



EC145, N-146DU

Hypothetical cockpit indications based on SafranHE simulation results concerning the potential engine behaviour in case of a gas generator rear bearing failure

HELICOPTERS

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9 May 2019

AIRBUS

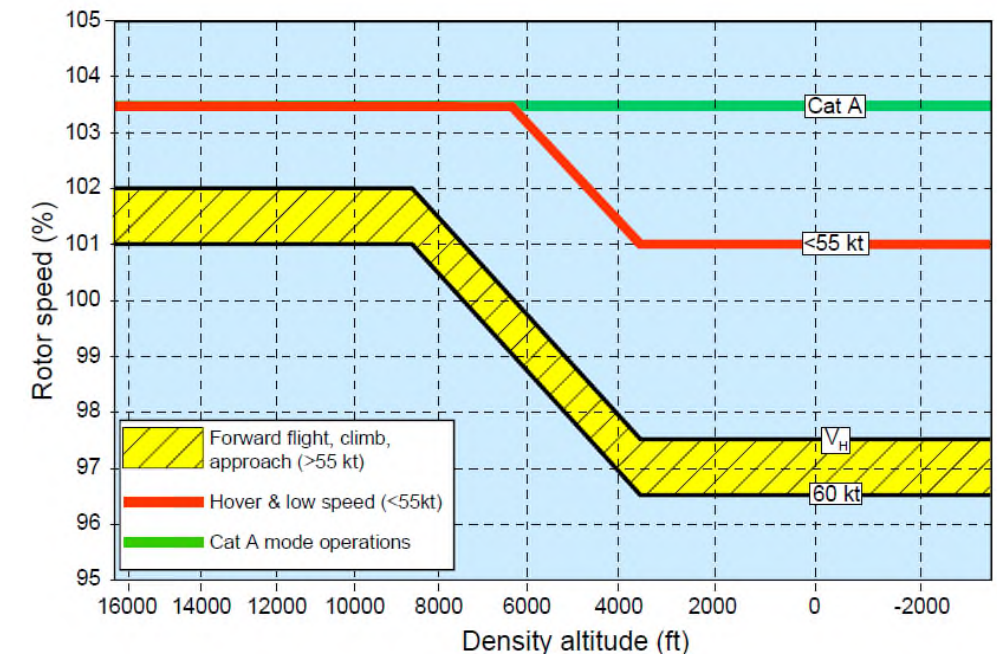
VARTOMS – Variable Rotor Speed and Torque Matching System

- Reduces pilots work load by providing automatic torque matching
- Reduces noise and improves performance by varying rotor speed as a function of airspeed and air density
- Improves performance and rotor speed margin in CAT A mode

Variable rotor speed

- The NORM mode varies the rotor RPM between 96.5 % and 103.5 % as a function of air density and airspeed.
- At speeds below 55 kts the rotor RPM is controlled between 101% and 103.5 %. Above 55 kts the VARTOMS reduces the rotor RPM and controls it between 96.5 % and 102 %. The torque of both engines is matched automatically.

VARTOMS adjusts the rotor speed according to the density altitude and airspeed as indicate in the diagram



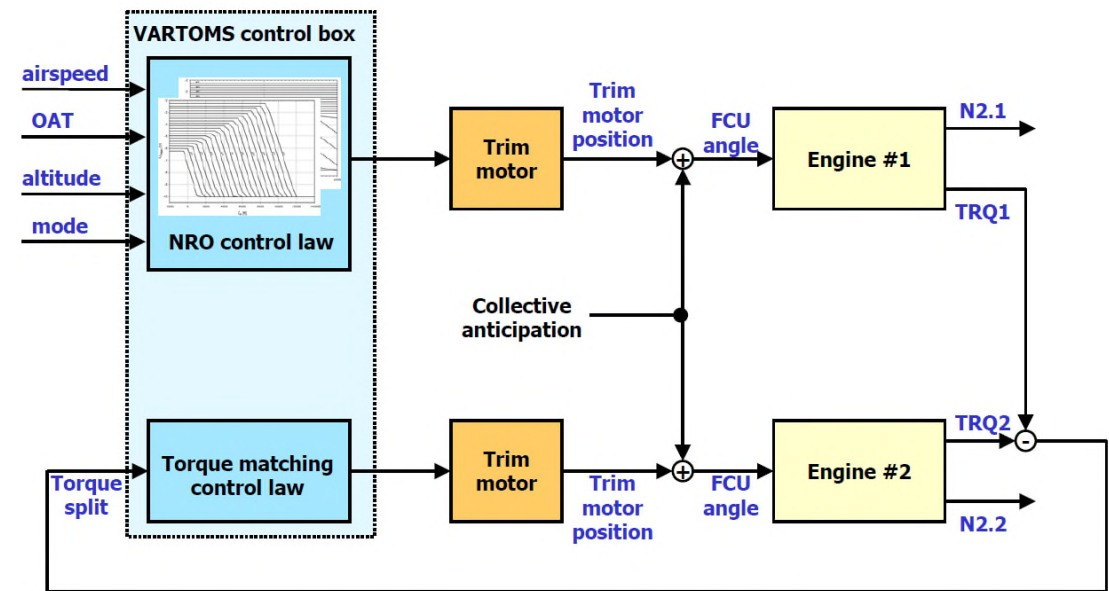
VARTOMS – Variable Rotor Speed and Torque Matching System

Torque matching

#1 engine is the master. VARTOMS will try to match the torque of engine #2 respectively within certain limits.

