Analysis
Accident C-130H Hercules

Airbase Eindhoven, the Netherlands
15 July 1996

by
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The turn of conclusions

Analysis of the accident with a C-130H Hercules on Airbase Eindhoven, the Netherlands on 15 juli 1996.

The turn of conclusions.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation/ Symbol	Meaning
FM	Flight Manual
GW	Gross Weight
kt	knots (in this analysis Knots Indicated Airspeed, KIAS)
lb	pound(s)
OAT	Outside Air Temperature
OEI	One Engine Inoperative
SL	Sea Level
SMP 777	Performance Manual
TEI	Two Engines Inoperative
TIT	Turbine Inlet Temperature
V_{MCA}	Air Minimum Control Speed
V_{MCA1}	Air Minimum Control Speed with one engine inoperative
V_{MCA2}	Air Minimum Control Speed with two engines inoperative

1. ABSTRACT

1.1. On 15 July 1996, a C-130H Hercules of the Belgian Air Force crashed on Airbase Eindhoven in the Netherlands following the failure of engines #1 and #2 due to bird ingestion during a go-around that was initiated just prior to touchdown. Engine #3 was already off before the approach.

1.2. The go-around (while n-1) was initiated at an airspeed close to 97 kt, which is far below the flight manual required go-around speed of V_{MCA2} (134 kt in this case). The flight manual requires acceleration to V_{MCA2} (V_{MCA} for n-2) before selecting full go-around power to be able to maintain control and in anticipation of another engine to fail on the same wing. If two engines fail on the same wing and the power setting on the other engines is high, the airplane will be uncontrollable at speeds below V_{MCA2}.

1.3. In this case, the airplane lost the thrust of three engines (# 1, 2 and 3). Only #4 was operating on max. thrust right after the bird ingestion. In this very special case, the actual minimum control speed was however V_{MCA1}. As the airspeed was even a little below V_{MCA1}, the airplane started to slowly roll and slide away in a direction away from the operating engine, until it impacted the ground.

1.4. The pilots of the airplane and the accident investigators did not know about the real value of the minimum control speeds of the airplane, not about the factors that influence V_{MCA}, not how the magnitude of V_{MCA} can be 'controlled' by the pilots and not what V_{MCA} really means for the controllability and safety of flight before and after engine failure, despite the fact that Lockheed provided good V_{MCA} data and explanations, including control limitations, in the airplane flight manual as well as in a very good booklet 'C-130 low speed flying qualities' that is available to all C-130 pilots.

2. INTRODUCTION

2.1. **The accident investigation committee** presented in § 5.1 of the Report as probable cause:

- *The accident happened as a result of a collision with a flock of birds during a go-around. The loss of engine power in combination with the landing speed subsequently led to the loss of control of the airplane. In combination with the low altitude, the accident could not be avoided.*

2.2. The Advisory Council for Airplane Accidents of the Minister of Defense stated on page 13 of their report 01-97 the most probable cause of the accident:

The accident was initiated by:

- *going around from a very low altitude, most probably as a reaction to the sighting of birds, during which a flock of birds could not be avoided.anymore.*

The accident became inevitable when:

- *following the bird hit, the thrust of both left engines was lost because of bird ingestion;*
- *the airplane became uncontrollable as a result of the loss of thrust at very low altitude and crashed.*

2.3. The first part of the conclusion of the accident investigation committee is in itself correct, but the accident could have been avoided. The conclusion does not go far enough and hence has no value for the prevention of accidents after engine failure. In this analysis, the true cause of this accident will be presented and explained, using the formal airplane manuals and the knowledge the author has on experimental flight-testing of multi-engine airplanes after being trained at the USAF Test Pilot School. The approach will differ from the formal investigation report and might lead to improving the recommendations for the prevention of similar accidents.
The formal manuals used for this analysis are the Flight Manual, and the Performance Manual (SMP 777) that is part of the Flight Manual of the C-130H Hercules, as well as a publication of Lockheed, the manufacturer of the Hercules, titled 'C-130 Low-Speed Flying Qualities'. This analysis is limited to the final flight phase and does not discuss the post-accident aid. Airplane and flight data out of the formal accident investigation report was used in this analysis.

2.4. **This Analysis**. In the analysis below, a reference to the page of the Flight Manual (FM) or the Performance Manual SMP 777 (SMP) of the presented data will be given in *italic* print between parentheses. In the Performance Manual, data of all Hercules versions are contained. The used Flight Manual however, was of a long-body Hercules (C-130H-30), because a Flight Manual of the Belgian C-130H version was not available. The quoted Warnings from the long-body Flight Manual will however, without any doubt, also be stated in the Flight Manual of the Belgian standard version of the Hercules, but may be on a different page.

