). The airplane then maintained level flight for about 12 s (Attachments 1 ⑨ and 4 ⑤) to intercept the PAPI glide path, which occurred at 37 s, after which the nose was pushed down to a pitch angle of 2.5° (Attachment 1 ⑩). The copilot even said "*PAPI hè*" (CVR transcript) to justify the level flight.
Until this time, this is normal procedure. The 'maneuver' is the consequence of the

transition of the descent in the Vertical Speed mode of the autopilot to the final part of the approach under manual control (on CWS); a normal procedure for a non-precision VOR/ DME approach and the only option for an approach to Faro airport (see also § 2.6.1 above).
Flying level for a few seconds to intercept the PAPI glide slope from underneath is standard procedure, and definitely not the consequence of external weather influences, such as windshear, up- or downdrafts.
NLR, in RoA Annex 4, explained the maneuver as crossing an area with downdraft, followed by updraft, which was not contradicted by the (pilots of the) DSB. Objective DFDR data however, do not support up- and or downdrafts or windshear; no changes in the light turbulence (Attachment 1 ⑪, no lateral accelerations (Attachment 1 ⑫), and no sudden in- or decreases of airspeed caused by changes of the wind either, but only small pitch and airspeed changes due to the copilots' control inputs and the 5 kt gust protection by the autothrottle (Attachment 1 ⑦).
Hence, there were no up- and downdrafts – no objective evidence.

5.5.3. **Sub conclusion.** Maintaining level flight for a number of seconds during the non-precision approach, being the only approach option, to airport Faro is quite normal and the consequence of the transition of the descent with a constant vertical speed, in the Vertical Speed mode of the autopilot, to the final approach flown manually supported by the CWS mode of the autopilot, while using the visual approach guidance of the PAPI. This short level flight is definitely not caused by up- or downdrafts as concluded by the NLR and not refuted by the DSB.
The glidepath, indicated with the red and white PAPI lights, was reached just in time, just before reaching the Minimum Decision Altitude (MDA) of 400 ft at Faro.
NLR was obviously not aware of this AOM-published approach procedure. The pilots of the Commission and the DSB must have been aware, but did not contradict the error of the NLR. Windshear, up- and/ or downdrafts cannot be confirmed following analysis of objective DFDR data and AOM approach procedures.

5.6. From 49 seconds before landing, passing 500 ft

5.6.1. **At 49 s**, 500 ft altitude was passed. AOM 3.3.5 – 08 required the captain, as pilot not-flying, to call "*Approaching Minimums*" at 100 ft above MDA; the copilot, as pilot flying, should have confirmed with "*checked*", after which the captain should have said "*contact*", "*approach lights*" or "*runway*". None of these calls were recorded on the CVR. Even ATC had to ask twice if they had 'runway lights in sight'.
BIM 3.4.4 – 05 requires: "*A 500 ft call shall be included in the final part of each approach to protect against subtle incapacitation and to serve as an awareness call for the landing clearance*". AOM 3.3.5 – 08 requires that the pilot not-flying, in this case the captain, should have given this call, after which the pilot flying, here the copilot, should have responded with "*cleared*" or "*not cleared*", and then both the captain and the flight engineer should have said "*checked*". These approach- and landing-safety-related 500 ft calls were 'forgotten'.
Since the altitude for both calls at Faro was the same, the 500 ft call should have been given earlier; the 500 ft call is, according to AOM 3.3.5 – 08, not a precision call. The call "*approaching minimums*" however, is always a precision call. The flight engineer noticed the failure and said: "*you missed the 500*", but the pilots did not respond. The captain reminded the copilot of the procedure 3 s later by suggesting: "*cleared hè*", after which the copilot responded with: "*yeah, yeah, check cleared*".
At the MDA (400 ft), the copilot, as pilot-flying, should have made the decision to either land or go-around, and should have informed the other crew members about his decision with either the call "*Landing*" or "*Go-around*". This call was not given either.

The flight engineer forgot to call "*fifty*" at 50 ft altitude, when normally the flare starts and the throttles are slowly closed (AOM 3.3.5 – 08).
The cockpit crew did neither adhere to their AOM and BIM prescribed 'crew co-ordination procedures' procedures nor to the ATC instructions. The reason might very well be the crew being in anxious suspense whether they would make it to the center of the runway or not. They did not approach on the extended runway centerline, but from the side, as will become clear at the end of this analysis.

5.6.2. **At 500 ft**, the airplane should have flown within 2° of the 111° approach radial for the approach to be allowed to continue; in BIM 3.3.4 – 06 this lateral limit is considered essential. The deviation was much larger (Figure 1) hence, for this reason a go-around should already have been initiated at this time. BIM 3.4.4 – 06 procedures leave no doubt about this, and neither about "*basic stability of speed and thrust*": "*On short or wet runways such factors become of paramount importance. It is therefore strongly recommended that no landing be attempted if the desired stabilization has not yet been achieved when passing 500 ft above threshold elevation*". In the same BIM paragraph, approach stability is defined as follows: "*Early stabilization on the final approach path with respect to glide path and centre line* [<2°, RoA § 2.2.3] *is considered essential. At not less than 500 ft above threshold elevation this flight path stabilization must also be accompanied by a basic stability of speed and thrust, thus ensuring that any disturbing influences or deviations in the latter stage of the approach can be readily recognized and rapidly corrected".*

5.6.3. DFDR magnetic heading data in Attachment 1 show that the heading of the airplane did not change during the last 80 s of flight, with exception of the periods during which the copilot pushed the left rudder pedal causing the airplane to yaw and hence, slip. The course over the ground does not change when yawing while keeping the wings level. The constant heading also proves that the crosswind component during the whole approach was nearly constant.

5.6.4. The magnetic heading was 125° (until 40 s before landing when the pilot-induced sideslips started). The heading of 125° was 14° larger than the 111° VOR approach radial, which is a ground course, as DFDR data shows (Attachment 1 ⑬), see also Figure 6 below. A drift angle of 14°, while the airspeed is 139 kt, is quite large and could only be caused by a crosswind component of 34 kt (139 · sin 14°), which is larger than the 30 kt crosswind limit for a landing with a DC-10 on a dry runway (AOM 3.7.1 – 06, see also

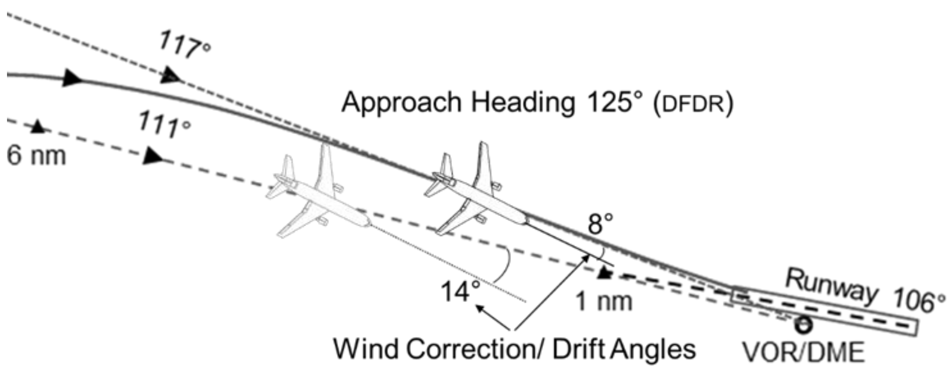


Figure 6. Comparison approach heading 125° (DFDR data) on approach radials 111° and 117° with accompanying drift angles.

§ 3.2.1). In addition, an experienced pilot knows the forward view during a crosswind approach; a runway is never that far left in the windscreen.

The captain should have realized that a 14° drift angle was not at all normal, even larger than the 12° angle at the maximum crosswind component of a DC-10 with the same landing weight on a dry runway (§ 3.2.1), and hence, also much larger than for a wet (15 kt) or a flooded (5 kt) runway. The heading change requirement using the rudder is only 15° (FAR/CS 25.147 for engine out flight).
In addition, as explained in § 4.1.3, the wind correction or drift angle could be read from the Horizontal Situation Indicator, provided this was correctly set.
The large drift angle of 14° during the approach (125° - 111°) should have rang a bell in the minds of the pilots. Lining up from 125°, as the heading data on the DFDR shows it was at 12 s before landing at less than ½ nm in front of the runway, with the 106° runway, meaning a required heading change of 19°, would not be possible.
In addition, the crosswind was way too strong for a landing on a flooded runway (max. 5 kt allowed) or on a wet runway (max. 15 kt; AOM 3.7.3 – 04).
After landing, the airplane would suffer a runway excursion because the friction of the nose gear on the contaminated runway would not be able to counteract the weathercock effect of the strong crosswind on the large vertical tail at the decreasing speed.
The conclusion now already can be that the airplane was not on the 111° approach radial, yet the analysis continues.

5.6.5. The large 14° drift angle mentioned in the previous paragraph leads to the question whether the true (ground) course of 117°, as taken from the ground radar data (Figure 1), indeed could be correct, rather than the 111° approach radial. This question can be answered by calculating the required wind correction or drift angles for both courses, using both the ATC provided wind with the landing clearance (150°/ 20 kt) and the wind that the captain read from his navigation display 10 s before landing (190°/ 20 kt). According to AOM 2.15.4 – 06, the crosswind component can be up to 5 kt in error because it is influenced by side slipping, such as de-crabbing. At the moment of reading, the sideslip angle was still small; the error must have been less than 2 kt.

In the table below, the results of the calculations are presented for several approach radials (true (ground) courses). The calculations will be discussed in the next paragraphs.

Approach radial (True course)	**Wind Correction (Drift) Angle and Magnetic Heading** (Airspeed 139 kt)				**Comment**
	Wind 150°/ 20 kt		Wind 190°/ 20 kt		
	WCA	Heading	WCA	Heading	
111°	5°	116°	8°	119°	No match to flown heading
114°	5°	119°	8°	122°	No match to flown heading
117°	4°	121°	8°	125°	Wind 190°/ 20 kt matches exactly
106°	6°	112°	8°	114°	For info, 106° is runway bearing

Table 2. Calculated Wind Correction Angles (WCA) / drift angles on three approach radials (all bearings magnetic).

