

**INCIDENT**

<b>Aircraft Type and Registration:</b>	Airbus A321-231, G-MEDJ	
<b>No &amp; Type of Engines:</b>	2 International Aero Engines V2533-A5 turbofan engines	
<b>Year of Manufacture &amp; Serial No:</b>	2004, MSN 2190	
<b>Date &amp; Time (UTC):</b>	24 August 2010 at 0225 hrs	
<b>Location:</b>	At FL360 over northern Sudan	
<b>Type of Flight:</b>	Commercial Air Transport (Passenger)	
<b>Persons on Board:</b>	Crew - 7	Passengers - 42
<b>Injuries:</b>	Crew - None	Passengers - None
<b>Nature of Damage:</b>	None	
<b>Commander's Licence:</b>	Airline Transport Pilot's Licence	
<b>Commander's Age:</b>	34 years	
<b>Commander's Flying Experience:</b>	Approximately 7,500 hours (of which approximately 1,400 were on type) Last 90 days - 165 hours Last 28 days - 61 hours	
<b>Information Source:</b>	AAIB Field Investigation	

**Synopsis**

The aircraft suffered an electrical malfunction during a scheduled night flight between Khartoum (Sudan) and Beirut (Lebanon). The more significant symptoms included the intermittent failure of the captain and co-pilot's electronic displays and the uncommanded application of left rudder trim, which was not annunciated to the flight crew. The flight crew also reported that the aircraft did not seem to respond as expected to control inputs. A large number of ECAM<sup>1</sup> messages and cautions were presented on the pilots' electronic display

units. The uncommanded rudder trim caused the aircraft to adopt a left-wing-low attitude and deviate to the left of the planned track. Normal functions were restored after the flight crew selected the No 1 generator to OFF in response to an 'ELEC GEN 1 FAULT' message. The aircraft landed safely at Beirut.

The No 1 generator was replaced, after which the fault did not recur. Damage was found on an electrical lead on the No 1 generator, but it could not be determined whether this had caused the symptoms experienced during the incident.

The aircraft manufacturer notified operators of this incident by issuing OIT 999.0105/10 on

**Footnote**

<sup>1</sup> Electronic Centralised Aircraft Monitoring system – this comprises two centrally mounted electronic display units, which present the flight crew with aircraft systems information, warning and memo messages and actions to be taken in response to systems failures.

19 November 2010 and also updated the Quick Reference Handbook procedure for '*Display Unit Failure*' to include a check of the rudder trim position.

### History of the flight

The incident occurred as the aircraft was cruising at Flight Level (FL) 360 over northern Sudan, with the commander as pilot flying and the No 1 autopilot (AP 1) and autothrust engaged. The conditions were night Instrument Meteorological Conditions, with slight turbulence. The commander reported that, without warning, his Primary Flight Display (PFD), Navigation Display (ND), and the ECAM upper Display Unit (DU) began to flicker, grey out, show lines or crosses, and go blank. Concurrently, there was a "chattering" heard coming from the rear circuit breaker panels, behind the two pilots' seats, which was thought to be relay operation. The abnormal behaviour ceased after a short time. The co-pilot checked the circuit breakers to see if any had operated and to look for signs of overheating, but nothing unusual was noted. The commander reviewed the ECAM electrical system page, which showed no abnormalities.

After a short interval the commander's PFD, ND, and ECAM upper DU began to flicker and grey out again, before blanking for longer periods. AP 1 was disconnected and the commander handed control to the co-pilot, whose display screens were unaffected at this time. The abnormal condition was once again short-lived and once conditions had returned to normal, the commander reassumed control and re-engaged AP 1.

The symptoms returned shortly thereafter, with the commander's displays becoming mostly blank, or showing white lines. When the displays were visible, the airspeed, altimeter, and QNH/STD indications were erratic. The co-pilot's PFD, ND, and the ECAM lower

DU began to flicker and were sometimes unreadable. The crew reported that the cockpit lights went off intermittently. The commander handed control to the co-pilot again, who flew the aircraft manually. Reference was made to the standby flight instruments, which operated normally throughout the incident.

During this period, the chattering sound from the rear circuit breaker panels resumed and was, at times, continuous. Numerous ECAM messages were presented and there were a number of master caution annunciations. Amber 'X' symbols indicating flight control system reconfiguration to Alternate Law<sup>2</sup> appeared on the PFDs, the flight directors were displayed only intermittently and the autothrust system went into 'thrust lock' mode. The aircraft rolled to the left and adopted an approximately 10° left-wing-low attitude, without any flight control input from the crew. The flight crew reported that the aircraft did not seem to respond as expected to their control inputs and shuddered and jolted repeatedly.

