Direction Générale de l'Aviation Civile

Service Technique de la Navigation Aérienne

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TRANSPONDER JAMMING

Abstract :

The purpose of this paper is to present an original case of transponder jamming.

1. Introduction

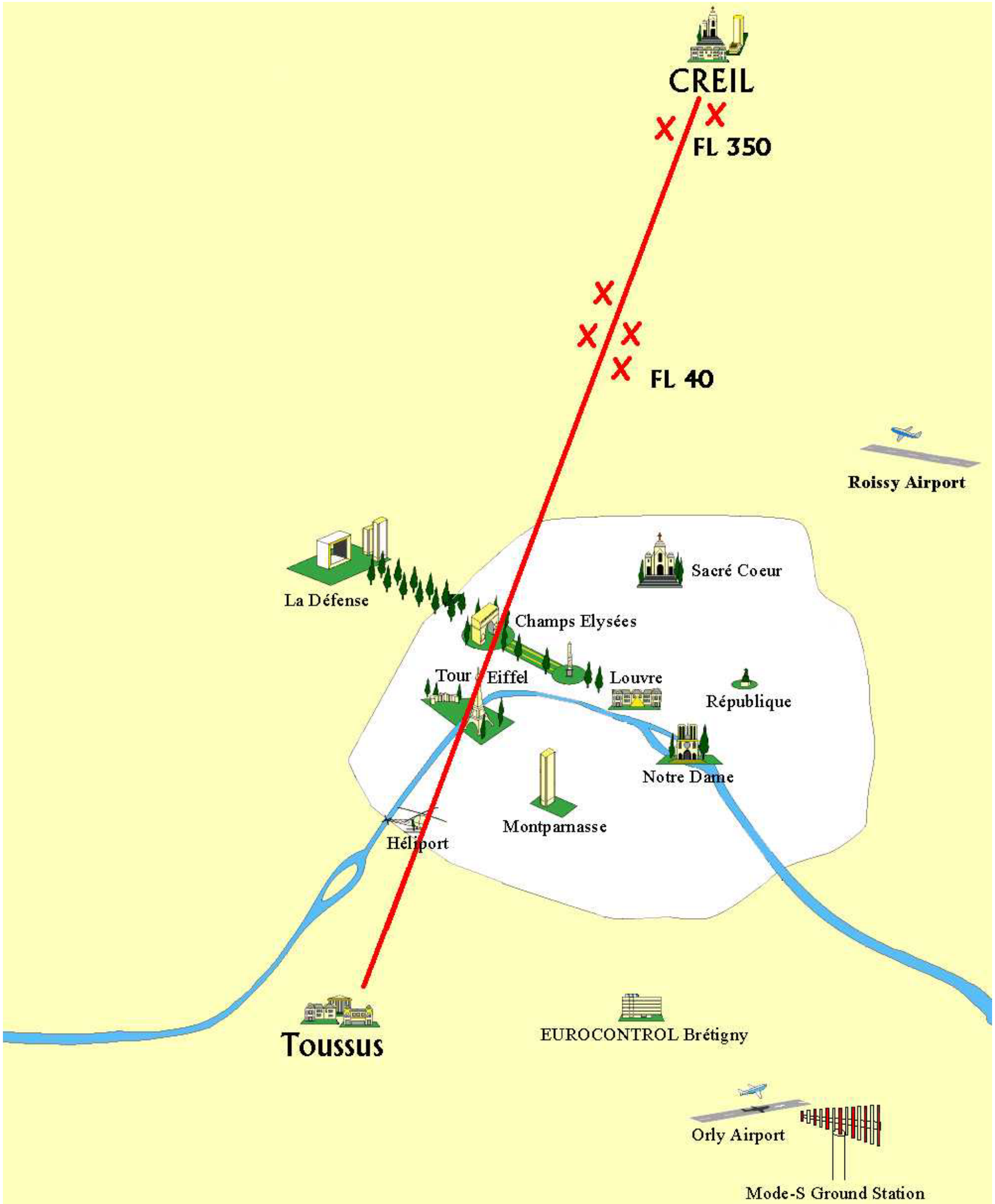
During the month of October 2000, Roissy Charles de Gaulle International Airport approach controllers reported several incidents of temporary label loss and multi-secondary surveillance radar track loss on their screens for periods ranging from one to two minutes.

The frequency of this phenomenon increased to reach a first maximum between the 9th and the 12th November 2000 leading to capacity restrictions. These incidents affected specific aircraft in a delimited geographical area.