2.5. The author of this analysis is a graduate Flight Test Engineer of the USAF Test Pilot School, Edwards Air Force Base, CA, December 1985. Following four engine failure related accidents (Hercules, Saab SF-340, Dakota DC-3, ElAl Boeing 747-300) in the Netherlands that happened within a relatively short period of time, he published a paper in the Netherlands Air Force flight safety magazine *'Veilig Vliegen'* in November 1999. Following retirement from his Air Force career, which he concluded as Chief Experimental Flight Test, he founded Avio*Consult* and dedicated himself to improve aviation safety using his knowledge of experimental flight-testing. He researched many catastrophic accidents with multi-engine airplanes that occurred after engine failure or while an engine was inoperative. He published several papers and reports on the prevention of this kind of accidents on his website and presented these to the European Aviation Safety Seminar of the Flight Safety Foundation, to the Dutch TSB, the Engine and propeller Directorate of the FAA and to a number of Airlines, Air Force and Navy organizations. He also wrote supplementary analyses of individual catastrophic accidents, of training and airplane flight manuals and of deficiencies in Aviation Regulations FAR, CS 23 and 25 and equivalent, all of which can be downloaded (for free) from the downloads page of www.avioconsult.com.

3. CHARACTERISTICS C-130H HERCULES

3.1. Before analyzing the accident, a limited explanation of the applicable and most important flight characteristics of the Hercules is presented. The four engines each drive a propeller that rotates at a constant speed during takeoff, cruise flight and approach & landing. The thrust of the propellers is set by the throttles in the cockpit which change the blade angle, the pitch of the propeller blades. If an engine fails, a difference in engine thrust on the left and right wing occurs, that causes a yawing moment in the direction of the failed engine. This yawing moment can only be compensated by deflecting the rudder to prevent the yawing angle to increase and reduce the sideslip (and therewith the drag). The aerodynamic force generated by the vertical tail and rudder is proportionate to the square of the airspeed (V^2). The lower the airspeed, the smaller the rudder generated side force is and the more rudder deflection is required or, if the rudder is already maximum deflected, the higher the airspeed must be to generate a high enough side force to counter the asymmetrical thrust. Besides rudder deflection, also aileron deflection is required to counter the rolling tendency due to the difference in propulsive lift on both wings. The engines are numbered from left to right; number 1 is the outboard engine on the left wing.

3.2. The airspeed at which the deflection of the aerodynamic controls is not sufficient anymore to maintain the heading is called the minimum control speed in the air: V_{MCA}. V_{MCA} is determined during flight-testing and is listed as an operational limitation in the Flight Manual. If the airspeed is below V_{MCA}, then the airplane might not be controllable anymore once an engine fails and the other engines are set to provide maximum thrust, as will be the case during takeoff or go-around. Both the C-130 Flight Manual and Performance Manual pay a lot of attention to the loss of control after engine failure. A lot of warnings are included to warn the pilots for inappropriate handling of the airplane after engine failure. Lockheed, the manufacturer of the C-130 Hercules, did not only write about the problems that might occur after engine failure in the Flight and Performance Manuals, but also issued the already mentioned booklet 'C-130 Low-speed Flying Qualities', that is solely devoted to explaining the not always benign flight characteristics of the Hercules at low flying speed while an engine is inoperative and to explain the real value of the published V_{MCA}. The author of this analysis also wrote many papers and reports about this subject.

3.3. The minimum control speeds are determined during experimental flight-testing and are prescribed in the Flight en Performance Manuals to be able to continue the flight safely following the failure of one or more engines, and to prevent catastrophic accidents from happening. If, however, these limiting speeds are not used appropriately, control of the airplane might still be lost after the failure of one or more of the engines at the moment that the airspeed is low and the thrust on the other engines is high.

4. AIRPLANE, METEOROLOGICAL AND AIRPORT DATA

4.1. The following airplane, meteorological and airport data were copied from the formal accident investigation report as they were during the accident. It was assumed that these data were correct.

Airplane:	Lockheed C-130H Hercules
Registration, operator:	CH-06, Belgian Air Force
Engine type:	T56-A-15
Gross weight:	98,000 lb
Flap position:	100 %
Landing gear:	Down
Fuel distribution:	Symmetrical over both wings
Engine thrust	at the moment of the accident *(Report §4.1.3)*:
#1:	–2,174 lb
#2:	0
#3:	0
#4:	+4,816 lb

Meteorological and airport data Airbase Eindhoven	
Date/ time:	15 July 1996/ 18:02
Temperature:	21.3º C
Air pressure (QNH):	1,027 hPa (mb)
Wind:	010º/11-17 kt
Runway in use:	04
Runway height:	74 ft

Table 1. Airplane, meteorological and airport data.