5.6.6. At the intended 111° approach radial, an airspeed of 139 kt and an ATC-reported wind of 150°/ 20 kt, a Wind Correction Angle (WCA) of 5° is required to maintain the 111° ground course. The magnetic heading would have been 111° + 5° = 116°. With a wind of 190°/ 20 kt, the WCA would have been 8° and the heading 111° + 8° = 119°. Neither of these two headings agree with the actual heading of 125° that was recorded in the objective DFDR heading data (Attachment 1), a heading that was obviously required during the approach to get to the runway.

5.6.7. At the 117° radial, an airspeed of 139 kt and the same winds, the required WCA's are 4° resp. 8°, and the corresponding headings 117° + 4° = 121° resp. 117° + 8° = 125°. This last heading is exactly equal to the heading that the airplane flew during the last 80 s of the approach (DFDR data, Attachment 1, until ⑬, see also Figure 6 above).
In addition, the calculated headings on the in-between radial 114° do not agree with the used heading of 125° either.
Hence, the wind during the last 80 s of flight was almost certainly a constant 190°/ 20 kt, the same wind that the captain read from the display of the navigation computer 10 s before landing.

5.6.8. This analysis makes it obvious that the airplane cannot have followed the 111° approach radial but, from the too wide final turn at 7 nm, flew a direct radial (117°) to the VOR/ DME, exactly as the ATC ground radar data show (Figure 1). The copilot did not steer the airplane back to the intended 111° approach radial, given the large 125° approach heading, and was not encouraged to do so either by the captain (CVR transcript), who even was a flight instructor.
Not only the DC-10 AOM and the Martinair BIM, but also the Approach and Landing Accident Reduction (ALAR) programs of ICAO and Flight Safety Foundation (FSF) emphasize the importance of approaching within 2° of the approach radial already for many years, even still today, because "*this increases the crew's overall situational awareness, and provides more time and attention for monitoring ATC communications, weather conditions and system operation, as well as more time for monitoring and backup by the pilot not-flying*". "*A stabilized approach also provides defined flight-parameter-deviation limits and minimum stabilization heights to support the decision to land or go-around*" (quotes out of FSF ALAR Tool Kit, Briefing Note 7.1).

5.6.9. **Sub conclusions**

5.6.9.1. The required calls for approach safety at altitudes 500 ft and 50 ft were not given by the captain and flight engineer, and not by the pilot-flying, the copilot, either. In addition, other procedural and safety related calls were not given either. The cockpit crew did not adhere to the AOM-prescribed crew coordination procedures.

5.6.9.2. The ATC radar data in RoA Annex 12 (Figure 1) shows that the radius of the final turn was too large because the known strong southerly wind was not taken into account by the pilot-flying; the airplane did not intercept, and was not steered back to the required 111° approach radial but approached the runway on a direct, near constant heading of 125°.

5.6.9.3. The DFDR data show that the heading did not change during the last 80 s of flight, with the exception of the small heading changes (yawing) due to (inappropriate) rudder inputs by the copilot. The wind and heading analysis proves that the wind during the last 80 s was a constant 190°/ 20 kt, as the captain read at 10 s before landing from the display of navigation computer. The wind and heading analysis above also proves that the airplane cannot have been on the 111° approach radial, but approached the airport at a ground course, a radial of 117°.

5.6.9.4. The 6° deviation from the 111° approach radial was three times larger than the AOM-required maximum 2°. Hence, at 500 ft, the approach did not comply with the AOM and BIM requirements for a stabilized approach. This should have been a reason for an immediate go-around. The captain however, did not intervene to prevent and correct this navigation error, and did not order a go-around.

5.7. From 42 seconds before landing

5.7.1. **At 42 s**, the copilot applied left rudder during 27 s with a short interruption, up to 30% (Attachment 3 ②), because of which the airplane yawed to the left to a heading of 117° (Attachment 1 ⑭). The roll control force also increased to the left (Attachment 5 ②), because of which, and as side effect of the yawing (§ 2.2.1), the bank angle to the left increased (Attachments 5 ③ and 3 ③), but was counteracted by the copilot (Attachment 5 ④) reducing the bank angle, but which stayed 1° to 5° to the left and not to the right, against the crosswind, as would be required during lining up for a crosswind landing to prevent drifting with the wind (§ 3.2).
The rudder input can be explained as an attempt to align the airplane with the runway, but this came too early, already at ≈ 1.5 nm in front of the runway threshold. This is not a normal control input under crosswind conditions at that distance, even before reaching the 5° offset correction to runway heading 106° at 1 nm from 111° (Figure 1 and Figure 4).
If the airplane indeed was on the 111° radial, then the rudder input was not yet applied, because the airplane had not yet crossed the 1 nm point and was not yet on the extended runway centerline. Furthermore, a rudder input alone does not change the course over the ground, not even with crosswind. A bank angle is required to turn the airplane in a different direction. Hence, the copilot allowed the airplane to slip on the near same (ground) course as before the rudder input.
The control inputs were sustained until after passing the 1 nm point, up to 0.5 nm from the runway threshold.
This control behavior also proves that the airplane cannot have been flying at the 111° radial, and at 25 s did not turn 5° left to establish on the extended runway centerline.

5.7.2. In § 5.6 above it was concluded the final approach course must have been 117°, exactly as was documented in the ATC radar data (Figure 1). Following the rudder control input, the heading decreased 8° from 125° to 117° (previous paragraph) and the wings were kept nearly level. The consequence of the rudder input was that the nose of the airplane, the longitudinal axis, pointed exactly at the runway. From the cockpit, it looked like the airplane cruised straight to the runway. The airplane however, continued to sideslip at the same 117° course as before the rudder input, now with a constant slip angle of 8° (the wind did not change). After some time, it must have become clear that they would not make it to the runway, because the runway must have shifted to the left in the forward view through the windscreen; the path over the ground did not change with the application of rudder only.
The captain obviously did not notice the rudder input, otherwise he would have made a remark, being an experienced instructor.
This paragraph also shows that the airplane cannot have been flying at the 111° radial, but approached the runway at the 117° radial and did not reach the extended runway centerline at a distance of 1 nm, at ≈ 25 s of remaining flight.

5.7.3. **Sub conclusion.** The copilot already applied rudder inputs at 42 s, even before passing the 1 nm point (Figure 1), without any roll control inputs to prevent drift due to the crosswind, which would be required to prevent drifting away from the intended (ground) course. This is not normal at that distance, and not if the airplane would have flown on the 111° approach radial either, not even with a strong crosswind. These control inputs were maintained during 27 s until after passing the 1 nm point, to about 0,5 nm in front of the runway threshold. This also proves that the airplane cannot have flown on the 111° approach radial, and did not make the 5° turn from the 111° approach radial to end on the extended runway centerline of 106°. The captain did not intervene when the copilot applied rudder too early.

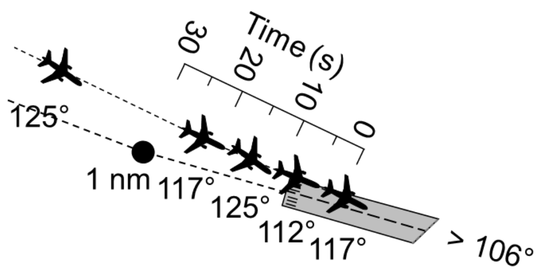
5.8. From 37 seconds before landing

5.8.1. **At 37 s**, the copilot reduced rudder to near zero (Attachment 3 ④) for a few seconds, decreased the bank angle also to near zero (Attachment 1 ⑮) and pitched down the airplane till a pitch attitude of 2° obviously to intercept the PAPI glide path (§ 5.5.2, Attachment 1 ⑩). The increasing pitch down control force (Attachment 4 ⑥) and hence increasing airspeed (Attachment 1 ⑯) made the autothrottle decrease the engine RPM (Attachment 1 ⑰).
The control forces by the copilot on the control wheel and column were not easy control motions as could normally be given while under CWS (Attachments 5 and 4, from 54 s). If the pilot requires a small change of the flight path, a little pressure with thumb and index finger on the controls will do. As explained in § 2.3.2, the CWS measures the control force via the force transducers in the controls and translates these into control commands to the aerodynamic control surfaces. When the required attitude is achieved, the pilot should release the control after which CWS maintains the attitude. The autopilot corrects for any outside disturbance from strong wind or turbulence, that must have been present.
The copilot however, disrupted the autonomous operation of the CWS autopilot mode by applying continuous unnecessary and near pulsating control forces, rather than releasing the controls as the intended pitch and bank angles were achieved, which is shown by the AIDS data in Attachments 4 and 5 from 54 s. The CWS mode of the autopilot remained engaged, hence the autopilot reacted to the control forces with quite large control movements, which might have given the impression of bad weather conditions, but in fact, the copilot caused the motions himself because he operated the CWS mode inappropriately. The US accredited representative, who was assigned to the Commission on behalf of the NTSB, confirmed this, because he wrote in his letter to the Commission, dated Oct. 26, 1994 (Appendix RoA): "***Once the autopilot was disengaged, CWS with ATS remained; functions which were inappropriately used by the flight crew***".

5.8.2. **Sub conclusion**. Both the letter of the NTSB, that is included as attachment in the RoA, and the analysis above show that the copilot himself induced unnecessary motions of the airplane (Pilot Induced Motions) by continuously acting against the CWS mode of the autopilot, that tried hard to maintain the set flight path and now also had to act against these inappropriate control inputs with large control deflections. The pitch changes caused RPM changes of the engines as well.
The variations in flight path and engine RPM were caused by the copilot, not by outside disturbances. Again, the captain did not intervene.

