Air Transat Flight 236: The Azores Glider

Peter B. Ladkin
RVS Group, University of Bielefeld
ladkin at rvs.uni-bielefeld.de

November 18, 2004

1 The Flight

On 24 August, 2001, Air Transat Flight 236, an Airbus A330-243 aircraft was flying from Toronto to Lisbon over the Atlantic Ocean at 4244N/2305W when the crew noticed a fuel imbalance at 05:33 UTC (UTC is known as "Zulu" time in aviation, denoted "Z". I shall use this designation). Upon checking the fuel quantities, the crew saw that the imbalance was close to 7 tonnes of fuel. (The aircraft uses about 5 tonnes per hour in cruise flight.) They followed the FUEL IMBALANCE procedure from memory. At 05:45Z, they began a diversion to Lajes airport on Terceira Island in the Azores, a set of mid-Atlantic islands which are part of Portugal. At 06:13Z they informed air traffic control (ATC) that the right engine had flamed out. At 06:26Z, they further informed ATC that the left engine had also flamed out and that a ditching at sea was possible. At this point, the aircraft was about 65 nautical miles (1nm = 6000ft =1.15 statute miles = 1.85km) from the airport at Flight Level 345 (= 34,500 feet pressure altitude = 34,500 ft altitude in an internationally-normed atmosphere). And it was a glider.

The aircraft glided in to the airport, carried out an engines-out visual approach at night, in good weather conditions and good visibility. The aircraft landed fast on the runway, with reduced braking possibilities due to lack of some electrical systems, and came to a halt. It was evacuated; some passengers were hurt during the evacuation. The lower landing gear of the aircraft was more or less destroyed through the hard landing and extreme braking. But no one died.

2 The Immediate Causes

Fuel had leaked out from a fractured fuel pipe on the right engine at a peak rate of an astonishing 13 tonnes an hour, about a gallon a second. The first indication of the leak turned out to be unusual oil temperature and pressure readings on the right engine. The increased cold fuel flow through the heat exchanger, coupled with bathing the parts in cold fuel through the leak, had

caused unusually low oil temperature and unusually high oil pressure due to a corresponding increase in viscoscity.

There is a fuel tank, called the "aft trim tank" in the hozizontal stabiliser in the rear of the aircraft, which contained 3.2 tonnes of fuel. The main tanks are in the wings, and consist of an inner tank and an outer tank in each wing. The engines are directly fed from the inner tank. Fuel is transferred fully automatically from the aft trim tank into the inner wing tanks to maintain the aircraft in balance (and thus save fuel). Figure 1 shows a schematic diagram of the A330 fuel system.

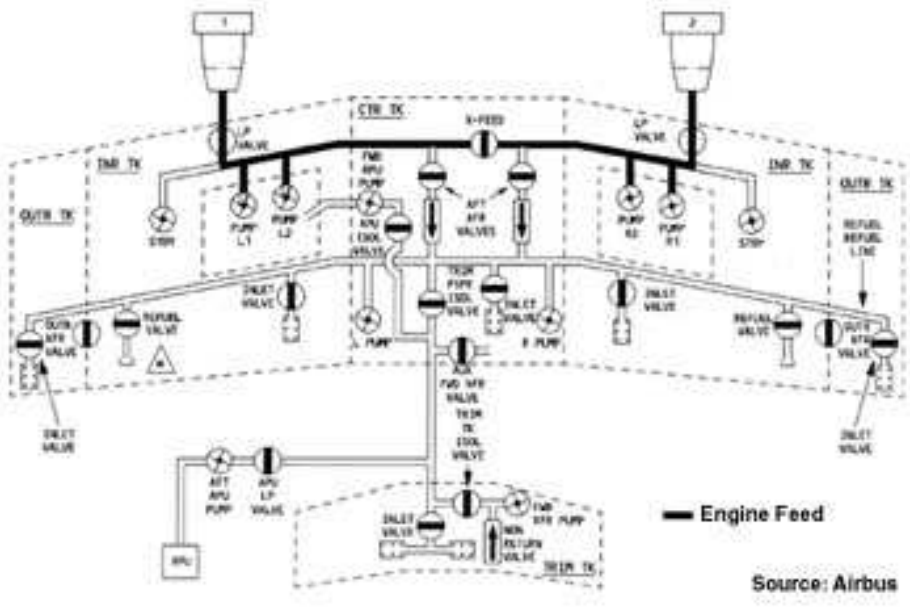


Figure 1: Fuel Schematic for the A330 (from [])

