Design factors and safety in air transport

Some examples of the role of design in aviation incidents and accidents

Martin Nijhof, Flight Safety Investigator, November 2021

World war II design issue: Flap & Gear levers


OFF VALVE
STEADY
OFF
RED
AMBER
KEY
STEADY
GEAR
UP
DOWN
ON
LANDING LIGHTS
OFF
ST PUMP
RECOGNITION LIGHTS
OFF
GREEN
WHITE
KEY
KEY
WARNING
NEVER EXCEED
147 MPH WITH
FLAPS DOWN
RECOG. LIGHTS MAX.
GROUND OPERATING
TIME TEN (10) SEC.

Alphonse Chapanis
Intuitive design

Mapping

Phot0 taken from THE DESIGN OF EVERYDAY THINGS by Donald Norman

Presentation Contents

- System design factors: two takeoff incidents involving erroneous weight entry
- Procedure design factors: Selecting takeoff flaps
- Human centered design: a few design principles

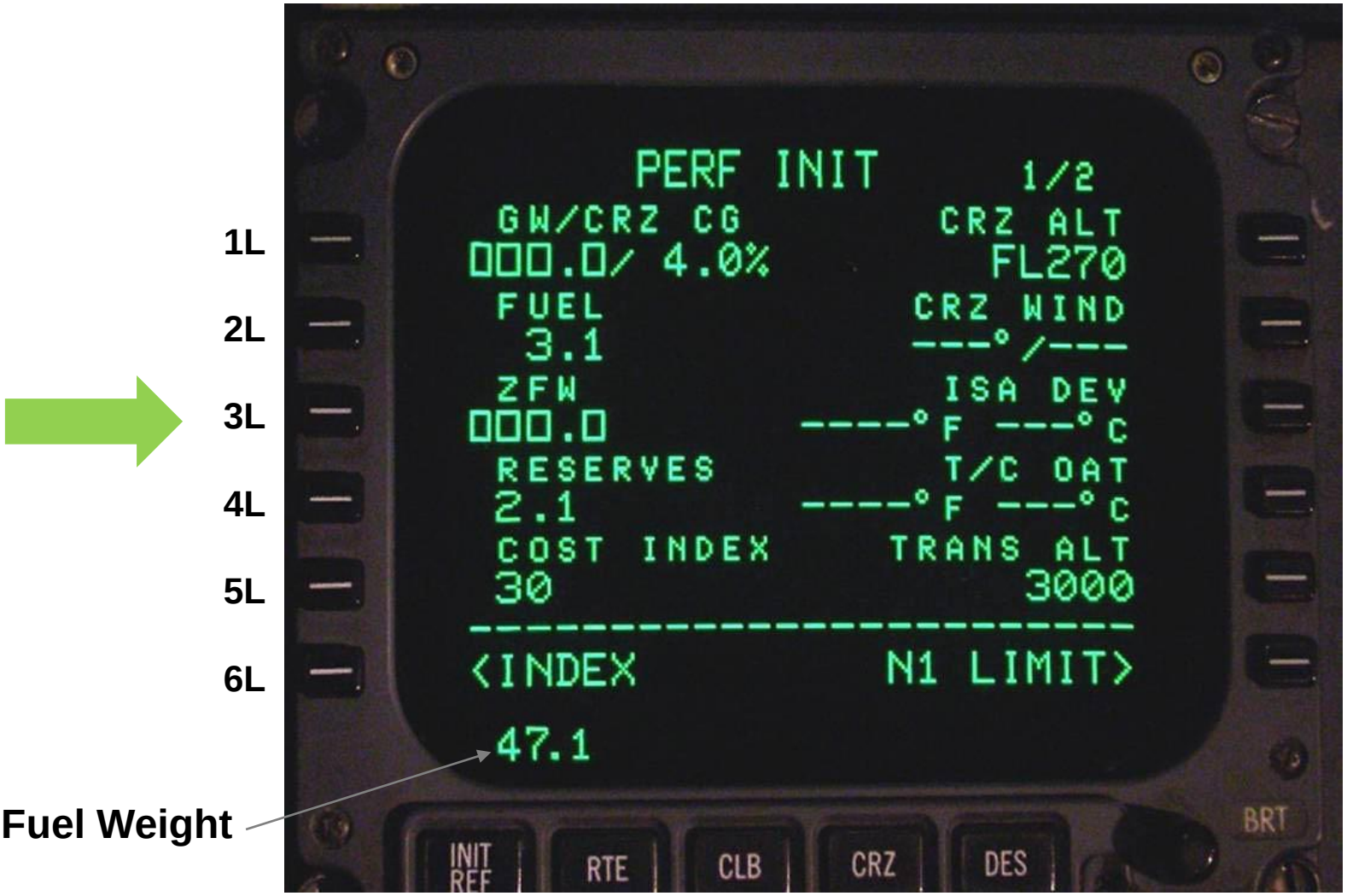
Case study: Tail strike following Zero Fuel Weight entry error

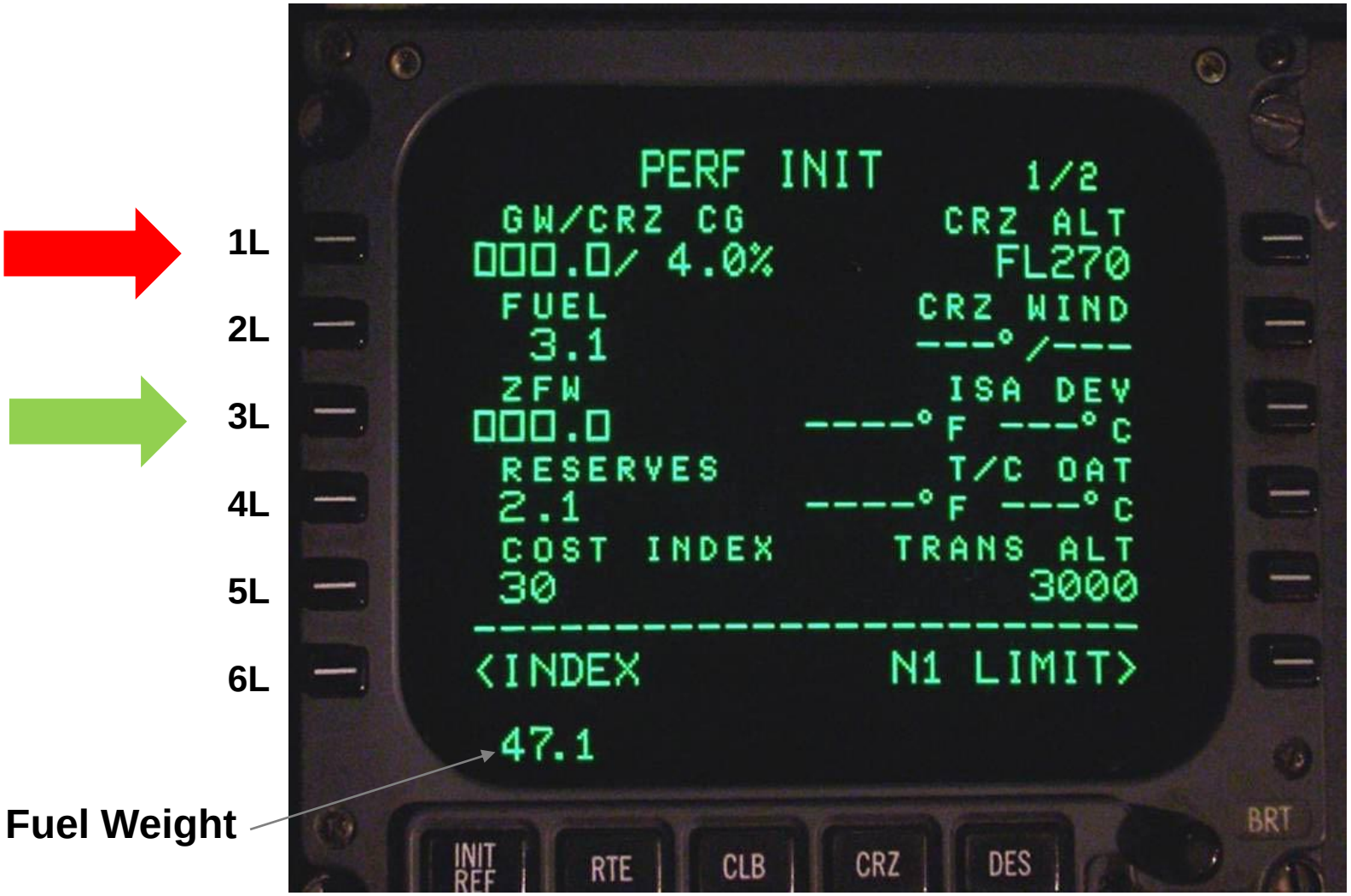
Procedure:

After receipt of the load sheet, enter the Zero Fuel Weight (ZFW) into the Flight Management System (FMS). *[The FMS will calculate the Gross Weight (GW)]*

Use the GW to calculate the takeoff data (V1, Vr, V2, flaps and thrust setting)

