



THE DUTCH  
SAFETY BOARD



**Rejected takeoff after the takeoff  
decision speed ' $V_1$ ', Boeing B737-800,  
at Eindhoven Airport**

4 June 2010

**REJECTED TAKEOFF AFTER THE TAKEOFF DECISION  
SPEED 'V<sub>1</sub>', BOEING B737-800, AT EINDHOVEN AIRPORT**

4 JUNE 2010

The Hague (project number 2010040)

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In case of conflict in interpretation, the Dutch text will be deemed binding.

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## LIST OF ABBREVIATIONS

A.C.	Advisory Circular
A.D.M.	Air Data Moduler
ADIRU	Air Data Inertial Reference Unit
AoA	Angle of Attack
BITE	Built in Test Equipment
CRM	Cockpit Resource Management
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FCOM	Flight Crew Operations Manual
FCTM	Flight Crew Training Manual
FDR	Flight Data Recorder
IAA	Irish Aviation Authority
ICAO	International Civil Aviation Organisation
JAA	Joint Aviation Authorities
NLR	(Dutch) National Aerospace space laboratory
NTSB	National Transportation Safety Board
PFD	Primary Flight Display
QRH	Quick Reference Handbook
RTO	Rejected Takeoff
$V_1$	Takeoff decision speed
$V_2$	Takeoff safety speed
$V_R$	Speed for rotating the aircraft

# 1 INTRODUCTION

## 1.1 INVESTIGATION MOTIVE AND BACKGROUND

The Boeing 737-800 operated by Ryanair was taking off from runway 04<sup>1</sup> on the 4th of June 2010 at Eindhoven Airport. At the time of rotating the aircraft to takeoff, the pilot flying decided to reject the takeoff because he believed the aircraft was unsafe to fly. The decision to reject was made after the takeoff decision speed ( $V_1$ ). The pilot performed a so-called high speed rejected takeoff. The aircraft was halted before the end of the runway and the aircraft was subsequently taxied back to the terminal. The aircraft sustained no damage and no passengers or crew were injured.

According to statistics published by Boeing, the takeoff of an aircraft is a critical phase of flight and accounts for approximately 1% of total flight time. Accident statistics show that the takeoff phase accounts for 16% of onboard fatalities and 12% of the fatal accidents. A takeoff event, particularly rejected takeoffs at high speeds have a high potential of runway overrun. The event on the 4th of June is considered a serious incident which was investigated accordingly.

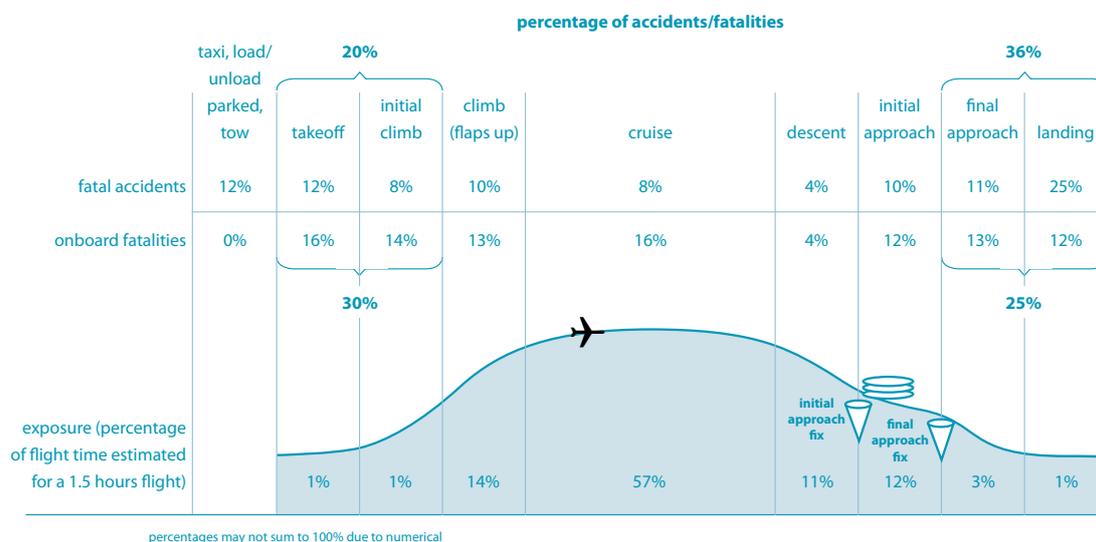


Figure 1: Percentages of accidents and fatalities per phase of flight. Source: Statistical Summary of Commercial Jet Airplane Accidents, 1959 - 2008, Boeing.

## 1.2 THE INVESTIGATION

### 1.2.1 Objective

This report presents the outcome of the investigation by the Dutch Safety Board into a rejected takeoff after the takeoff decision speed ' $V_1$ '. The investigation has two objectives. The primary objective of the Board is to learn from this event and try to prevent a similar occurrences from happening again in the future. The secondary objective of the investigation is to inform parties involved, including passengers and authorities, what took place on 4th of June 2010. The purposes of Board's investigation is not to apportion blame or liability.

1 Runway 04, is the designation of a runway with a heading of approximately 40 degrees magnetic

### *1.2.2 Investigation questions*

The primary investigation questions related to the serious incident are:

“Why did the pilot decide to perform a rejected takeoff?”

“Under what circumstances is a rejected takeoff necessary?”

### *1.2.3 Scope and working procedure*

The investigation into the cause describes and analyse the facts up to and shortly after the moment the takeoff was rejected at Eindhoven airport.

## 1.3 READER’S GUIDE

This report comprises six chapters. The facts of the serious incident and other factual information is described in chapter two. In chapter three the assessment framework is explained. The parties involved and their responsibilities are described in chapter four. Chapter five describes the analysis of this event and underlying factors of the serious incident. From the analysis in chapter five, conclusions are drawn in chapter six.

The International Civil Aviation Organisation (ICAO) has established guidelines and recommended working methods for investigating civil aviation accidents and serious incidents. These are included in Annex 13, ‘Aircraft Accident and Incident Investigation’. A report based on Annex 13 has a set structure: factual information, analysis, conclusions and recommendations. The structure of Chapter 2, ‘Factual Information’, is in line with Annex 13.

## 2 FACTUAL INFORMATION

### 2.1 INTRODUCTION

This chapter presents the essential facts to determine the causes and answer the investigative questions regarding the rejected takeoff event. In section 2.2 background information is given on the aviation 'V-speeds'. In section 2.3 the relevant technical systems of the Boeing 737-800 are briefly discussed. Section 2.4 describes the history of flight. Section 2.5 through 2.10 describe other factual information which is required for the subsequent analysis of the event.

### 2.2 BACKGROUND INFORMATION

In aviation, V-speeds or velocity-speeds are standard terms used to define airspeeds important or useful for operating an aircraft. These speeds are derived from data obtained by aircraft designers and manufacturers during aircraft flight testing and certification. In some cases the V-speeds are specified in the certification specifications. Using these speeds is considered best practice and maximises aviation safety, aircraft performance or both.

The speed  $V_1$  is an operational speed which is used for takeoff. Several definitions exist for the  $V_1$  speed, some from an operational perspective others from a certification point of view (in appendix B examples are given).  $V_1$  is defined in the Flight Crew Operations Manual used by this operators flight crews as the "takeoff decision speed".

The speed  $V_1$  is used during takeoff to aid the pilots decision making process in the event of an engine failure or other significant problem. Below  $V_1$ , the aircraft is able to stop within the available runway distance, whereas above  $V_1$  it is uncertain or unable to do so. Attempting to stop above  $V_1$  is considered hazardous due to the possibility of overrunning the end of the runway. If the runway distance for reaching  $V_1$  is equal to the remaining runway distance, the takeoff is called a balanced field takeoff<sup>2</sup>. The chance for an overrun is especially high when a balanced field takeoff is performed.

The weather, weight of the aircraft, the runway altitude, conditions and length affect the  $V_1$  speed. During flight testing, for a range of takeoff weights, the  $V_1$  speeds are determined which are then published in the flight manual. This information in the flight manual is then used by the flight crew to determine the  $V_1$  speed for each takeoff.

In addition to the  $V_1$  speed, the speeds at which the pilot flying should start rotation ( $V_R$ )<sup>3</sup> and the takeoff safety speed ( $V_2$ )<sup>4</sup> are determined. These speeds are established by flight testing and published in the flight manual. All three of the V-speeds are determined by the flight crew for each takeoff.

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- 2 A balanced field takeoff is a condition where the accelerate-stop distance required (ASDR) is equal to the takeoff distance required (TODR) for the aircraft weight, engine thrust, aircraft configuration and runway condition. In general, the balanced field length represents the minimum runway length that can be used for takeoff.
  - 3  $V_R$  is the speed at which the pilot flying starts pulling on the controls causing the aircraft to pivot around the axis of its main landing gears which are, at that time, on the ground.
  - 4  $V_2$  is the speed is the speed required to maintain a minimum climb gradient with one engine-out.

For the event flight the V-speeds were determined by the flight crew and given in Table 1.

$V_1$	140 knots <sup>5</sup>	Takeoff decision speed
$V_R$	141 knots	Rotation speed
$V_2$	147 knots	Takeoff safety speed

Table 1: The V-speeds which were used by the flight crew.

## 2.3 BOEING 737-800 RELEVANT SYSTEMS

### 2.3.1 The Air Data Inertial Reference Unit

The Air Data Inertial Reference Unit (ADIRU) is a computer which supplies data, including airspeed information, to the primary flight display of the pilots. There are two, left and right, ADIRU computers installed onboard the aircraft. The airspeed is calculated by the ADIRU computer using sensors which measure the air pressure outside the aircraft. The pressure measurements are taken by two sensors, the pitot probe and the static port. These sensors are located on both the left and right side of the aircraft and connected to the left or right ADIRU computers. For the calculation of the airspeed the angle of attack of the aircraft, sensed by the alpha vane, is also incorporated. Both ADIRU computers are monitored internally and generated data is compared. If a threshold is exceeded a warning is generated.

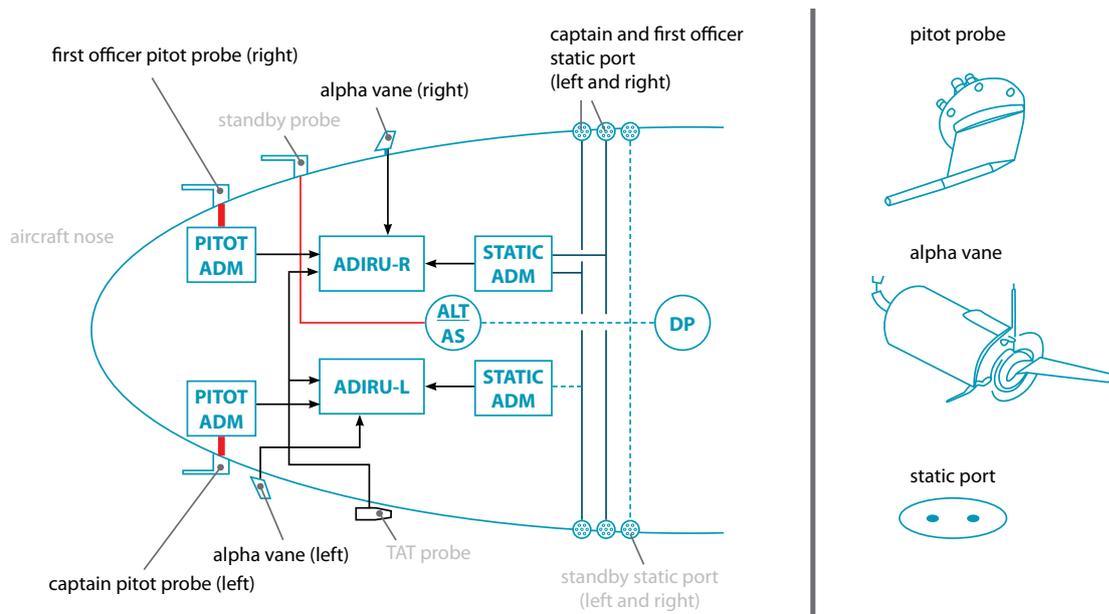


Figure 2: Schematic system diagram showing major system components and sensors for airspeed calculation.