A message that fuel is being transferred from the aft trim tank is raised on the Electrical Central Aircraft Monitoring (ECAM) system display in the cockpit. The trim tank fuel was transferred into the right inner wing tank, feeding the leak. When the fuel imbalance between the left wing and the right wing had reached 3 tonnes (about equivalent to 36 minutes of cruise flight), a FUEL IMBALANCE warning was raised on the ECAM. The crew ran the FUEL IMBALANCE check list from memory; this included opening the cross-feed valve, which allows fuel to be transferred between the left and right wing tanks to correct the imbalance. This led to fuel being transferred from the left wing tank to the right tank and out through the leak.

The FUEL IMBALANCE abnormal procedure includes a caution not to use it if a fuel leak is suspected. But that caution is not necessarily retained in memory; the crew had practiced fuel imbalance situations many times in the

simulator, but not a situation in which there was in fact a leak.

When the crew received the fuel imbalance notification and checked the fuel, they found that an astonishing 7 tonnes was missing. They didn't suspect a fuel leak; they believed the digital-electronic monitoring systems were malfunctioning. They did ask cabin crew to look at the wings from the cabin to see if they could see fuel streaming out, but it was at night. It wasn't until the right engine flamed out, some 40 minutes after the ECAM imbalance message, that they realised it was a leak after all. From that point on, the crew exhibited brilliant airmanship.

3 The Reports

The investigation of this astonishing tale of superb hands-on flying in an engines-out situation, carried out by the Portuguese Gabinete de Prevenção e Investigação de Acidentes com Aeronaves, lasted over three years. The report was released on 18 October 2004 [Gab04].

I reported on some aspects of the accident in Risks 23.94 [Lad02]. Articles on the Final Report may be found in the professional press at [Lea04, Eva04].

4 Sequence of Events

The following summary sequence of flight events is largely taken from [Lea04].

0052Z Take-off from Toronto

0438Z Fuel leak starts, but no "noteworthy indications of fuel loss" for a further 20 minutes or so

0504Z Unusual No.2 engine oil readings. There followed extensive HF-radio communications with the airline's base about the oil problem, which occupied the crew's attention

0533Z ECAM advisory "TRIM TANK XFRD", notifying that all the fuel from the aft trim tank had been transferred to the wing tanks – unusually early in the flight for that to have occurred

0534Z ECAM fuel page selected; shows fuel imbalance between left and right wing tanks

0536Z Crew select fuel crossfeed

0545Z Crew decides to divert to Lajes

0602Z Cabin crew told to prepare for ditching

0613Z No.2 engine flames out at FL390

0626Z No. 1 engine flames out at FL345

0645Z Aircraft lands on RWY 33 at Lajes

5 The Quick-Reference Handbook Procedures

The procedures for abnormal conditions are contained in a Quick-Reference Handbook (QRH) required to be carried on board the aircraft. The QRH procedure for a fuel imbalance is shown in Figure 2. Although this is for an A340 aircraft, the procedures are identical to those for the A330. The corresponding fuel leak procedure referred to in the caution note is shown in Figure 3.

I addressed the logic of these procedures at the October 2001 Bluecoat conference at the British Midland building in West Drayton, near London Heathrow airport.

It was observed at the time that the first sign of a fuel leak would be the ECAM raising the fuel page displaying a *Fuel Imbalance* warning. The Portuguese investigators went further, and said that

> A fuel imbalance in the range of the 3.0-ton magnitude required to generate a FUEL ADV would only likely occur if there were a significant fuel leak. [Gab04, Section 2.4.1,p78]

These procedures are like a computer program: a sequence of instructions to be followed. They include conditionals on procedure state, just as imperative computer programs do. So we may think of them as pseudo-code and apply transformations. Here are the procedures as in the QRH:

```
Procedure: Fuel Imbalance

Caution: Do not apply this procedure if a fuel leak is suspected.
         Refer to FUEL LEAK procedure.

      X FEED (all) ............ ON
               even if automatically open

  On the lighter side:
   (ALL) FUEL PUMPS (STBY then NORM) ............. OFF

  When fuel balanced
   PUMPS (NORM then STBY) ............. ON
   X FEED (all) .......................AUTO

Procedure: Fuel Leak

A fuel leak may be detected by [.....]

 When a leak is confirmed
   Leak from engine [....]

   Leak not from engine or Leak not located
       X FEED 1+2+3+4 .......................MAINTAIN CLOSED
```

```
       [....]
```