- In case the torque difference between the 2 engine exceeds 15% VARTOMS switches to manual mode. Torque matching and RPM changes now need to be done by the pilot using the 4-way beep trim switch on the collective lever.
- The system is designed to make changes to engines N2 values slowly. E.g. the time to manually trim the rotor speed from the minimum value to the maximum value (96.5 % to 103.5 %) is close to 20 seconds. It would not be able to counteract rapid erratic changes in engine torque and thus have no influence on the engine behavior in the scenario of a bearing failure.

System Overview



HELICOPTERS Central Panel Display System CPDS and Warning Unit

General

The Central Panel Display System is an electronic indicating system and presents various parameters of the on-board systems on three screens. It consists of the CAD and VEMD

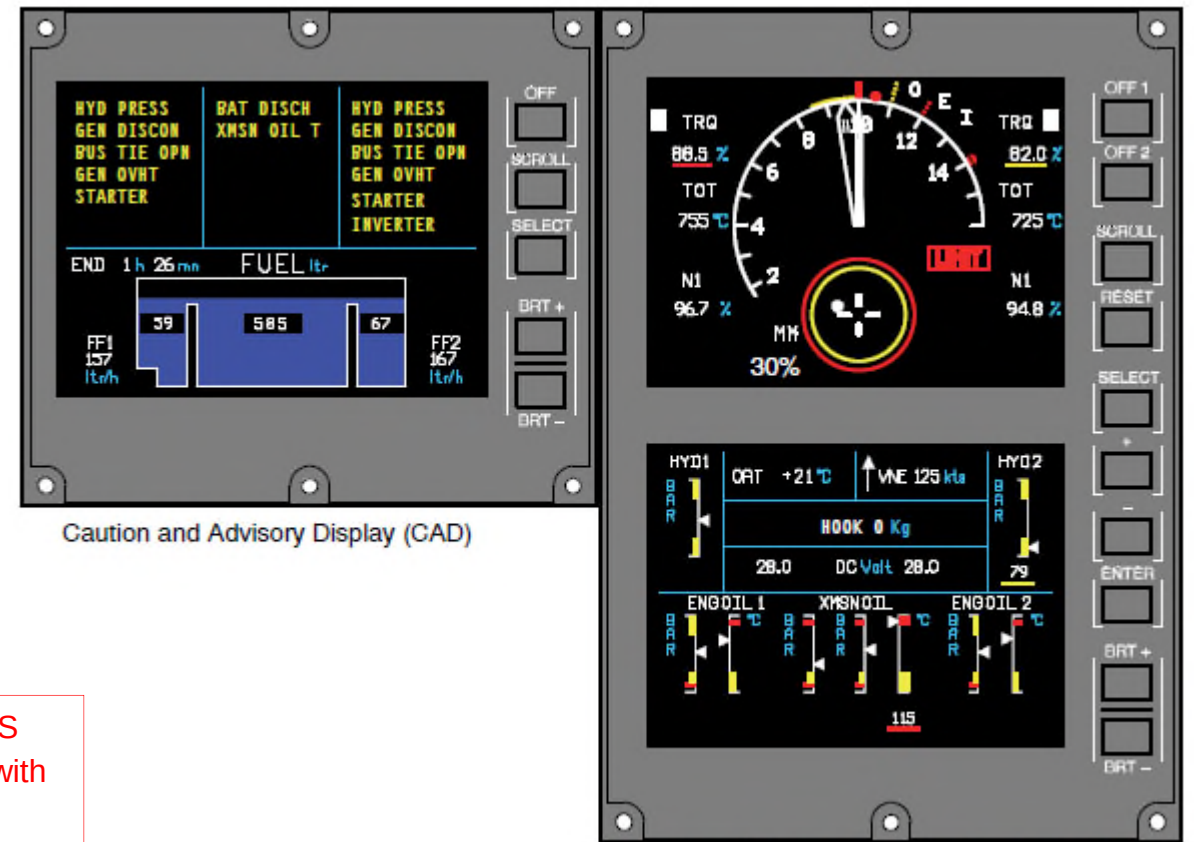
CAD (Caution and Advisory Display)

The CAD displays cautions, advisory messages and fuel system indications. If the VEMD fails, the CAD can take over and display selected parameters from it. The display instrument of the CAD consists of a colour screen, integrated in the left-hand side of the centre section of the instrument panel.

VEMD (Vehicle and Engine Monitoring Display)

The VEMD displays engine and dynamic system parameters. In addition, it can present data relating to on-board systems (e.g. aircraft electrical system, autopilot) and to optional equipment (e.g. cargo hook).