### 2.3.2 Primary Flight Display (PFD)

In the cockpit both the captain and first officer have a primary flight display (PFD) at their disposal. On this primary flight display a range of flight information such as the attitude, airspeed, heading, rate of descent or climb, pressure altitude is displayed.

5 1 knot = 1852 meter per hour.

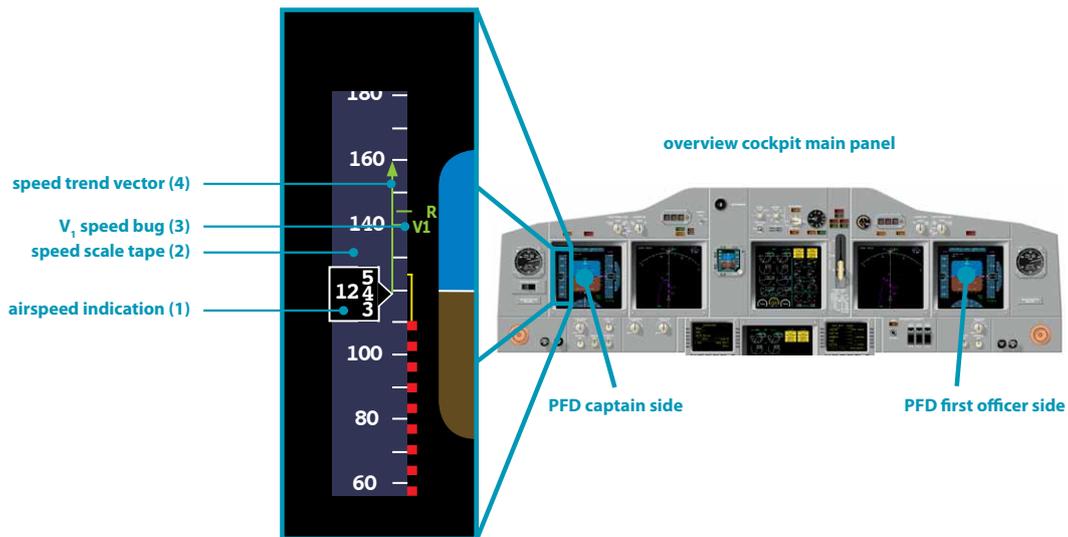


Figure 3: Overview B737-800 cockpit with detailed schematic of the speed indications of the primary flight display.

The (computed) airspeed information is displayed in numerical format on the left side of each primary flight display (Figure 3 – (1)). A dynamic moving speed scale tape (Figure 3 – (2)) displays additional speed information depending on the airspeed and phase of flight. For takeoff V-speeds are determined and input into the Flight Management Computer. Subsequently the  $V_1$  (Figure 3 – (3)) and  $V_R$  speed are displayed on the speed tape. Superimposed onto the speed scale tape is a green arrow (Figure 3 – (4)) which is the speed trend vector. The tip of the speed trend vector shows the predicted airspeed after 10 seconds. The prediction is based on the concept that change in airspeed and longitudinal acceleration stay the same. The speed trend vector points upward when the aircraft speed increases (acceleration) or down in case the speed decreases (deceleration). When the calculated speed trend vector is below a threshold it will not be displayed. The speed trend vector is designed as a helpful in-flight tool to set appropriate thrust setting and fly the desired speed. This reduces pilot workload when changing or maintaining an airspeed or altitude.

## 2.4 HISTORY OF FLIGHT

On the morning of June 4th 2010 the Boeing B737-800, with registration EI-DPX arrived from Faro (Portugal) at Eindhoven Airport. The flight from Faro to Eindhoven was flown by the captain, the first officer would become the pilot flying on the return flight to Faro. The aircraft was scheduled to depart for the return flight to Faro at 09.30<sup>6</sup> hours. The crew performed the standard checklist items and followed the operators procedures for the flight. As part of the flight preparation the different operational speeds ('V-speeds') were calculated using the approved aircraft manuals provided to the crew.

After engine start the aircraft taxied from the parking stand to the threshold (beginning) of runway 04 using the parallel taxiway (Figure 4). Eindhoven control tower directed the Boeing B737 to exit FOXTROT. The flight crew requested exit GOLF and the control tower agreed. The crew was given holding instructions to allow a general aviation aircraft takeoff first.

6 The time in this report is the recorded FDR UTC time.

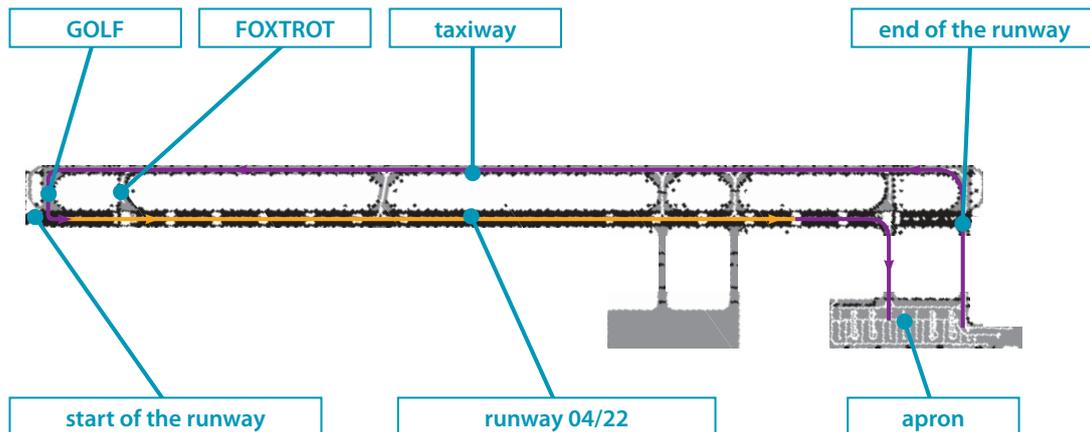


Figure 4: Airport map of Eindhoven Airport with the aircraft track in purple (taxi) and yellow (takeoff).

At approximately 09.45 hours the aircraft lined up on runway 04 and the crew received takeoff clearance from air traffic control. As per procedures, the first officer applied takeoff thrust by pushing the TO/GA<sup>7</sup> switches. As part of the takeoff procedure the captain placed his hand near the thrust levers.

During the start of the takeoff, at low airspeed, the first officer reported having difficulties in keeping the aircraft on the centreline. At 80 knots an airspeed crosscheck was performed which was satisfactory and no speed deviations were noted. When the aircraft deviated again from the centreline at 90 knots the captain checked the engine parameters (N1) once more as he suspected an engine problem. The left and right engines parameters were found to be correct and symmetric.

At around 140 knots the pilot flying observed a speed trend vector in the negative direction. The captain stated that at the same time he observed a large trend vector in the positive direction. The captain did not find this discrepancy an issue and made no comments about this. As the airspeed reached  $V_{1r}$ , the ' $V_1$ ' and ' $V_R$ ' calls were made and the captain removed his hand from the thrust levers.

According to the first officer when the aircraft reached the  $V_1$  speed the control column was moving aft without the application of force. The first officer stated that he experienced back pressure from the column and the aircraft rotated on its own. At this time he had the feeling that the aircraft was unsafe to fly and pulled back the thrust levers. The auto brake system and speed brakes were automatically activated and a rejected takeoff was initiated.

After the throttles were pulled back the captain took over the flight controls and completed the rejected takeoff procedure. The aircraft stopped approximately 500 metres from the end of the runway. The flaps were kept at 5 and the captain deemed an evacuation not necessary.

Following the rejected takeoff procedure the tower was contacted by the first officer to inform them of the rejected takeoff. The tower acknowledged the transmission and asked if further assistance was required. The tower was informed by the crew that no assistance was required. A master caution light illuminated in the cockpit, the warning indicated was related to the centre fuel pump.

The crew requested the tower to check 'if everything is fine with the rubber' and later 'check our wheels are fine'. Because of the high speed rejected takeoff the brakes of the aircraft became hot. The flight crew was concerned about overheated brakes and possible wheel fire. At the parking stand smoke was observed coming from the brakes. Consequently, the crew decided to disembark the passengers and let the brakes cool off.

7 TO/GA switches – engage the Autopilot Flight Director System and Autothrottle in takeoff mode when armed.

## 2.5 PERSONAL INFORMATION

The captain, at the time of the event, had 3628 hours total flying experience with 2061 flying hours on type (B737). The captain's last proficiency check, line check and Cockpit Resource Management (CRM) training all occurred in the period February to March 2010.

The first officer, at the time of the event, had 2300 hours total flying experience and 1170 hours on type (B737). The first officer's last proficiency check, line check and Cockpit Resource Management (CRM) training all occurred in the period January to March 2010.

On the morning of the event flight both crew members reported for duty at the Faro base station. Flight crew history shows that both crew members met the rules and standards of flight crew duty and rest times.

## 2.6 AIRCRAFT INFORMATION

The records provided show that the aircraft had a valid certificate of airworthiness and no outstanding maintenance actions were present. According to the weight and balance information of the event flight the aircraft was loaded within aircraft weight limits. The weight distribution and loading of the aircraft kept the centre of gravity within specified limits.

## 2.7 METEOROLOGICAL INFORMATION

The weather conditions reported to the crew by air traffic control were a wind speed of 5 knots with gusts to 10 knots. The wind came from the north east (magnetic heading 30 degrees). The temperature was 19 degrees Celsius and the dew point was 9 degrees Celsius. The reported pressure was 1021 hectopascal.

## 2.8 AERODROME INFORMATION

Eindhoven Airport is a joint civil and military airport with a single runway. The magnetic heading of the runway is 40 degrees and 220 degrees (04/22). The takeoff run available (TORA) is 3000 metres. The runway friction coefficient or average braking coefficient was measured during the day of the event. The friction coefficient was determined to be 0.81 which makes braking conditions 'good'.

## 2.9 FLIGHT RECORDER

After the event the data from the flight data recorder (FDR) was provided to the Dutch Safety Board for use in the investigation. The data was analyzed using conversion factors provided by the aircraft manufacturer. In appendix C a plot of various parameters recorded on the flight data recorder is presented. The cockpit voice recorder (CVR) was not available for the investigation.

Analysis of the flight data showed that at 09.35 hours movement of the aircraft was recorded and the aircraft changed heading and gained groundspeed. At this time the aircraft was steered towards the runway. At 09.40 hours a control check was performed, all the flight controls in the cockpit and the associated control surfaces on the aircraft moved to the full deflection positions.

The flight data showed that the aircraft lined up on the runway at 09.45:08 hours. Engine power was applied and 46 seconds later and the aircraft started to roll down the runway. Between 0 and 50 knots, changes in magnetic heading were recorded. The changes in heading were counteracted by rudder (pedal) inputs and at around 60 knots the aircraft heading became stable and in the direction of the runway.

At 09.46:24 hours the aircraft reached an airspeed of 80 knots. Between 100 and 150 knots the data on the flight recorder showed deviations in the computed airspeed. At 135 knots the computed airspeed jumps 10 knots in one second.

At 09.46:45 hours the aircraft pitched nose up to a maximum of 1.4 degrees and the FDR recorded that the nose gear was off the runway for nearly 2 seconds. Simultaneously a lateral (left and right movement) acceleration deviation is recorded with a minimum of -0.126 and a maximum of 0.093 g's.