5. NORMAL PRESCRIBED PROCEDURES

5.1. **Takeoff and landing data**. Using the data presented in Table 1 above, the airspeeds that should have been used by the flight-crew of this flight were determined from the graphs in the Performance Manual SMP 777 of the C-130H. With each data item, the source where the data was found is included within parenthesis. A brief explanation of the data is presented in the next paragraph.

Speed	**kt**	**Configuration, conditions en *source***
Approach speed	118	Is threshold speed + 10 kt, prescribed in Performance Manual *(SMP page9-2)*.
Threshold speed	108	For grossweight (GW) 98,000 lb *(SMP page 9-7)* with throttle at flight idle.
Touchdown speed	97	For GW 98,000 lb *(SMP page 9-10)*. This is the lowest approved threshold speed.

Speed	**kt**	**Configuration, conditions en *source***
V_{MCA1} in ground effect	103	Gear down, 50% flaps, OAT 21,3º C, Sea Level, 5º of bank into good engines, max. permissible power on operating engines, full rudder or 180 lb of rudder force, minimum weight *(SMP pages 3-17 and 3-62, 3-63)*. Data with 100% flaps is not available. V_{MCA1} is minimum control speed in the air with one engine inoperative; V_{MCA2} is minimum control speed in the air with two engines inoperative.
V_{MCA2} in ground effect	134	
V_{MCA1} out of ground effect	107	
V_{MCA2} out of ground effect	136	
Power-off stall speed with bank angle: 0º 30º	 78 85	For GW 98,000 lb, 100% flaps. *(SMP page 3-118)*
Go-around speed	134	Warning in FM: go-around not to be attempted if airspeed is below V_{MCA2} *(FM pages 3-12 and 3-51)*
Rotation speed	103	Is 5 kt lower than take-off speed but never lower than V_{MCA} in ground effect *(SMP page 3-17)*
Take-off speed	91	With 3 & 4 engines, 50% flaps, 98,000 lb *(SMP 3-58)*. In this case (low gross weight) lower than rotation speed, so not useful.

Table 2. Prescribed airspeeds and airplane configuration.

5.2. The meaning and intention of the airspeeds presented above are:

- Approach speed is the airspeed required during the approach for landing;
- Threshold speed is the airspeed required during overflying the runway threshold;
- Touchdown speed is the airspeed at which the airplane at first touches the runway surface;
- V_{MCA1} is de Air Minimum Control speed with one engine inoperative.
  The airplane is *in ground effect* if the height of the airplane is within one half wingspan above the ground. At greater heights, the airplane is *out of ground effect*;
- V_{MCA2} means the same as V_{MCA1} but now if two engines (on the same wing) are inoperative;
- Power-off stall speed is the lowest speed at which the wings produce just enough lift to maintain altitude while

the power of the engines is off (throttles idle). When the airspeed is lower, the wings loose lift generating capability;

- Go-around speed is the airspeed at which a go-around can be safely initiated and performed;
- Rotation speed is the airspeed at which, during the takeoff run, the nose wheel can be 'pulled' off the ground to initiate the climb;
- Take-off speed is the speed at which the main gear wheels leave the ground.

5.3. Before and during every flight, these data are calculated or copied from graphs in the Performance Manual and recorded on a so-called C-130 Take-off and Landing Data Card (TOLD) that is always positioned in direct view of the pilots.

5.4. **In the Flight Manual**, the normal and emergency procedures are prescribed for all flight phases like take-off, approach, landing, go-around, etc., that have to be applied by the flight crew. Each of the procedures is accompanied, if applicable, by safety measures and Warnings and Cautions that warn the flight crew for dangerous flight conditions. The relevant Warnings and Cautions out of the Flight Manual for this analysis are presented below to present an appreciation of the many warnings that are included for flying at low speed and with inoperative engine(s). In addition, also Warnings are quoted that are not directly relevant for this analysis, but because these present an impression of the hazards that are threatening the safety in case an engine fails and that contribute to the knowledge required for flying the Hercules.

5.5. In the Flight Manual in Chapter Flight Characteristics on page 2-66, and in the Emergencies on page 3-10, the following Warning is stated:

- *Improper use of the rudder coupled with improper bank angle control during asymmetrical thrust conditions may* ***result in immediate loss of control of the airplane****. Rapid yaw to very high sideslip angles will cause a drastic loss of airspeed and abrupt roll toward the thrust-deficient wing. Recovery to balanced flight with coordinated flight controls* ***and symmetrical power*** *must begin immediately; the loss of altitude during recovery may exceed 5,000 ft.*

5.6. In the Flight Manual, in the figures on page 2-190 and 2-192 for typical approaches on two engines, the following Warnings are printed:

- *A go-around is not recommended after flaps are lowered;*
- *Do not extend full flaps or slow below 2 engine minimum control speed until landing is assured.*

These Warnings are not directly applicable to the mishap airplane, because 3 or 4 engines were still operating during the approach, but the Warnings do indicate that if the flaps are lowered, and the airspeed is below V_{MCA2}, and two engines fail or are inoperative, a dangerous situation would occur if a go-around would be initiated.