The commander recalled selecting the Display Management Computer (DMC) switch from 'NORM' to 'CAPT 3' to switch the source for the captain's displays from DMC 1 to DMC 3, but this had no effect in restoring his displays. The switch was left in the 'CAPT 3' position for the remainder of the flight.

The flight crew became concerned that the aircraft was malfunctioning. The ECAM was only sometimes visible and did not identify the root cause of the problem and there were no fault indications visible on the overhead panel. Moreover, they were not aware of any procedure applicable to the symptoms experienced. The

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#### Footnote

<sup>2</sup> Alternate Law is a mode of the flight control system in which certain protection features are unavailable.

commander contemplated transmitting a MAYDAY, but considered that his priorities were to retain control of the aircraft and identify the problem.

At one point the commander saw the ECAM ‘ELEC GEN 1 FAULT’ message and associated checklist appear momentarily. The checklist required the No 1 generator to be selected to OFF. On doing so the juddering motion ceased, the chattering noise stopped, and all displays reverted to normal operation, although the aircraft’s left-wing-low attitude persisted. The checklist directed that the generator should be selected ON again, and following discussion and agreement that it would be immediately deselected should the problems return, the commander selected it to ON. This caused the symptoms to return, prompting him to select it to OFF again.

The Auxiliary Power Unit was started and its generator was selected to power the systems previously powered by the No 1 generator. Shortly thereafter, the flight crew noticed that the rudder trim display indicated several units from neutral<sup>3</sup>, although they had not made any rudder trim inputs. When the rudder trim was reset to neutral, the aircraft readopted a wings-level attitude. The aircraft had deviated approximately 20 nm to the left of the intended track during the incident.

The aircraft was flown manually for the remainder of the flight and landed at Beirut without further incident.

The aircraft was inspected in Beirut and the No 1 Integrated Drive Generator (IDG1) was removed as unserviceable and sent for overhaul. There was no recurrence of the symptoms reported in this incident in subsequent flights.

## Reporting of the event

The commander reported the event shortly after arrival, both verbally by telephone to his managers, and in writing using an Air Safety Report (ASR) form which was placed in the operator’s internal mail system when the flight crew returned to the UK. However, the full significance of the event was not apparent during the telephone call and the ASR form became lost in the operator’s internal paperwork system. Consequently, an investigation was not commenced until several weeks later, when the commander enquired as to what progress had been made in finding the cause of the event. The operator stated that it had since taken actions to improve its processes for the reporting and tracking of air safety incidents.

## Flight recorders

Because of the late notification of the event to the AAIB, both the Cockpit Voice Recorder (CVR) and the Flight Data Recorder (FDR) data for the incident were overwritten. Attempts were made to obtain information from various sources of non-volatile memory; however, such was the delay in reporting the incident, no information from the incident flight was available.

However, flight data was obtained from the operator’s Flight Data Monitoring (FDM) programme, which recorded a similar set of parameters to the FDR. The systems associated with the FDM were powered by the No 2 electrical supply and so continued recording throughout the event.

Recorded parameters associated with the electrical supply system showed no loss of the AC 1, AC 2, DC 1 or DC 2 supplies<sup>4</sup> throughout the flight. However, these

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### Footnote

<sup>3</sup> The rudder trim indicator is at the rear of the centre pedestal.

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### Footnote

<sup>4</sup> AC denotes alternating current and DC denotes direct current.

parameters were only recorded every four seconds so a transient interruption may not have been captured. The status of each of the electrical system contactors was not recorded but some recorded parameters exhibited signs of electrical transients, as evidenced by data spikes during each power reset.

The recorded data largely confirmed the flight crew's recollections. The effects of electrical transients were recorded at 0225 hrs and 0237 hrs. At 0240:00 hrs, further transients were recorded, this time leading to an increase in the recorded rudder position from 0° to +3.6° within 20 seconds (rudder trim was not recorded). Positive rudder deflection is deflection of the surface to the left which causes the aircraft to yaw to the left. As the secondary effect of yaw is roll, the aircraft then rolled to the left. The autopilot attempted to counter this with a right roll command and associated aileron and roll spoiler deflection.