2. Phenomenon analysis

In late 2000 the incident analyses showed that in certain cases aircraft had not been detected by any mono-pulse radars for one to two minutes. However, the Mode-S radar located in the Paris area received information coming from the transponders, correctly and without loss, from these same aircraft.

The varied technical investigations executed during the period when the problem occurred have allowed us to exclude jamming induced by a Paris area Mode-S station (radar) that is still experimental and disconnected from the operational system.



Nevertheless, it has been proved that the aircraft involved in these incidents were all fitted with the same brand of transponders. Two distinct kinds of transponders were involved : the General Aviation and the civil Airliner versions. They both had the same receiver board design.

Laboratory analysis lead by Eurocontrol Brétigny (France) has allowed us to confirm a deficiency in this equipment concerning the response rate. The standard requires that the transponder must reply with a probability of one hundred percent to interrogation rates of 1200 per second in mode A/C. The results showed that transponders responded at a rate of only 50 per cent. (only 600 responses per second).

The presence of a jamming device was soon suspected because the incidents often occurred in the same geographical areas (5 to 20 nautical miles north west of Roissy) and from flight levels 80 to 120.

The disappearances could happen at any time; day, night, week day or week-end.

The phenomenon suddenly reappeared between the 21st and the 26th March 2001 and then again between the 13th and the 26th April 2001. Radar losses were identified at several locations to the west and the north of Roissy airport. The altitudes related to the radar echo disappearance were variable and seemed to increase in the northern Paris area.

These incidents occurred in a well defined area along the Toussus/Creil axis and between flight levels 40 (Roissy) and 350 (north east).

The duration of each occurrence was variable depending on the aircraft track. Indeed the phenomenon was of short duration (about ten seconds) for paths perpendicular to the axis but could occur for longer (a few minutes) for paths parallel to the axis.

Moreover we have to note that in late March 2001 Air France pilots, flying B767s equipped with new transponders, reported many TCAS warnings in the Roissy Charles De Gaulle Airport area.

3. OPERATIONAL CONSEQUENCES

Globally, these events put the operational services into sensitive situation because the label disappearances did not affect all aircraft and their random nature caused stress and uncertainty to controllers.

At Roissy, during the label losses, only the primary radar information remained displayed on the screen.

At least two of these incidents could have been serious. One of these cases concerned a close proximity event between two aircraft, one at flight level 110 and the other at flight level 100. The controller only had the primary radar returns of these two aircraft.

When the phenomenon occurred, capacity restrictions were taken. The normal capacity of the control centre is about 70 arrivals per hour. While the label loss incidents were occurring, the controller work load increased significantly. Internal measures were taken to limit the departure flow rate when too many label losses were reported along the runway axis. For instance, on 18th April, simultaneous departures were stopped and on 24th April the departure rate was limited to 37 per hour. This situation generated a total of 23085 delay minutes during the three concerned periods.

4 PHENOMENON PROBABLE CAUSES AND FALSE TRACKS

The principal difficulty in the management of such an anomaly lies in the impossibility to turn off the operational radar in order to isolate a jamming signal.

4.1 THE MODE S EXPERIMENTAL STATION LOCATED IN THE PARIS AREA

The first suspected device was the experimental Orly MODE S radar.

Indeed, the first outage of the experimental radar coincided with the disappearance of the phenomenon but the jamming resumed soon afterwards whilst the Orly mode S radar was still out of service. However this radar station was to become of great utility to STNA (Service Technique de la Navigation Aérienne) in analysing the communication losses of the three Air Traffic Control Centres affected and the localisation of the problem source.

4.2 DEFENSE MINISTERY INSTALLATIONS

The first incidents appeared in Creil area, Creil being the site of a military base. So this installation was suspected because wide spread military exercises had been in preparation. Moreover notices of the new system trial campaign were communicated to the DGAC (Direction Générale de l'Aviation Civile).

4.3 AERONAUTICAL MAINTENANCE ORGANISATIONS AND AERONAUTICAL COMPANIES

Preliminary STNA analysis quickly allowed us to suspect tests conducted by an industrial or aeronautical maintenance organisations working on aircraft equipment. All the known companies were made aware of the importance of the issue of jamming. One of the suspected industrial companies located in the south of Paris was contacted twice in order to confirm the absence of tests.

4.4. TV BROADCASTING

TV broadcasting signal harmonics were identified as a potential jamming origin for transponders. The disrupted area included the Eiffel Tower which hosts many radio frequency transmitters.

The DNA (Direction de la Navigation Aérienne) contacted the Conseil Supérieur de l'Audiovisuel, the broadcasting regulation organisation, to find out exact locations of transmission sites in the Paris area.