Enter takeoff data into FMS


PERF INIT 1/2
GW/CRZ CG
000.0/ 4.0%
CRZ ALT
FL270
FUEL
3.1
CRZ WIND
---°/---
ZFW
000.0
ISA DEV
-----°F ---°C
RESERVES
2.1
T/C OAT
-----°F ---°C
COST INDEX
30
TRANS ALT
3000
<INDEX
N1 LIMIT>
47.1
1L
2L
3L
4L
5L
6L
Zero Fuel Weight
INIT REF
RTE
CLB
CRZ
DES
BRT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3L
4L
5L
6L
Zero Fuel Weight
INIT REF
RTE
CLB
CRZ
DES
BRT

1L

2L

3L

4L

5L

6L

Loadsheet design

```
.
DOW       35131
TRFLD     13206
ZFW       48337 FOUR-EIGHT-THREE-THREE-SEVEN
TOF        8290
TOW       56627 FIVE-SIX-SIX-TWO-SEVEN
TRPF       2979
LAW       53648 L
UNDLD      1236
TXW       56819
TXF         192
.
```

```
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DOW       35131
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TXF         192
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```

Case study: Tail strike following Takeoff Weight entry error

Electronic Flight Bag (EFB)

Flight Management System (FMS)

Flight Management Computer

Electronic Flight Bag (EFB)

Procedure:

Enter airport data and TOW into the EFB. The EFB calculates takeoff data.

After receipt loadsheet: enter loadsheet ZFW into the FMS, then **manually** enter EFB calculated flap setting, thrust and takeoff speeds.

Note: FMS calculates its own (less refined) takeoff speeds based on FMS GW, flaps & thrust

Check EFB data versus data entered into FMS.

Incident:

- Crew entered TOW of 247,6 tons instead of 347,6 tons into the EFB. EFB calculates low thrust setting and low takeoff speeds.

- Crew entered correct ZFW into FMS, followed by EFB calculated flap setting and thrust.

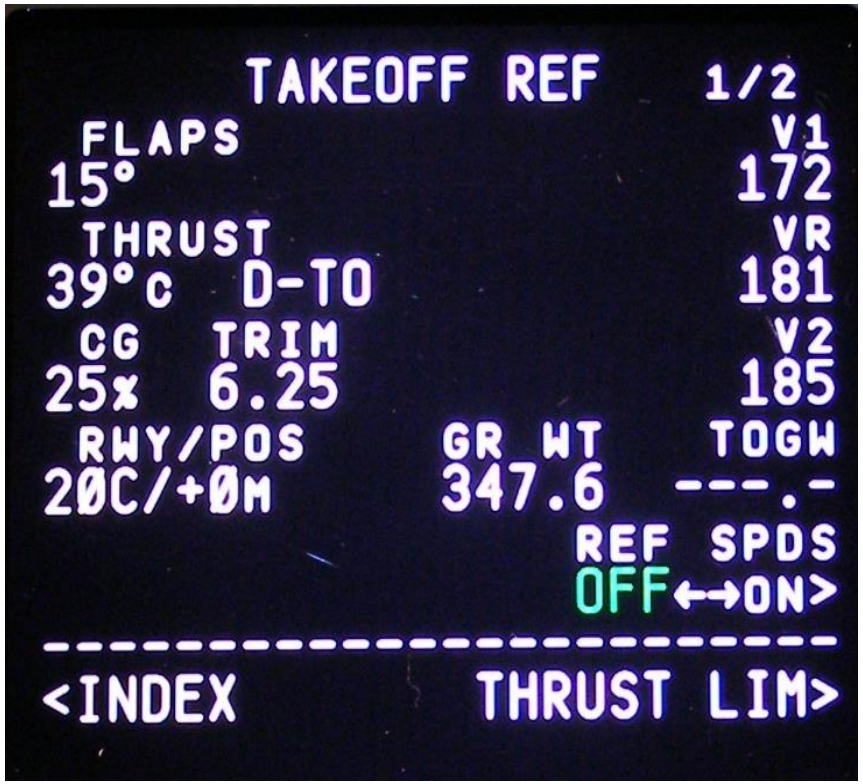
- FMS can not calculate FMS takeoff speeds for the unrealistic combination of the high (FMS) TOW and low (EFB calculated) thrust setting.

- So it will present this message:

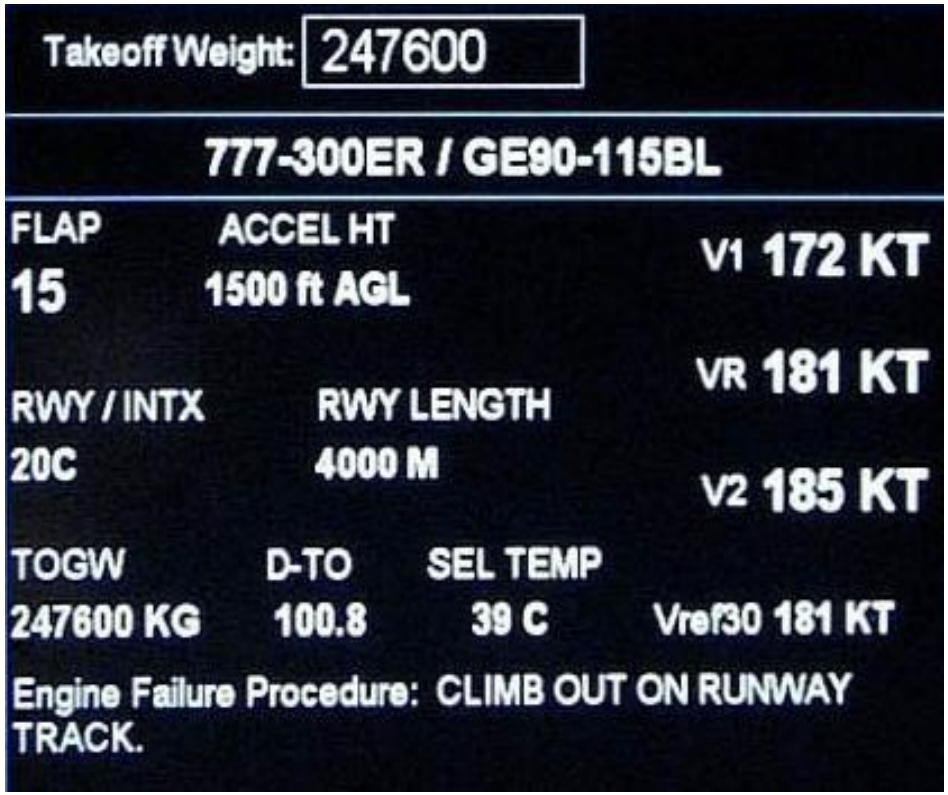
- Crew doesn’t understand message and the EFB takeoff speeds are entered into the FMS.

- Crew should now compare FMS vs EFB data

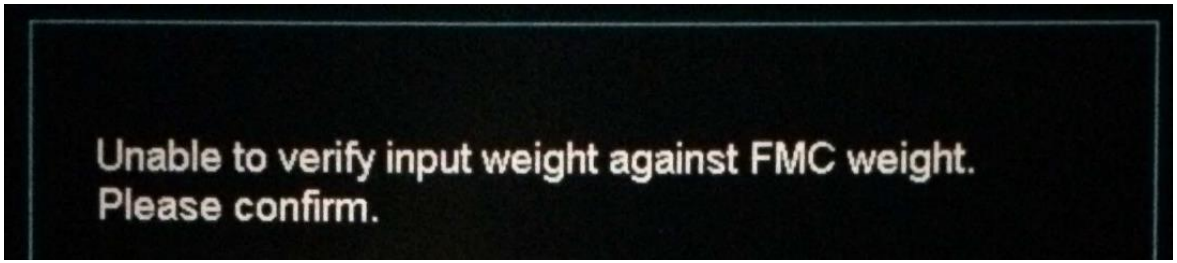