At 0240:16 hrs, the recorded 'DMC transfer' parameter changed state, representing the DMC switch moving from the 'NORM' position to either the 'CAPT 3' or the 'F/O 3' position. Two seconds later, the autopilot disconnected and the roll angle increased to a maximum of 11.6° to the left before the co-pilot levelled the wings by commanding right roll with the sidestick.

The autopilot was re-engaged but the aircraft continued to yaw left as the rudder position remained at +3.6°. This again induced a left roll which was countered by the flight director commanding a right roll input. However, with the autopilot engaged and at an airspeed of 260 kt, the control surface deflection is automatically limited to  $\pm 9^\circ$  for the ailerons and  $4^\circ$  for the roll spoilers. As a result, there was insufficient roll authority to allow the autopilot to roll the aircraft level and the aircraft continued to roll left to a maximum roll angle of  $11^\circ$ .

At this point, the rudder deflection was  $+3.6^\circ$  with the right aileron deflected  $9^\circ$  down, left aileron  $9^\circ$  up, right roll spoilers deflected to  $4^\circ$  and the aircraft heading decreasing at  $0.5^\circ$  per second.

The autopilot then disconnected and the aircraft was flown manually. In manual flight, the travel limits for the ailerons and roll spoilers are their maximum travel ( $\pm 25^\circ$  and  $35^\circ$  respectively). As a result, each time the autopilot was re-engaged, the aircraft rolled to the left and when disconnected, the co-pilot's control inputs were sufficient to maintain a wings-level attitude.

After the final autopilot disengagement at 0245 hrs, the aircraft was flown manually for the rest of the flight. At 0246:31 hrs, the rudder position began reducing from  $+3.6^\circ$  to zero over a period of 17 seconds, six and a half minutes after the rudder surface first moved from the zero position.

### **Manufacturer's simulation**

The aircraft manufacturer performed a simulation using the data available from this incident and reported that the aircraft performance was as expected. They also confirmed that in the event of maximum rudder trim being applied at this airspeed, sufficient aileron authority is available in manual flight to maintain the desired flight path.

### **Aircraft information**

#### *General*

The A320 family of aircraft has extensive electrical services, fed from a system that broadly comprises two electrical networks, a left and a right, denoted No 1 and No 2, respectively. No 1 and No 2 networks are normally independent of one another, so that the failure of one network should not adversely affect the other. The power supplies for flight-critical systems are for

the most part segregated, with the aim that the loss of a single power source should not result in concurrent failures of systems necessary for continued safe flight.

#### *Electrical power generation system*

The electrical system is powered primarily from AC sources (3-phase, 115/200 Volt (V) at a frequency of 400 Hz). Two engine-driven generators, one mounted on each engine, normally power the system. Each generator is driven from the engine high-pressure spool via an engine accessory gearbox and an integrated hydro-mechanical speed regulator. The regulator transforms variable engine rotational speed into a constant-speed drive for the generator. The constant-speed drive and the generator collectively form an assembly known as the Integrated Drive Generator (IDG).

Mounted externally on each IDG is an electrical cable referred to as the 'jumper lead'. This is for maintenance purposes and to provide commonality between different electrical system standards. The generator manufacturer uses several different suppliers for this lead. The lead is approximately 20 cm long and is formed into a tight 180° bend with a connector at each end. The jumper lead is supported halfway along its length by a 'P' clip. The lead comprises an outer protective layer, a layer of woven metal braid, and then seven individual wire cables. Each of the seven individual cables comprises an outer insulation layer, a layer of woven insulation and thin foil, and a central multi-strand electrical wire.

A Generator Control Unit (GCU) associated with each IDG monitors the IDG output and opens the Generator Line Contactor (GLC) if it detects an aircraft-manufacturer-specified out-of-limits condition, thus isolating the IDG from the electrical system.

#### *Electronic flight instrument system*

Information for the flight crew is presented primarily on an Electronic Flight Instrument System (EFIS), comprising six DUs on the flight deck forward panel. These include the PFD and ND in front of each pilot and two ECAM displays located one above the other on the central part of the panel (Figure 1). The ECAM is a tool to:

- display aircraft system information
- monitor aircraft systems
- indicate required flight crew actions, in most normal, abnormal and emergency situations

The DUs are driven by three identical DMCs, identified as DMC 1, 2 and 3. In the normal configuration, DMC 1 (which is powered by the No 1 electrical system) drives the captain's (left) PFD and ND, and the ECAM upper DU; DMC 2 (which is powered by the No 2 electrical system) drives the co-pilot's (right) PFD and ND and the ECAM lower DU. DMC 3 (which is normally powered by the No 1 electrical system) is available as a backup and can be manually selected to replace DMC 1 or DMC 2.