5.9. From 33 seconds before landing

5.9.1. **At 33 s**, with about 1.3 nm to go, the copilot again applied left rudder, up to 15% (Attachment 3 ⑤), 7 s later even with two peaks to 30% (Attachment 3 ⑥). The average rudder input was not that large that the heading changed (Attachment 1 ⑭). Attachment 2 ① shows that the rudder peaks are not that large; the yaw damper was also controlling the rudders. In the meantime, the airplane approached the 1 nm point from the runway threshold and could have started to align with the runway thereafter (§ 3.2). This might have been the intention of the copilot by applying rudder input already from 42 s, but then you do not release the rudder under the strong crosswind conditions, but it happened, at 22 s following the second peak (Attachment 3 ⑥). As side effect, and because of a roll control force (Attachment 5 ⑤), the airplane banked 5° to the right (Attachment 3 ⑦), after which the copilot applied left aileron control force to zero bank (Attachment 5 ⑥). The DFDR recorded small rolling movements as side effect of the yawing due to rudder input (Attachment 1 between ⑮ and ⑳), but not a prolonged constant bank angle to the right that would be required to counteract the drift caused by the crosswind and stay above the (extended) runway centerline. These control inputs and airplane motions are not normal if the airplane approaches on the extended centerline, straight in front of the runway, but support both the conclusion that the airplane approached from the left side on course 117° and the attempt to displace the airplane towards the (extended) runway centerline.



Again, a confirmation of the fact that the airplane did not approach on the 111° radial, but that there was light panic because the airplane still had to be maneuvered to the middle of the runway while the decent continued.

5.9.2. **Sub conclusions**

5.9.2.1. Even before reaching the 1 nm approach radial offset point in front of the runway, the copilot tried to align the airplane with the runway by applying left rudder. This is not a normal control input when the airplane would have approached on the 111° radial, not even under strong crosswind conditions.

5.9.2.2. The DFDR data do not show bank angle and heading changes for the transition from the 111° approach radial to the runway heading of 106° at 1 nm in front of the runway. This also proves that the airplane cannot have approached on the prescribed 111° approach radial.

5.10. From 20 seconds before landing

5.10.1. **At 20 s** before landing, the altitude was, to the opinion of the captain, a little too low, but was corrected following his remark "*bit low, bit low, bit low*". The DC-10 is a big airplane in which the distance from the eye balls of the pilots, with which the PAPI approach lights are observed, to the underside of the wheels of the landing gear is much larger than of a small airplane. If the airplane is just a little below the PAPI glide path, the landing gears could hit the ground even before passing the runway threshold, which might cause damage; AOM 3.3.5 – 14 warns to prevent a too low PAPI approach and contains the procedure that below 200 ft above the runway threshold, the aircraft must be brought gradually above the "on glide slope" indication to provide a 30 to

40 ft wheel clearance at the threshold. The captain was obviously aware of this procedure and warned the copilot (CVR-transcript, at 15 s). The copilot therefore pulled on the controls (Attachment 1 ⑱) to stay clear of the ground.
By pulling the pitch control, the autothrottle system also increased the engine RPM, in this case to 102%, in anticipation of a go-around (§ 2.3.3). Immediately thereafter, at 15 s, the pitch was reduced to again continue the glide path (Attachments 1 (21) and 4 ⑦). The NLR explained this maneuver as crossing a downburst, which of course is not correct. The crew applied the procedure to avoid touchdown ahead of the threshold.

5.10.2. **At 20s** the airplane was approximately 0.7 nm from the runway threshold, and should have been on the extended runway centerline, on the runway bearing (106°). The rudder that, from 42 s, was applied to the left too early and inappropriately with interruptions, was reduced from 30% to the left to 8% to the right (!) between 22 s and 15 s (Attachment 3 ⑧), after which the heading slowly returned from 117° to the earlier used approach heading 125° (Attachment 1 ⑲), which is not to the correct side for landing with a crosswind component from the right, if the airplane would fly at the extended runway centerline. Obviously, the airplane still had to be displaced to the right, before landing.
The side effect of the reduction of the rudder input, and the average roll control force to the right (Attachment 5 ⑦) increased the bank angle from wings level (0°) to 10° to the right (Attachment 1 ⑳). This bank angle was subsequently counteracted by rotating the control wheel to back to the left causing the bank angle to decrease to wings level (0°, Attachment 5 ⑧). This is strange, because when at low altitude and above the extended centerline of the runway, a pilot does not allow the heading to increase again, away from the runway heading, and therewith increasing the crab angle. In addition, the bank angle should be maintained against the crosswind to avoid drifting away and not move the roll control to the left, as the copilot did. These facts are also evidence that the airplane was not on the (extended) centerline.

5.10.3. **At 20 s** and an altitude of 200 ft, the copilot said "*Windshield anti-ice, I don't see anything*" (CVR-transcript and Figure 5). Because at that moment it was not known how long the visibility would be interrupted, a go-around should have been initiated. Since the call "*Landing*" was not given, it was unsure whether the copilot indeed had visual contact with the runway; here also the supervision by the captain was lacking.

5.10.4. **Sub conclusions**

5.10.4.1. The DFDR and AIDS recorded control input and heading data do not show a heading change of 5° to the left at the 1 nm approach offset point from the runway threshold. Bank angle and heading did not change. This is another indication that the airplane was not on the 111° approach radial or the extended runway centerline.

5.10.4.2. At a distance of about 0.5 nm in front of the runway, the increase of the heading was not counteracted; the airplane obviously had to be displaced further to the right, to the middle of the runway. The conclusion is that the airplane flew left of the runway and definitely not above the (extended) centerline.

5.10.4.3. The visibility restriction at 240 ft altitude, below the MDA and at only 20 s before touchdown, should have led to an immediate go-around, also because the copilot as pilot-flying had not given the call "*Landing*".

5.11. From 13 seconds before landing

5.11.1. **At 13 s,** at an altitude of 150 ft, the copilot pulled the throttle handles back to flight idle, with some force against the engaged autothrottles (Figure 7 below). Just prior to this moment, the autothrottle system had increased the RPM of the engines because the copilot increased the pitch angle (Attachment 1 ⑱, refer to § 2.3.3 above). One reason for closing the throttles could be that the increased RPM would accelerate the airplane after which the touchdown spot would be further down the (short) contami-

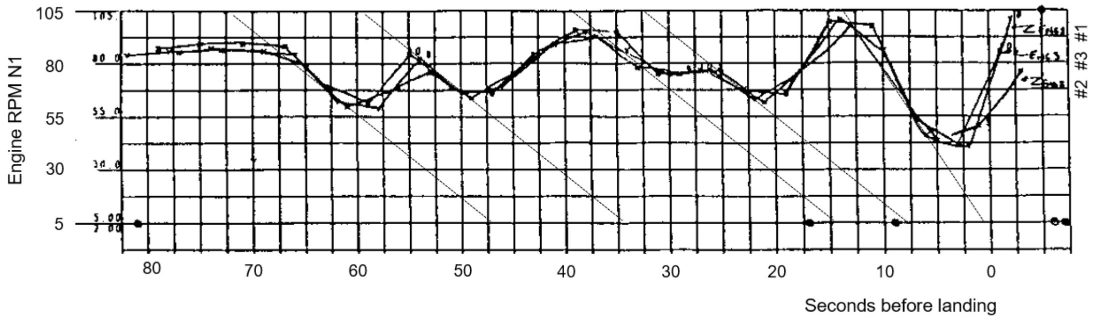


Figure 7. Comparison RPM decrease by autothrottle (4x) and manually by the copilot (1x); this last rate of decrease is larger (DFDR-data, Attachment 1).

nated runway, which the copilot did not want to occur.
The rate of the RPM decrease was larger than at four earlier occasions during the last 80 s of flight by the autothrottle system, which proves that the closure of the throttles was a pilot action (refer to the thin dashed straight lines in Figure 7 below). In addition, the RPM decreased to a much lower value than the autothrottle system would do and did on earlier occasions, as Figure 7 shows.
The copilot closed the throttles that far that it would become impossible to execute an immediate go-around at low altitude without further altitude loss because of the increased spool-up time of the large turbofan engines from an RPM lower than the autothrottle would maintain.
The autothrottle system is programmed to start decreasing the engine RPM after passing 50 ft, in accordance with a certain schedule, that leaves the option for an immediate go-around, even from the ground just after touchdown.

5.11.2. **At 13 s,** a rudder pedal input was applied to the left again (Attachment 3 ⑨), but now up to 90%, which looks like an attempt to align the airplane with the runway. The airplane yawed to the left (Attachment 1 (23)) and started to roll to the left slowly, as side effect of the yawing (Attachments 1 (22) and 3 ⑩), while it could be expected that a bank angle to the right would have to be attained and maintained to prevent drifting to the left due to the strong crosswind and therewith remain positioned at the (extended) runway centerline. But there came no roll control input to the right at this time, on the contrary, at 12 s there was a roll control input to the left (Attachment 5 ⑧), that reversed at 11 s to peak to the right, which had no effect on the increasing bank angle to the left. Roll control input then decreased to zero at 7 s. The increasing bank angle to the left was not counteracted immediately as could be expected when alignment with the runway was the intention of the large rudder input.
The side effect of the large 90% rudder input resulted in a bank angle that increased to 14° to the left at 6 s (Attachments 1 (22) and 5 ⑨), despite of the small roll control input to the right.

5.11.3. Not maintaining adequate roll control input to the right, against the crosswind, at the same time as the large rudder input to the left, is also an indication that the airplane was not above the (extended) runway centerline, but still to the left of the runway. The airplane was side slipping to the runway from the left side, as shown in Figure 4 right side.

5.11.4. As a result of the near maximum (90%) rudder control input to the left, the heading decreased from 125° to 112° in 7.5 s, a change of 13° which was however, not adequate to reach the runway bearing of 106°, as DFDR data show (Attachment 1 (23)). The heading change of 13° however, was approximately equal to the heading change that is required to align the airplane at the maximum approved crosswind component of the DC-10 (30 kt) at the threshold speed for lowest landing weight (124 kt) for which the rudder is designed (14° with max. rudder, AOM 6.4.3 – 01). The difference between the approach heading to align from (125°) and the runway bearing (106°) to align to, being 19°, exceeded the control power of the rudder at the given approach speed (see also § 5.6.4 above).
If the airplane would have been flying at the extended runway centerline, with the on-board measured crosswind (190°/ 20 kt), then the wind correction angle would have to be 8° and the heading within 1 nm from the threshold had to be 106° + 8° = 114°. There would have been ample rudder control power to yaw to the 106° runway bearing. Even if the wind would have been 220°/35 kt, as was suggested, then still adequate rudder control power would have been available to line up with the runway. The 90% rudder input by the copilot however, was not adequate to align the airplane with the runway; hence, the aircraft was not approaching on the extended runway centerline.