Takeoff data presentation
Flight Management System



Takeoff data presentation
Electronic Flight Bag



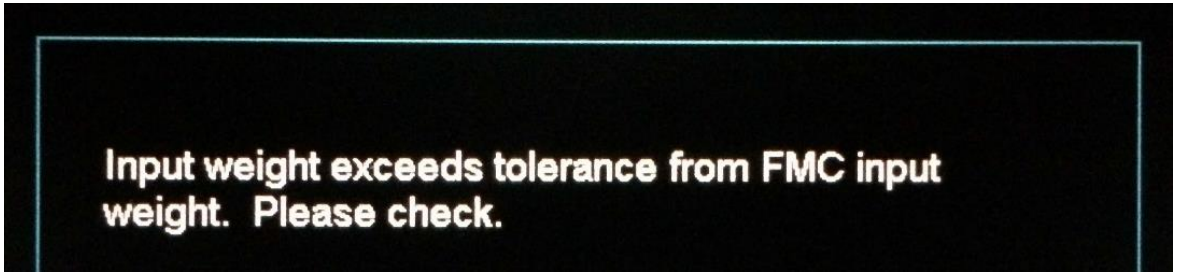
Software update following various incidents:



Normal procedure: enter the EFB weight before entering weight into the FMS.

Result: EFB generates message on each and every flight

Action: Clear message



Entry error: entry is made causing a significant difference to exist between the EFB TOW and the FMC GW.

Result: an EFB message presented only when significant weight discrepancy exists.

Likely action: clear message and continue without checking input weight.

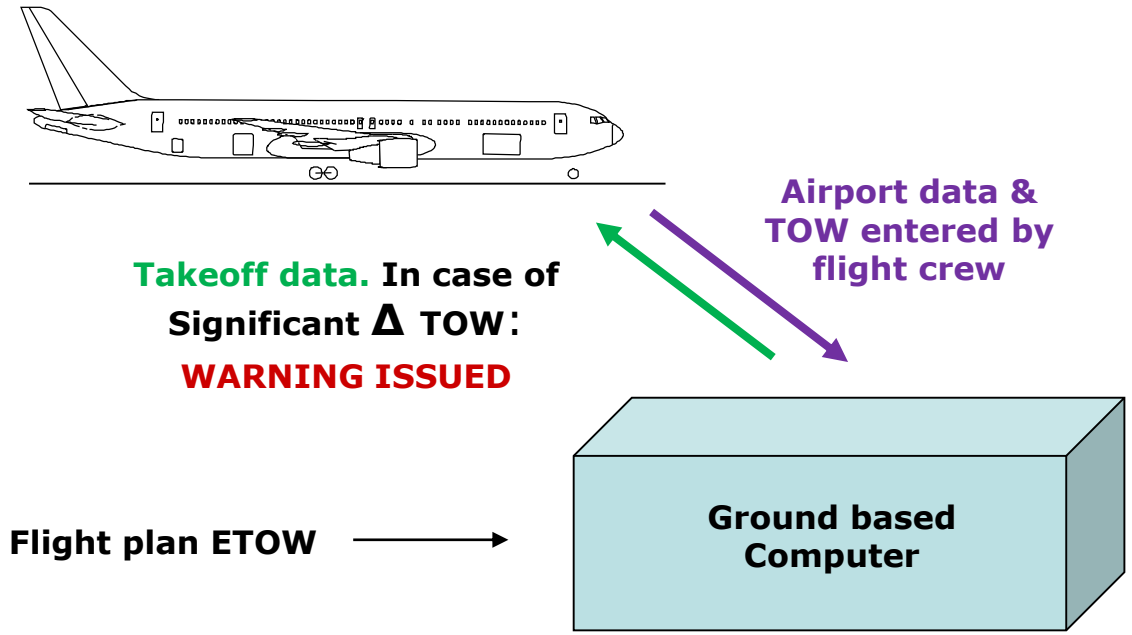
Independent calculations

"The loadsheet and TODC SOPs developed by the airline were robust and contained numerous crosschecks to ensure takeoff performance data was calculated correctly. Despite this, the crew used incorrect information to calculate takeoff performance and, even though the pilots noticed the high *FLEX* temperature, it did not prompt them to investigate whether they had made an error."

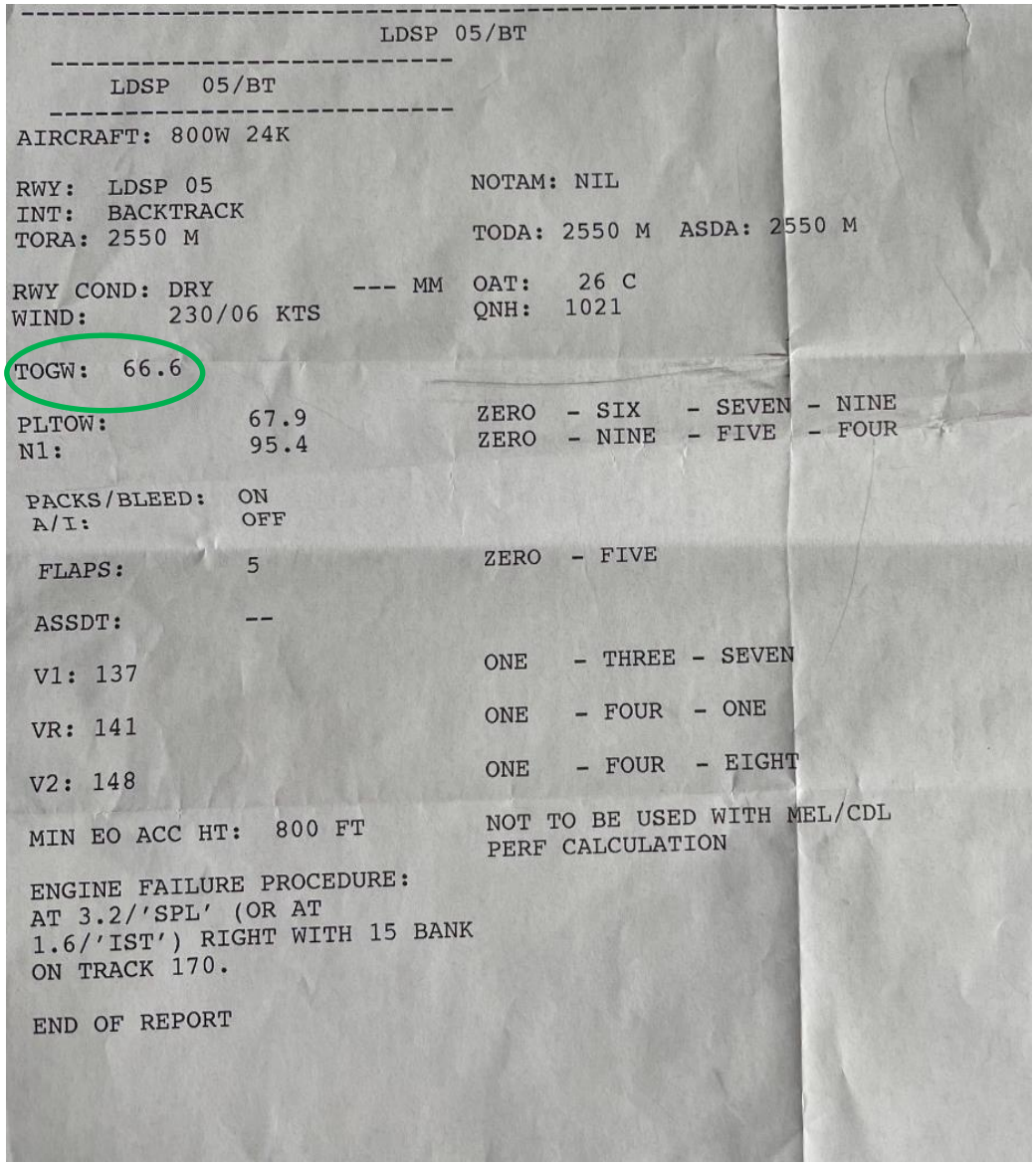
AAIB Report EW/G2009/12 /04,
Airbus A340-600, LHR, 12-12-2009

Solution: Really independent weight verification

Non-aircraft based takeoff data calculation:
independent comparison of the pilot entry versus flight plan ETOW or loadsheet TOW



Independent weight verification



LDSP 05/BT

LDSP 05/BT

AIRCRAFT: 800W 24K

RWY: LDSP 05
INT: BACKTRACK
TORA: 2550 M

NOTAM: NIL

TODA: 2550 M ASDA: 2550 M

RWY COND: DRY --- MM
WIND: 230/06 KTS

OAT: 26 C
QNH: 1021

TOGW: 66.6

PLTOW: 67.9
N1: 95.4

ZERO - SIX - SEVEN - NINE
ZERO - NINE - FIVE - FOUR

PACKS/BLEED: ON
A/I: OFF

FLAPS: 5

ZERO - FIVE

ASSDT: --

V1: 137

ONE - THREE - SEVEN

VR: 141

ONE - FOUR - ONE

V2: 148

ONE - FOUR - EIGHT

MIN EO ACC HT: 800 FT

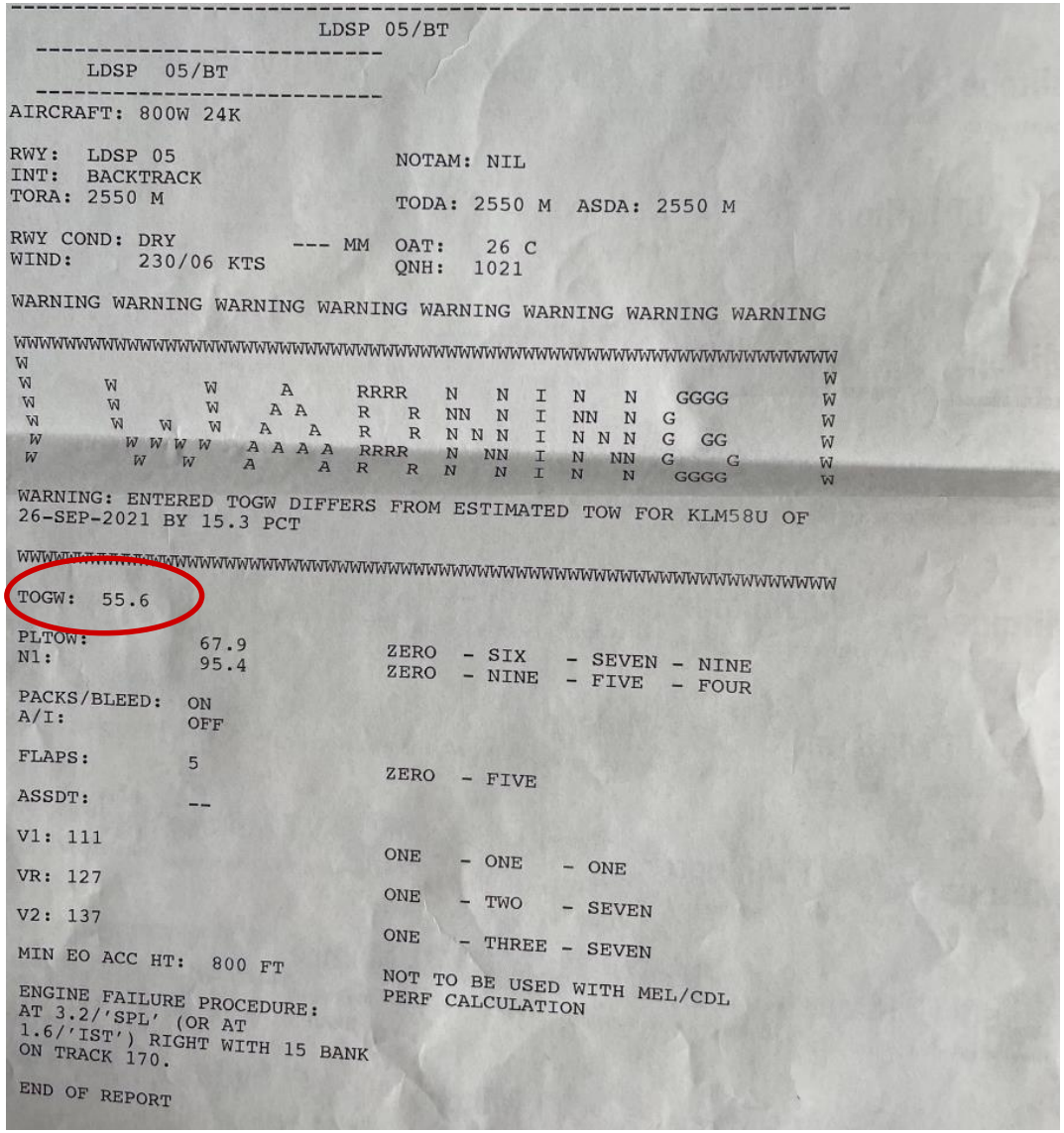
NOT TO BE USED WITH MEL/CDL
PERF CALCULATION

ENGINE FAILURE PROCEDURE:
AT 3.2/'SPL' (OR AT
1.6/'IST') RIGHT WITH 15 BANK
ON TRACK 170.

END OF REPORT

CORRECT TOW: 66.6 t

Independent weight verification