The DUs and DMCs have different transient response times in the event of a power loss. For the DUs this is around 25 ms and for the DMCs this is around 100 ms. In the event of an intermittent interruption in power to the No 1 electrical system and with DMC 3 selected to drive the co-pilot's displays, the different transient response times of the DUs and DMCs are likely to produce a greater effect on the captain's DUs than the co-pilot's.

#### *Flight augmentation computers*

A320 family aircraft have two Flight Augmentation Computers: FAC 1 and FAC 2. These perform several functions, one of which is to provide input commands to



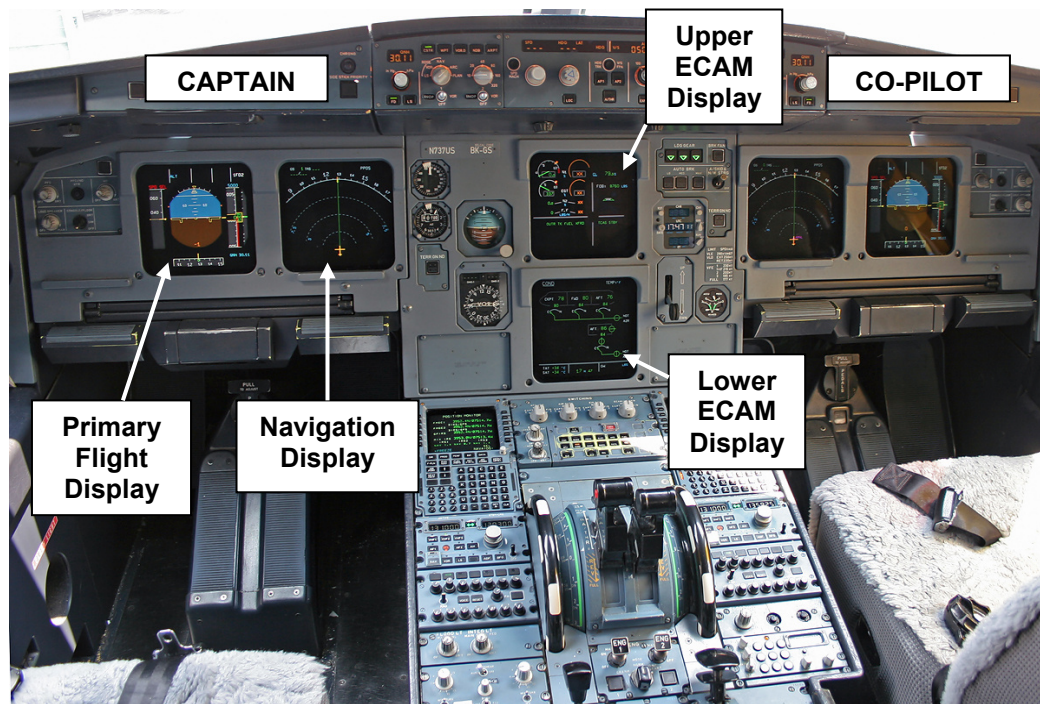


Figure 1

Electronic Flight Instrument System

the rudder trim actuator. The units operate with FAC 1 having priority and they are powered by a 28V DC Essential bus. If the power supply goes below 16V for more than 10 ms the FAC units will reset. This causes an offset of approximately  $0.2^\circ$  of rudder trim to be commanded. Multiple resets result in cumulative rudder trim offsets. The rudder trim limits are determined by the Rudder Travel Limiter (varying from  $\pm 3^\circ$  at high speed to  $\pm 30^\circ$  at low speed) or, if the logic in the FAC for a rudder trim runaway is triggered, no further rudder trim is input. At the aircraft speed in this incident the maximum available rudder trim was  $\pm 7^\circ$ .

The aircraft manufacturer confirmed that a similar architecture is used on A330 aircraft and there is therefore the potential for a generator fault to cause similar problems with the DUs. However, no such faults have so far been reported on the A330 fleet in nearly 19 million flying hours.

## Engineering investigation

### *Post-flight report*

Although the fault memories of the onboard maintenance systems were overwritten, a copy of the Post-Flight Report (PFR) was available. This report contained 23 flight deck warnings and 44 fault messages for the incident flight, mainly attributed to the loss of electrical supply to the No 1 network. Of note was an 'AUTO FLT RUD TRIM1 FAULT' ECAM warning indicating that FAC 1 had detected a rudder trim fault. This warning is for crew awareness only. Additionally, the PFR listed a 'AFS: FAC1/RT ACTR 10CC' fault message which is generated when the rudder trim runaway monitoring is triggered by FAC 1. The outcome of this failure message is that the rudder trim function in FAC 1 is disengaged and automatically transferred to FAC 2.