The logic of this procedure is as follows:

```
Procedure: FUEL IMBALANCE

If (FUEL LEAK SUSPECTED)
   then (DO NOT APPLY THIS PROCEDURE &)
       go to (Procedure FUEL LEAK)

 [Procedure-Body FUEL IMBALANCE]

End Procedure FUEL IMBALANCE

Procedure: FUEL LEAK

A fuel leak may be detected by [Procedure FUEL LEAK DETECTION]

Procedure-Body FUEL LEAK:

When a leak is confirmed
   If (Leak is from engine)
     then [Procedure LEAK FROM ENGINE];
   If ((Leak not from engine) or (Leak not located))
     then [Procedure OTHER LEAK]

End Procedure-Body FUEL LEAK

End Procedure FUEL LEAK
```

One notices that within the Procedure *Fuel Imbalance* there is a conditional *go-to* instruction to jump to the other procedure. One may raise this jump with its condition to the outmost level. This is particular apt, given that the condition is only likely to be raised on the ECAM in the case of a significant fuel leak.

Observe that the entry into the procedure is a *Fuel Imbalance* indication on the ECAM fuel page. I introduce this explicitly.

```
If FUEL IMBALANCE INDICATION then:

   DETERMINE IF FUEL LEAKING:
       [Fuel Leak Detection Procedures];
   If FUEL LEAK
       then  [Procedure-Body FUEL LEAK];
   If  FUEL LEAK NOT INDICATED
       then  [Procedure-Body FUEL IMBALANCE].
```

The logic is simpler. The significant condition, that of determining whether there is a fuel leak, which is held to be the most likely reason why one has the FUEL IMBALANCE INDICATION, is raised to the top level.

Such logic simplification procedures are easy, even in this case trivial, to apply. A decade ago, I proposed such logical analyses be performed [Lad95], and with Harold Thimbleby presented a prototype software which generated handbook schema automatically from the specifications in [LT96], based on an analysis of the FCOM entries concerning the A320 braking systems in light of the 1993 Lufthansa A320 accident in Warsaw [Lad95]. In the intervening years since that work was published, it seems as if the same old coherence problems in handbooks persist.

References

[Eva04] David P. Evans. Report of dual engine flameout on trans-atlantic flight raises significant safety issues. *Aviation Safety Week*, 18(43), 8 November 2004.

[Gab04] Gabinete de Prevenção e Investigação de Acidentes com Aeronaves, Government of Portugal. Accident Investigation Final Report: All engines-out landing due to fuel exhaustion, air transat, Airbus A330-243 marks C-GITS, Lajes, Azores, Portugal, 24 August 2001. Available at `www.GPIAA-portugal-report.com`, 18 October 2004.

[Lad95] Peter B. Ladkin. Analysis of a technical description of the a320 braking system. *High Integrity Systems*, 1(4):331–349, 1995.

[Lad02] Peter B. Ladkin. Air Transat incident, Aug 24, 2001. *Risks Forum*, 23(94), 11 March 2002. Available at `catless.ncl.ac.uk/Risks/23.94.html#subj11.1`.

[Lea04] David Learmount. A330 'glider' drama facts revealed. *Flight International*, 4957(166):12, 26 October 2004.

[LT96] Peter B. Ladkin and H. W. Thimbleby. From logic to manuals again. *Software Engineering Journal*, 11(6):347–354, 1996.

FUEL LEAK

A fuel leak may be detected by either :

R *. the sum of the FOB and the F. USED is significantly less than the FOB at departure, or*
. passenger observation (fuel spray from engine or wing tip), or
. total fuel quantity decreasing at an abnormal rate, or
R *. fuel imbalance, or*
R *. a tank emptying too fast (leak from engine or a hole in a tank), or*
R *. a tank overflowing (due to a pipe rupture in a tank).*

LAND ASAP

WHEN A LEAK IS CONFIRMED

■ **LEAK FROM ENGINE :**

– THR LEVER (of affected engine) . . . . . IDLE

– ENG MASTER (of affected engine) . . . . . OFF

R *The Xfeed valves can now be selected open for rebalancing or to allow use of the fuel*
R *from both wings. Do not restart the engine.*

■ **LEAK NOT FROM ENGINE or LEAK NOT LOCATED**

– X FEED 1 + 2 + 3 + 4 . . . . . MAINTAIN CLOSED

R *The Xfeed valves must remain closed to prevent the leak affecting both sides.*

– L + R INR TK . . . . . SPLIT

Shut INR TK SPLIT valve to isolate fuel leak.