At 09.46:46 hours the flight data recorder shows the throttle levers were pulled back to idle. A second later the nose gear came back on the ground and a maximum computed airspeed of 160 knots was recorded. The autobrake system and speed brakes were activated and the thrust reversers were deployed. The auto brake system applied brake pressure and the aircraft decelerated with a maximum of -0.56 g's.

At 09.47:01 hours the aircraft came to a halt and a master warning light illuminated. Both angle of attack (alpha vane) sensors turned to large negative values (right AOA to -90 degrees, left AOA to -25 degrees) after the aircraft came to a standstill, as is typical.

## 2.10 TESTS AND RESEARCH

### 2.10.1 Tests carried out by maintenance

Following the rejected takeoff, tests and maintenance actions were carried out on the aircraft. The built in test equipment (BITE) of various systems did not produce any faults stored from the last flight leg. The data from the autothrottle computer memory showed that the rejected takeoff was initiated at 152 knots.

The pilots informed maintenance that there was a airspeed indication problem. Therefore troubleshooting and maintenance actions focused on finding the cause of the unreliable airspeed. First, an inspection for unreliable airspeed without disturbing the aircraft systems and components was carried out. The result of this test was an airspeed indication disagreement between the left and right side.

Next the unreliable airspeed procedure was carried out according to the steps described in the Fault Isolation Manual. To fulfil the requirements and complete the unreliable airspeed test the right hand angle of attack sensor (alpha vane) required adjustment. The result of the test was satisfactory and no airspeed disagreement between the left and ride side was found.

During the maintenance activities a dent beyond limits on the (left) captain's side pitot probe was discovered, this probe was subsequently replaced. Additionally the alpha vane, pitot probe and Air Data Inertial Reference Unit (ADIRU) on the first officer's (right hand) side were replaced. No other anomalies were reported.

### 2.10.2 Simulator tests carried out by the Dutch Safety Board

The first goal of simulator testing was to get an understanding of the operational conditions and procedures for a rejected takeoff. Using a Boeing B737-800 flight simulator at Amsterdam Schiphol Airport the event flight was re-enacted using available data and flight crew procedures. During these simulator trials several rejected takeoff were performed including a number at Eindhoven airport with a 3000 metre runway. In one instance during trials the aircraft became airborne for a very short period and was put on the ground straight away. In this case the automatic rejected takeoff brakes were disarmed per design and manual braking was necessary, which made stopping the aircraft very difficult. In the simulator trials it was shown that after the high speed rejected takeoff a master warning light illuminated. This was due to a low pressure centre fuel tank pump warning.

Apart from the operational investigation, the B737-800 simulator tests were also conducted to determine the length of the speed trend vector during the takeoff roll. Using video equipment the length of the arrow was recorded and analysed later. These tests and video analysis showed that on average the speed trend vector length was approximately 40-45 knots. The maximum the tip

of the speed trend vector arrow can point to is 60 knots. Therefore the length of the speed trend arrow was about 2/3 of the maximum length. A detailed description of the determination of the speed trend vector length is given in appendix D.

### *2.10.3 Rejected takeoff studies*

As part of this investigation the following information on rejected takeoffs has been used and incorporated into this report:

- Special Investigation Report Runway Overruns following high speed rejected takeoffs National Transportation Safety Board PB90-917005 NTSB/SIR-90/02.
- Takeoff safety training aid announcement of availability AC No. 120-6.2 Federal Aviation Administration 1994.
- Takeoff safety training aid PB93-780013 U.S. Department of Transportation Federal Aviation Administration 1993 available through the National Technical Information Service.
- Reducing the Risk of Runway Excursions Report of the Runway Safety Initiative Publication of the Flight Safety Foundation may 2009.
- Rejecting a takeoff after  $V_1$ ...Why does it (still) happen? NLR-TP-2010-177 NLR Air Transport Safety Institute 2010.

## 3 ASSESSMENT FRAMEWORK

### 3.1 GENERAL

An assessment framework is an essential part of an investigation of the Dutch Safety Board. It provides a description of the situation as may be expected based on regulations, guidelines and the specific details of individuals responsibility. Insight can be gained into where improvement is possible and/or additions are required by testing based on this and by identifying abnormalities.

In this report the assessment framework consists of three parts. The first part concerns legislation and regulations that are in force for civil aviation. The second part is based on sector guidelines as well as internal corporate guidelines and manuals. The third part describes the expectations of the Board with regard to the manner in which the involved parties fulfil their responsibility for safety and safety management.

This chapter makes a distinction between, on the one hand, binding legislation and regulations and, on the other hand, non-binding standards. Many of the international regulations are not binding directly but become binding when the regulations are implemented in national legislation. This type of international regulations is grouped under the first category of binding legislation and regulations because the referred to implementation takes place nearly continuously in European countries.

### 3.2 LEGISLATION AND REGULATIONS

The regulations of civil aviation are strongly focused on an international level. The basis for this part of the reference framework is, therefore, mainly formed by international regulations.

The international regulations relevant to this investigation include:

- The 'Standards and Recommended Practices' in the annexes to the Chicago Convention of
- the International Civil Aviation Organization (ICAO).
- European Union Regulations.
- Certification specifications (CS) of Aviation Safety Agency (EASA) and the requirements of the Joint Aviation Authorities (JAA) on the use of aircraft for commercial air transport and flight crew licensing.
- Certification requirements of the Federal Aviation Administration (FAA).

### 3.3 GUIDELINES

#### 3.3.1 *Manuals*

Ryanair operating procedures are presented in the Flight Crew Operations Manual (FCOM) Vol 1, Normal Procedures, Quick Reference Handbook (QRH) , Flight Crew Training Manual (FCTM) and performance manual.

The Flight Crew Operations Manual (FCOM) has been prepared by The Boeing Company. The FCOM contains information which has been included at the request of Ryanair for airplanes covered by this manual. This information may differ from Boeing recommended information. By including this information in the manual, Boeing is providing a publishing service only. The purpose of this manual is to provide the necessary operating limitations, procedures, performance, and systems information the flight crew need to safely and efficiently operate the 737 aircraft during all anticipated airline operations.

The FCOM contains checklists which have been duplicated together with other information for ready reference in the Quick Reference Handbook (QRH) for use in the cockpit.

To operate a certain route, the operator has collected pertinent information for the flight crew to operate a certain route in the Performance Manual. Performance Manual provides airfield performance for specific runways in a format which is readily useable by Flight Crew members. The manual is available in the flight Operations office for flight preparation and a copy is carried in the aircraft when flying a particular route.

### 3.3.2 *Rejected takeoff*

The operational procedure related to the rejected takeoff is explained in the QRH. The first procedure (appendix E) describes a number of conditions to reject the takeoff before 80 knots. This procedure also describes the conditions to reject above 80 knots but prior to  $V_1$ .

In another part of the QRH the rejected takeoff is also described (appendix F). The first part describes the conditions in case the takeoff should be rejected before 80 knots. The procedure also describes the conditions in case the takeoff should be rejected for speeds above 80 knots.

The Flight Crew Training Manual states that regardless of which pilot is making the takeoff, the captain should keep one hand on the thrust levers until  $V_1$  in order to respond quickly to a rejected takeoff decision. After  $V_1$ , the captain's hand should be removed from the thrust levers.

The manual does not recommend to reject the takeoff unless the captain judges the aircraft incapable of flight. Even if excess runway remains after  $V_1$ , there is no assurance that the brakes have the capacity to stop the aircraft before the end of the runway.

### 3.3.3 *Aircraft separation*

In Annex 2 – Rules of the Air, of the International Civil Aviation Organisation provisions relating to aircraft separation for wake turbulence are given. General guidance, as does the operators operations manual part A, prescribes the minimum separation time between aircraft to be 2 to 3 minutes depending on aircraft weight and/or category.

## 3.4 ASSESSMENT FRAMEWORK FOR SAFETY MANAGEMENT

A safety management system plays a crucial part in controlling and improving safety. This applies to all organisations, private and public, that are involved directly from a distance in activities where people are exposed to hazards. In principle, the way in which the organisation's responsibility for safety is defined in more detail can be assessed from different points of view. There is, therefore, no universal preamble that can be used in all situations. The Board has, therefore, selected five safety items to be addressed that provide an idea about which aspects may play a role:

- Insight into risks as the basis for the safety approach
- Demonstrable and realistic safety approach
- Implementing and enforcing the safety approach
- Tightening the safety approach
- Management steering, commitment and communication

These items are based on (international) legislation and regulations and a large number of broadly accepted and implemented standards. The Board recognises that the interpretation of the way in which organisations define the details of their own responsibility with regard to safety will depend on, for example, the nature or size of the organisation. These aspects may be important within this context and should, therefore, be taken into account in the assessment.

## **4 INVOLVED PARTIES AND THEIR RESONSIBILITIES**

### **4.1 RYANAIR**

Ryanair is an airline company established in 1985 and has its registered office in Dublin, Ireland. Ryanair flies to over 150 destinations in Europe and operates a fleet of approximately 275 Boeing 737-800 aircraft. Ryanair is as holder of an air operator certificate, in accordance with EU-OPS, responsible for the flight execution and the maintenance of aircraft.

It's Ryanair's responsibility not to operate an airplane for the purpose of commercial air transportation other than in accordance with OPS part 1. Ryanair is required to comply with applicable airworthiness requirements for airplanes operated for the purpose of commercial air transportation. Ryanair is required to comply with all of the provisions of EU-OPS and JAR-FCL, the European Working Time Directive, the Irish Aviation Authority Operation Order and ICAO Annexes and will conduct air transportation operations only when in possession of a valid Air Operators Certificate issued by the Irish Aviation Authority under the applicable Statutory Instrument and Operation Order. In Ryanair the chief pilot is responsible for the safe conduct of all flight operations conducted under the Ryanair Air Operators Certificate issued by the Irish Aviation Authority.

### **4.2 FLIGHT CREW**

#### *4.2.1 Captain (commander)*

The operator will designate one flight crew member to act as commander when the mandatory two person flight crew is put together. The authority vested in the commander is delegated from the chief pilot of Ryanair. The captain is responsible for the operation and safety of the aircraft and for the safety of all persons on board during flight time. For this purpose, he shall have final authority for the disposition of the aircraft during the time in which he is in command. He shall have authority to give all commands he deems necessary for the purpose of securing the safety of the airplane and of persons or property carried therein. All persons carried in the airplane shall obey such commands.

Before commencing take-off, a commander must satisfy himself that, according to the information available to him, the weather at the aerodrome and the condition of the runway intended to be used should permit a safe take-off and departure. This information is available in the Performance Manual Preamble. The decision to reject the takeoff is the responsibility of the captain except if the captain is incapacitated.

#### *4.2.2 First officer (co-pilot)*

The first officer is responsible to the commander during the preparation for and operation of the assigned flight, and to the base captain for duties other than a flight duty. If required, he must question the decision of the captain in the interest of safety. If the captain should be taken ill, the first officer will take over the tasks of the captain. The first officer assists the commander in the management of the flight and the manipulation of the aircraft controls in accordance with the directions of the commander who will be guided by the modern principles of crew resource management. The first officer shall indicate to the captain if there is disagreement with a course of action during any flight phase.

#### *4.2.3 Pilot flying and pilot monitoring*

Both flight crew members can take the role of pilot flying or pilot monitoring. The captain has the authority to assign which crewmember is the pilot flying and pilot monitoring. Depending on the role of the flight crewmember certain required tasks need to be carried out.