```
                          LDSP 05/BT
  ---------------------------
      LDSP  05/BT
  ---------------------------
AIRCRAFT: 800W 24K

RWY:  LDSP 05                      NOTAM: NIL
INT:  BACKTRACK
TORA: 2550 M                       TODA: 2550 M  ASDA: 2550 M

RWY COND: DRY            --- MM    OAT:   26 C
WIND:     230/06 KTS               QNH:   1021

WARNING WARNING WARNING WARNING WARNING WARNING WARNING WARNING

WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW
W
W      W       W     A     RRRR   N   N  I  N   N   GGGG          W
W      W       W    A A    R   R  NN  N  I  NN  N  G              W
W      W   W   W   A   A   R   R  N N N  I  N N N  G  GG          W
W       W W W W   A A A A  RRRR   N  NN  I  N  NN  G    G         W
W        W   W    A     A  R   R  N   N  I  N   N   GGGG          W

WARNING: ENTERED TOGW DIFFERS FROM ESTIMATED TOW FOR KLM58U OF
26-SEP-2021 BY 15.3 PCT

WWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWWW

TOGW:  55.6

PLTOW:          67.9
N1:             95.4                ZERO - SIX   - SEVEN - NINE
                                    ZERO - NINE  - FIVE  - FOUR
PACKS/BLEED:    ON
A/I:            OFF

FLAPS:          5                   ZERO - FIVE

ASSDT:          --

V1: 111                             ONE  - ONE   - ONE

VR: 127                             ONE  - TWO   - SEVEN

V2: 137                             ONE  - THREE - SEVEN

MIN EO ACC HT:  800 FT              NOT TO BE USED WITH MEL/CDL
                                    PERF CALCULATION
ENGINE FAILURE PROCEDURE:
AT 3.2/'SPL' (OR AT
1.6/'IST') RIGHT WITH 15 BANK
ON TRACK 170.