Note: The cockpit indications shown in this presentation were created by using a CPDS training tool which allows to enter exact parameter values. The aircraft was delivered with software version v2006 which is the same version on which the training tool is based



Caution and Advisory Display (CAD)

Vehicle and Engine Monitoring Display (VEMD)

First Limit Indicator (FLI)

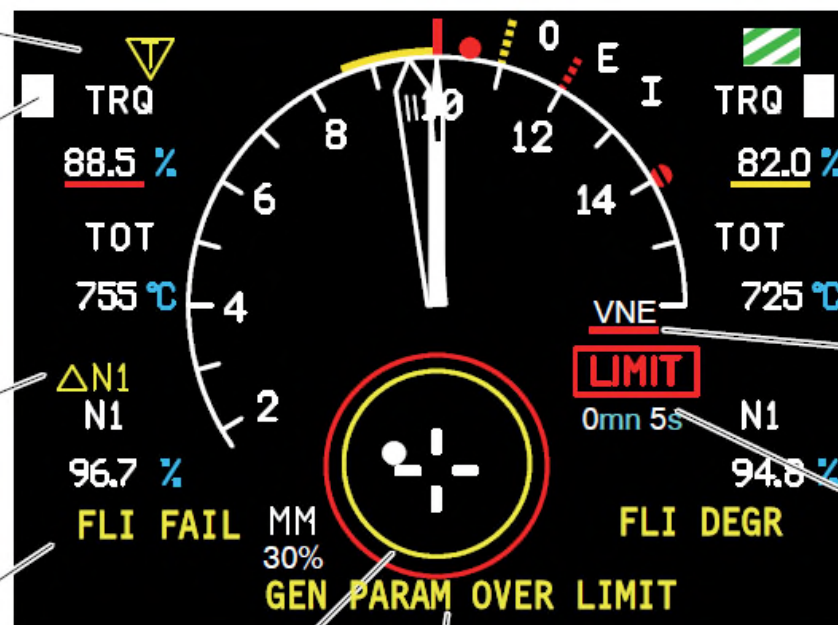
Generic picture depicting the complete available FLI symbolics

ENG FAIL warning, training and bleed valve symbol (may appear on both sides)

Solid white rectangle marks the parameter limiting and represented by the pointer

△ N1 Failure

FLI FAIL
FLI DEGR
may appear as CAUTION
on both sides



Mast Moment
Indication

Message Zone

V_{NE} Exceed

LIMIT Warning

AIRBUS
HELICOPTERS

FLIGHT MANUAL BK 117 C-2

LIMITATIONS

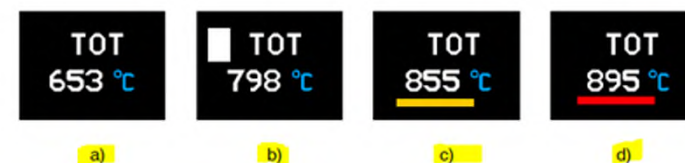


Fig. 2-10 Digital data display

A value that is within the normal operating range is displayed as shown in Fig. 2-10 a). A solid white rectangle associated with a parameter indicates which is the limiting parameter (Fig. 2-10 b)). If operation in a yellow range is detected, a countdown timer is automatically switched on and the digital data is yellow underlined (Fig. 2-10 c)).

For the 5 min. limit (AEO TOP) the counter is invisible. 5 seconds before the timer reaches zero the timer is displayed and a flashing red box appears around the word "LIMIT" (Fig. 2-8).

EFFECTIVITY If CPDS-Software V2006 or subsequent is installed

For the 5 min. limit (AEO TOP) the counter is invisible, until 1min 30 sec before timer expires. 15 seconds before the timer reaches zero a flashing red box appears around the word "LIMIT" (Fig. 2-9).

EFFECTIVITY All

For the 2.5 min limit (OEI) counter, five seconds before the timer reaches zero a flashing red box appears around the word "LIMIT" (Fig. 2-8 and 2-9). When the countdown has expired or if the limit has been exceeded, the red box is fixed and the red underlining of the digits flashes (Fig. 2-10 d)).

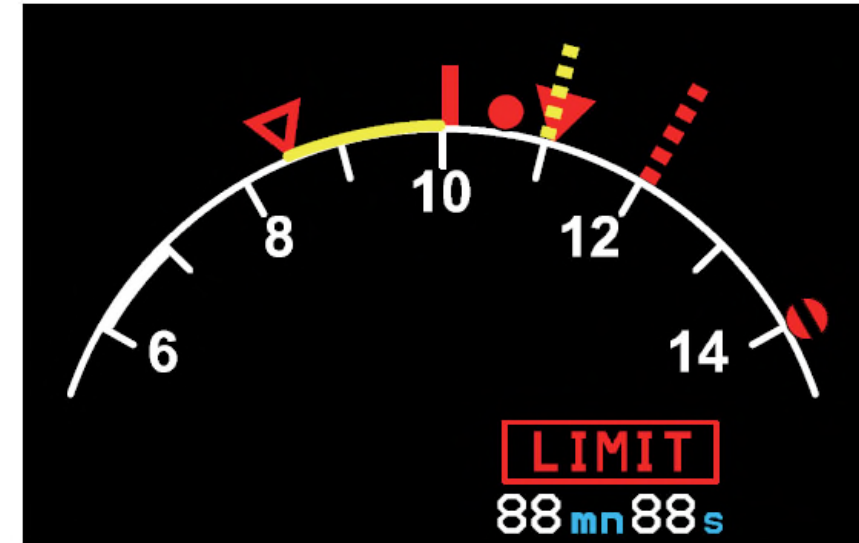
If one of the parameters is invalid, a yellow failure symbology replaces the information concerning the faulty parameter.

First Limit Indicator (FLI)

and in OEI (the logic is assuming the start up of the engine which is off)

	Max. TOT starting (appears only during starting)
	TOT starting transient max. 5 sec (appears only during starting)
	TOT Starting Range (appears only during starting)
	AEO Take-off Power Range; max. 5 min. (71%-88%)
	AEO Max. Take-off Power
	OEI Max. Continuous Power
	OEI 2.5 min. Power
	AEO Transient; max. 12 sec. (torque, ΔN_1)
	OEI Transient; max. 12 sec. (torque only)

OEI
limits are
dashed



Limitations

HELICOPTERS



FLIGHT MANUAL BK 117 C-2

FLIGHT MANUAL BK 117 C-2



LIMITATIONS

LIMITATIONS

2.7 AIRSPEED LIMITATIONS

NOTE All airspeed values given in this manual are indicated airspeed (IAS) unless otherwise indicated.