Pilot flying (PF)	Pilot monitoring (PM)
<ul style="list-style-type: none"> <li>• flight path and airspeed control</li> <li>• airplane configuration</li> <li>• navigation.</li> </ul>	<ul style="list-style-type: none"> <li>• checklist reading</li> <li>• communications</li> <li>• tasks requested by PF</li> <li>• start levers and fire switches (with PF concurrence.)</li> </ul>

*Table 2: Responsibility of the Pilot Flying (PF) and Pilot Monitoring (PM).*

The first officer, when flying the aircraft, performs the duties listed under PF, and the captain performs those duties listed under PM [Table 2]. Both the PF and the PM have a responsibility to monitor air traffic control transmissions and to query any transmission that is not received fully and/or understood. In critical phases of the flight the pilot monitoring must inform the pilot flying of any deviations.

### 4.3 IRISH AVIATION AUTHORITY

The Irish Aviation Authority (IAA) is a commercial state-sponsored company which was established on 1 January 1994 to provide air navigation services in Irish-controlled airspace, and to regulate safety standards within the Irish civil aviation industry through:

- Certifying and registering aircraft airworthiness
- Licensing personnel and organisations involved in aircraft maintenance
- Licensing pilots, air traffic controllers and aerodromes
- Approving and monitoring air carrier operating standards through Air Operator Certificates.

Internationally set safety standards emanating from the International Civil Aviation Organisation (ICAO); European Joint Aviation Authorities (JAA); EUROCONTROL; the European Civil Aviation Conference (ECAC), the European Aviation Safety Agency (EASA) and the European Union (EU) guide the IAA in ensuring that Irish civil aviation operates to international safety standards. As Ryanair is an Irish operator the IAA is responsible for the oversight, approve and monitoring of the air carrier operation.

## 5 ANALYSIS

### 5.1 INTRODUCTION

This chapter uses the collected information to analyse the event flight and the subsequent rejected takeoff decision. The event flight is analysed in the first paragraph. Next the available procedures to the flight crew on rejected takeoff are analysed. The third paragraph analyses the rejected takeoff from an historical perspective whereby previous studies and developments are considered. Finally, the decision dilemma to reject a takeoff is discussed.

### 5.2 THE EVENT FLIGHT

This paragraph is divided into four subparagraphs. The first subparagraph deals with the takeoff roll where it was difficult to keep the aircraft on the centreline. The second subparagraph details the timeframe where irregular speed trend vector indications were observed. The third subparagraph deals with a perceived controllability problem at the time of rotation of the aircraft. The fourth subparagraph will describe the time frame of the rejected takeoff.

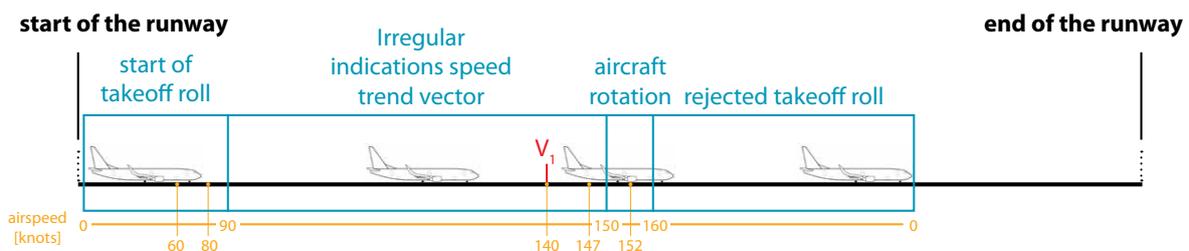


Figure 5: Timeline of takeoff with the four events which will be analyzed in this paragraph in more detail.

#### 5.2.1 Start of takeoff roll

After the event the first officer stated he had trouble in keeping the aircraft on the centreline at low speed. According to the first officer the heading deviation was interpreted as an engine power asymmetry. The captain, who was the pilot monitoring the instruments, also noted the deviations in aircraft heading. The captain also interpreted the feeling as engine asymmetry. Therefore the captain performed an additional engine cross check during the takeoff roll. However, no difference in engine indications was observed. Nor was the cross-check communicated to the first officer who was flying, this was however not mandated either.

The flight data shows a deviation in aircraft heading at low airspeed. The analysis of engine parameters flight data during this timeframe does not show engine asymmetry or large differences in engine performance which could explain the observed heading changes.



Figure 6: Timeframe start of takeoff roll, from standstill to 90 knots computer airspeed.

The data from the flight data recorder shows that the aircraft reacted to the given rudder pedal inputs and it was possible to get the aircraft lined up with the runway. The tiller which controls the nose steering of the aircraft is not recorded, heading changes as a result could not be analyzed. The changes in aircraft heading could possibly be related to over controlling the aircraft or an outside disturbance.

One possible atmospheric disturbance known in aviation is wake vortices.<sup>8</sup> This disturbance is created by a preceding aircraft which has taken off from the same runway. The time between the general aviation aircraft and the B737 takeoff clearance was 4 minutes. The elapsed time and weight category of the aircraft make it unlikely that a wake vortex was encountered due to the general aviation aircraft.

Another possible cause of atmospheric disturbance is gusty winds or turbulence created by buildings or structures near the runway. The reported weather conditions from air traffic control at the time of the event indicated a wind speed up to 10 knots. Prior to and after the event the meteorological information does not show the presence of gusting conditions. At the airport structures and buildings are present which could create turbulence. However given the distance between the buildings and the runway with the reported wind conditions it is unlikely that turbulence was generated by buildings. No information to substantiate either possibility or any other explanation which may have caused heading changes could be determined.

### 5.2.2 Irregular indications speed trend vector

After the event each crew members reported an irregular speed trend vector indication. According to the first officer the speed trend vector was negative between 90 and 140 knots, which would indicate the aircraft was expected to slow down in the next 10 seconds. The captain stated that around 140 knots airspeed, a large speed trend vector in positive direction was observed on his display.

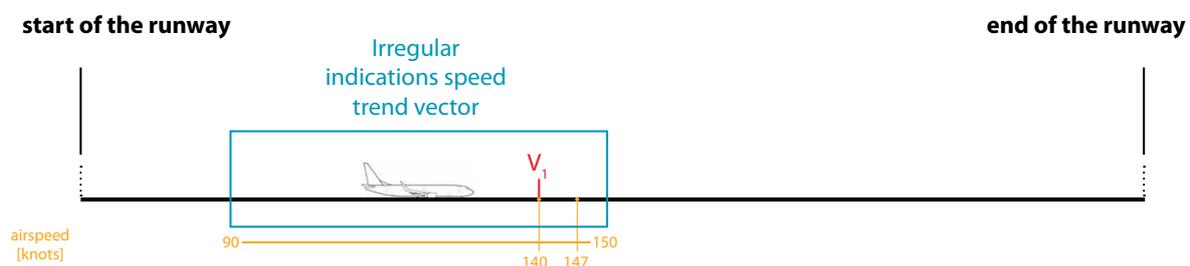


Figure 7: Timeframe airspeed from 90 to 150 knots where irregular speed trend vector was observed.

The captain as the pilot monitoring should be observing and verifying conditions of aircraft systems during the takeoff roll. The captain had noticed a large positive speed trend vector but deemed this not an issue for takeoff. The first officer also observed an irregular speed trend vector during the takeoff roll. This implies that the instruments in cockpit were showing large deviations which were noticed by both crewmembers.

The speed trend vector is intended to assist the crew in-flight with throttle selection to fly appropriate airspeeds. There is no reference in any manual or training program as to how the speed trend information should be used or monitored during takeoff. The speed trend vector is calculated using the computed airspeed and the aircraft longitudinal acceleration. According to the data from the flight data recorder the longitudinal<sup>9</sup> acceleration was smooth. The flight data shows that speed variations began appearing in the data at 110 knots of airspeed. The recorded computed airspeed, by contrast, showed sharp increases and decreases around 135 knots. Calculations based on the available recorded airspeed data showed that the speed trend arrow could have increased to the full length of the display in positive direction. Also, the later steep decrease in the recorded airspeed,

8 Appendix G: aircraft wake turbulence an explanation is given on this phenomenon.

9 Longitudinal acceleration, a speed increase in the forward direction of the aircraft.

may have caused a negative speed trend vector. The recorded computed airspeed is available from the captain's side only; no data is available from the first officer's side because it is not recorded.

The observations made by both crew members regarding the speed trend vector being large positive and negative could be explained by a difference in measured airspeeds between the left and right side airspeed computers (ADIRU) of the aircraft. Analysis of the angle of attack sensor, which measures the airflow direction passing over the aircraft, showed that there were differences between the left and right side. This angle of attack difference leads to the conclusion that the airflow was disturbed and the airflow was asymmetric between the left and right side. In any event when airspeed or angle of attack deviations are large for a certain period, warnings will appear<sup>10</sup>. Such warnings were not noted by the crew or recorded. Analyses show that the period where large changes occurred lasted for a short time. It is thus very likely the differences would not have triggered warnings.

Although the recorded airspeed was only available from the captain's side it is likely that similar deviations occurred on the first officer's side. However, since the available airspeed data was from the captain's side only, a definitive conclusion could not be reached. It is possible that some sort of atmospheric disturbance occurred which explains the sharp deviation in computed airspeed. A explanation or cause for a atmospheric disturbance could not be determined. However in the previous timeframe, start of takeoff roll, an atmospheric disturbance was deemed to be the likely cause.

### 5.2.3 Aircraft rotation

The first officer stated that the control column was moving towards him at a speed around  $V_1$ . Both the control column positions and the control column forces were recorded on the flight data recorder. The data showed that around  $V_1$  no movement or force was applied on the control column. The data from the flight data recorder showed that the first officer performed a flight control check during taxiing, at that time no anomalies were detected. Analysis and comparison of the control column positions and forces with previous flights did not reveal any difference. A possibility exist whereby the aircraft could rotate on its own due to improper weight and balance or large trim setting. However the weight and balance of the aircraft was within prescribed limits. Also the trim setting according to the flight recorder was as to be expected.

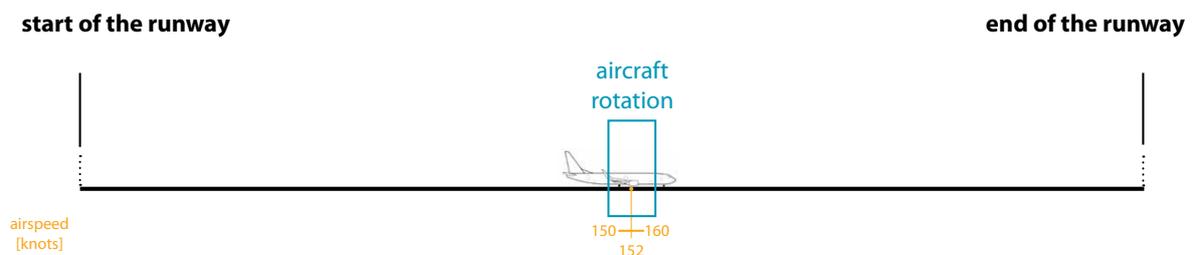


Figure 8: Timeframe between 150 and 160 knots where the aircraft rotated.

Data on the flight data recorder shows that around the time of rotation of the aircraft, large lateral accelerations (left and right movement) were recorded. The heading of the aircraft subsequently changed and the rudder pedals were used to align the aircraft back to the runway heading. These large lateral accelerations occurred around the same time the control column was moved aft in order to rotate the aircraft. The lateral accelerations were quite large and could have induced a feeling (tactile input) to the first officer which gave him the impression the aircraft was unsafe to fly. This input may have led the first officer to deem the aircraft to be unsafe to fly and reject the takeoff.

10 Indicated airspeed warning will appear if the difference between the left and right side is more than 5 knots for 5 seconds. The angle of attack disagree warning will appear if difference is 10 degrees for 10 seconds.