### *IDG and GCU testing*

After the incident IDG1 was removed and sent for overhaul by the operator but nothing significant was found. When AAIB were notified of the event several weeks later, the IDG1 and GCU1 were quarantined and subsequently taken to the aircraft manufacturer's 'iron bird'<sup>5</sup> test rig facility for a functional check and to attempt to simulate the characteristics of the incident flight. Although both units functioned normally on the rig, it was possible to create symptoms that appeared similar to those reported by the crew. When repeated electrical shorts at a certain frequency were simulated on either wire No 1 or wire No 2 in the jumper lead, the DUs flickered, more so on the captain's side, and small and cumulative increments in rudder trim were produced. However, these symptoms only occurred when the co-pilot's DUs were selected to be powered by DMC 3. Other combinations of wires were equally exercised in this testing, but they did not produce these symptoms.

IDG1 and GCU1 were then taken to their manufacturer for further inspection. The IDG was subjected to a detailed strip examination under AAIB supervision with experienced overhaul and design specialists from the manufacturer present. The jumper lead appeared distorted (Figure 2) and when the outer cover was removed significant material damage to the wire braid was found at both ends, near the connectors (Figure 3).

The jumper lead was taken to a forensic laboratory for examination. Evidence that the strands of wire braid had been chafing against each other was found (Figure 4). It was confirmed that wear marks made by the braid were present on the insulation of the seven wires inside

the braided outer sheath (Figure 5). The insulation was worn down on some of the cables, exposing the central conductor inside. Some cables exhibited holes in the insulation containing debris that was confirmed by an EDAX<sup>6</sup> technique as being of the same composition as the wire braid. Using a Scanning Electron Microscope (SEM), evidence of arcing was found on wire No 5 (Figure 6). Despite extensive efforts, it was not possible to positively identify arcing or a short on any of the other wires. It was concluded that the failure mechanism of



**Figure 2**

Jumper lead as removed



**Figure 3**

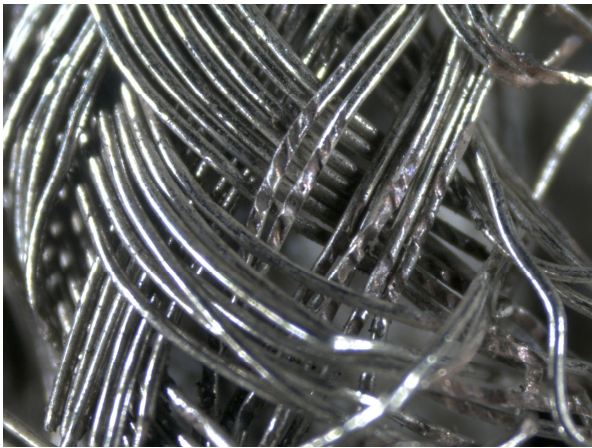
Jumper lead with outer cover removed

#### **Footnote**

<sup>5</sup> The iron bird is a static test rig which allows aircraft systems to be tested in laboratory conditions in the presence of all the aircraft systems. It also has a representative cockpit for flight simulation.

#### **Footnote**

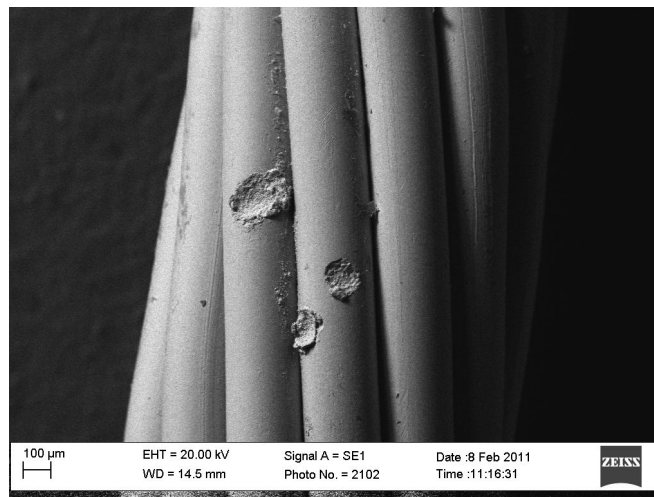
<sup>6</sup> Energy-dispersive X-ray spectroscopy which can be used to determine the composition of material.