5.11.5. **At 10 s** before landing, the captain read a wind of 190°/ 20 kt from the display of the navigation computer (see also § 5.6.5). Although the wind provided by ATC (150°/ 15 max 20 kt) would be the wind to be applied for planning the landing, the crew was, because of the large wind correction angle required during the entire approach (heading 125°), aware of the larger actual crosswind. The winds read by the captain from his navigation computer two times during the final approach, as well as the ATC reported wind directions and speeds exceeded the limits for landing at a flooded runway, and even for a wet runway.
In the RoA was stated that the ATC reported winds were of the opposite runway end and were not right for the approach to runway 11. The wind correction angles needed by MP495 during the approach prove that the actual wind was stronger than the ATC reported wind. In the end, the captain is responsible for a safe conduct of the flight, not the ATC controller.

5.11.6. **At 8 s** before landing, at an altitude of 125 ft, the heading should have been 106° to be aligned with the (extended) runway centerline for landing (§ 3.2 and Figure 4 middle), and the bank angle should have been to the right to compensate for the 20 kt crosswind, therewith preventing drifting away from the runway centerline. There was no bank angle to the right, on the contrary, the bank angle increased to the left and peaked to 14° (Attachment 1 (22)).
Because of the bank angle peak to the left during the side slip towards the center of the runway, the ground course of the airplane did change to the left a few degrees. An average 7° bank angle during 3 seconds to the left results in a ground course decrease of approximately 3°. At this time, the airplane might have been flying above the left edge of, and in the direction of the runway.

5.11.7. The approach speed during the whole approach was already 5 kt too low (§ 2.4). The premature closure of the throttles, the increase of pitch angle from 8 s and the increased drag due to the sideslip angle following the large rudder input caused the airspeed to decrease to below the 139 kt threshold speed (Attachment 1 (24)).

5.11.8. **Sub conclusions**

5.11.8.1. At 13 s before landing, at an altitude of 150 ft, the copilot closed the throttles manually against the autothrottle, while this would normally occur from 50 ft. The

RPM of the engines decreased further than the autothrottle would do. The too low RPM increased the spool-up time of the engines, preventing the thrust from increasing quickly enough for the initiated go-around at low altitude to be successful.

5.11.8.2. At 13 s before landing, the copilot also applied rudder to the left to 90% of maximum pedal travel. This looks like an attempt to align the airplane with the runway to avoid a traversing landing, but the pilot allowed the bank angle to increase to 14° to the left, at 6 s, rather than attaining and maintaining a bank angle to the right to counteract the large crosswind from the right and avoid drifting to the left (away from the runway centerline). The airplane obviously needed to be displaced towards the runway centerline. Another indication that the airplane was not approaching at the extended runway centerline.

5.11.8.3. The heading change due to the large 90% rudder input from 13 s was 13°, but not adequate to reach the runway bearing of 106° from 125°. The rudder of the DC-10 is not designed for this yawing angle of 19°. If the airplane would have approached above the extended runway centerline, then the 13° heading change / rudder authority would have been sufficient, and the traversing landing could have been avoided. This also proves that the airplane did not approach the runway at the extended runway centerline, but under an angle from the left.

5.11.8.4. The approach speed that was selected 5 kt too low, decreased further, even below the threshold speed before reaching 50 ft altitude, after the throttles were closed too early, the pitch angle increased and the rudder input increased the sideslip, hence the drag.

5.12. From 7 seconds before landing

5.12.1. **At 7 s** before landing, the copilot reduced the rudder pedals from 90% left to the middle (Attachments 2 ② and 3 ⑫), after which the heading slowly increased. Why would a pilot reduce the rudder if the airplane would be on the extended runway centerline, as some 'experts' say, while a strong crosswind is blowing from the right? The crab angle started to increase and resulted in a crabbed landing which is not approved for a DC-10.
Hence, reducing the rudder at this time is another indication that the airplane was not above the runway centerline, but obviously still had to get there.

5.12.2. When the bank angle was increasing to 14° at 7 s (Attachment 5 ⑨), the captain grabbed the controls and both he and the copilot applied aileron control force to the right (Attachments 2 ③ and 5 ⑨). The captain did not call "*my controls*", hence the copilot did not release the control wheel. At 6 s, the copilot applied left aileron control force again, but the captain increased it to the right. These conflicting control inputs caused the CWS mode to disengage automatically (Attachment 5 ⑩).
At the same time, the captain had also increased the throttles to maximum thrust, without calling "*go-around*". He did not push the go-around button, which would rapidly configure the required airplane systems for the go-around. Only at 1 s before touchdown he called "*throttles*". Because the RPM of the engines had reduced to a low, near idle level, the spooling-up of the engines took too long; there was no adequate power level available in time, before touchdown, for a safe go-around. If the throttles had not been closed by hand, the go-around would have been successful without much loss of altitude. The failure of the go-around was due to poor crew coordination.

5.12.3. According to AOM § 3.3.5 – 08, the minimum altitude to disengage CWS is 150 ft. In this case, this happened at 6 s, at approximately 80 ft altitude following the conflicting roll control force inputs of captain and copilot. If disengaging the CWS mode would be dangerous at this altitude and would contribute to an abrupt flare followed by a hard landing, then the autopilot would not have been certified by aviation authorities, and would at least an audible alarm be implemented besides the implemented indicator light.

5.12.4. When the CWS is off, or after it disengages, then the pilot not only has to control the required flight path, but also compensate for external disturbances, increasing the workload. But it is the question whether a pilot, in a busy flight phase as the landing, would notice the disengagement of CWS, because he is, at this low altitude and only 6 s prior to touchdown, certainly 'in the loop'. DFDR and AIDS data of roll and pitch control of the last 6 s do not show any other control behavior than before. The recorders do not show any effect of the disengagement of CWS.

5.12.5. It could be that due to all commotion because of the oblique approach path and the control take-over by the captain, the 50 ft call was not given by the flight engineer (who used to be a pilot as well). The 500 ft and 400 ft calls were not given by the captain (as pilot-non-flying) and the copilot either (§ 5.6.1).

5.12.6. **Sub conclusions**

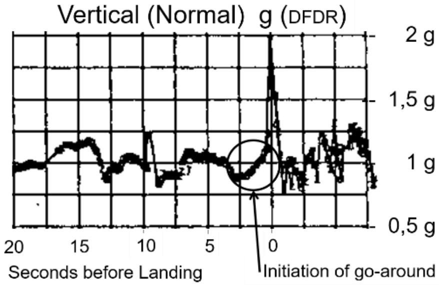
5.12.6.1. At 7 s before landing, the pilot reduced the rudder control input from 90% left to zero, causing the heading to increase slowly, rather than decreasing the heading further which would be required to align the airplane with the runway. The bank angle also decreased from the left to 0°. The release of the rudder, and a bank angle that was kept at wings level, rather than to the right as would be required with the strong 20 kt crosswind from the right, prove that the airplane was not above the runway centerline, but obviously still had to get there from the left side.

5.12.6.2. At 6 s before touchdown, the captain decided to take control of the airplane when the bank angle started to increase to the left, following the large rudder input to the left. He increased the roll control input to the right, but did not call "*my controls*", and did not call "*go-around*" either when he increased the throttles to maximum. He did not push the go-around button of the flight management system to quickly configure the airplane systems for the go-around. All of this was not in accordance with the good principles of crew coordination and adequate operation of aircraft systems as prescribed in the AOM.

5.12.6.3. Although the CWS mode of the autopilot disengaged itself because of conflicting roll control inputs by captain and copilot, DFDR data show no adverse effects on the controllability of the airplane.

5.13. The landing

5.13.1. During the last seconds of flight, the pitch angle was increased to 9°, with a dip at 2.5 s because the pilot did not maintain control column input up (Attachment 4 ⑧) while the throttles were pushed forward, both for the go-around. These control inputs, including the dip, are shown by the graph of the vertical acceleration (Attachment 1 (28)), of which the relevant part is shown in the adjacent figure. The graph proves that the airplane was not pushed down by a downdraft during the last 2.5 s of flight but that, on the contrary, the descent must have reduced because of the re-



sponse of the airplane to the elevator-up control input for the go-around (Attachment 2 ⑨).
Because of the roll control input by the captain to the right (Attachments 5 ⑩ and 2 ③), the airplane rolled back from the left to wings level, to 0° (Attachment 1 (25)).
Then the ailerons returned to zero (Attachment 2 ④), which prevented to attain a bank angle to the right (Attachment 1 (25)) that would be required to counteract the crosswind from the right.
The reduction of the large rudder deflection, and at 3 s before touchdown a bit of rudder to the right (Attachment 2 ⑤), caused the heading, that was 112° until 2.5 s before landing, to increase to 117° at touchdown, which is 11° right of the runway heading of 106° (Attachment 1 (26)).
Because of the roll control input at 3 s to the right (Attachment 2 ⑥), the airplane rolled to 5.62° to the right (Attachment 1 (27)).
Both motions were immediately counteracted with both the rudder and ailerons (Attachment 2), but had no effect anymore. These control inputs also prove that the airplane did not approach on the runway centerline.
The control power of the aerodynamic control surfaces had decreased because of the decreasing airspeed. During the last 2 s of flight, the airplane did not respond in time to the 50% rudder input to the left (Attachment 2 ⑦).
If the wind would have increased just before landing, then the roll control wheel would not have moved to the left, but to the right.

5.13.2. Because the RPM of the engines could not increase fast enough from flight idle due to the closed throttles, the descent continued and the airplane landed traversing with an angle of 11°, half outside of the runway on the left side, but in the runway direction as proven by a deep groove of one of the rims of the center landing gear in the asphalt, as shown by a police report and in Figure 8 below. The airplane never reached the runway centerline.

5.13.3. The go-around also failed because the ground spoilers deployed within one second after touchdown while the throttles were advanced (Attachment 2 ⑧). The ground spoiler system of this DC-10 must have malfunctioned, because deployment should and may not occur when maximum thrust is selected.