The reason for the large lateral accelerations was probably caused by an external, possibly atmospheric, phenomena. This would be a third time an anomaly could be related to an outside atmospheric phenomena. Up to this moment in time no warnings or failures were recorded on the flight data recorder.

5.2.4 Rejected takeoff roll

Data from the autothrottle and flight data recorder indicated that the takeoff was rejected at 152 knots, which was above the 141 knots  $V_1$  speed determined by the crew. The applicable  $V_1$  speed was obtained prior to takeoff from the regulated takeoff mass (RTOM) tables presented in the aircraft manual. Included in this manual are circumstances in which the V-speed need to be adjusted (runway condition, runway slope, wind conditions or temperature etc). On the day of the event no adjustments were made nor were they required.

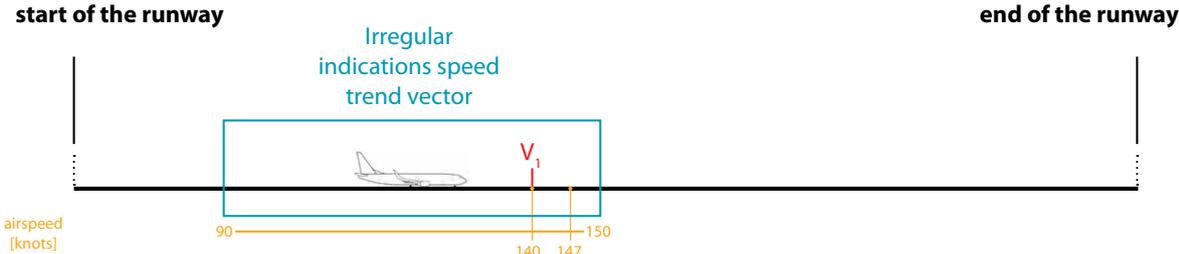


Figure 9: Timeframe of the rejected takeoff starting from the maximum of 160 knots to standstill.

The available runway length at Eindhoven and weather conditions at the day of the event were not a limiting factor for the aircraft. Favourable conditions (aircraft weight and good runway friction) were present. The friction coefficient of 0.81 means that the braking action was good. The runway length of 3000 metres was sufficient and the flight crew elected to request exit GOLF during taxi, thereby utilising the full length of the runway. The aircraft stopped approximately 500 metres from the runway end despite rejecting the takeoff at a speed above  $V_1$ .

The information available in this investigation and the flight data show that the aircraft systems were operating normally and no warnings were given for system malfunctions. The collected information further shows that during the takeoff roll the aircraft experienced an undetermined atmospheric disturbance. The first officer felt and interpreted this disturbance as an unsafe condition to continue the takeoff. This feeling led to the decision to reject the takeoff after the takeoff decision speed  $V_1$ .

5.3 REJECTED TAKEOFF PROCEDURES RYANAIR

Procedures are laid down for pilots to help them in the decision process to reject a takeoff. In the Quick Reference Handbook (QRH) two procedures are written down under which circumstances the takeoff should be rejected. It must be noted that the two procedures do not match up with respect to the speed conditions. The first procedure described circumstances to reject above 80 knots and prior to  $V_1$ . The second procedure described the same circumstances but only says above 80 knots.

QRH procedure	Condition 1	Condition 2
MAN 1.1	Prior to 80 knots	Above 80 knots and prior to $V_1$
MAN 2.5	Prior to 80 knots	Above 80 knots

Table 3: Textual comparison of the speed conditions for rejecting a takeoff given in the Quick Reference Handbook in section 1.1 and 2.5.

From the two procedures in the same manual it is unclear which condition should be used at any given time. However, in section 1.1 of the QRH an overriding statement is given that the decision must be made in time start the reject the takeoff manoeuvre by  $V_1$ .

From various information(literature and manuals) received it is assumed that when the aircraft is unsafe or unable to fly the takeoff should be rejected even if the airspeed is beyond  $V_1$  as flying

under this circumstance could be more dangerous than rejecting the takeoff. In other circumstances described in the procedure it is preferred to continue the takeoff.

In the Quick Reference Handbook, rules on the rejected takeoff can be divided into two aspects, prescriptive and general rules. An example of a prescriptive rule on rejected takeoff is; if a fire warning appears before 80 knots reject the takeoff. The prescriptive rule specifies an occurrence and an appropriate action, an if-then rule. This if-then rule is accommodating in the decision making process and takes little processing time if such a circumstance is detected.

General rules are universal rules and less specific. The general rule is to reject the takeoff in case the aircraft is "unsafe or unable to fly". The QRH does not define the terms "unsafe" or "unable", thus leaving room for interpretation. This general rule takes time to process, evaluate circumstances, apply and take appropriate action.

On the request of the Safety Board the terms "unsafe" and "unable to fly" were defined by the aircraft manufacturer Boeing.

*Unsafe to fly*      *the circumstance whereby rejecting the takeoff carries significantly less risk than flying the aircraft.*

*Unable to fly*      *the circumstance where there is a reasonable probability of not being able to control the aircraft if the takeoff is continued and the aircraft becomes airborne.*

The clarification given is a universal explanation and focuses on a result which again requires interpretation and pilot judgment. The reason given for not defining circumstances which fall under the "unable" or "unsafe" to fly is that this may lead to misunderstanding amongst crews and ultimately to incorrect decision making. On the other hand not defining the circumstances leaves room for interpretation. During takeoff the time to make a decision and take action is minimal, guidance and training is therefore essential. With rules that require interpretation and judgment pilots face a dilemma in a potentially critical time situation.

In the operators guidance and rules it is written that the captain is the only one with the authority to reject the takeoff. For this reason the hand of the captain is near engine controls in case of a decision to reject the takeoff. In the event of a controllability issue it is very likely the pilot flying is the crewmember who experienced and is faced with the problem, in this case it was not the person authorised to make the rejected takeoff decision.

#### 5.4 REJECTED TAKEOFFS IN A HISTORICAL PERSPECTIVE

It is clear from previous paragraphs the decision to reject the takeoff is not always clear. Rejected takeoffs are not uncommon and in the past have resulted into accidents. Several studies and investigations were performed on rejected takeoffs, a general overview of these studies will follow.

In 1990 a Special Investigation Report Runway Overruns following high speed rejected takeoffs was published by the National Transportation Safety Board (NTSB) of the United States of America. The NTSB conducted this investigation to determine how the safety of rejected takeoffs could be enhanced and the rate of incidents reduced. The investigation used a variety of information on rejected takeoffs including historical accident data and airline procedures. In this special investigation report several recommendations are made to the Federal Aviation Administration (FAA) on improving safety for rejected takeoffs. An overview of the recommendations are presented in appendix H.

In 1994 the FAA in a joined effort with industry created a training tool for rejected takeoffs, the Takeoff Safety Training Aid. The main purpose of this training tool was to reduce the number of rejected takeoffs by improving flight crew decision making process, knowledge and awareness. The Takeoff Safety Training Aid describes the background of events and lays down training methods and simulator scenarios for pilot training on rejected takeoff decision making. The "Takeoff Safety

Training Aid” training program is designed to facilitate flight crews in reaching and maintaining proficiency in:

- Recognising and understanding situations and factors that make high speed rejected takeoff decisions critical.
- Making appropriate Go/No Go decisions.
- Executing rejected takeoff procedures and employing techniques that maximises the stopping capability of the airplane should a high speed rejected takeoff be necessary.
- Continuing the takeoff safely should that be deemed the most appropriate course of action.

In this safety training aid, data and background information on rejected takeoffs from 1959 up to 1990 is presented. It is reported that 76% of all rejected takeoffs are initiated at speeds of 80 knots or less. The rejected takeoffs at low speed almost never result in an accident. About 2% of the rejected takeoffs are initiated at speeds above 120 knots. Statistically more than half of the runway overruns or excursions have occurred when the rejected takeoffs were initiated at high speeds (greater than  $V_1$ ).

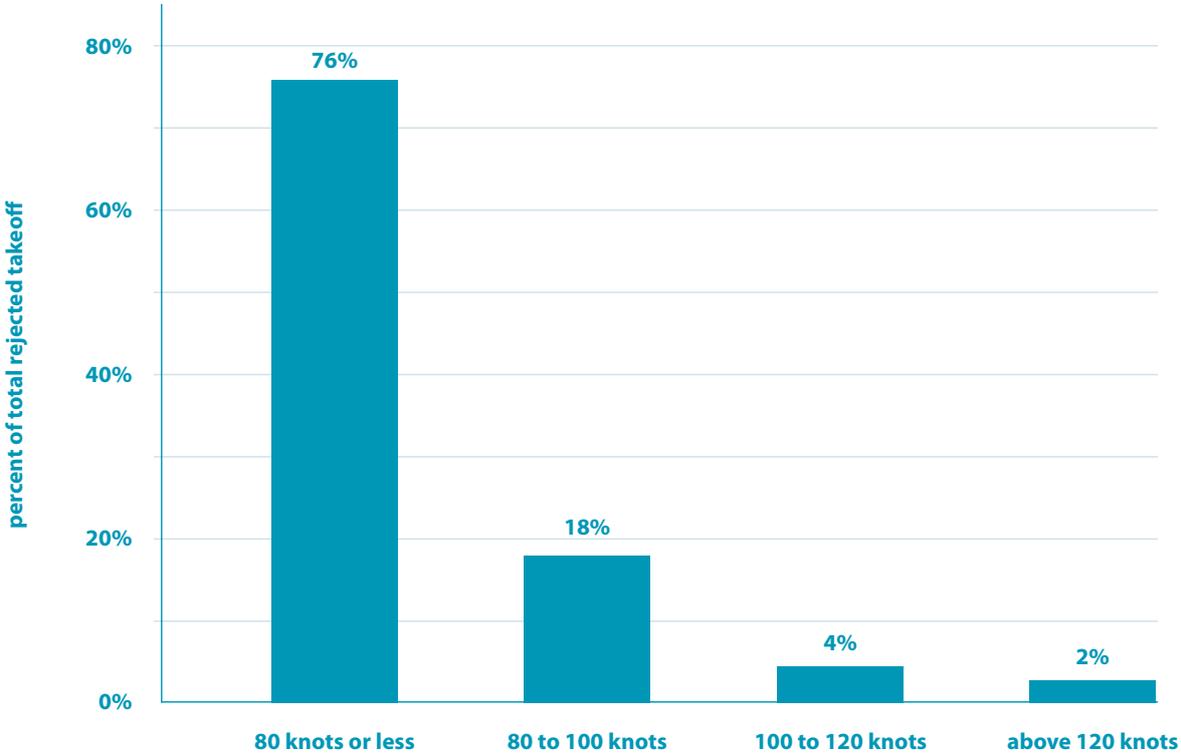


Figure 10: Distribution of rejected takeoff initiation speeds. Source: Takeoff Safety Training Aid – U.S. Department of Transportation - Federal Aviation Administration.

According to the Takeoff Safety Training Aid in the event the airspeed is beyond  $V_1$  a “go decision” is less hazardous and the takeoff should therefore not be rejected. The reasoning is that the problem faced by the flight crew may be handled more safely as an in-flight problem than a high speed rejected takeoff. The reasons for rejecting a takeoff vary from an indicator/light to wheel or tire failure. Engine failure make up 24% of the reasons to reject a takeoff.