5.7. In the emergency procedures in the Flight Manual on page 3-8 under Take-off continued after engine failure:

- *Maintain directional control with flight controls **and engine power** as necessary.*

5.8. Under the head Three-engine ferry operation, the following Warnings are printed:

- *It is imperative that the following limitations be observed and procedure followed exactly since the **loss of an additional engine after lift-off and prior to reaching two-engine minimum control speed results in a hazardous situation**. In addition, failure to follow the procedure may result in loss of directional control and destruction of the airplane.*
- *It is important to obtain two-engine minimum control speed as soon as possible after take-off.*

In this procedure it is stated that as soon as the airplane is airborne, the heading has to be maintained using 5 degrees of bank in the direction of the good engines, or away from the inoperative/failed engine and rudder as required, and that only after attaining V_{MCA}, the throttle of the operating asymmetrical engine may be advanced to the same torque setting as the symmetrical engines.

5.9. In paragraph In-flight Emergencies under Flight Characteristics under Partial Power Conditions on pag. 3-10 is stated: *Failure of an outboard engine may **require power reduction** on the opposite outboard engine.*

5.10. In the same chapter under Turns: *Turns into inoperative engine(s) are not recommended due to the increase in V_{MCA} encountered when the 5-degree favorable bank angle (into the operative engines) is reduced.*
The effect of bank angle and weight on V_{MCA} is illustrated in Figure 1 on page 12.

In the same chapter, under Propeller malfunctions during take-off the following Note:

- *Propeller malfunctions during take-off may be difficult to analyze at this most critical phase. If the engine is shut down immediately and the propeller fails to feather, it is possible that higher than normal minimum control speed may result. When fire is not indicated, it is recommended that the engine be allowed to run until at least two-engine inoperative air minimum control speed is reached.*

and the following procedure:

*Continue the take-off; maintain directional control with flight controls **and engine power** as necessary.*

and the following Warnings:

- *Below two-engine inoperative air minimum control speed it may be necessary **to reduce power** on the opposite engine to help maintain directional control.*
- *A go-around should not be attempted if airspeed is below two-engine inoperative air minimum control speed.*

5.11. On page 3-51, under Go-around procedure with one or two engines inoperative, the following Warning is included:

- *The use of 5 degrees of bank away from the inoperative engine is necessary to maintain directional control when power is applied during go-around. <u>Attempting to fly with wings level increases minimum control by as much as 20 knots.</u> Go-around with two-engines inoperative should be avoided unless absolutely necessary. Every precaution should be taken so as not to let a situation develop that necessitates a go-around under these conditions. Descents below safe, comfortable altitudes and airspeeds should not be made until absolutely assured of landing.*

and the following procedure:

Begin the 'go-around' at or above air minimum control speed.

Advance the throttles for all operating engines to maximum power as directional control will permit. Power applied to the asymmetrical engines will depend on the airspeed of the airplane at initiation of 'go-around'.

and the following Warning:

- ***Two-engine minimum control speed must be obtained as soon as possible after initiation of go-around.***

5.12. **In the Performance Manual**, the Air Minimum Control Speeds are presented in numbers and are explained *(page SMP 3-17 etc.).* The following remarks are included in the explanatory text:

- *Because of the powerful influence of bank angle on minimum control speed, it is important to maintain a bank angle away from the failed engine;*
- *Reduction of power on the opposite engine will reduce the yawing tendency caused by the asymmetric thrust and thus lower the minimum control speeds; however, a sacrifice in climb performance will result;*
- *The importance of maintaining 5 degrees of bank away from the failed engines is shown in figure 3-5* (is Figure 1 in this analysis on page 12).

5.13. These were the most important and applicable statements out of the Flight Manual en Performance Manual for analyzing this accident.

6. C-130 LOW-SPEED FLYING QUALITIES

6.1. Lockheed, manufacturer of the C-130 Hercules, has issued an already mentioned publication titled *C-130 Low-Speed Flying Qualities*. The 3rd printing is dated October 1992. This document contains text and illustrations that were prepared to provide a better understanding of the low-speed flying qualities and the minimum control speeds of the C-130 series aircraft and should be used in addition to the Flight Manual.
The page numbers between parentheses below refer to the pages in the Lockheed publication. Although there are some incorrect statements in the publication, the content does provide the readers with a well-documented insight to the flight characteristics of a high-powered airplane after engine failure end presents several do's and don'ts. The quotes from the publication were supplemented by additional remarks by the author of this analysis.