5.13.4. With a wind of 190°/ 20 kt, as read in the cockpit, a larger bank angle of approximately 7° would have been required during a longer time, to prevent the airplane from drifting to the left, than the 5.62° that was attained one second before touchdown (Attachment 1 (27)).

5.13.5. The DFDR and AIDS data (in Attachments) do not show any trace of motions and accelerations caused by external influences, such as windshear or up- and downdrafts, with the exception of light turbulence. All abnormal airplane motions during the last 80 s of flight were caused by unnecessary control inputs by the copilot, in both the command as well as the CWS modes of the autopilot. Besides commenting on the use of the autopilot by the crew (§ 5.8.1), the US accredited representative, who was assigned to the Commission on behalf of the NTSB, also wrote: "***If the commission feels that windshear was present during the approach then consideration should be given to recommending implementation or review of crew training for windshear recovery***". A diplomatic way of saying that the NTSB did not read any sign of windshear in the DFDR data either.

5.13.6. The airplane landed at the point as shown in Figure 8 below, half outside of the runway, with an 11° crab angle to the right, but in the direction of the runway as shown by the scratches A – E. Despite the near maximum rudder to the left during 7 s, and

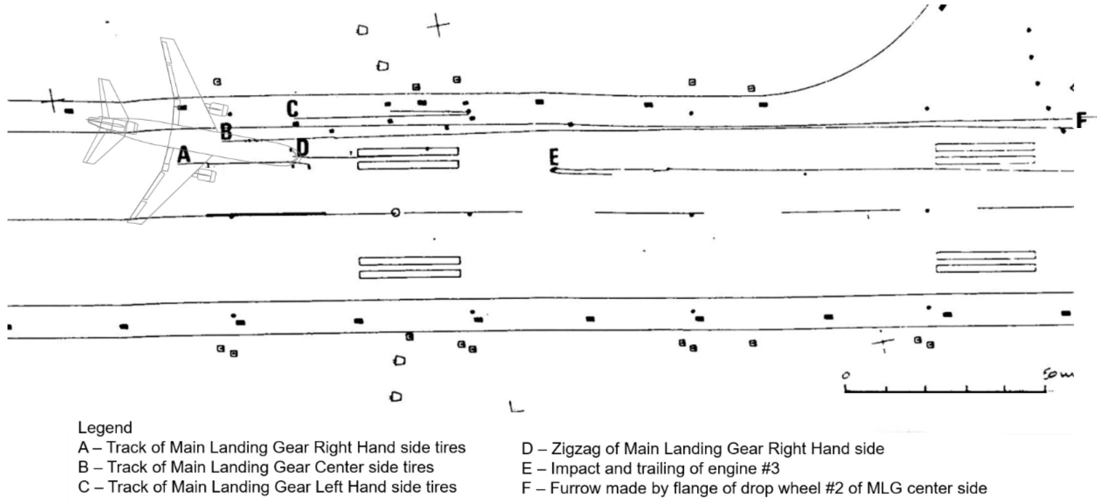


Figure 8. Impact area MP495 on runway 11, RoA Annex 11.

until 7 s before touchdown, the runway heading was not reached because the airplane did not approach on the extended runway centerline, and the copilot reduced the rudder input to the center, even a little to the right and in the last 2 s of flight more than 50% to the left again, resulting in a rudder deflection of 10° to the left (Attachment 2 ⑦). Yawing from the approach heading 125° to runway heading 106° would have taken approximately 10 s, provided the rudder control power would be adequate (refer to § 5.11.4 above), and rudder pedal input would be sustained. The airplane then would have attained the runway heading just 2 s prior to touchdown, which is too late. Hence, the rudder input was too late for alignment with the runway, but had no sense either, because the airplane was not yet above the runway centerline.
The control inputs, the point of touchdown and the direction of the traces on the runway prove that the airplane did not approach above the runway centerline.

5.13.7. In § 5.6.4 was explained that exceeding crosswind limits after landing on a contaminated runway also results in a runway excursion because of the reduced friction of the nose gear wheels on the runway surface (like aquaplaning) cannot counteract the weathercock effect of the large vertical tail. If the touchdown would have been successful, then the airplane would have vacated the runway to the right side, resulting in an accident as well.

5.13.8. **Sub conclusions**

5.13.8.1. At 7 s before touchdown, the captain took control, applied right roll control force and pushed the throttles forward for a go-around. The engine RPM could not increase fast enough to provide for go-around thrust and stay clear of the ground, because the copilot had manually closed the throttles to idle against the engaged autothrottle. The initiation of a go-around at this time is also an indication that the airplane did not approach on the runway centerline.

5.13.8.2. Due to a malfunction in the ground spoiler system, the spoilers deployed within 1 s after touchdown, while the throttles were advanced for go-around, which made a go-around impossible because of the reduced wing lift. In fact, the premature closure of the throttles and the ground spoiler malfunction were contributing factors to the accident.

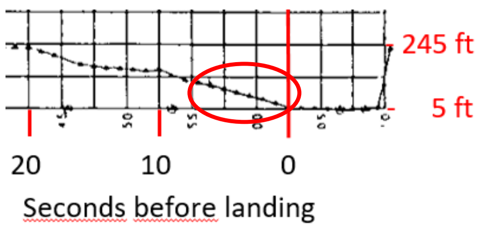
5.13.8.3. DFDR data show no evidence of airplane motions due to external influences such as windshear, up- or downdrafts; there was light turbulence though. The NTSB also concluded that there was no windshear during the approach. The airplane motions recorded by the DFDR were not only caused by the light turbulence, but also by the copilot who acted against the autopilot frequently and inappropriately.

5.13.8.4. The airplane landed with a crab angle of 11°, but in the direction of the runway; the left main landing gear touched down outside of the runway.
The bank angle, control inputs of rudder and ailerons and the heading during the last 1.5 s of flight also prove that the airplane was not, and was not being aligned for a landing under crosswind conditions (Figure 4 middle), which also is evidence that the airplane was not approaching above the center of the runway just before landing. Control inputs do not show any response to sudden wind changes.

5.13.8.5. If the touchdown would have been successful, the airplane would also have vacated the runway on the right side because the crosswind (20 kt) exceeded the limit (5 kt) for the flooded runway, and even for a wet runway (15 kt). The reduced friction of the nose gear wheels on the runway surface (like aquaplaning) would not be able to counteract the weathercock effect of the large vertical tail at decreasing taxi-speeds, which is one of the reasons for crosswind limits.

5.14. Rate of Descent

5.14.1. At 7 s before touchdown, the altitude was 93 ft as shown by the DFDR radio altitude data in Attachment 2, of which a small section is shown in the adjacent figure. As the data shows, the final descent was a straight line; no sign of an increased rate of descent during the last seconds of flight. The final rate of descent was a constant 93/7*60 = 797 ft/min, which is higher than normal, but within the limits of the landing gear, which were presented by manufacturer McDonnell Douglas in an NTSB report of a similar accident (DCA97MA055). The landing gear survives a rate of descent of 1014 ft/min at maximum landing weight; no damage will occur to the fuel cells in the wings above the landing gear at normal touchdown accelerations up to 2 g.



The landing weight of MP495 was 161,400 kg, which was 30,900 kg (16%) below the maximum landing weight of 192,300 kg. The rate of descent could have been higher without damaging the airplane.
However, the airplane landed traversing, with a crab angle of 11° which increased the aft acting and torsional forces on the landing gears. See also the next paragraph for additional forces due to the prematurely operated brakes.

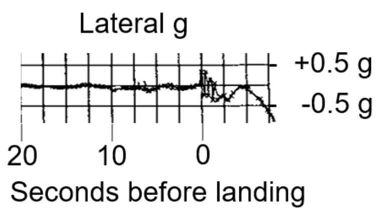
P.S. 5 ft in the figure above is the approximate height of the radio altimeter antennae when the airplane is on the ground.

5.14.2. In § 5.2.1 was explained that the right brake pedal was actuated already before touchdown, while this is only allowed following 'firmly' contact of the nose gear with the runway (AOM 3.3.5 – 15). The application of brakes during or short after touchdown will have contributed to the build-up of large forces on the right landing gear that failed, although not right at touchdown, but – as indicated by the place from which the right engine nacelle touched the runway (point E in Figure 8) – about 70 m further down the runway. The "zigzag", D in Figure 8, could be the place where the brakes were energized by the anti-skid system, but could also be the place where the fuse pin of the right landing gear failed. This pin sacrifices the landing gear in case of large aft forces on the landing gear to prevent parts of the landing gear from puncturing the fuel tank above the landing gear. This was not investigated by the Commission.

5.14.3. **Sub conclusion**. The rate of descent during the last 7 s of flight was less than the maximum rate of descent for which the landing gear was designed. In addition, the landing weight was 16% lower than the design landing weight. The failure of the landing gear was not caused by the higher than normal rate of descent.
The right landing gear could have failed because the brakes were already actuated during touchdown causing the brake pressure to energize the brakes at wheel spin-up even before the nose gear was firmly on the ground. This developed forces that, in combination with the additional forces due to the crabbed landing, increased the limits of the landing gear and/ or of the fuse pin.

5.15. Sideward displacement

5.15.1. Martinair stated that the airplane was approaching on the (extended) runway centerline, and was displaced by a windshear shortly before touchdown. With an airspeed of 140 kt, a sudden increase of the wind from 190°/ 20 kt to the mentioned 220°/ 35 kt, initially yaws the airplane approximately 6° to the right slowly (weathercock stability) as if the rudder is applied a bit to the right. The ground course does not change immediately if the wings are kept level. Thereafter, the new "wind correction angle" might change the ground course slowly, because a mass of 161 tons is not easily and only displaced sideward.