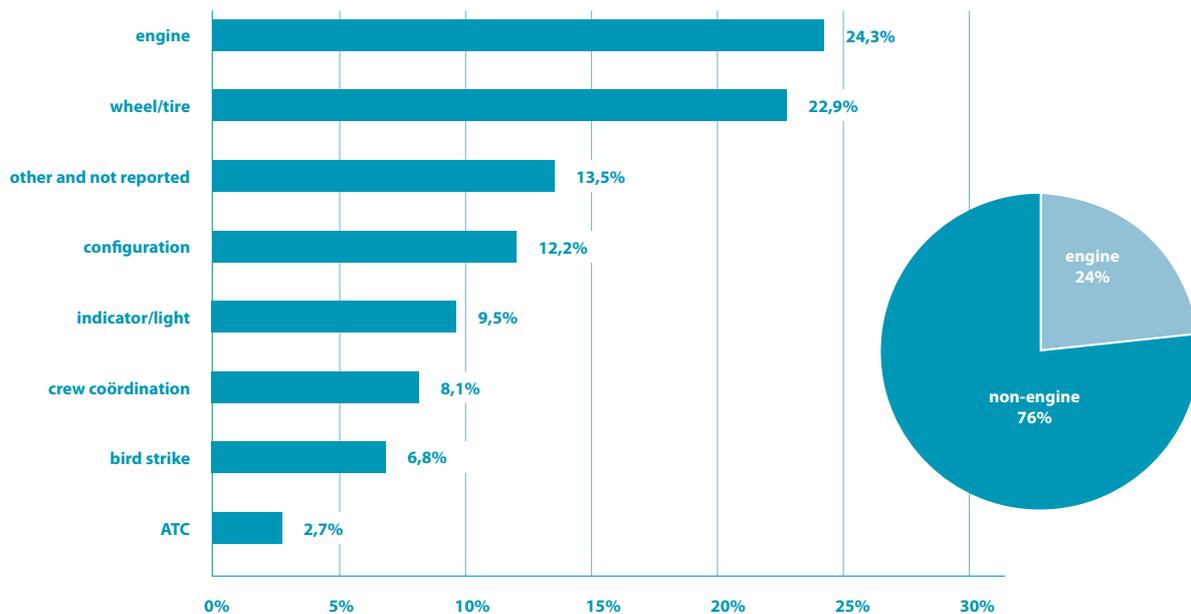


Figure 11: Reason for initiating an rejected takeoff total of 74 events for all speeds. Source: Takeoff safety training aid – U.S. Department of Transportation - Federal Aviation Administration 1993.

In an advisory circular AC no: 120-62 the FAA recommends the use of the Takeoff Safety Training Aid to operators. It is recommended that the training aid is incorporated in the operators flight crew training and qualification programs of operators. FAA inspectors are required to check the operators manuals and training to asses if the Takeoff Safety Training Aid is used and guidelines are followed.

In 2004 the pilot guide to takeoff safety (section 2 of the training aid) was updated. The study period was extended from 1959 up to 2003 and accident data was supplemented with 25 additional rejected takeoffs. The additional data showed that the rate of rejected takeoff decreased. The engine related rejecting takeoffs decreased and wheel/tire failures increased by a small percentage.

In late 2006, the Flight Safety Foundation initiated a project entitled Runway Safety Initiative (RSI) to address the challenge of runway safety. An in-depth study was conducted of all runway excursion accidents from 1995 through March 2008 to investigate the causes of runway excursion accidents and to identify the high-risk factors. Data was analysed to identify the most common risk factors, both in takeoff excursions and landing excursions. The most common risk factor in takeoff excursions was a rejected takeoff initiated at a speed greater than  $V_1$ . Loss of pilot directional control was the next most common, followed by rejecting the takeoff before  $V_1$  was reached. This study concludes that a mishandled rejected takeoff increases the risk of takeoff runway excursion. Operators should emphasise and train for proper execution of the rejected takeoff decision and training should emphasise recognition of takeoff rejection issues. Furthermore Cockpit Resource Management and adherence to Standard Operating Procedures are essential in time-critical situations such as rejected takeoffs.

A recent study (2010) by the National Aerospace Laboratory, in the Netherlands compared rejected takeoff events for the period 1980-1993 with the period 1994-2008. The split 1993-1994 was chosen because in 1994 the Takeoff Safety Training Aid was introduced. The NLR study shows that the occurrence rate of rejected takeoffs in general has decreased, however the rate of high speed rejected takeoffs has not changed.

In the NLR study the decision to reject a takeoff is also examined. The study shows that the correctness of the decision to reject a takeoff before and after 1994, the introduction of the Takeoff Safety Training Aid, has not increased. The statistical information on the correctness of the decision to reject a takeoff is based on hindsight. Pilots at the time thought they were making the right decision. The study concludes that especially in complex situations, for example a combination of engine failure with significant vibration, it is difficult to assess. Assessing a complex situation and

deciding to reject the takeoff is also not well trained. The study points out that the lack of reference as to what might make the aircraft unsafe to fly makes it difficult for crews in recognising such a situation to make an appropriate decision. It should be noted that care must be taken in comparing the positive (yes) and negative (no) decision to reject the takeoff. The undetermined reasons of correctness of the decision has increased in the period 1994-2008 versus 1980-1993.

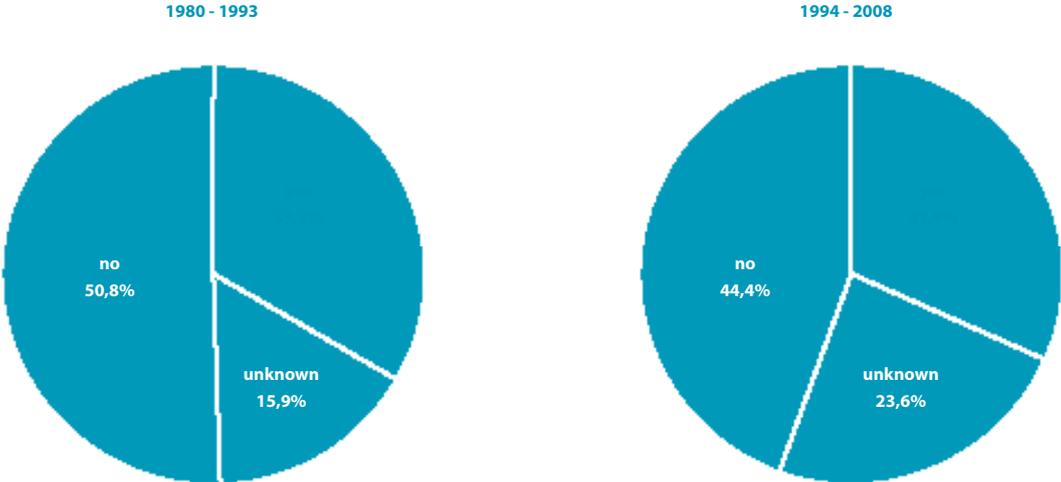


Figure 12: Correct decision to reject a takeoff. Source: NLR-TP-2010-177 NLR Air Transport Safety Institute 2010.

5.5 REJECTED TAKEOFF DILEMMA

In the past industry initiatives and studies have identified that rejected takeoffs are a high risk area. Analysis of available data highlighted that after  $V_1$  and  $V_R$  a runway overrun is likely and could potentially result in aircraft damage and/or loss of life. Statistics further show that the rate of rejected takeoff is declining. However the rate of high speed rejected takeoffs is not. In general past studies conclude that if procedures were followed the outcome would have been different. This conclusion it subsequently followed by the recommendation that flight crew should follow procedures and act accordingly.

Despite simulator training on rejected takeoffs and instruction on the risks of (high speed) rejected takeoffs flight crews, when faced with a problem in reality, do not always react desirably and follow procedures. This is mainly due to the fact that during takeoff the interaction between the aircraft, environment and crew are tightly related. This interaction may result in a complex situation which is unfamiliar and difficult to assess.

Technical monitoring and warning system were introduced into aircraft in the past which, when appropriate, would warn flight crew of a problem. This warning system monitors aircraft condition and should help flight crew in assessing situations correctly. In this event no warnings were triggered and the aircraft did not indicate there was a problem. From a manufacture standpoint the aircraft was therefore airworthy and safe to fly. The control check performed before flight is, in part, to assess the aircraft state and verify control responses. The environmental conditions like snow and rain on a runway are addressed in manuals to help flight crew in determining aircraft performance and make adjustments. This information is used to set preconditions and determine decision speeds.

The fact remains that despite aircraft monitoring and managing preconditions impacting aircraft performance unexpected situation may occur. On takeoff the flight crew rely on perception and interpretation of situations. This perception and interpretation provides opportunity for errors in decision making. Guidance, procedures and training should help pilots in the decision making process in the critical phase of flight. With the current state of technology and human factors theories available, a re-evaluation of the rejected takeoff concept and procedures may be useful and warranted.

## 6 CONCLUSIONS

During the takeoff at Eindhoven airport the pilot flying perceived two control issues and one speed trend vector anomaly.

- The explanation for the control issues and speed trend vector anomaly was likely related to an outside atmospheric phenomenon. The origin of this atmospheric phenomenon could not be determined or explained with the information available.

The takeoff was rejected after the decision speed  $V_1$  and while the nose wheel was off the ground for approximately two seconds.

- The First Officer who was the pilot flying considered the control and speed trend vector problems to be serious enough and decided to reject the takeoff.
- According to company procedures only the Captain is authorized to make a rejected takeoff decision.
- To reject a takeoff above  $V_1$ , especially when the nose wheel is off the ground, is in principle considered to be improper and unsafe.

There is no specific guidance from the operator or manufacturer on dealing with control issues at the time of rotating the aircraft.<sup>11</sup>

- Specific guidance on rejecting a takeoff exist in case of an engine failure.
- Review of past statistics and studies show that pilot training and requirements focus on rejected takeoffs due to an engine failure. Studies and statistical information show that this accounts for less than 25% of the reasons for rejected takeoffs. Thus 75% of the reasons the reject a takeoff is not trained for.

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11 It has been suggested that in this case guidance is given in the FCTM and a Memo of the Chief Pilot. This gives pilots extensive guidance how to manage an aircraft before and during rotation when gust or crosswind are present ("outside atmospheric phenomena").

## APPENDIX A: JUSTIFICATION OF INVESTIGATION

### *Scope*

The investigation of the Dutch Safety Board focuses on determining the causes or probable causes, the underlying conditions and possible structural safety shortcomings that form the basis which caused the event.

The following aspects were not investigated further, nor partly investigated:

- Specific individual flight crew training and performance
- Aircraft systems and components removed from the aircraft
- Emergency response of the airport

### *Interviews*

Interviews were held with the two flight crew members. A statement was received from the avionics engineer who performed test and maintenance on the aircraft after the event. General information on the operation and flight crew training was received from Ryanair.

### *Draft report*

A draft report was submitted to the parties directly involved in accordance with the Dutch Safety Board Act in order to review the report on factual inaccuracies. The draft version of this report has been submitted to the following parties:

- The captain
- The copilot
- Air Accident Investigation Unit, Ireland
- Operator Ryanair, Ireland
- National Transportation Safety Board, United States of America
- Boeing Commercial Airplanes, United States of America
- European Aviation Safety Agency

To the extent of non-textual, technical aspects and factual inaccuracies are concerned, the Safety Board has incorporated the comments received into the final report. The received comments to which the Board has not amended the report the Board has formulated a response given here.

Comments not incorporated: paragraph 2.4

AAIU comment: I would respectfully suggest that a new paragraph be inserted here which concerns an operational aspect to the event. At the beginning of the takeoff run, the aircraft was completely serviceable with no indications of any defects. Yet by the  $V_1$  call, the First Officer was of the opinion that the aircraft was 'unsafe to fly'. Apart from the standard '80 kts' call, there was no communication between either Flight Crew that anything was amiss or perceived to be amiss during the entire takeoff run. While an operational issue, the lack of effective crew co-ordination during the take-off run may need to be discussed. Had the First Officer communicated his misgivings regarding the directional control earlier then the problem 'perceived' by him may have been resolved or the decision made to stop by the Commander at a safe speed well below  $V_1$

Board response:

The goal of the investigation was to answer the investigative questions as described in chapter 1 paragraph 1.2.2 with the facts that are available. The takeoff roll was described using the available information from the flight data recorder and the statements made by the crew during interviews. Because the Cockpit Voice Recorder was not available there was no factual evidence available that would allow the assessment of the cockpit crew co-ordination. To assess the cockpit crew co-ordination based on statements alone is insufficient.