6.2. The minimum control speeds contained in the Flight Manual are intended to preclude operation of the aircraft below speeds at which a sudden loss of engine thrust or the reduction of control capability could produce an uncontrollable situation with potentially catastrophic consequences *(page 2).*

6.3. Air minimum control speed (V_{MCA}) is defined as the lowest airspeed at which it is possible to maintain control of the airplane after the (sudden) loss of thrust of an engine or while an engine is inoperative *(page 6)*, whichever is highest. V_{MCA} is determined during flight-testing while engine #1 is (made) inoperative, the center of gravity is aft, the weight is as low as possible, the rudder deflection is either maximum or up to a control force of 180 lb and the thrust of the opposite engine is maximum. This configuration, besides other factors, provides the highest, worst case V_{MCA}. In addition, during the test straight flight is maintained while the bank angle is 5 degrees away from the inoperative engine. As illustrated in Figure 1, any other bank angle results in a higher actual V_{MCA}. Hence, the V_{MCA} listed in the Flight manual is valid only during straight flight while a bank angle is maintained 5 degrees away from the inoperative engine (and the thrust of the opposite engine is maximum takeoff). Any other bank angle increases V_{MCA} to a value higher than the Flight Manual listed V_{MCA}. Although V_{MCA} is determined while engine #1 is (made) inoperative, it applies and should be used after failure of any of the engines.

6.4. If an engine fails when the airspeed is higher than the Flight Manual published V_{MCA}, then less rudder deflection is required than maximum to maintain straight flight. If however, an engine fails while the airspeed is below V_{MCA}, then the aerodynamic forces generated by the vertical tail and rudder are not high enough to maintain straight flight. The airplane deviates from its intended heading and cannot be controlled anymore. If the altitude is low, this can lead to a catastrophe, like this accident.
Maintaining the airspeed above the Flight Manual listed V_{MCA} and maintaining straight flight while banking 5 degrees away from the inoperative engine ensures controlled flight following an engine failure.
Of course, the total thrust generated by the remaining engines is less then maximum, which affects performance. If more engines are inoperative, the remaining thrust could not be adequate to maintain altitude *(page 6).*

6.5. The asymmetric power condition following an engine failure generates yawing and rolling moments that must be balanced either by reducing thrust on the opposite engine or by using the aerodynamic flight controls: rudder, ailerons and elevator. These controls are however only effective enough if the airspeed is higher than V_{MCA}.
During takeoff and go-around, the reduction of thrust on the opposite engine (§ 5.11second bullet above) could lead to the loss of climb performance. Then only aerodynamic control is available for which the airspeed needs to be high enough. If not a bank angle of 5 degrees is maintained away from the inoperative engine, V_{MCA} is at least 10 kt higher than the V_{MCA} that is listed in the Performance Manual (Figure 1 below).
Because of the powerful influence of bank angle on V_{MCA}, it is extremely important to maintain a bank angle away from the failed engine *(page 14).*

6.6. Go-arounds are best accomplished by initiating the maneuver as early in the approach as the need becomes evident. The best procedure is:

(1) engines to full takeoff power;

(2) flaps 50%;

(3) continue down the glides lope, while airspeed is increased at least to V_{MCA} for 50% flaps.

Once V_{MCA1} (or V_{MCA2} if one engine is already inoperative) has been attained, the climb out can be initiated *(page 34)*.

If the altitude is too low for the aforementioned procedure (as was the case on Eindhoven) then the flight crew must be particularly alert as the throttles are brought up toward takeoff thrust. Slow response of one or more engines can lead to the loss of control if the situation is not recognized and if corrective action is not immediately taken *(page 34)*.

6.7. If at any time during the go-around, the pilot does not have both performance and control margins, then the pilot should immediately pull back the remaining engines and land straight ahead. An off-runway landing under positive control is preferable to ground impact out of control *(page 34).*
Controllability without climbing capability is not desirable; but uncontrollability is even worse *(page 35).*

6.8. So far, the quotes out of the Lockheed booklet. Please also refer to the report *Airplane Control after Engine Failure* by Avio*Consult* that is downloadable for free from website www.avioconsult.com and in which almost all there is to know about V_{MCA} is presented, including improved takeoff and go-around procedures.