The heading increased shortly before landing from 112° to 117°, but this was caused by the rudder decreasing from the left to the center (Attachment 2 ② and ⑤); the wings were kept level, rather than banked right to counteract a sideward displacement (Attachment 1 (25)).
The DFDR lateral acceleration and airspeed data (Attachment 1 and adjacent figure) do not show any changes as a result of an increasing crosswind, tailwind or sideward gust. All data show that the wind during the last 80 s of flight was a constant 190°/ 20 kt, as calculated in § 5.6.5 above and as read by the captain from his navigation computer. The crosswind component hereof was 20 kt, 15 kt higher than the limit for a flooded runway, and even 5 kt higher that the limit for a wet runway. A runway excursion would be unavoidable after a successful landing because of aquaplaning of the nose gear wheels under increasing yawing moments at decreasing taxi-speed (§ 5.13.7).
As discussed in § 5.13.6 above, the scratches of airplane parts in the runway asphalt and the analysis of heading and control inputs in the paragraphs above prove that the airplane shortly before, during and after touchdown was definitely not displaced sideward from the runway centerline. This statement by Martinair about the sideward displacement is incorrect.

5.15.2. Even without precipitation, limits would be exceeded, such as the too large radius of the final turn, and not returning to the approach radial. The crosswind limit of the DC-10 on a dry runway was 30 kt, but the personal limit of the pilot-flying was 50% lower.

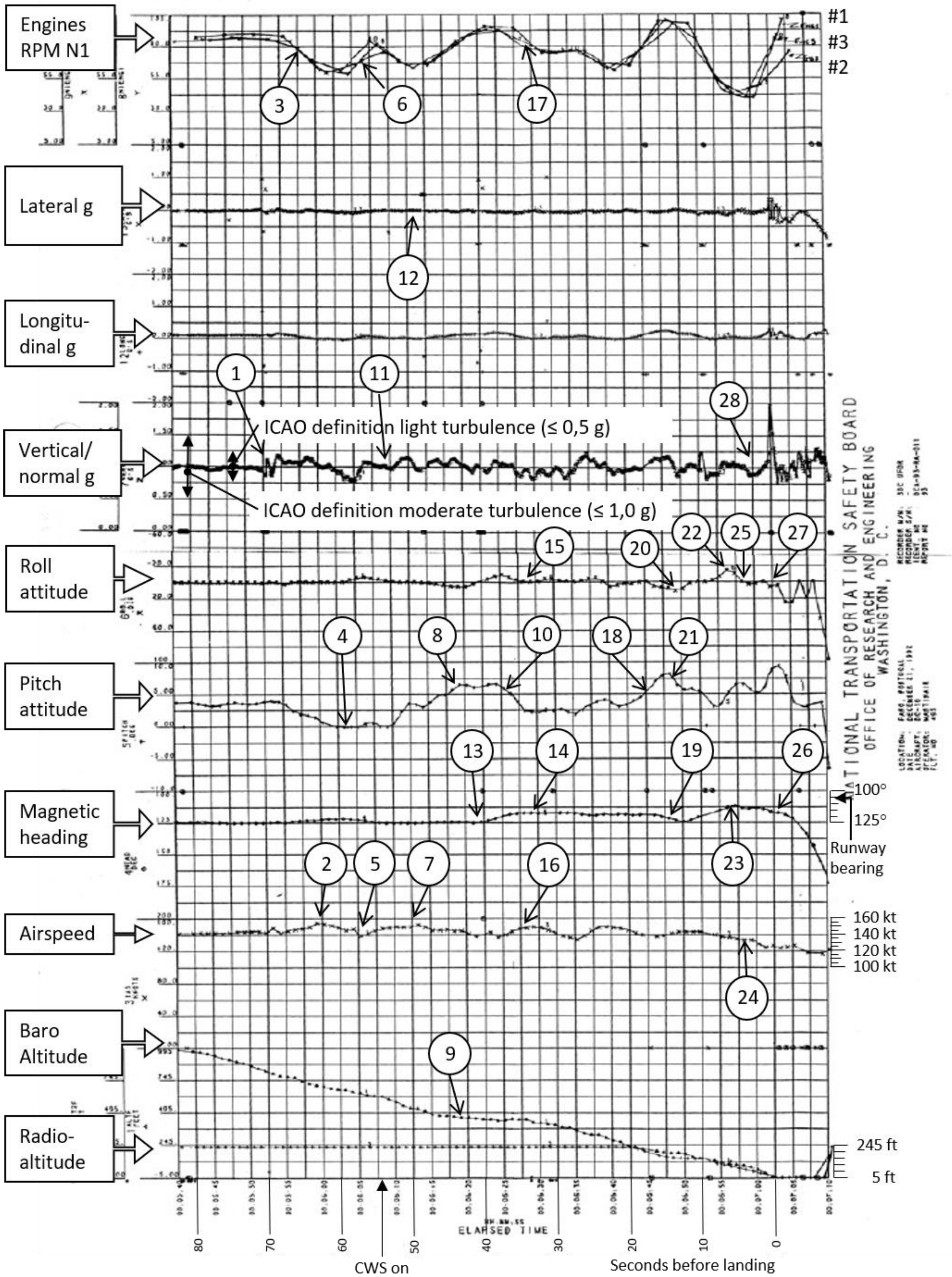
5.15.3. **Sub conclusion**. Both the DFDR data and the direction of scratches and grooves on the runway after touchdown do not support the statement of a sideward displacement just prior to touchdown.
Indeed, crosswind limitations of the DC-10 and of the pilot-flying were exceeded for landing at a flooded runway. The actual crosswind requiring a wind correction angle of 11° at touchdown was even too high for landing on a wet runway. If the right landing

gear would not have failed, the airplane would have suffered a runway excursion because of aquaplaning of the nose gear wheels while reducing speed with the current large crosswind and runway conditions, resulting in an accident as well. The crew infringed many landing procedures and limits as prescribed in their airplane and company manuals. ■

List of Abbreviations

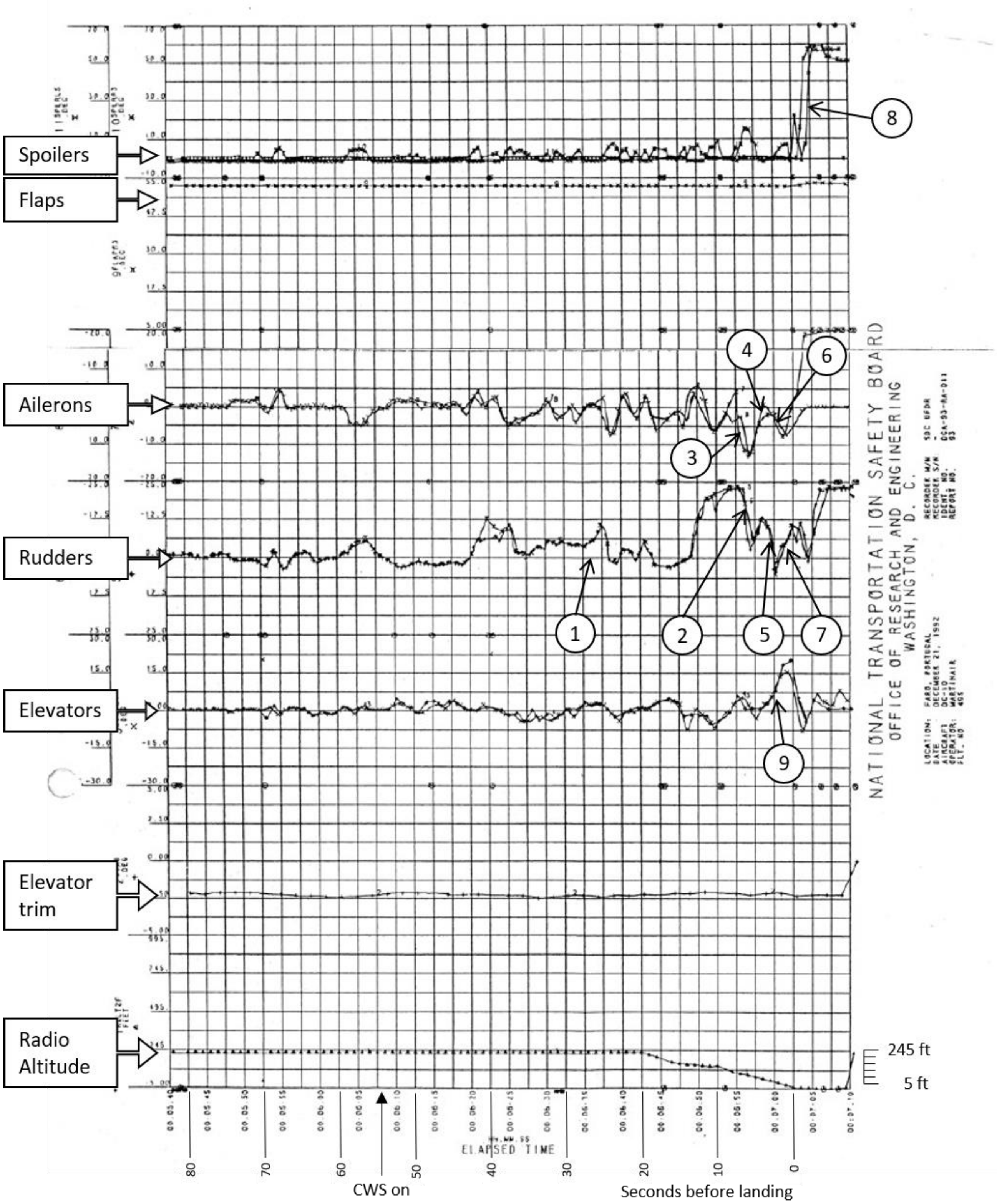
Abbreviation	Meaning
A/T of ATS	Autothrottle (System)
AIDS	Airborne Integrated Data System
ALAR	Approach and landing Accident Reduction
AOM	Aircraft Operations Manual
BIM	Basic Instructions Martinair
CMD	Command (mode van autopilot)
CVR	Cockpit Voice Recorder
CWS	Control Wheel Steering (mode van de autopilot)
DSB	Dutch Safety Board
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
FAR/ CS	Federal Aviation Requirements/ Certification Specification
ft	foot of feet
FSF	Flight Safety Foundation
FWD	Forward
g	Normal gravity acceleration (9.81 m/s^2)
HDG	Heading
ICAO	International Civil Aviation Organization
kt	knot(s)
m	meter(s)
METAR	Meteorological Aerodrome Report
N1	Revolutions of the compressor
NLR	National Aerospace Laboratory, Amsterdam
nm	Nautical Mile (1 nm = 1852 m)
NTSB	National Transportation Safety Board
PAPI	Precise Approach Path Indicator
RoA	Report of Accident (by the Portuguese Commission)
s	second(s)
TAF	Terminal Area Forecast
UTC	Universal Time Coordinated (Greenwich Mean Time)
VOR	VHF Omni Directional Ranging