2.7.1 Forward flight

The following tables (Table 2-1 and 2-2) show the airspeed limits under various atmospheric conditions (Pa, OAT). Table 2-1 applies when the helicopter's gross mass is up to 3000 kg, Table 2-2 applies when the helicopter's gross mass is greater than 3000 kg.

Pressure Altitude - ft -	OAT - °C -										
	-45	-35	-30	-20	-10	0	+10	+20	+30	+40	+50
0	150	150	150	150	150	150	150	150	150	150	150
2000	150	150	150	150	150	150	150	150	145	145	140
4000	145	145	145	145	145	145	145	145	140	140	130
6000	140	140	145	145	145	145	145	140	135	130	
8000	135	135	140	145	145	145	140	135	130	120	
10000	125	130	130	135	135	135	130	125	120		
12000	115	120	125	130	130	125	120	115	110		
14000	110	115	120	125	120	115	110	105	100		
16000	105	110	115	115	110	105	100	95			
18000	100	105	110	105	100	95	90	85			
V _{NE} -KIAS- for any H/C gross mass up to 3000 kg											

Table 2-1 Never-exceed speed for any H/C gross mass up to 3000 kg (V_{NE} – kts IAS)

Pressure Altitude - ft -	OAT - °C -										
	-45	-35	-30	-20	-10	0	+10	+20	+30	+40	+50
0	145	145	145	145	145	145	145	145	145	140	140
2000	140	140	140	140	140	140	140	140	140	135	130
4000	135	135	135	140	140	140	140	135	135	130	120
6000	130	130	130	135	135	135	135	130	125	120	
8000	130	130	130	130	130	130	125	120	115	110	
10000	125	125	125	125	125	120	115	110	105		
12000	115	120	120	120	115	110	105	100	95		
14000	110	115	115	110	105	100	95	90	85		
16000	105	105	105	100	95	90	85	80			
18000	100	95	90	85	85	80	80	75			
V _{NE} -KIAS- for any H/C gross mass above 3000 kg											
BK117 C-2											

Table 2-2 Never-exceed speed for any H/C gross mass above 3000 kg (V_{NE} – kts IAS)

V_{NE} for OEI operation under all conditions is **110 kts**
or as shown in the V_{NE}- tables (Table 2-1 or 2-2), whichever is less.

V_{NE} for steady autorotation under all conditions is **90 kts**
or as shown in the V_{NE}- tables (Table 2-1 or 2-2), whichever is less.

2.11 ENGINE AND TRANSMISSION POWER LIMITATIONS

Engine: Turbomeca ARRIEL 1E2

Transmission: Kawasaki B632K1001-051

CAUTION THE OEI POWER RATINGS ARE LIMITED TO USE ONLY AFTER ACTUAL FAILURE OF AN ENGINE OR FOR MAINTENANCE CHECKFLIGHTS (ACC. TO THE MAINTENANCE MANUAL), EXCEPT FOR THE MCP VALUES, WHICH MAY ALSO BE USED FOR TRAINING (ONLY IF TRAINING DEVICE, FMS 9.1-3 IS NOT INSTALLED) OR DEMONSTRATION PURPOSES.

CONDITION	FLI marking	Transmission (helicopter) limits max. torque %	Engine operating limits	
			max. N ₁ -SPEED ²⁾ %	max. TOT °C
Starting transient (max. 5 sec)	11.0			865
Starting	8.5			785
All engines operating				
Takeoff power (5 min) V ≤ V _y	10.0	2 x 88	100.2–101.9	
Max. continuous power	9.0 8.5 ⁴⁾	2 x 71	98.8–100.0	845 ³⁾
One engine inoperative				
2.5 min. power	12.0	125	101.8–103.3 ¹⁾	885 ¹⁾³⁾
Max. continuous power	11.0	91.5	100.2–101.9	845 ³⁾

1) Record the duration, maximum N₁ and maximum TOT in the helicopter and engine logbooks. After a maximum total of 15 minutes, maintenance action is required (refer to the engine maintenance manual). Only times of application greater than 10 s for a single event are to be accumulated.

2) N₁ speed (true value) as shown on the N₁ digital display. Since the true N₁ speed limits are functions of PA and OAT, the table shows the ranges of variability for the upper limits. The engine is protected against a continuous N₁ overspeed/over TOT by a limiting device in the fuel flow system. This stop is set above the 2.5min power limits at approx. 104.4% N₁.

However, inadvertant dynamical overshoot in N₁ and TOT may occur when this stop is reached.

The engine is not protected against over-TOT by a limiting device in the fuel flow system during engine start.

3) These TOT numbers are not directly related to the FLI setting in the first column as FLI in these conditions is based on either TQ or N₁.

4) If CPDS Software V2006 or subsequent is installed

NOTE • The N₂-speed limitations are the same as the rotor rpm limitations (see para 2.10)

• The N₁-speed limitations change according to PA and OAT

• FLI limitations may be torque limits (low altitude) or compressor rating limits (N₁), depending on the flight conditions (PA, OAT)

• A transient AEO torque limit of 2 x 97% (10.5 FLI) and a *transient OEI torque limit of 140% torque (14.0 FLI)* have been established for V ≤ V_y and unintented use of max. 12 seconds duration only.