7. ANALYSIS OF THE ACCIDENT

7.1. The information in the paragraphs above is presented to gain an appreciation for the many directions, procedures, Warnings & Cautions for the flight crew to work with during the execution of flights and during handling an engine failure. Lockheed wrote a lot about, and issued many warnings for, dangerous situations that might occur after the failure of one or more of

the engines. The C-130 should be handled by properly trained flight crew using extreme care before and after engine failure, because of the powerful engines.
In this chapter, the accident at Eindhoven Airbase is analyzed using the airplane and flight data presented before.

7.2. Assumed is that the approach to the runway in use was flown in accordance with the normal procedures and that there were no control problems until the bird hits occurred. The applicable V_{MCA}'s for the landing weight and runway altitude should have been looked up in the Performance Manual and recorded on the C-130 Takeoff and Landing Data (TOLD) Card prior to the approach. This TOLD card is to be clipped in the direct view of the pilots in order to be able to read the required data quickly as it becomes necessary. The speeds for the approach under the weather conditions and aircraft configuration at the time of the accident, as determined from the Performance Manual, are presented in Table 2. The required approach speed was 118 kt, the threshold speed 108 kt and the touchdown speed 97 kt. At the instant of the bird hits, the airplane was passing the runway threshold, so the airspeed must have been close to 97 kt.

7.3. According to the Report, the #3 propeller was feathered. It did not become clear from the Report whether engines #1 and #2 quit first due to the birds hitting the engines and that engine #3 was subsequently shut down by the crew, or that engine #3 was already shut down before the bird hit, probably already before or during the approach. The answer is as follows.
If engines #1 and #2 quit first following the bird ingestion, and engines #3 and #4 generated full thrust for initiating the go-around, then the actual V_{MCA} would have been at least 134 kt (V_{MCA2}), the minimum control speed for two engines inoperative on the same wing, provided the bank angle was 5 degrees away from the failed engines. If this bank angle was not attained, then the actual V_{MCA2} for a gross weight of 98,000 lb must have been almost 17 kt higher than the value that is listed in the Performance Manual, in this case approximately 150 kt, see Figure 1 below, which is copied from the C-130 Performance Manual SMP 777, and which also is used in the Lockheed publication that was presented in Chapter 6 above.
The actual airspeed however, must have been between close to 97 kt. The consequence of the big difference between this speed and V_{MCA2} would have been that control would be lost immediately following the failure of engines #1 and #2 and that abrupt yawing and rolling moments to the left would have caused the airplane to impact the ground a lot quicker than actually happened during this accident. The remaining flight time following the failure of engines #1 and #2 was 12 seconds. No vigorous rolling motions occurred; the left wing tip touched the ground at approximately 190 m from the runway centerline.

7.4. If engine #3 was shut down and the remaining engines were all generating maximum thrust for the go-around, then the minimum control speed to be observed was 103 kt, provided the other conditions, such as a 5 degrees bank angle away from the failed engine (in this case to the left), are complied with. If however the wings are maintained level, then the actual V_{MCA} at 98,000 lb gross weight is nearly 10 kt higher than the V_{MCA} that is listed in the Performance Manual (see Figure 1 below). Then the minimum control speed is 103 + 10 = 113 kt, instead of 103 kt. Because engine #3 is an inboard engine on the less critical right hand side, the actual V_{MCA} was most probably lower (safer), and almost equal to the touchdown speed (97 kt). The airspeed was indeed not much lower than the actual V_{MCA}, which can be concluded from the very slow increase of banking to the left and the path that the airplane flew in the 12 seconds after the bird hit.

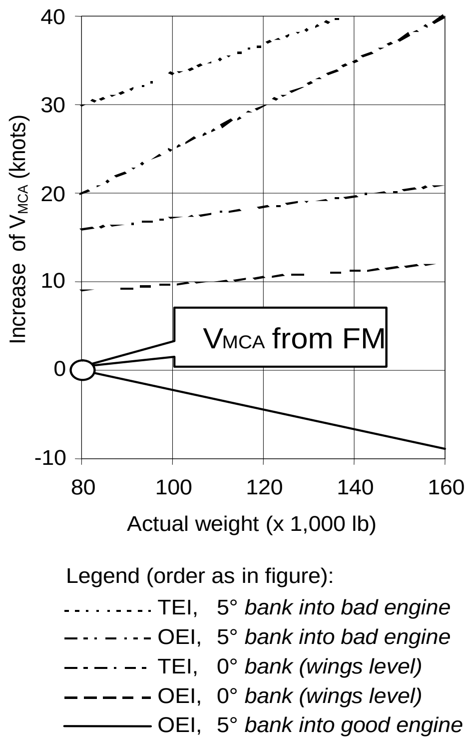

Figure 1. Effect of bank angle and weight on V_{MCA}

7.5. Therefore it is likely that engine #3 was shut down by the crew before engines #1 and #2 were ingested by birds and quit operating.