Attachment 1. Page 1 out of RoA, Annex 15. Part of DFDR Factual Report NTSB



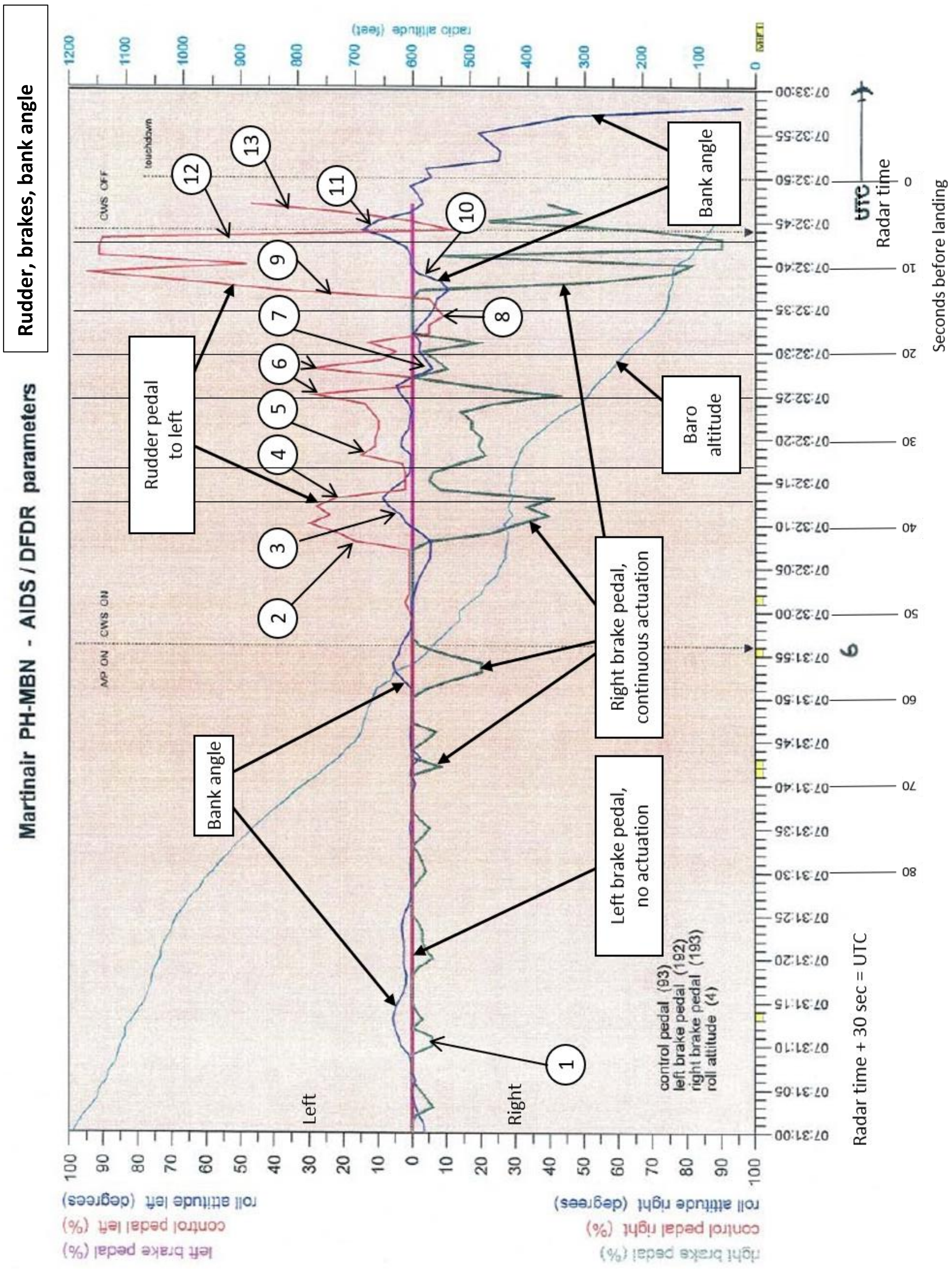
Attachment 1

Attachment 2. Page 2 out of RoA, Annex 15. Part of DFDR Factual Report NTSB



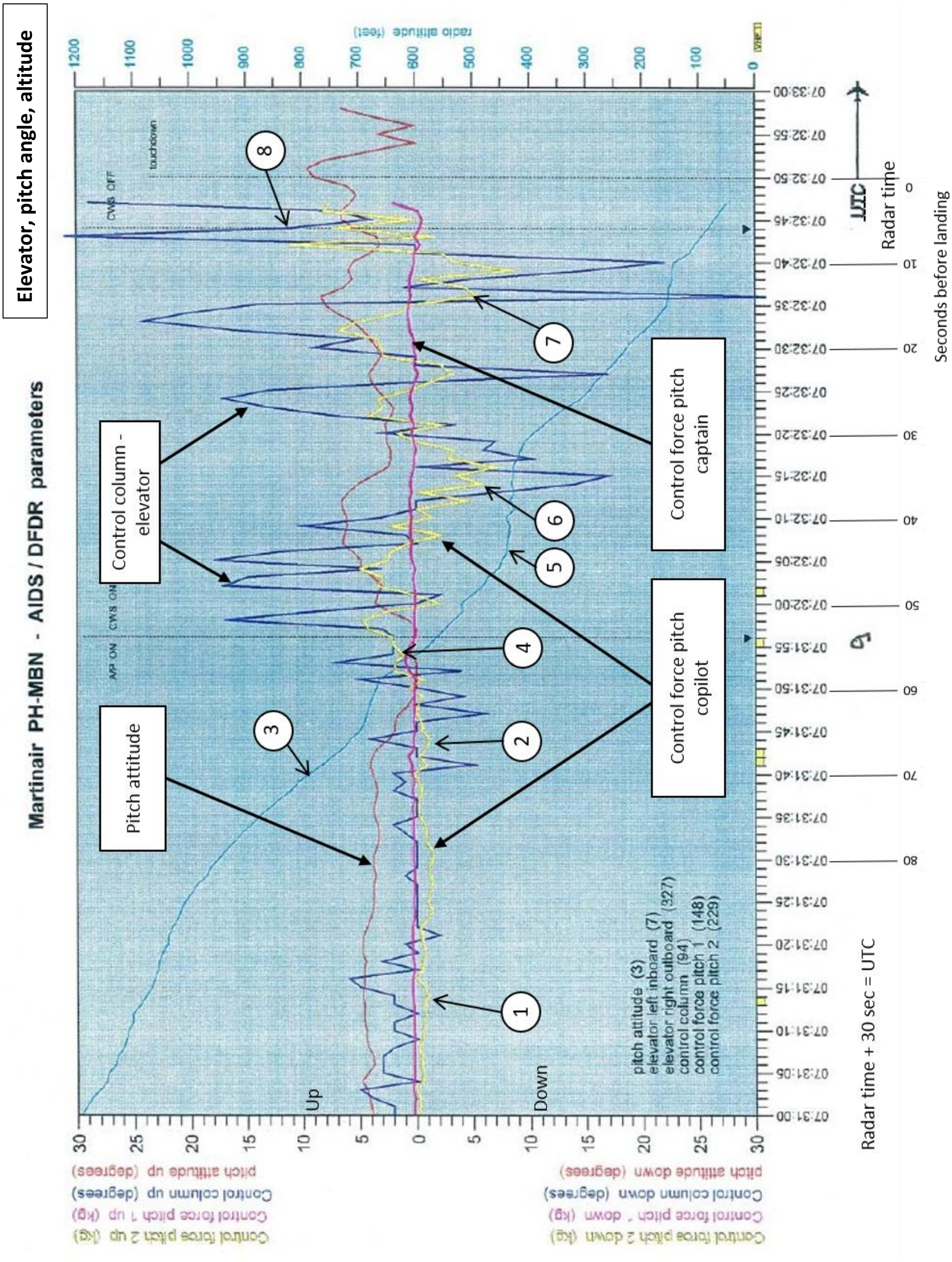
Attachment 2

Attachment 3. Graph 6 out of RoA, Annex 9, AIDS data. Rudder, brakes, bank angle



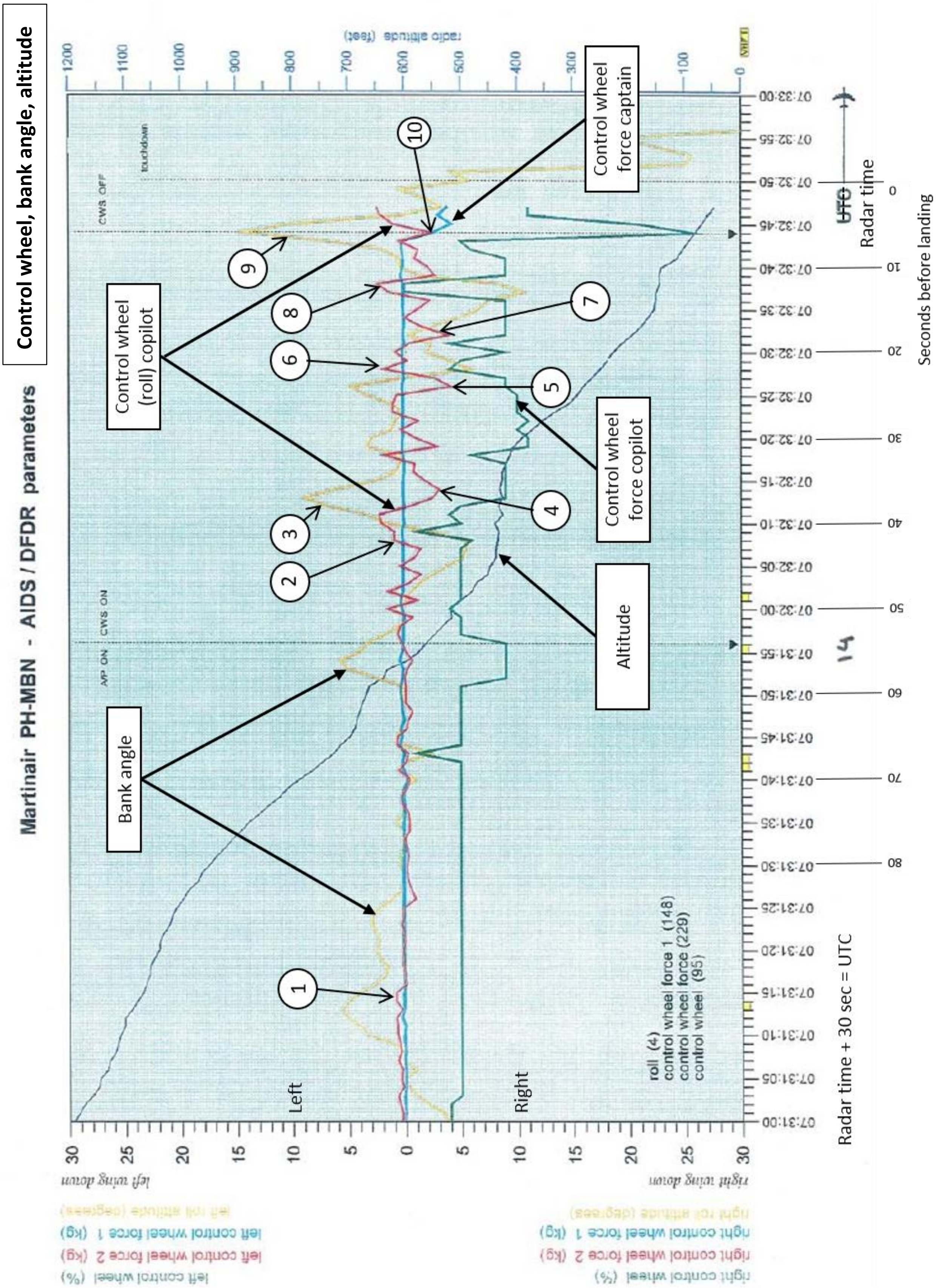
Attachment 3