END OF REPORT
```

INCORRECT TOW: 55.6 t

Procedure design

- Selection of takeoff flaps
- Memory items

Selection of takeoff flaps

Manufacturer's procedure:

- Following pushback and engine start, when ground equipment is clear (upon receipt of the ALL CLEAR signal) the captain calls for takeoff flaps to be set.

- Takeoff flap setting is checked when the BEFORE TAKEOFF Checklist is done

NORMAL CHECKLIST of MANUFACTURER

BEFORE TAXI

Generators . . . . . On
Pitot heat . . . . . ON
Anti-ice . . . . . ___
Isolation valve . . . . . AUTO
Engine start switches . . . . . CONT
Recall . . . . . Checked
Autobrake . . . . . RTO
Engine start levers . . . . . IDLE detent
Flight controls . . . . . Checked
Ground equipment . . . . . Clear

BEFORE TAKEOFF

Flaps . . . . . 5, Green light
Stabilizer trim . . . . . ___ Units

NORMAL CHECKLIST - OPERATOR

BEFORE TAXI

Generators . . . . . On
Pitot heat . . . . . ON
Anti-ice . . . . . ___
Isolation valve . . . . . AUTO
Engine start switches . . . . . CONT
Recall . . . . . Checked
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Flaps . . . . . 5, Green light
Engine start levers . . . . . IDLE detent
Flight controls . . . . . Checked
Ground equipment . . . . . Clear

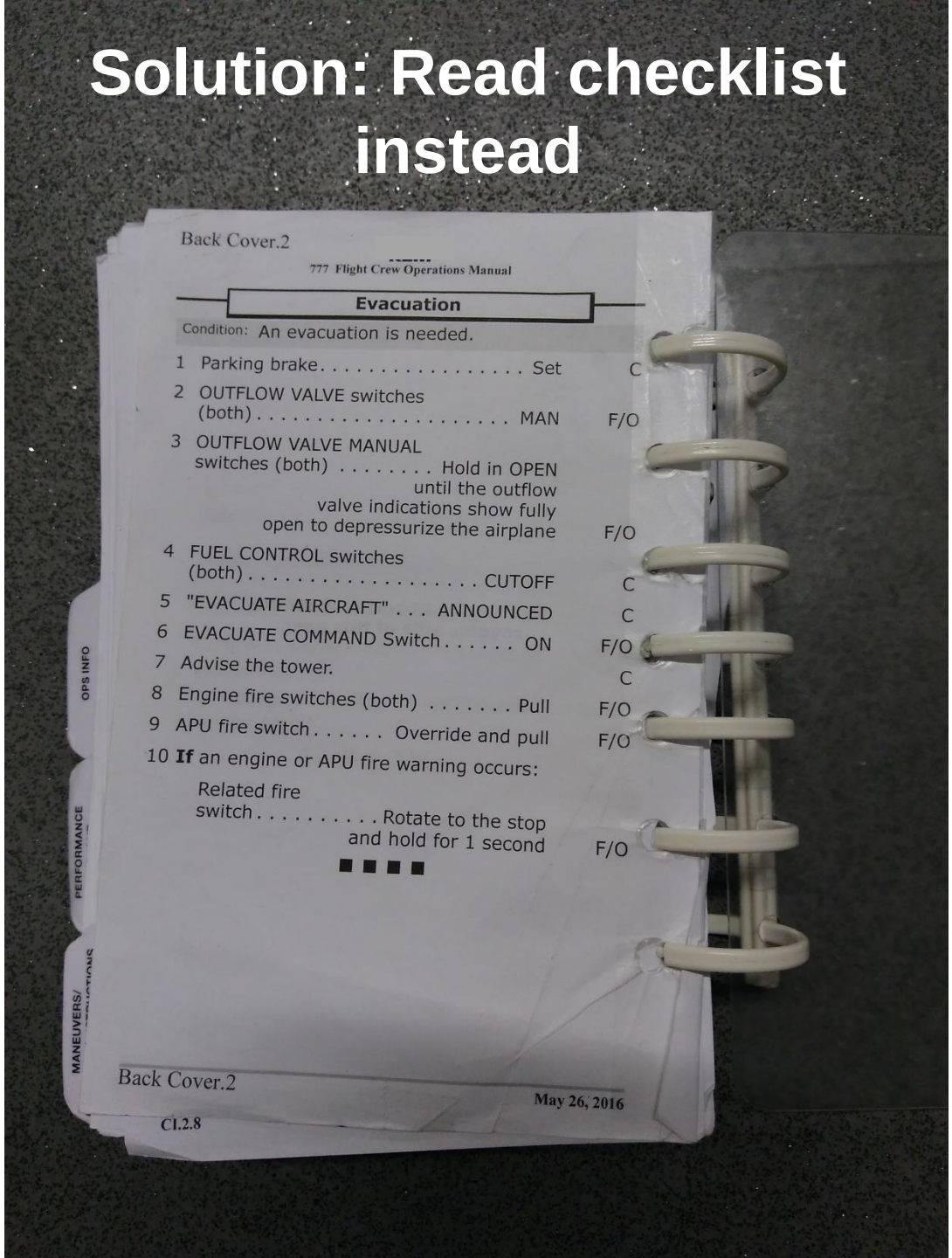
BEFORE TAKEOFF

Flaps . . . . . 5, Green light
Stabilizer trim . . . . . ___ Units

Memory items

AAIB UK Report EW/G2017/10/06

Solution: Read checklist instead



Back Cover.2

777 Flight Crew Operations Manual

Evacuation