7.6. If engines fail while the power setting of all engines is low, as is the case during a normal approach, then of course no control problems occur.

7.7. The flight crew decided to go-around after observing birds and following the intentional shutdown of engine #3 while the airspeed was between close to 97 kt. In accordance with the Flight Manual *(page 3-51, 3-12)* however, the airspeed for initiating a go-around needs to be at least V_{MCA2}, in this case 134 kt as should have been listed on the Takeoff and Landing Data Card. In other words, if a go-around should become necessary when the airspeed is as low as the threshold or touchdown speed, whether engine(s) have failed or not, the airspeed has to be increased first using operating symmetrical engines before commencing the climb. This procedure guarantees controllability in case an(other) engine would fail after moving the throttles forward. If it is not possible to accelerate to V_{MCA2}, in this case 134 kt, first, then a go-around may just not be initiated and the airplane is committed to land. See the corresponding Warnings in § 5.10 and § 5.11 above and the remarks by Lockheed as presented in § 6.7.

7.8. The bird ingestion caused engines #1 and #2 to quit, leaving only engine #4 operating at high thrust. For the distribution of forces and moments on the airplane, it was favorable that engine #3 was already off when #1 and #2 quit (§ 7.3). The response of the airplane was therefore not as vigorous as would have been the case if both engines #3 and #4 would have been operating at high thrust. The moments around the yaw axis, which are most relevant for the magnitude of V_{MCA}, now were as if only engine #1 failed, because the symmetrical engines #2 and #3 were off and did not contribute to the yawing moments (nor to the rolling moments). The minimum control speed with engines #1, #2 and #3 inoperative would, according to the Performance Manual, have been approximately 103 kt, provided the bank angle was 5 degrees into the operating engine #4. This banking was opposite of the bank angle that the pilots would have had to apply after shutting down engine #3 and while advancing the throttle. It the wings were kept level, the actual V_{MCA} was 10 kt higher or 113 kt, as was explained in § 7.3 above.

7.9. The yawing and banking motions under influence of the thrust of engine #4 only could obviously not be avoided, despite the without any doubt applied yaw and roll controls against by the pilots. These are indications that the airspeed was (slightly) below the actual minimum control speed. The only way out, as described by Lockheed in the Flight Manual, Performance Manual and in the publication mentioned before is to reduce thrust on the asymmetrical engine, in this case #4, as much as possible for the controls to become effective again. But since only engine #4 was operating, the performance was most probably already insufficient to achieve a climb. Closing the throttles and landing with the wings level (in the dirt) was in this case the only option. Please refer to the statement by Lockheed as presented in § 6.7 above. A controlled wings-level landing is preferable above an uncontrolled landing with a wing tip hitting the ground first, as happened during this accident.

7.10. Another indication for the fact that the airspeed was slightly below minimum control speed V_{MCA1} was the small bank angle that the airplane had at the first impact with the ground, given the small distance between the imprint of wingtip and that of both engine #1 and the left pylon tank. If the airspeed would have been much lower than the actual V_{MCA}, then the roll rate would have been higher and the bank angle would have been greater in the remaining flight time. Then, after the wingtip would have contacted the ground first, the nose of the airplane would have hit the ground next and not propeller #1 and the left pylon tank.

7.11. The thrust of one engine is not high enough to establish a positive climb; the Performance Manual does not present data on this configuration. Therefore, following the loss of thrust of three engines at an altitude of just a few feet, the airplane was committed to land. The pilots should have closed the throttles and land straight ahead. If engine #3 was indeed already shut down before or during the approach, then the pilots should have realized that the airspeed for initiating a go-around should have been increased to V_{MCA2}, in this case 134 kt, first. If this is not possible because of the low altitude or number of failed engines, the airplane is committed to land.

7.12. The pilots initiated a go-around at an airspeed way below the Flight Manual-prescribed go-around speed V_{MCA2}, while it was impossible to accelerate to this speed using symmetrical thrust first.

7.13. It is possible to simulate the course of events during flight at a safe altitude in order to confirm this analysis, provided it is performed or supervised by an experimental test pilot or a flight-test engineer, because they know how to determine V_{MCA} and its real value. A flight simulator should not be used, because the low speed flying qualities while one or more engines are inoperative might not be reliable enough to draw the right conclusions.