Attachment 4. Graph 9 out of RoA, Annex 9, AIDS data. Elevator, pitch angle, altitude



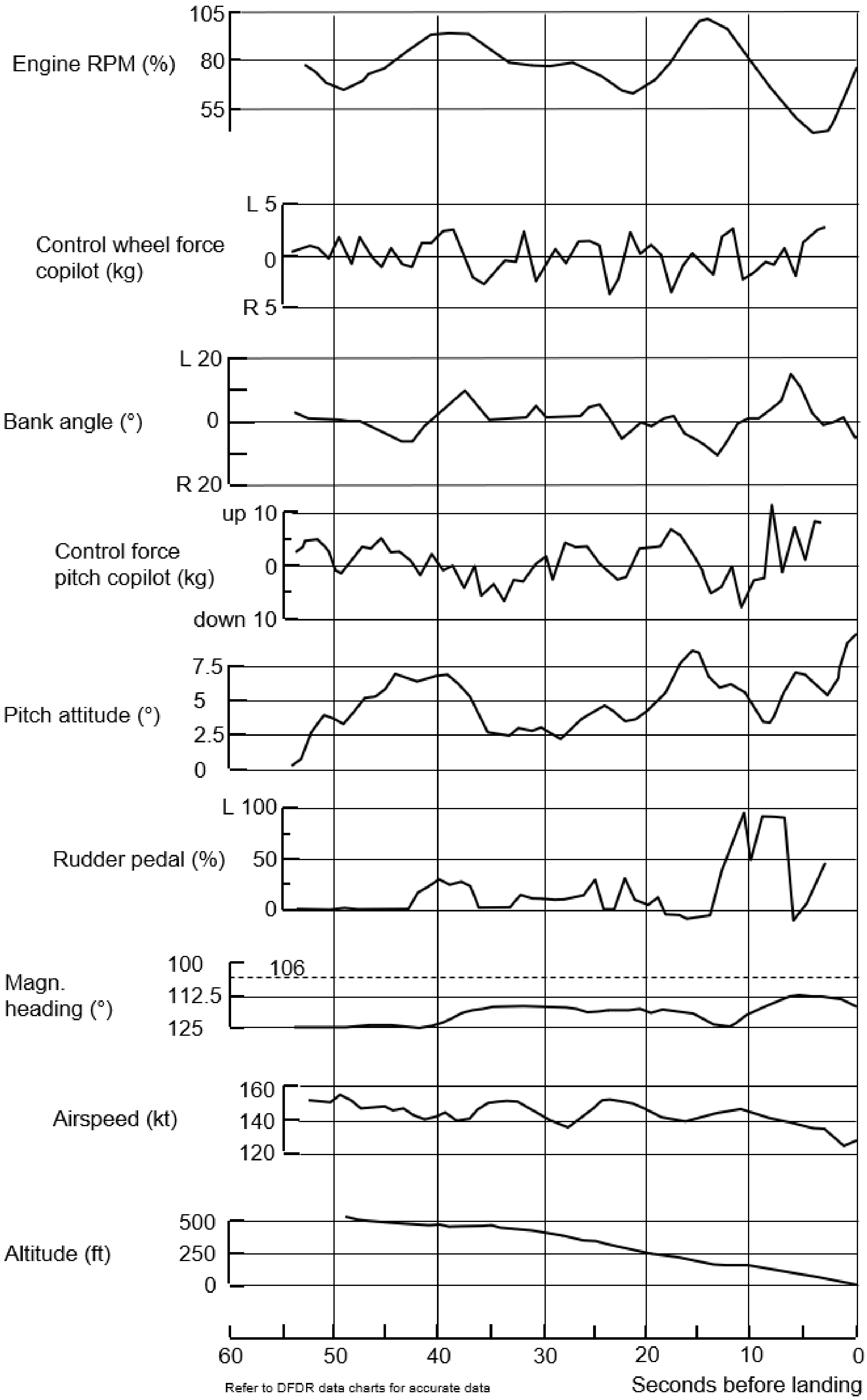
Attachment 4

Attachment 5. Graph 14 out of RoA, Annex 9, AIDS data. Control wheel, bank angle, altitude



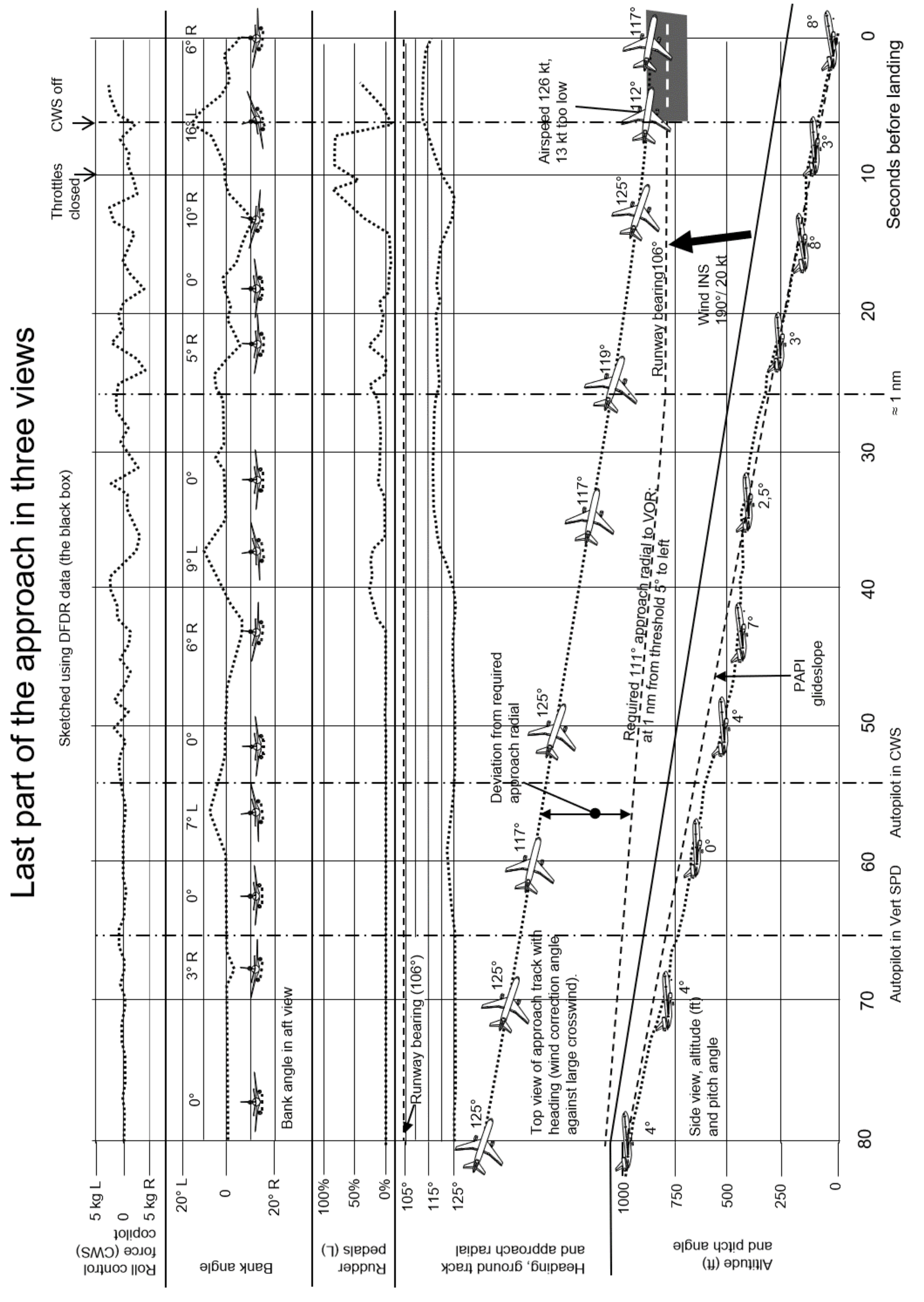
Attachment 5

Attachment 6. Combined control input and control data out of DFDR and AIDS



Attachment 6

Attachment 7. Last 80 seconds of the approach in three views



Attachment 7