• A transient AEO N₁ limit of 103.3% (if CPDS Software V2006 or subsequent is installed 10.5 FLI) and a transient OEI N₁ limit of 107.5% for inadvertent use of max. 12 seconds duration only, have been established. Exceeding of any one of those limits requires maintenance action (refer to the maintenance manual)

Overview recorded ground speeds in Sky Connect

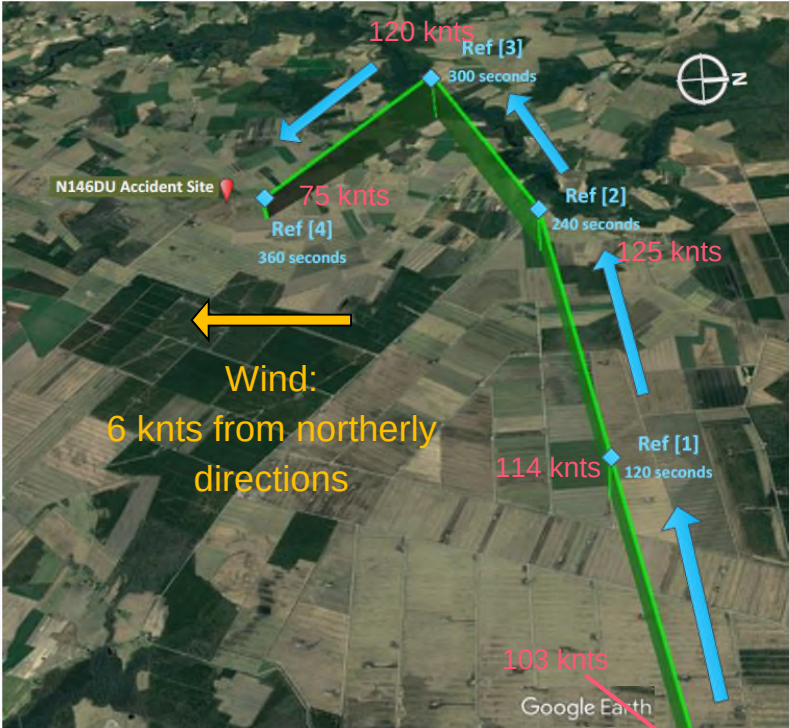


Figure 1: Showing accident site and reference points (flight path) available by Sky-Connect Data (green)



Ref Point	Time	Time Delta [seconds]	Latitude [degrees]	Longitude [degrees]	Altitude [feet]	Course [degrees]	Groundspeed [knots]
[0]	15:12:00	0	36.349833°	-76.334997°	2297	261	103
[1]	15:14:00	120	36.339831°	-76.417000°	2543	261	114
[2]	15:16:00	240	36.333333°	-76.471000°	2530	261	125
[3]	15:17:00	300	36.318500°	-76.511833°	2605	189	120
[4]	15:18:00	360	36.296333°	-76.482833°	1168	132	75