Condition: An evacuation is needed.

1	Parking brake . . . . . Set	C
2	OUTFLOW VALVE switches (both) . . . . . MAN	F/O
3	OUTFLOW VALVE MANUAL switches (both) . . . . . Hold in OPEN until the outflow valve indications show fully open to depressurize the airplane	F/O
4	FUEL CONTROL switches (both) . . . . . CUTOFF	C
5	"EVACUATE AIRCRAFT" . . . ANNOUNCED	C
6	EVACUATE COMMAND Switch . . . . . ON	F/O
7	Advise the tower.	C
8	Engine fire switches (both) . . . . . Pull	F/O
9	APU fire switch . . . . . Override and pull	F/O
10	**If** an engine or APU fire warning occurs:	
	Related fire switch . . . . . Rotate to the stop and hold for 1 second	F/O

■ ■ ■ ■

OPS INFO

PERFORMANCE

MANEUVERS/

Back Cover.2

May 26, 2016

CI.2.8

Some human-centered design principles

- Mapping
- Use both *Knowledge in the head and knowledge in the world*
- Design for error

Mapping

- Flap and gear lever design
- Mapping of data via congruent page design

Knowledge in the head and knowledge in the world

- Support the user by having knowledge required for a task available externally.
- The knowledge in the world should be presented such that it supports the user instead of impeding the user.

Case study: Cockpit - cabin interphone

Case study: Cockpit - cabin interphone

NTSB Report NTSB/AAR-18/01


But things are not that simple…
DOOR 1L 11
DOOR 2L 12
DOOR 3L 13
DOOR 4L 14
DOOR 1R 21
DOOR 2R 22
DOOR 3R 23
DOOR 4R 24
DOOR 1 AREA 81
DOOR 2 AREA 82
DOOR 3 AREA 83
DOOR 4 AREA 84
ALL CALL 55