R – DESCEND TO GRVTY FUEL FEEDING CEILING

R *See GRVTY FUEL FEEDING procedure.*

R – ENG START SEL . . . . . IGN

R – ALL TK PUMPS (when gravity ceiling is reached) . . . . . OFF

R *In almost all cases, switching the pumps off will prevent any further loss of fuel.*
R *All pumps must be switched off, even if the leak is from one wing only, as there are some*
R *failures on one side that will result in fuel loss from the other side.*

R – AVOID NEGATIVE G FACTOR

R ● **If one engine flames out when there is still fuel in the feeding**
R **tank :**

R – LEAK FROM ENGINE proc . . . . . APPLY

R – ALL TK PUMPS . . . . . ON

R *NOTE : The flameout is due to air suction from a leak from the engine.*

FOR LANDING

CAUTION

. Do not use reverse.
. Notify ATC.

R *NOTE : Even with a fuel imbalance of one inner tank full/one inner tank empty there is no special procedure required for approach and landing.*

Figure 2: A340 Fuel Imbalance QRH entry

TRIM TANK FUEL UNUSABLE

T TANK MODE ..... FWD
T TANK FEED ..... OPEN

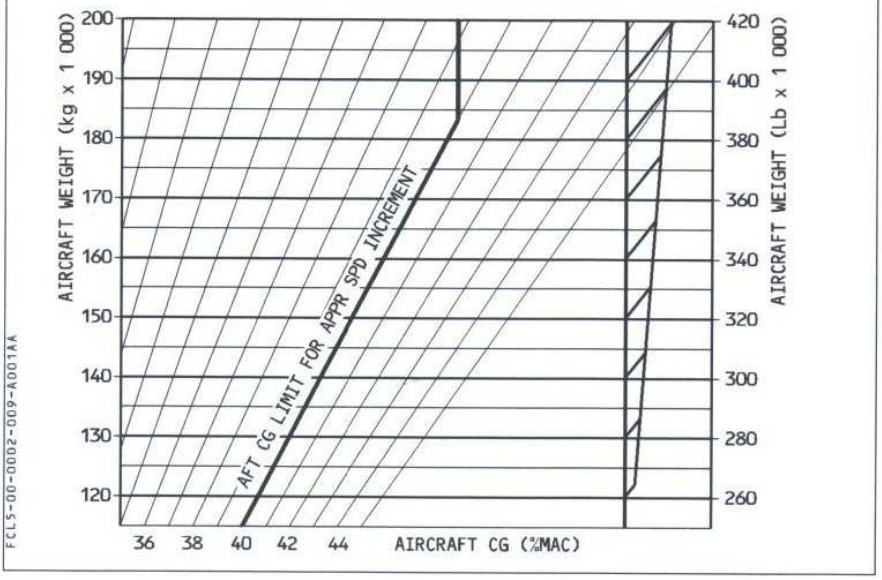
● **If TRIM TANK FUEL still unusable**
- OUTR TK XFR ..... ON
- CTR TK PUMPS ..... OFF

MAXIMUM FLIGHT TIME ..... 4 HOURS

After 4 hours depending on the fuel distribution the aft CG limit may be reached.

FOR LANDING

● **if CG > aft CG limit shown below :**
- APPR SPD ..... VLS + 10 KT
- LDG DIST ..... MULTIPLY BY 1.2



FUEL IMBALANCE

CAUTION
Do not apply this procedure if a fuel leak is suspected. Refer to FUEL LEAK procedure.

- X FEED (all) ..... ON

Select X FEED ON even if already automatically open.

● **On the lighter side :**
- (ALL) FUEL PUMPS (STBY then NORM) ..... OFF

● **When fuel balanced :**
- PUMPS (NORM then STBY) ..... ON
- X FEED (all) ..... AUTO

Figure 3: A340 Fuel Leak QRH entry