Comments not incorporated: paragraph 2.9 .... Position of the AOA sensor.....

Remark - Air Accident Investigation Unit – "AOA comment is not relevant and should be removed. AOA movement with the aircraft stopped is entirely normal and not relevant to this incident."

Board response:

One of the reasons to reject the takeoff was the irregular speed trend vector indications. The AOA sensor is part of the calculation of speed trend vector. As mentioned in the report the airspeed disagree which was determined during testing was caused by the AOA being misaligned for the test. Therefore it is pertinent to address the position of the AOA sensor in this report.

## APPENDIX B: V-SPEEDS

Definitions of V-speeds according to the US Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) are:

$V_1$  Maximum speed in the takeoff at which the pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes) to stop the airplane within the accelerate-stop distance.  $V_1$  also means the minimum speed in the takeoff, following a failure of an engine at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance.

$V_R$  Rotation speed.

$V_2$  Takeoff safety speed.

Other definitions:

$V_1$  Maximum speed at which a rejected takeoff can be initiated in the event of an emergency and at which a pilot can safely stop the aircraft without leaving the runway.

$V_R$  Speed at which the pilot makes a control input, with the intention of lifting the airplane out of contact with the runway or water surface.

$V_2$  Minimum speed that needs to be maintained up to acceleration altitude, in the event of an engine failure after  $V_1$ . Flight at  $V_2$  ensures that the minimum required climb gradient is achieved, and that the aircraft is controllable.

Current certification requirements and rules require the following speed conditions:

$V_1$  must not be greater than  $V_R$ .

$V_2$  may not be less than  $V_R$  plus the speed gained before reaching a height of 35 feet above the takeoff surface.

Therefore  $V_1$  is smaller or equal to  $V_R$ , which is smaller than  $V_2$ .

Apart from the V-Speeds a high and low speed regime is also distinguished. The low speed regime is the region where the airspeed is below 80 knots. At 80 knots the flight crew cross check their instruments. Above 80 knots the aircraft is in the High speed regime.

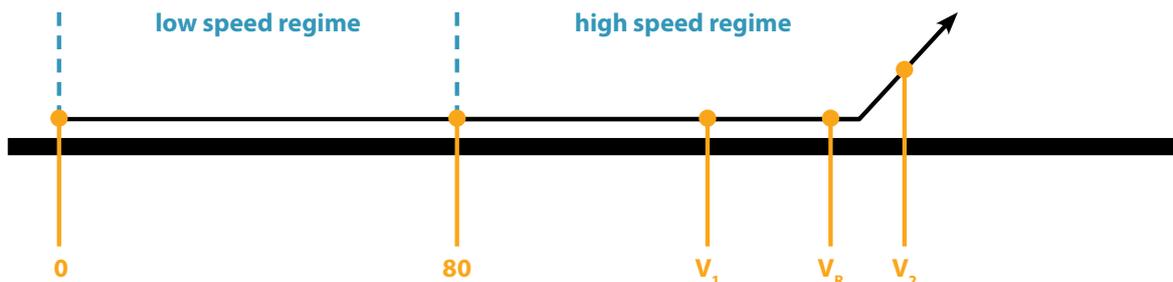


Figure 13: Schematic overview of the V-speeds and the high and low speed regime.

## APPENDIX C: FLIGHT DATA RECORDER PLOT

Parameter	Description
ANGLE OF ATTACK L	The angle between the airflow and aircraft body axis - left.
ANGLE OF ATTACK R	The angle between the airflow and aircraft body axis - right.
BRAKE PRES L	Pressure of the brake system – left.
BRAKE PRES R	Pressure of the brake system – right.
CAP DISPLAY HEADING	The aircrafts magnetic heading .
CAPT DISPLAY PITCH ATT (DEG)	Nose attitude of the aircraft displayed on the PFD of the captain. A positive angle means nose up.
COMPUTED AIRSPEED	The speed of the aircraft in relation to the air.
CTRL CLMN POS CAP	Position control column captain side. Positive value means control column aft, nose of the aircraft goes upward.
CTRL CLMN POS F/O	Position control column first officer side. Positive value means control column aft, nose of the aircraft goes upward.
FLAP HANDLE POSN	Position of the flap handle in the cockpit.
GROUNDSPEED	The speed of the aircraft in relation to the ground.
LATERAL ACCEL	The acceleration in the lateral direction of the aircraft body.
LONGITUDINAL ACCEL	The acceleration in the longitudinal direction of the aircraft body.
NOSE GEAR AIR-GRND	Indicates if the nose wheel is on the ground or in the air.
RUDDER PEDAL POSN	The position of the rudder pedals.
SEL TRA FILTERED E1	The position of the throttle in degrees. (E1 = left). The value of 35 degrees corresponds to 'idle'.
SEL TRA FILTERED E2	The position of the throttle in degrees. (E2 = right). The value of 35 degrees corresponds to 'idle'.
SPD BRAKE HNDL POSN	Position of the speed brake handle.

*Tabel 4: Overview parameters Flight Data Recorder*

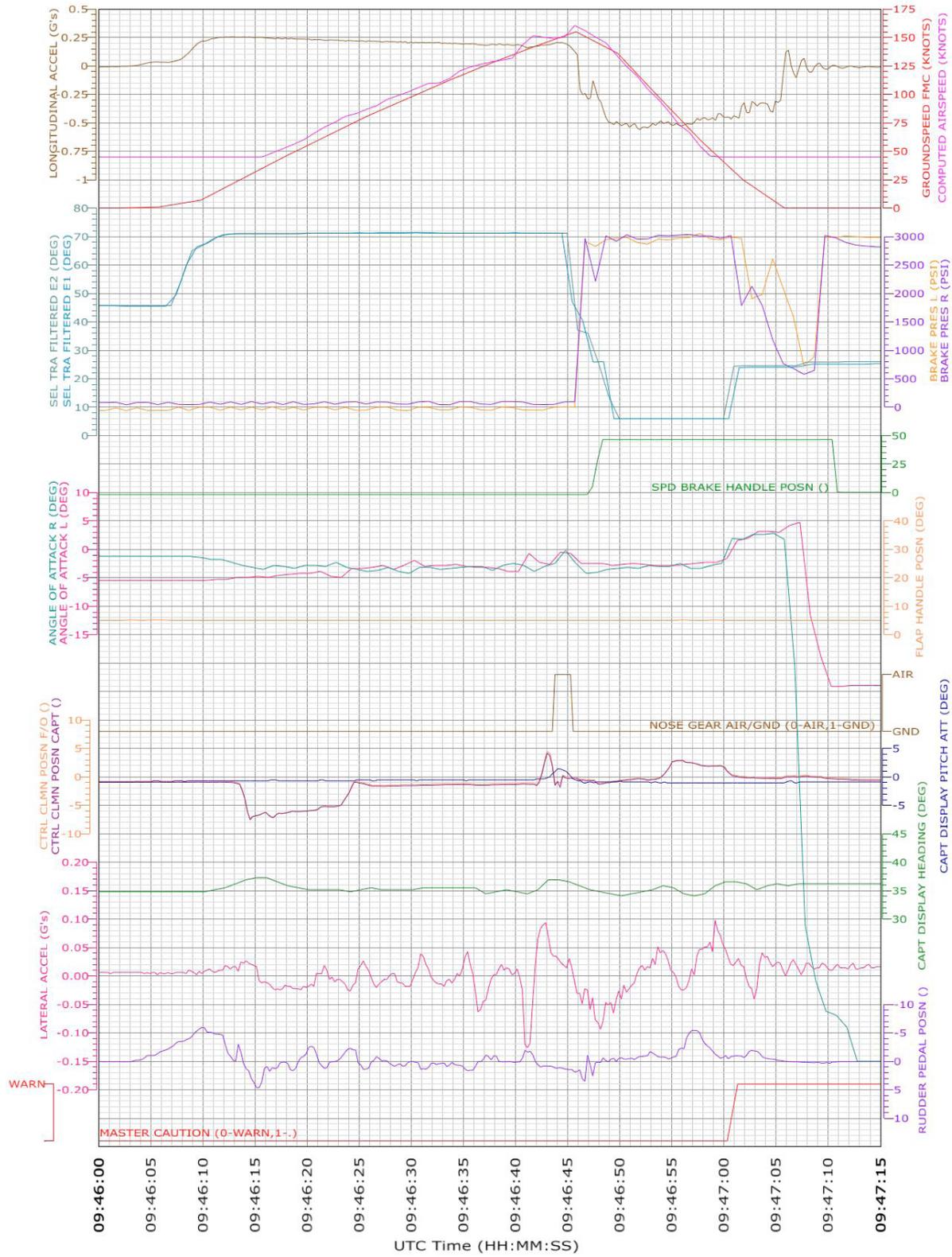


Figure 14: Flight Data Recorder plot.

**APPENDIX D: DETERMINATION OF THE SPEED TREND VECTOR LENGTH**

Apart from the operational investigation, the B737-800 simulator tests were also conducted to determine the length of the speed trend vector during the takeoff roll. Using video equipment the length of the arrow was recorded and analysed later. These tests and video analysis showed that on average the speed trend vector length was approximately 40-45 knots. The maximum the tip of the speed trend vector arrow can point to is 60 knots. During the takeoff roll the length of the speed trend arrow was about 2/3 of the maximum length.

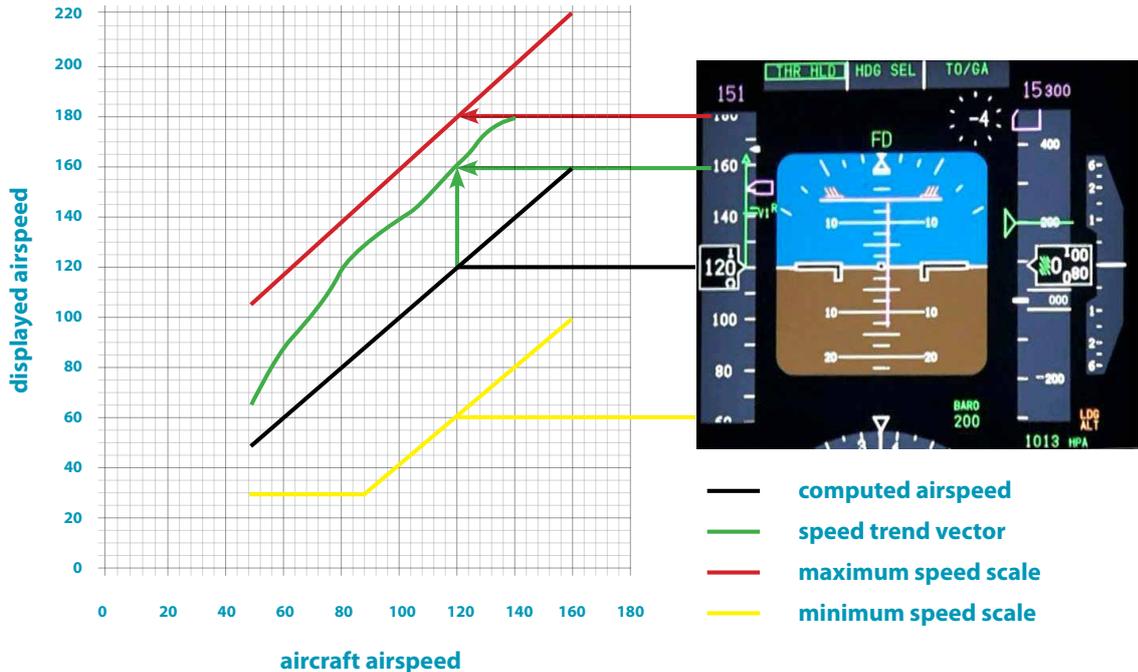


Figure 15: Graphical representation of the recorded airspeed and speed trend vector length.