4.5 TV AMATEUR TRANSMISSION

The kind of signal suspected, a narrow beam, and the activity period, a few days in November and March, and the Easter holidays, allowed us to believe that the jamming could have originated from a TV amateur broadcast. The frequency band normally used is 1230 MHZ-1300 MHz but sometimes radio amateurs broadcast on the 1000 MHz frequency for testing. With the help of the National Frequency Agency and some radio amateurs, this suspected jamming source was soon discounted.

5. METHOD USED TO IDENTIFY THE ANOMALY

During the three periods it was observed that certain mode S transponders did not detect interrogations transmitted by secondary mono pulse radar in mode A/C even though the same transponders in the same aircraft, at the same time, responded to mode S radar interrogations on the same frequencies (1030 MHz and 1090 MHz).

As indicated above in the document, the duration and the frequency of the phenomenon were variable and depended on the aircraft track which was related to the operational configuration of Roissy.

5.1 SECONDARY SURVEILLANCE RADAR FUNCTION MODE

A ground radar transmits interrogations to aircraft fitted with a transponder. The uplink frequency is 1030 MHz and the downlink frequency is 1090 MHz.

The ground stations transmit pulses cyclically at a certain frequency. Generally all ground stations have a specific interrogation rate in order to avoid ambiguous responses. If a ground station interrogates at a 400 Hz rate, an aircraft will be requested every 2.5 milliseconds when it is illuminated by the antenna beam (figure 1). Measuring the time between two responses coming from the transponders, we obtain 2.5 milliseconds and we can easily deduce the identity of the radar interrogating the aircraft equipment (figure 2).

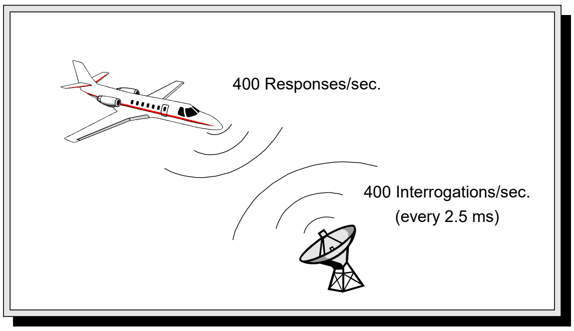


Figure 1 : aircraft detection via a ground station

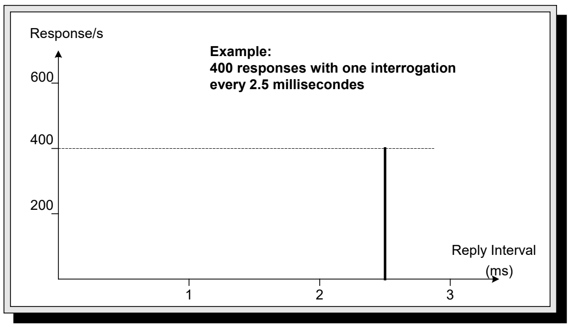


Figure 2 :cyclic response spectrum

On board the transponder shares the frequency band 962 MHZ-1215 MHz with distance measuring equipment (DME) and the anti-collision system (TCAS). As the power broadcast by these systems is very high (700 W), a link connects all the equipment to avoid simultaneous transmissions and to signal transmission in progress. This link, called the Suppressor, is implemented using an electrical signal line which is put to +28 volts during each transmission period by the transmitting equipment.

By analysing the suppressor signal, it is possible to identify the transponder response rates and to distinguish different ground stations (figure 3).

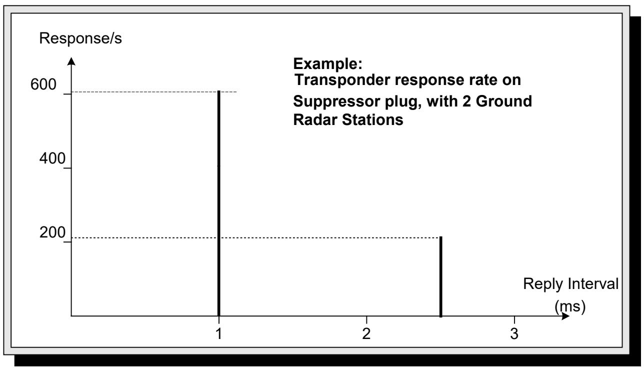


Figure 3 : response spectrum for two ground radar

6. THE REAL ORIGIN OF RADAR ECHO LOSSES

The Eurocontrol measurement bench allows the real time visualisation of the response spectrum of an aircraft transponder. All airline transponder systems available on the market can be connected to this measurement bench.

The spectrum generally displayed in the Paris area is shown in Figure 4. It identifies the interrogations from four ground radars.