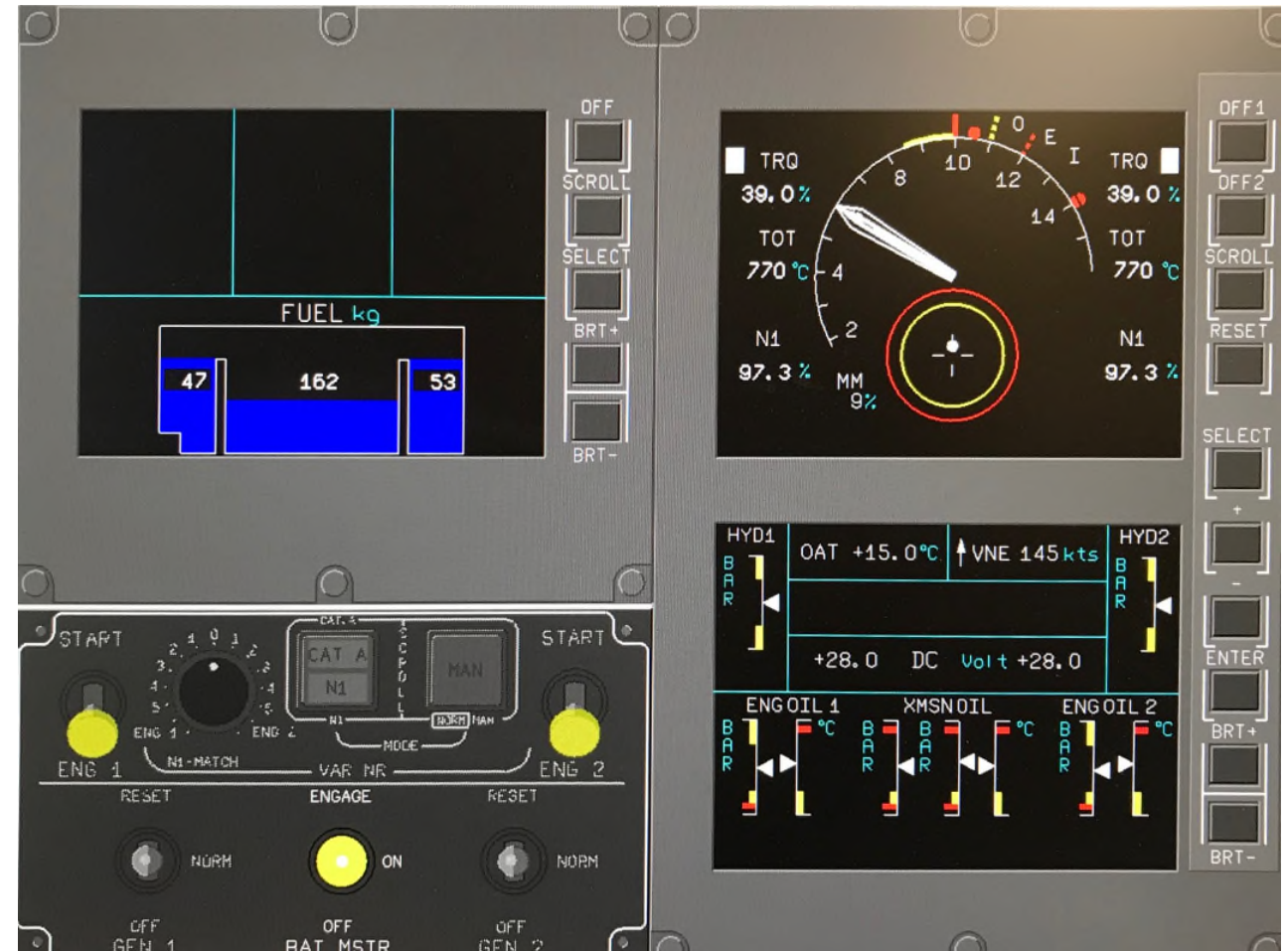
Tableau 1: Sky Connect Data Overview

FLI indication before bearing failure – AEO, 80 KNTS, 2500ft

- Operation within limits
- Limiting parameter for both engines is torque as indicated by the white rectangles
- No cautions or warnings present

Note:

- All indications shown in the presentation apply to the „no friction“ condition of the engine which means no contact between the blade tips of the HP Turbine and the surrounding static parts.
- The FLI indications shown in the presentation are static. Depending on the changes in friction inside the engine the needles would change their position (move up and down) possibly having an impact on a pilot's analysis.
- The Mast Moment indication (yellow and red circle) would not be shown at speeds above 55 knts in a real aircraft



(1/3) FLI indication after bearing failure – AEO, 80 KNTS, 2500ft (assuming maximum theoretical power value without friction)

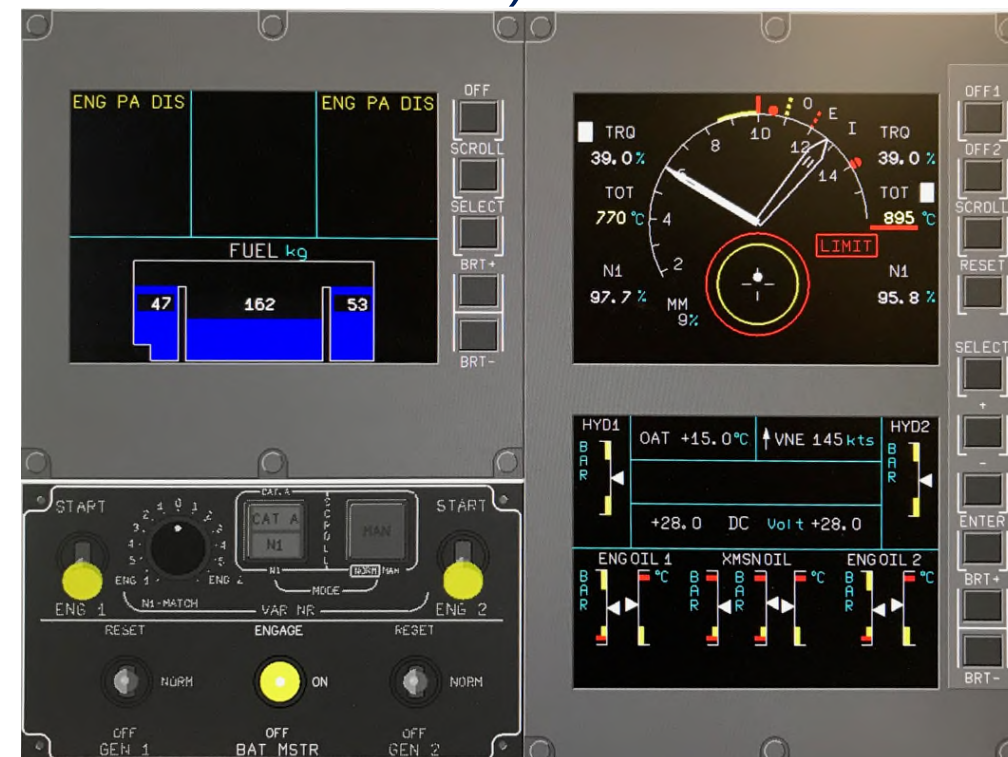
- The turbine outlet temperature TOT(T45) of engine #2 exceeds the All Engines Operative AEO limit of 845°C (see FLM excerpt below).
- This causes the FLI needle for engine #2 to switch from torque to TOT indication. (white rectangle is now placed next to TOT)
- Torque value for both engines is unchanged as indicated by the numeric values
- N1 of engine #2 slightly decreases
- ENG PA DIS** caution is displayed, accompanied by the master caution light
- LIMIT** warning is triggered accompanied by a GONG
- VARTOMS is not making any input as the torque values are still matched. Hypothetical rapid erratic changes in torque on engine #2 could not be compensated by the system.