OCR DOOR 1 96
OCR 1 SEATS 97
OCR 1 BUNKS 98
OCR DOOR 3 61
PA CABIN 46
PA CAB PRIO 40
PA C-CLASS 41
PA M CLASS 42
PA OCR DOOR 1 99
PA OCR DOOR 3 44
GRND CREW 01
DOOR TRIM

Knowledge in the head and knowledge in the world

Design for error

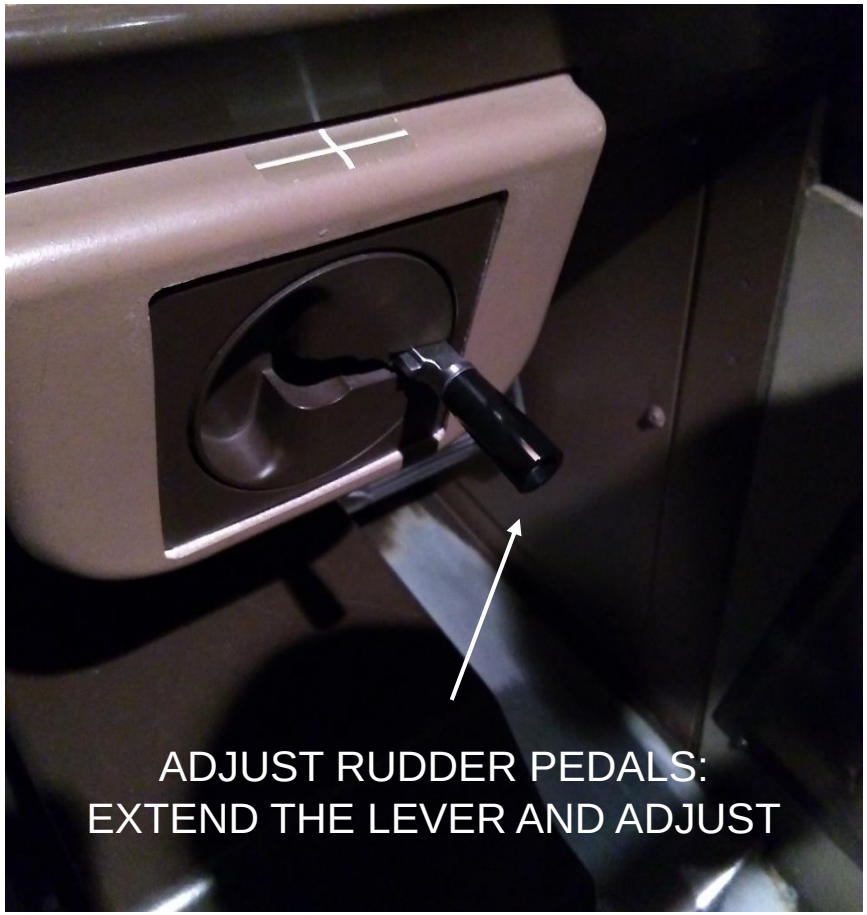
- Assume that if an error can be made, it will be made.
- Plan for it, adapt the design.

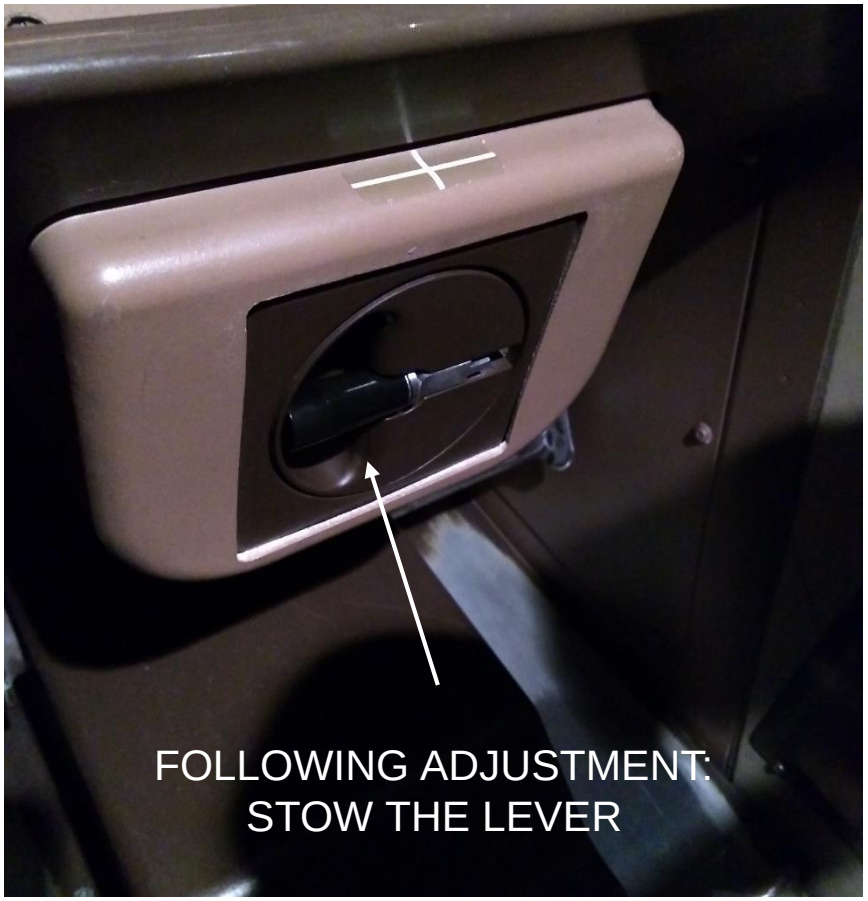
Case study: Inadvertent rudder pedal movement

The flight crew rejected the takeoff at high speed, after the PF felt that both rudder pedals started moving away from his feet during the high speed portion of the takeoff roll.

After the aircraft had been brought to a stop on the runway the PF observed that the rudder pedal adjust crank of his rudder pedal adjustment system was not in the stowed position, leaving the rudder pedals in an unlocked state.

Rudder pedal adjustment

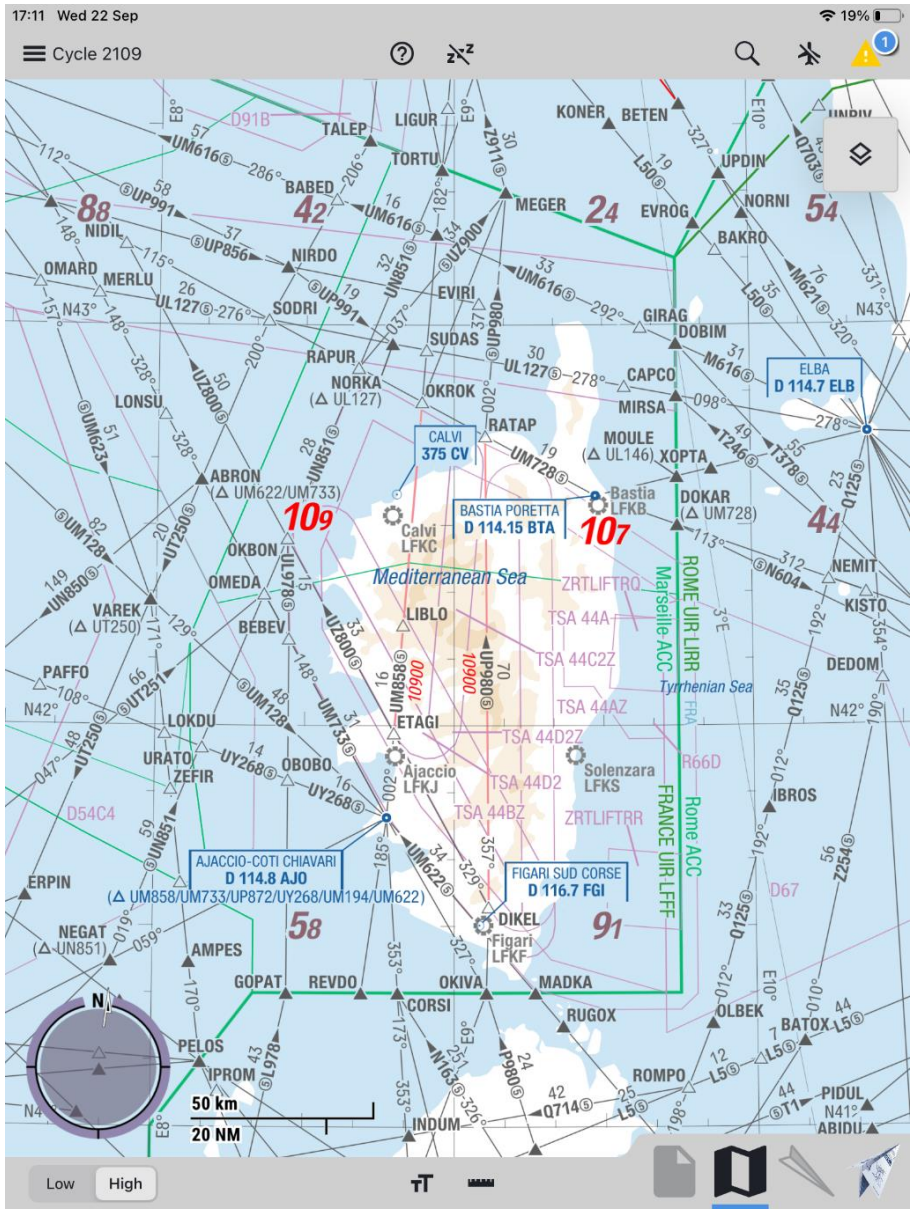


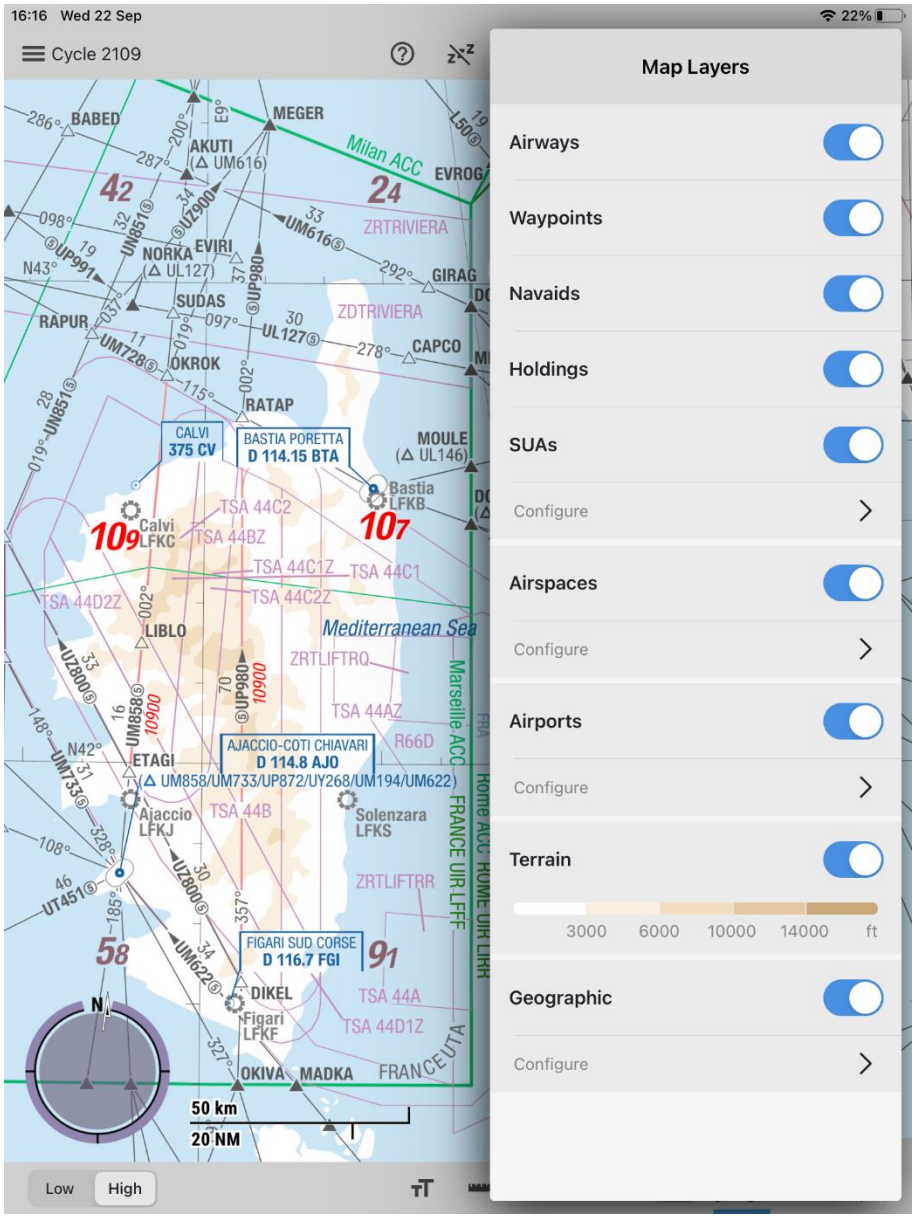


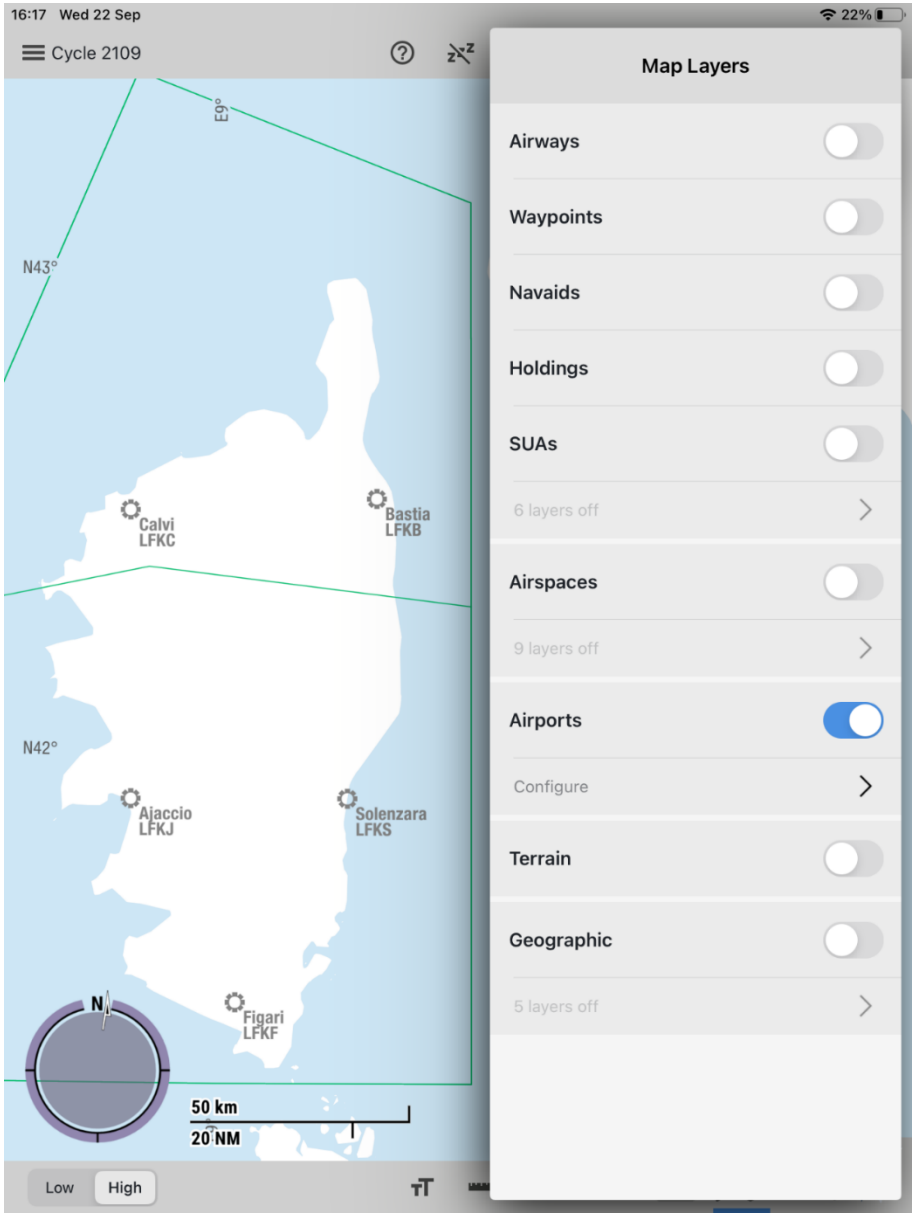
FCOM Note: *To avoid inadvertent rudder pedal movement, the crank handle should be stowed when not in use.*

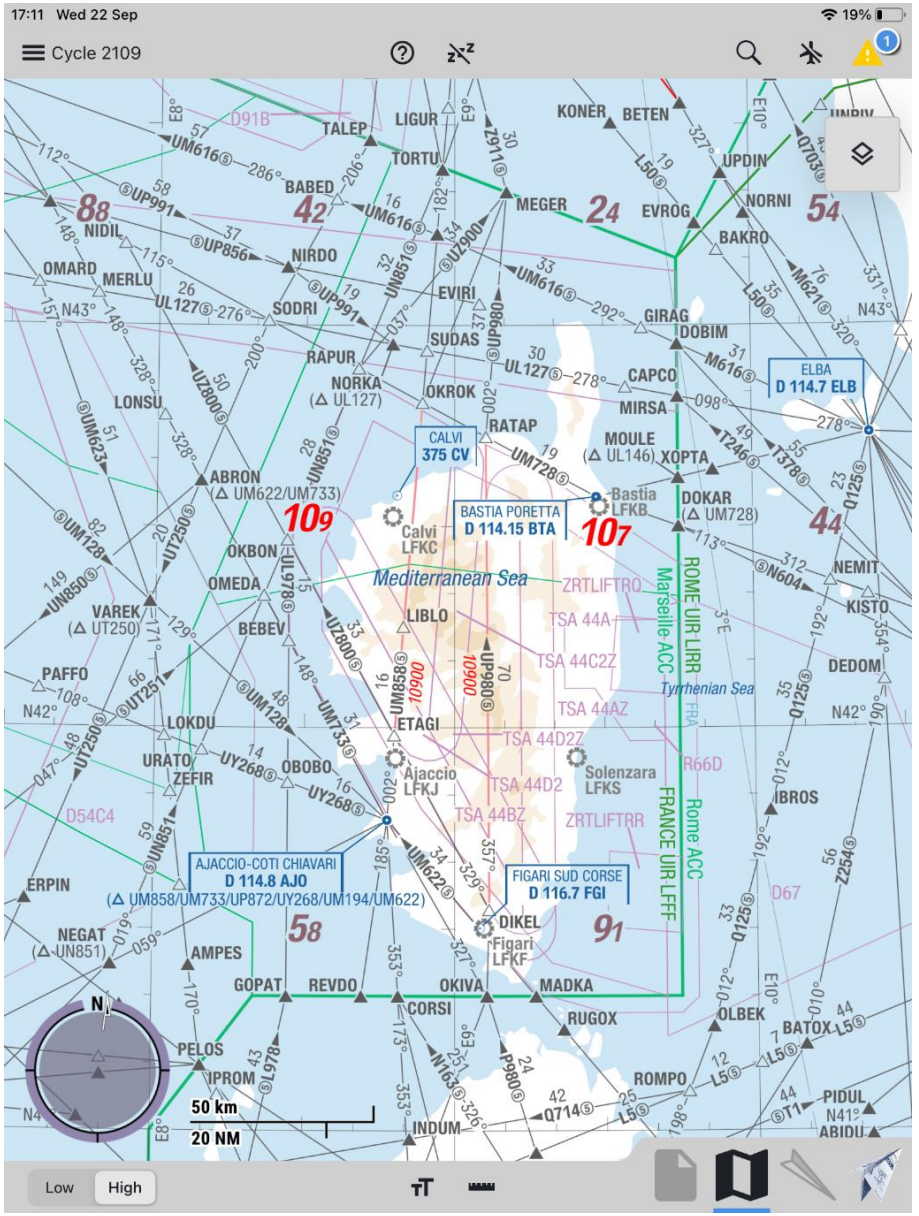
What's wrong here?

An example of human centered design

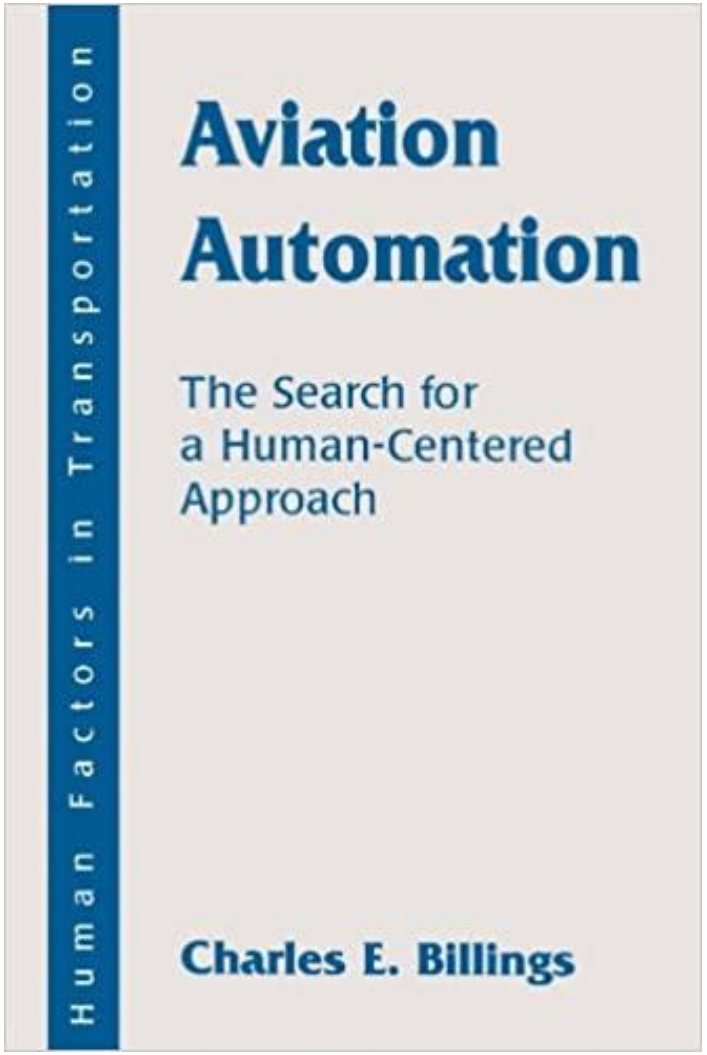


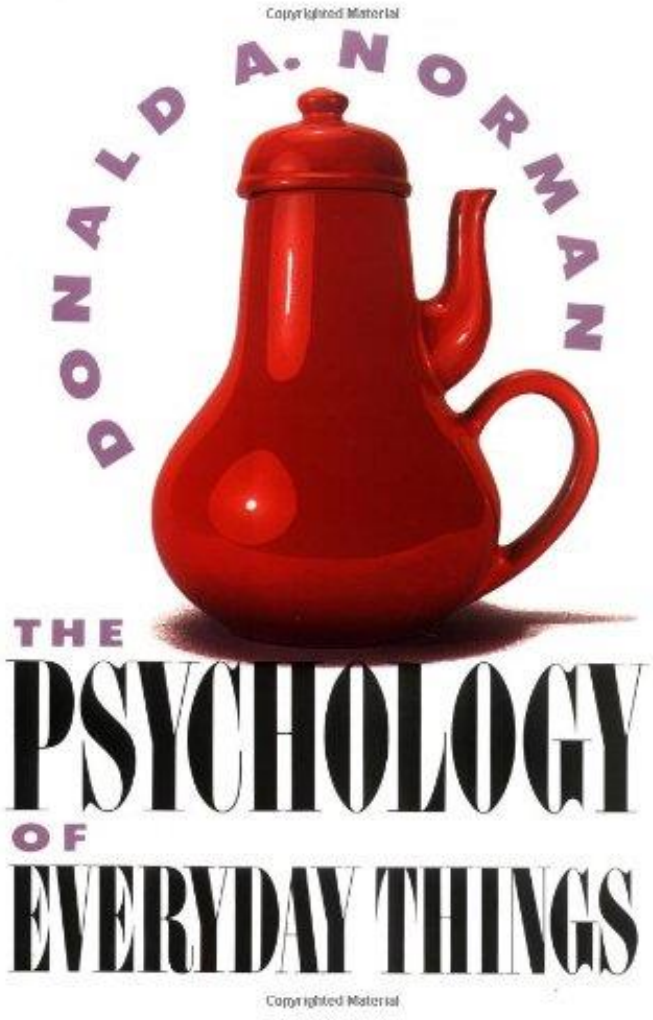



16:17 Wed 22 Sep
22%
Cycle 2109
Map Layers
Airways
Waypoints
Navaids
Holdings
SUAs
6 layers off
Airspaces
9 layers off
Airports
Configure
Terrain
Geographic
5 layers off
N43°