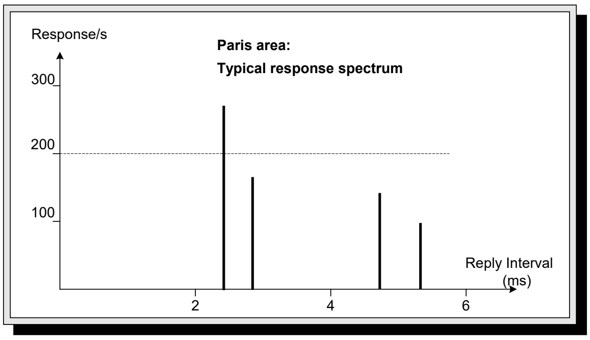


Figure 4 : response spectrum in the Paris area

During laboratory tests, the suspected transponder type showed a deficiency when over-interrogated. So firstly the idea that a ground station was transmitting at abnormally high interrogation rates was investigated. This line of research gave no result.

However spatial modelling of lost aircraft labels showed a possible origin of a jamming signal south west of Paris. This lead was more fruitful.

In this area, the transponder response spectrum (for all transponder brands interrogated in the 1030 MHz band) became particularly alarming. The aircraft equipment practically did not respond to any ground station and seemed to be held in permanent transmission. This kind of behaviour is totally unforeseen under normal transponder operational conditions (figure 5).

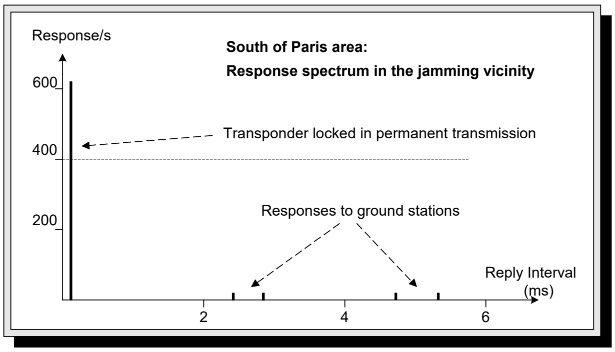
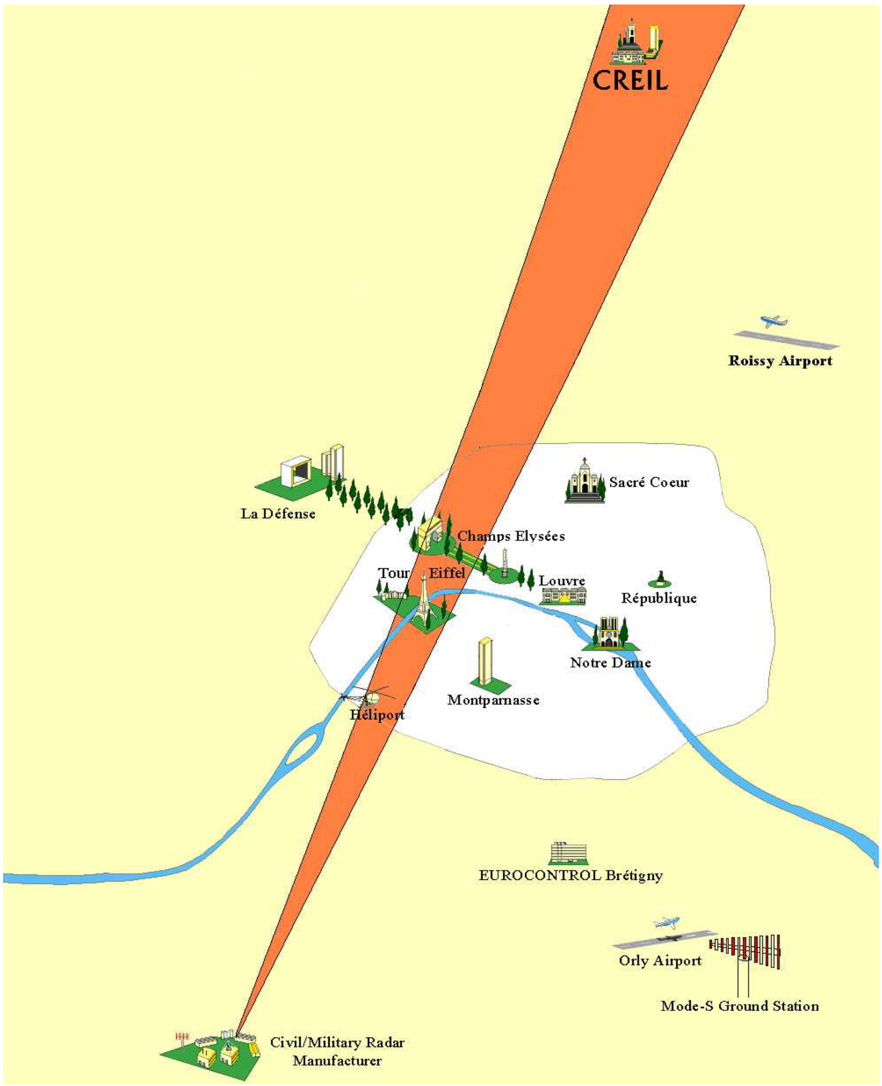