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Max. continuous power	11.0	91.5	100.2–101.9	845 ³⁾



before



after

(2/3) FLI indication after bearing failure – AEO ENG PA DIS caution

The Master caution will illuminate with each caution message on the CAD. If acknowledged by depressing the push button on the cyclic stick grip, labelled RESET, the Master caution will extinguish. The Master caution will be activated again by the next caution message on the CAD.



Acknowledged ENG PA DIS caution on CAD

The ENG PA DIS caution is triggered because the conditions for “TOT discrepancy” are met

- $TOT_{eng1} - TOT_{eng2} > 80^{\circ}C$ $(895^{\circ}C - 770^{\circ}C = 125^{\circ}C)$
- $N1_{eng1} - N1_{eng2} \leq 4\%$ $(97.7\% - 95.8\% = 1.9\%)$

ENG PA DIS thresholds

N1 Discrepancy is detected when:

$|N11 - N12| > 4\%$ least for 5 sec

and

$|TOT1 - TOT2| \leq 80^{\circ}C$

TOT Discrepancy is detected when:

$|TOT1 - TOT2| > 80^{\circ}C$ at least for 5 sec

and

$|N11 - N12| \leq 4\%$

TRQ Discrepancy is detected when*):

$|N11 - N12| > 4\%$ at least for 5 sec

and

$|TOT1 - TOT2| > 80^{\circ}C$ at least for 5 sec

(3/3) FLI indication after bearing failure – AEO **LIMIT** warning



Limit Warning Light

The limit light and counter is shown in the right center part of the FLI screen. Whenever a FLI limit is exceeded (incl. VNE and mast moment) the limit light in red a box becomes visible in combination with an audio warning (gong). The respective parameter is underlined in red.

FLI OEI indication after Engine #2 bearing failure and engine #1 shutdown via throttle

- After the engine was shut down by the pilot the remaining available power of the aircraft would have allowed to keep the altitude at 80knts IAS.
- Down to 65knts IAS the power requirement decreases, allowing level flight
- Approximately around 50knts IAS and below the available power would not have been sufficient for level flight.
- In a turn the power requirement would increase
- With the maximum available power, below 50knts IAS in a turn, a high decent rate would have rapidly build up
- Note the recommended airspeed for autorotation in the flight manual is 75knts.
- **ENG PA DIS** caution is still displayed
- In addition, because of the engine shut down **GEN DISCON**, **FUEL PRESS**, **ENG OIL P**, **VAR NR**, **OVSP FAIL** and **TWIST GRIP** are displayed
- In addition to the **LIMIT** warning the **ENG FAIL** warning is triggered. ENG FAIL warning comes on (Warning Unit and VEMD) with a warning gong, when the N1 RPM of the engine drops below 50%. The warning gong accompanying these warnings can be suppressed by the pilot.
- The only warning tone which cannot be suppressed by the pilot is for high N_{rotor} (>110%)



3.4.18 Autorotation

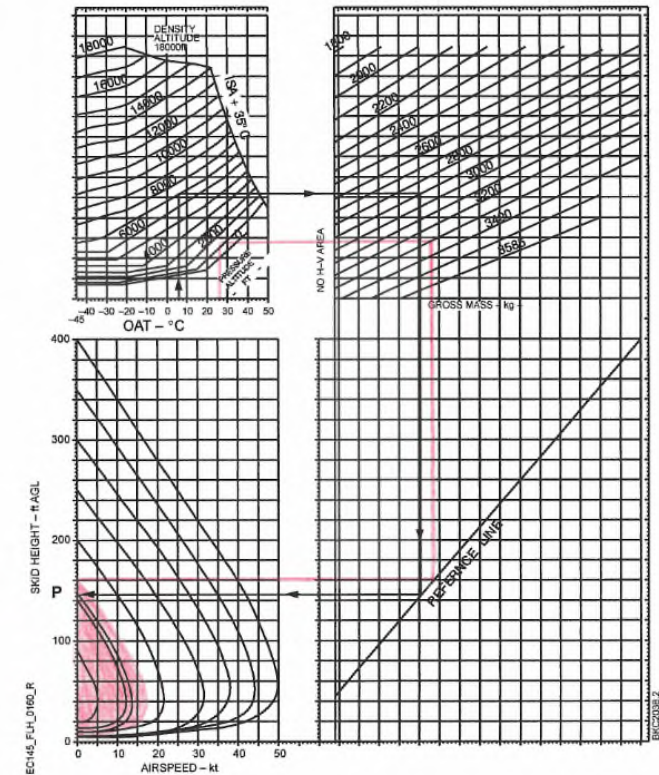
Procedure

- | | |
|---------------------|---|
| 1. Collective lever | – Reduce to maintain N_{RO} within limits |
| 2. Airspeed | – 75 KIAS recommended |