N42°
Calvi
LFKC
Bastia
LFKB
Ajaccio
LFKJ
Solenzara
LFKS
Figari
LFKF
50 km
20 NM
Low
High


17:11 Wed 22 Sep
19%
Cycle 2109
TALEP
LIGUR
TORTU
BABED
MEGER
EVROG
KONER
BETEN
UPDIN
NORNI
BAKRO
NIDIL
NIRDO
EVIRI
SODRI
OMARD
MERLU
SUDAS
GIRAG
DOBIM
RAPUR
NORKA
(△ UL127)
OKROK
CAPCO
MIRSA
LONSU
CALVI
375 CV
RATAP
MOULE
(△ UL146)
XOPTA
ELBA
D 114.7 ELB
ABRON
(△ UM622/UM733)
BASTIA PORETTA
D 114.15 BTA
Bastia
LFKB
Calvi
LFKC
DOKAR
(△ UM728)
Mediterranean Sea
OKBON
OMEDA
VAREK
(△ UT250)
BEBEV
LIBLO
ZRTLIFTRO
TSA 44A
TSA 44C2Z
TSA 44AZ
TSA 44D2Z
TSA 44D2
TSA 44BZ
ZRTLIFTRR
ROME UIR LIRR
Marseille ACC
Tyrrhenian Sea
FRANCE UIR LFFF
Rome ACC
PAFFO
LOKDU
ETAGI
URATO
ZEFIR
OBOBO
Ajaccio
LFKJ
Solenzara
LFKS
NEMIT
KISTO
DEDOM
IBROS
AJACCIO-COTI CHIAVARI
D 114.8 AJO
(△ UM858/UM733/UP872/UY268/UM194/UM622)
FIGARI SUD CORSE
D 116.7 FGI
ERPIN
NEGAT
(△ UN851)
AMPES
DIKEL
Figari
LFKF
GOPAT
REVDO
OKIVA
MADKA
CORSI
RUGOX
OLBEK
BATOX
PELOS
IPROM
ROMPO
PIDUL
INDUM
ABIDU
50 km
20 NM
Low
High

Classics


Human Factors in Transportation
Aviation Automation
The Search for a Human-Centered Approach
Charles E. Billings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DONALD A. NORMAN
THE PSYCHOLOGY OF EVERYDAY THINGS
Copyrighted Material


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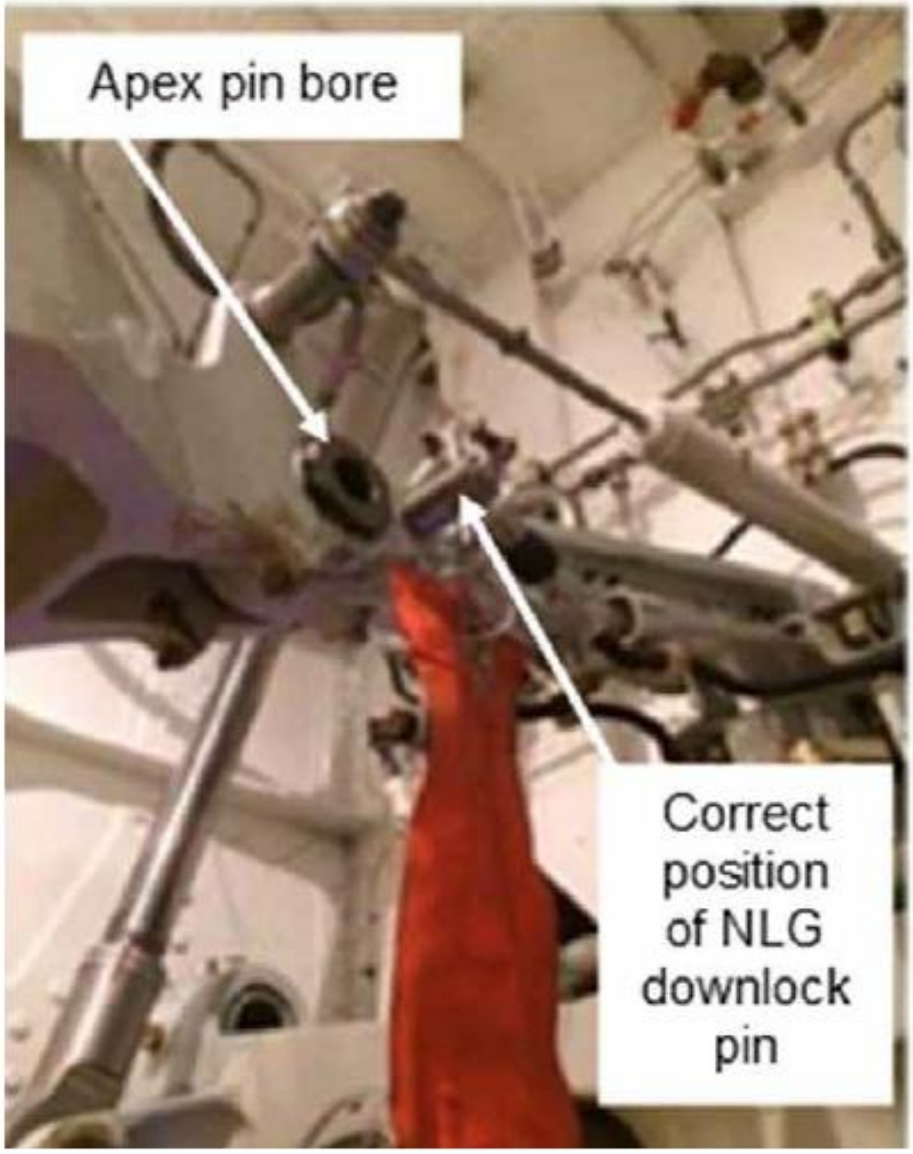
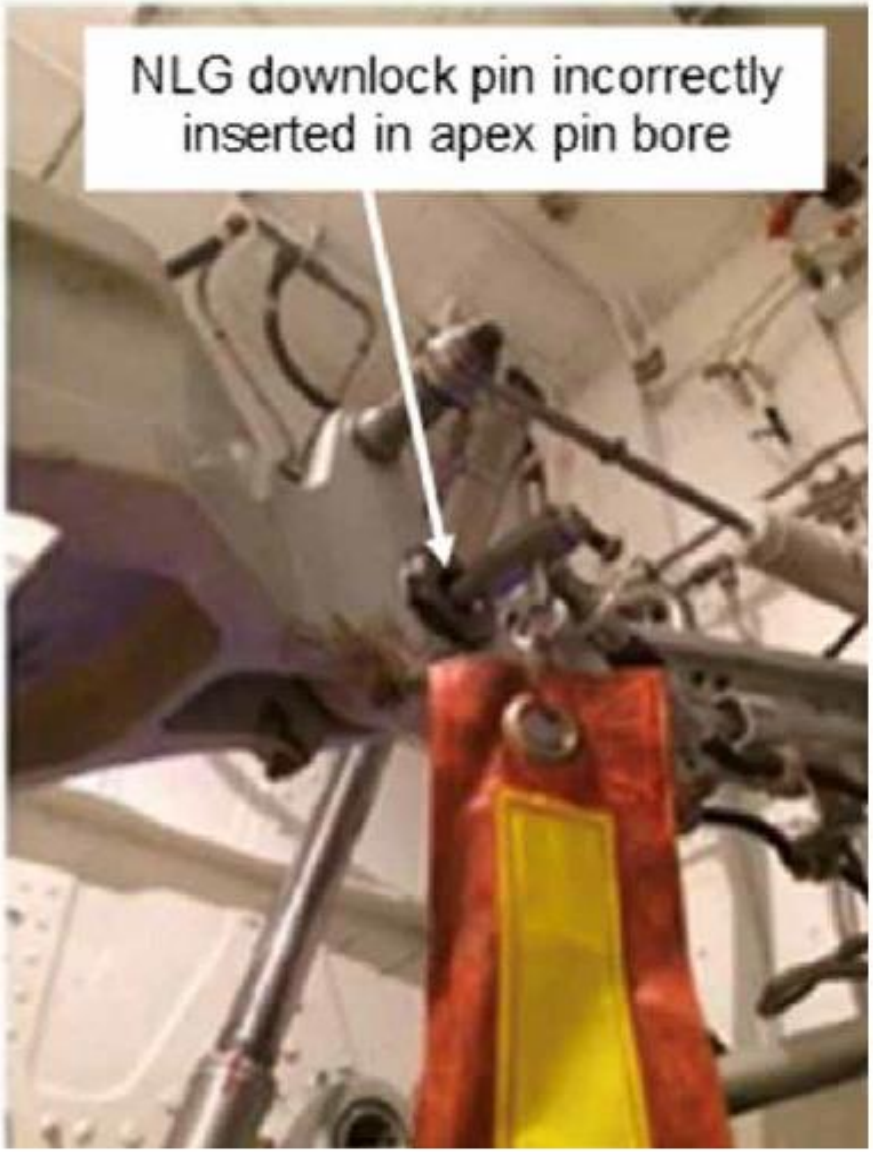

Apex pin bore
Correct position of NLG downlock pin


NLG downlock pin incorrectly inserted in apex pin bore

THANK YOU!