Figure 5 : response spectrum in the jamming vicinity



In the vicinity of the nearest village, a national TV broadcasting station relay, a radio amateur conducting transmission tests and a large company making civil and military primary and secondary radar antennas were identified. Different measurements have shown that the company transmitted a 1030 MHz carrier-wave produced by a laboratory generator linked to a small tube amplifier. This system was connected to a 6 meter diameter parabolic antenna pointed towards their test receiver installations which were in Roissy direction... The tube amplifier often tripped due to a temperature protection system and then was automatically retriggered several hours later. This narrow beam carrier wave transmission using a high gain parabolic antenna provoked an immediate transponder lock-out with permanent transmission. This particular case is not foreseen by the standards defining normal transponder functioning. The competent DGAC services have been informed of this event and will contribute to its resolution for the next generations of equipment.

7. PROBLEM RESOLUTION CONDITIONS

During this investigation, we had great difficulties, and it took us a long time to find the origin of the phenomenon. Indeed the cumulative jamming period was only four weeks, in total, between November 2000 and April 2001.

7.1 THE DIFFICULT ANALYSIS OF THE PROBLEM

The impossibility to stop radar transmission in the Paris area.

It was difficult to localise a specific area because the jamming signal (about 100 W power) was masked by the operational signals. Moreover the receiver antenna directivity did not allow us to detect a measurable field outside the transmission antenna beam. The efficiency of the STNA aircraft was reduced because only field measurement were possible. Without other information, it was difficult to accurately determine the jamming origin.

A long delay in processing affected aircraft tracks

The first reports concerning the November 2000 events given by the Air Traffic Control Centres, contained neither the A/C mode transponder codes nor the flight numbers. This essential information was received a posteriori. Even the event times and positions were approximate.

After long and arduous study, the Mode S address and the aircraft A code were found which allowed us to identify, via DGAC services, the aircraft registration and consequently its associated on board equipment. This pragmatic method showed that all incidents were related to a certain kind of transponder which could be identified easily.

During March and April 2001, more complete information about the events (A code, registration, estimated position, time) were provided by the different control organizations.

With these new data and software tools, STNA could determine, with great accuracy ,the geographical origin of the jamming signal; south west of Paris

A new jamming phenomenon for our services

Not prepared for this kind of incident, the different DGAC services responsible for jamming research have had great difficulties isolating this phenomenon and localising the real origin. Was it a parasite signal transmitted via a point source or a malfunction of one of the radar-transponder chain elements ? The difficulty was increased because the suspected company twice answered to the DGAC request stating that they did not test on their site.

Jamming conditions were not favourable to efficient investigation

The intermittent aspect did not allow easy phenomenon analysis.

The activity period of the jamming coincided with personnel unavailability periods (week-ends, Easter holidays) delaying the problem analysis.

These elements confirmed the idea the origin could be a single individual.

The absence of adequate research equipment

The absence of equipment able to work in the 1 GHz band in the DGAC hindered the investigation.

The STNA managed to find the jamming signal due to Eurocontrol support located in Paris area (Brétigny sur Orge).

In Europe, a ground and inflight monitoring system of mode S equipment was put in place during 2000. Eurocontrol Brétigny, who is in possession of a mode S transponder analysis bench, acts as the European centre of expertise and centralizes mode S transponder malfunction reports. It liases closely with equipment manufacturers and plays the role of an information source for airline companies and national authorities.

7.2 THE TECHNICAL SOLUTION TO THIS PROBLEM

The investigation showed us that a radio frequency spectrum analyser was totally useless for detecting this kind of jamming.

Conversely, the best tool to detect such jamming is the on board transponder itself. We only have to monitor the suppressor signal line to detect the transponder, DME and TCAS responses. Software processing extracts the transponder responses to visualize the response spectrum and identify possible lock-out permanent transmission. Such a complete system, implemented in hardware and software, has been developed by an electronic engineer trainee. The next research campaign will be used to test this new equipment in real conditions and to improve it if necessary.