NOTE Maximum range airspeed 90 KIAS
 Minimum rate-of-descent airspeed 60 KIAS

Autorotation aspects

HEIGHT-VELOCITY DIAGRAM

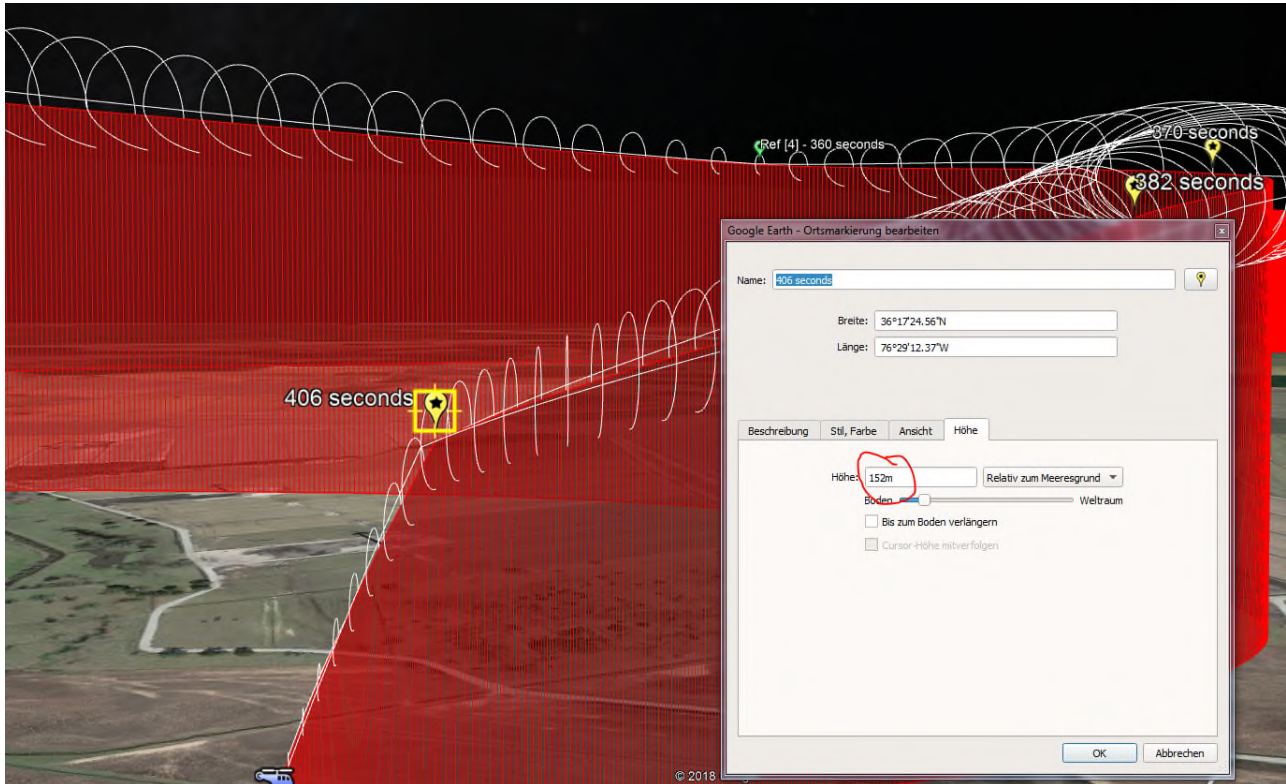


3.4.18 Autorotation

Procedure

- | | |
|---------------------|---|
| 1. Collective lever | – Reduce to maintain N_{RO} within limits |
| 2. Airspeed | – 75 KIAS recommended |

NOTE Maximum range airspeed 90 KIAS
Minimum rate-of-descent airspeed 60 KIAS



- It is unknown whether the pilot tried to initiate an autorotation.
- He might have dropped the RPM before entering into an autorotation or the RPM was consumed during the flare.
- It is known that the aircraft impacted without forward speed.
- According to the witness statements it is likely that the forward speed almost completely consumed before the vertical decent started.
- The IWI reconstruction shows that the final almost vertical decent started at about 500 ft. AGL.
- This means initiation of an autorotation would have been possible at this point. (see red area in H-V diagram)
- With the given -very high- impact loads which were observed with the wreckage it is most likely that the RPM was not lost during a flare at the end of an autorotation but rather when entering into autorotation

Engine Chip Caution

- Metallic particles were found when the chip detector of the gas generator rear bearing of engine #2 was examined.
- Thus it is possible that the pilot was confronted with an ENG CHIP caution light during the final phase of the flight. One of the 2 alternatives given in the FLM is to perform a single engine emergency shut down.

CAUTION INDICATIONS	
ENG CHIP (SYSTEM 1)	ENG CHIP (SYSTEM 2)
Conditions/Indications Metal particles detected in engine oil.	
Procedure	
● ON GROUND	
1. Affected engine	– Identify
2. Single engine emergency shutdown	– Perform
● IN FLIGHT	
1. OEI flight condition	– Establish
2. Affected engine	– Identify
1. Alternative:	
3. Single engine emergency shutdown	– Perform
2. Alternative:	
3. Twist grip (affected engine)	– Rotate slowly to IDLE, check indications
CAUTION THE SECOND ALTERNATIVE ENABLES THE CREW TO USE THE AFFECTED ENGINE FOR LANDING IF NECESSARY. BE PREPARED FOR ENGINE FAILURE. MONITOR N1, TOT, TORQUE, OIL PRESSURE AND TEMPERATURE OF AFFECTED ENGINE CLOSELY. IF THE PARAMETERS FLUCTUATE OR THEIR LIMITS ARE EXCEEDED PERFORM SINGLE ENGINE EMERGENCY SHUTDOWN IMMEDIATELY.	
4. LAND AS SOON AS PRACTICABLE	



Thank you