**Figure 4**

Close up of wire braid on jumper lead showing evidence of chafing

**Figure 5**

Close up of wire in jumper lead showing wear marks

**Figure 6**

SEM image showing arcing damage on surface of strands in wire No 5

the jumper lead was the wire braid rubbing against the seven wires, with the vibration of the engine and the tight bend in the routing of the jumper lead providing the conditions conducive to wear. It was not clear if the 'P' clip, mid-way along the jumper lead, was a factor in the failure mechanism.

#### **AAIB Special Bulletin S2/2010**

In November 2010 AAIB published a Special Bulletin which contained preliminary findings of the investigation and the following Safety Recommendation:

#### **Safety Recommendation 2010-092**

It is recommended that Airbus alert all operators of A320-series aircraft of the possibility that an electrical power generation system fault may not be clearly annunciated on the ECAM, and may lead to uncommanded rudder trim operation.

Airbus notified operators of this incident by the issue of OIT 999.0105/10, dated 19 November 2010.



## Analysis

The delay in this incident being reported meant that potentially useful information in non-volatile memory, both in systems and the voice and data recorders was not available to the AAIB investigation. The delay in being able to interview the flight crew might have reduced the quality of their accounts.

The incident appeared to have posed a number of challenges for the flight crew, in that they were presented with numerous and significant symptoms, including malfunctioning electronic displays and uncommanded rudder trim input, of which they were not aware, and the cause of which was not evident. The ECAM did not clearly annunciate the root cause of the malfunction, nor were any fault captions observed on the overhead panel. No information or procedures were available to assist the flight crew in effectively diagnosing the problem.

The aircraft manufacturer concluded that the aircraft responded as expected to the rudder trim inputs, which suggests that the rudder input alone was responsible for the divergence from the intended flight path. The 'ELEC GEN 1 FAULT' message during the incident, the resolution of the problem in flight when IDG1 was switched off and the lack of any further reported problems after IDG1 was replaced are good evidence that IDG1 had a fault which had affected aircraft equipment, causing the incremental rudder trim inputs.

The symptoms experienced during the incident may have been attributable to a short in the jumper lead on IDG1. Whilst the lead was clearly damaged, and

a plausible failure mechanism identified, this was only valid if DMC 3 was selected to power the co-pilot's DUs, which is inconsistent with the crew's report.

## Safety action

As a result of other incidents involving blanking display units, the aircraft manufacturer was, at the time of this incident, developing an update to the Quick Reference Handbook (QRH) for display unit failures. Whilst it was not possible to determine with any degree of certainty the cause of this incident, as a result of this investigation the QRH update was amended to account for the possibility that rudder trim could be affected (Figure 7).

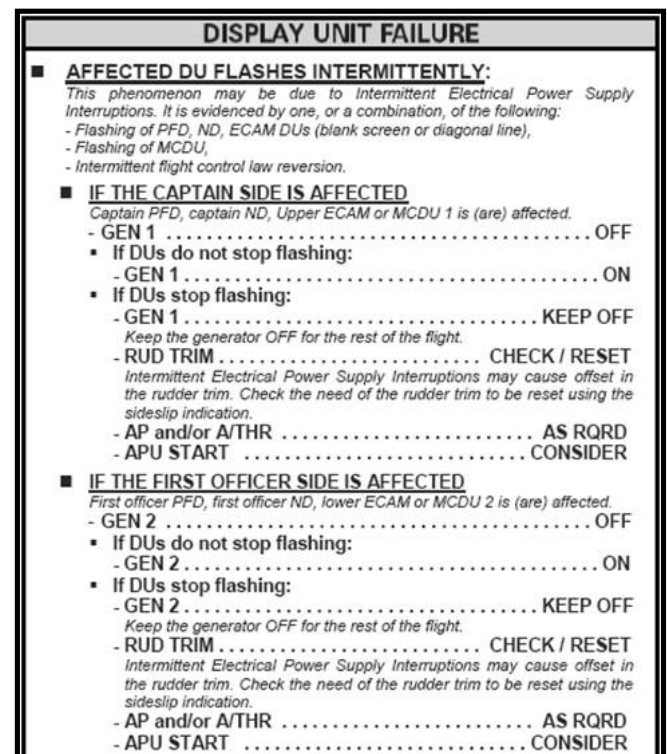


Figure 7

Updated page from Quick Reference Handbook