8. CAUSE OF THE ACCIDENT

8.1. The main cause of the accident was the initiation of a go-around at a much too low airspeed and its continuation following the failure of two engines. The manufacturer prescribes that the safe speed for performing a go-around is always V_{MCA2}, in this case 134 kt. When the pilots initiated the go-around, the airspeed was close to 97 kt, meaning that the appropriate warnings by the airplane manufacturer, that a go-around should not be initiated unless the airspeed is increased to V_{MCA2} first, were disregarded.
The go-around speed (V_{MCA2}) is prescribed in the Flight Manual because the failure of both engines on one side is anticipated, which tragically indeed happened during this accident. If the airspeed during the approach is below V_{MCA2} and acceleration to V_{MCA2} is not possible by exchanging altitude for speed, or by increasing the airspeed using symmetrical thrust of the remaining engines, then a go-around may not be performed, even if there are no birds, and the landing must be continued (see §5.10 and § 5.11). The airplane was committed to land.

8.2. After the bird ingestion, three of the four engines were off, but the distribution of yawing forces and moments on the airplane was as if only engine #1 had stopped. Only engine #4 was generating maximum thrust leading to an actual minimum control speed of 103 kt, or 113 kt if the required 5 degrees of bank were not maintained but the wings were kept level instead, and not 134 kt (V_{MCA2}). The used bank angle is unknown. Because of the fact that the longitudinal axis of the airplane could not be maintained at runway heading, but that the heading unintentionally changed to the left, the airspeed must have been lower than the actual V_{MCA1} (103 kt) and therefore certainly way too low for initiating a go-around.

8.3. If the thrust of engine #4 would have been reduced to recover controllability, as the Flight Manual prescribes, even if that would have been done if the Hercules was away from the runway above the grass, the accident could have been prevented, although the airplane would have suffered damage. This is an emergency procedure for which the Flight Manual presents numerous directions (§ 5.5, 5.7) and that are also discussed in the Lockheed publication presented above (§ 6). A cause of the accident also is not reducing the thrust of engine #4.

8.4. The decision to initiate a go-around at a way too low speed, but also to not reduce the thrust on engine #4 as the nose of the airplane started to divert from the runway centerline, indicating out of control, show that the flight crew was unfamiliar or inexperienced with the prescribed procedures, Warnings and explanatory material on flight at low speed and with an inoperative engine. This might be caused by inadequate flight crew training. The flight crew, without doubt, had access to the manuals and publications that were mentioned and used in this analysis at their home base and/ or in the airplane.

8.5. Contrary to the conclusions of the accident investigation committee and the Advisory Council for Airplane Accidents of the Minister of Defense, the accident was not unavoidable because of the loss of engine thrust in combination with the landing speed that led to the loss of control, but the accident was caused by initiating a go-around at an airspeed approximately 37 kt below the speed that the Flight Manual prescribes to initiate a go-around, even if all engines would have been operating. At this low speed, the thrust on engine #4, after #1 and #2 were ingested by birds, was maintained rendering the airplane out of control after which it crashed.
The flight crew did not apply the procedures that are prescribed in the Flight Manual for performing a go-around.

9. PREVENTIVE MEASURES

9.1. The Advisory Council for Airplane Accidents of the Minister of Defense did not order, or recommend improving the theoretical and practical training of (Hercules) pilots for flight at low speed with an inoperative engine. This analysis showed that this is absolutely required to prevent engine failure related accidents from happening again.

9.2. The C-130 Hercules is a difficult to handle airplane after engine failure and should not be the first airplane type for pilots who only have experience on single-engine airplanes or helicopters and hence, have limited experience on multi-engine airplanes. The requirements for Hercules crews should be adapted to the degree of complexity of the airplane.

9.3. The author of this analysis published a number of analyses of similar accidents, and wrote an extensive report and papers on the control of multi-engine airplanes after engine failure. This report is referred to in the next list. ■

LIST OF REFERED DOCUMENTS

Accident investigation Report	Accident on Airbase Eindhoven, The Netherlands, on 15 July 1996, with a Lockheed C-130 Hercules, registration CH-06, of the Belgian Air Force. Report by the Belgian en Netherlands Air Forces, dated 3 October 1996 (in Dutch language)
Final Report 01-97	The Hague, March 1997, Advisory Council for Airplane Accidents of the Minister of Defense
FM 382T-50F	Flight Manual of C-130H-30, being the long-body version of the C-130H as is in use with the Royal Netherlands Air Force
SMP 777	Flight Manual/Performance Manual for all C-130 Hercules versions
C-130 Low-Speed Flying Qualities	Publication of Lockheed, 3rd printing, October 1992
Veilig Vliegen met een uitgevallen motor	Article in the Dutch language by Lt-Col Harry Horlings in flight safety magazine 'Veilig Vliegen' of the Royal Netherlands Air Force, November 1999.
Airplane Control after Engine Failure	A report by Harry Horlings, Avio*Consult*, June 2005, downloadable from website www.avioconsult.com.