In Figure 15, the yellow and red line depicts the minimum and maximum displayed airspeed on the moving scale tape. In black the displayed airspeed is shown and in green the airspeed which the tip of the speed trend vector. The length of the speed trend vector on the display is the vertical difference between the displayed airspeed (black) and the tip of the speed trend vector (green).

## APPENDIX E: REJECTED TAKEOFF PROCEDURE RYANAIR [MAN 1.1]

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### Rejected Takeoff < RYR >

The captain has the sole responsibility for the decision to reject the takeoff. The decision must be made in time to start the rejected takeoff maneuver by V1. If the decision is to reject the takeoff, the captain must clearly announce "STOP," immediately start the rejected takeoff maneuver and assume control of the airplane. If the first officer is making the takeoff, the first officer must maintain control of the airplane until the captain makes a positive input to the controls.

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MAN.1.1

Maneuvers -  
Non-Normal Maneuvers



737 Flight Crew Operations Manual

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Prior to 80 knots, the takeoff should be rejected for any of the following:

- activation of the master caution system
- system failure(s)
- unusual noise or vibration
- tire failure
- abnormally slow acceleration
- takeoff configuration warning
- fire or fire warning
- engine failure
- predictive windshear warning
- if a side window opens
- if the airplane is unsafe or unable to fly.

Above 80 knots and prior to V1, the takeoff should be rejected for any of the following:

- fire or fire warning
- engine failure
- predictive windshear warning
- if the airplane is unsafe or unable to fly.

During the takeoff, the crewmember observing the non-normal situation will immediately call it out as clearly as possible.

# APPENDIX F: REJECTED TAKEOFF PROCEDURE RYANAIR [MAN2.5]



## Rejected Takeoff < RYR >

<p><b>Reasons to Reject;</b> Prior to 80 kts</p> <ul style="list-style-type: none"> <li>• Master Caution activation</li> <li>• System failure(s)</li> <li>• Unusual noise or vibration</li> <li>• Tire failure</li> <li>• Abnormally slow acceleration</li> <li>• Takeoff configuration warning</li> <li>• Fire or fire warning</li> <li>• Engine failure</li> <li>• Predictive windshear warning</li> <li>• If a side window opens</li> <li>• Airplane unsafe or unable to fly</li> </ul>	<p><b>Captain's Actions</b></p> <ul style="list-style-type: none"> <li>• Captain calls "STOP" and takes control of airplane</li> <li>• Closes thrust levers, disengage autothrottle</li> <li>• RTO braking or max manual braking as required</li> <li>• Raise speed brake lever</li> <li>• Apply maximum reverse thrust consistent with runway conditions</li> <li>• Stop aircraft on runway heading or consider turning into wind if the takeoff was rejected due to fire warning.</li> <li>• Set parking brake</li> </ul>	<p><b>First Officer's Actions</b></p> <ul style="list-style-type: none"> <li>• Verify all items for the reject have been actioned by the Captain and call any omissions</li> <li>• Note the brakes on speed</li> <li>• Call "100, 80 and 60" kts</li> <li>• Call "Autobrake disarm"</li> <li>• Alternating red and white runway lights call "900 meters." Steady red lights call "300 meters" of runway remaining</li> <li>• Select Flaps 40 when parking brake is set</li> <li>• Inform ATC including information on airplane position</li> </ul>
<p>Above 80 kts</p> <ul style="list-style-type: none"> <li>• Fire or fire warning</li> <li>• Engine failure</li> <li>• Predictive windshear warning</li> <li>• Airplane unsafe or unable to fly</li> </ul>	<p><b>NOTE: CSS calls the flight deck using the interphone. It is important for the capt to establish communications at this point.</b></p>	<p><b>NOTE: UK airfields fire frequency is 121.6 MHz</b></p>



**APPENDIX G: AIRCRAFT WAKE TURBULENCE**

The lift of an aircraft is generated by a pressure differential over the wing surfaces. The lowest pressure occurs over the upper wing surface and the highest pressure under the wing. This pressure differential triggers an airflow rollup aft of the wing resulting in swirling air masses trailing downstream of the wing-tips (vortices).

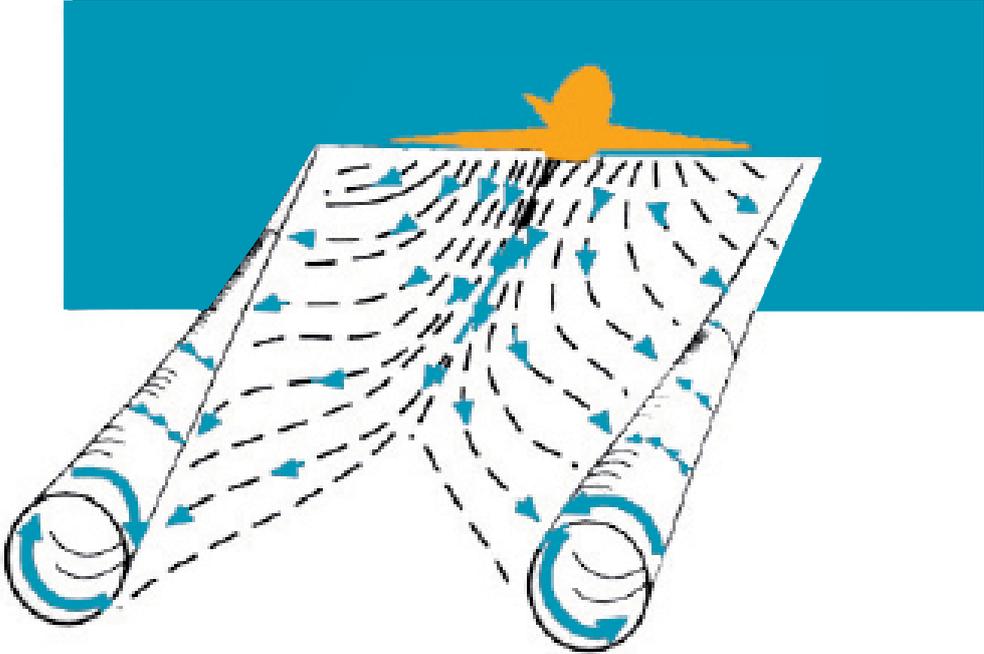


Figure 16: view from the rear of the aircraft showing the vortex coming from the left and right wing.

The vortices are generated from the moment an aircraft leaves the ground, since trailing vortices are a by-product of wing lift. The strength of the vortex is governed by the weight, speed, and shape of the wing of the generating aircraft. The vortex characteristics of any given aircraft can also be changed by extension of flaps or other wing configuring devices. However, as the basic factor is weight, the vortex strength increases proportionately with increase in aircraft operating weight. The vortex will lose its strength over time, in general between two to three minutes is the rule of thumb between aircraft taking off.

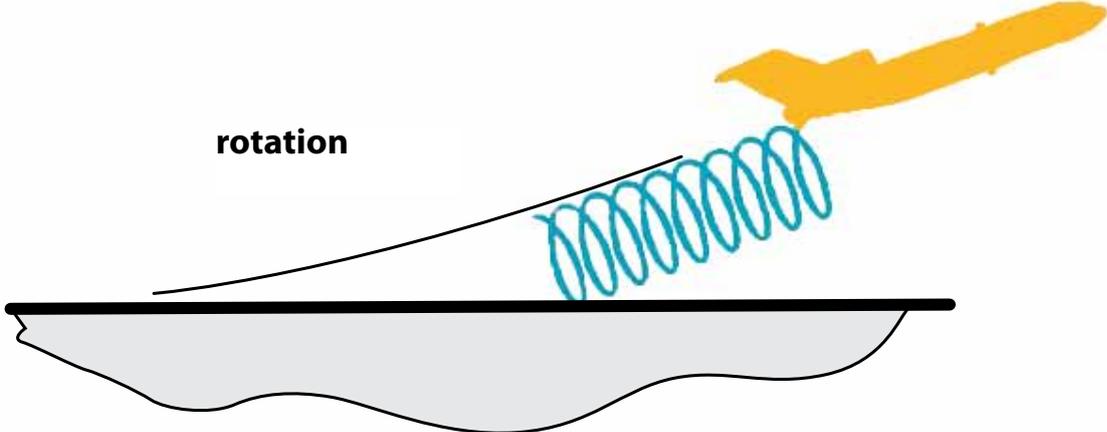


Figure 17: view from the side showing an aircraft taking off with the vortex behind the aircraft.

## **APPENDIX H: NTSB RECOMMENDATIONS ON ENHANCING REJECTED TAKEOFF SAFETY 1990**

The National Transportation Safety Board (NTSB) made recommendations in the special investigation runway overruns following high speed rejected takeoffs report. A total of nine recommendations were made to the Federal Aviation Administration (FAA).

*Redefine  $V_1$  in 14 CFR 1.2 and 14 CFT 25.107 (2) to clearly convey that it is the takeoff commitment speed and the maximum speed at which rejected takeoff action can be initiated to stop the airplane within the accelerate-stop distance. (Class II, Priority Action)(A-90-40)*

*Require Principal Operations Inspectors to review the accuracy of information on  $V_1$  and rejected takeoff that 14 CFR 121 operators provide to flight crews to assure that they provide correct information about pilot actions required to maximise the stopping performance of an airplane during a high speed rejected takeoff. (Class II, Priority Action) (A-90-41)*

*Require 14 CFR 121 operators to present to flight crews the conditions upon which flight manual stopping performance is predicated and include information about those factors which adversely affect stopping performance. (Class II, Priority Action) (A-90-42)*

*Require that simulator training for flight crews of 14 CFR 121 operators present, to the extent possible, the cues and cockpit warnings of occurrences other than engine failures that have frequently resulted in high speed rejected takeoffs. (Class II, Priority Action) (A-90-43)*

*Require that simulator training of 14 CFR 121 operators present accurately the stopping distance margin available for a rejected takeoff initiated near or at  $V_1$  on runway where the distance equals or just exceeds balanced field conditions. (Class II, Priority Action) (A-90-44)*

*Require that simulator training for flight crews of 14 CFR 121 operators emphasise crew coordination during rejected takeoffs, particularly those rejected takeoffs that require transfer of control from the first officer to the captain (Class II, Priority Action) (A-90-45)*

*Require 14 CFR 121 operators to review their policies which permit first officers to perform takeoffs on contaminated runways and runways that provide minimal rejected takeoff stopping distance margins, and encourage the operators to revise those policies as necessary. (Class II, Priority Action) (A-90-46)*

*Require that the takeoff procedures of 14 CFR 121 operators are standardised among their airplane types to the extent possible, and that the procedures include appropriate callouts to alert flight crew members clearly and unambiguously when the airplane is entering the high speed takeoff regime and when the rejected takeoff is being initiated. (Class II, Priority Action) (A-90-47)*

*Require 14 CFR 121 operators to require pilots to adopt a policy to use the maximum brake capability of autobrake systems, when installed on the airplane, for all takeoffs in which runway conditions warrant and where minimum stopping distances are available following a rejected takeoff. (Class II, Priority Action) (A-90-48)*

The recommendations have been partially fulfilled according to available records. Recommendation A-90-40 has been adopted and the  $V_1$  has been redefined in new rulemaking. Recommendations A-90-41 through A-90-48 were addressed by the FAA by creating the Takeoff Safety Training Aid. Although not required to be implemented the FAA has issued advisory circular and that surveyed operators were using this training aid [1996]. The NTSB has classified the recommendations A-90-41 through A-90-48 as closed.

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