All-Weather Automatic Landing Concepts and Operations: Review of Aerospatiale Experience

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This paper reviews Aerospatiale's experience and achievements in the field of all-weather automatic landing and describes the Automatic Flight Control Systems installed on the following aircraft: Caravelle, equipped with a fail-passive system; Airbus, equipped with a "double-multiple"-type, fail-operational system; and Concorde, equipped with a duplicated monitored-type fail-operational system. The certification conditions are discussed for each of these systems together with a brief description of their design principles and operational limits. Finally, the experience gained by the French domestic airline Air Inter in the field of low-visibility automatic landing with its Caravelles is detailed both as far as the means implemented and the results obtained are concerned.

I. Introduction

A GREAT deal of effort has been spent in many countries on the problem of all-weather approach and landing on civil transport aircraft and it is more than probable that this same problem will demand at least an equivalent amount of effort for another decade. There always will be, of course, the traditional arguments and discussions which are inevitable when even specialists in the field meet. In order to avoid falling into the trap of giving a too specialized, and often biased discussion, or favoring a particular philosophy and approach, an objective consideration in the light of Aerospatiale's design and operational experience will be attempted.

Before discussing the subject in depth it is necessary to note a few key points which limit the scope of this paper: 1) the fact that the principal means used for controlling and guiding the aircraft in all-weather landing and approach is the autopilot associated with ILS radio beams; 2) much of the effort spent by Aerospatiale on all-weather landing and approach has been oriented toward bad visibility conditions associated with reasonable atmospheric movements (wind, turbulence, and gradient) (Experience in very turbulent atmospheric conditions is very limited and the problem is still being studied.); and 3) this paper is limited to discussion of Aerospatiale's design work which has come into commercial operation.

II. Concepts

Aerospatiale made the decision to develop a system capable of use in weather minima of less than 400 m RVR in 1962. Since that date this objective has been pursued and attained on Aerospatiale's three major projects in the field of commercial transport aviation.

A. Caravelle

Background

The Caravelle autoland system was designed with the aid of the equipment manufacturer Lear Siegler mainly because Lear Siegler had already supplied the aircraft's autopilot. As a first step, this system was qualified for Category II approaches in 1964. It was granted its certificate of airworthiness for Category III approaches in 1966. The French internal airline, Air Inter, was the first in the world authorized to operate in 1968 for Category III operations on the basis of French Regulations DTA/O no. 4382. Since then, 15,000 automatic landings, more than a thousand of which were in RVR conditions less than 400 m, have been carried out in commercial operation with a success rate greater than 95%. No incidents or accidents have been reported to date.

Description

This system can be classed, a posteriori, as a fail-passive system. It consists of: 1) an autopilot which receives its data from a set of single unmonitored sensors, 2) a monitoring device which receives its data from a second set of single unmonitored sensors, 3) a master takeover warning system, 4) a standby horizon fully independent from the rest of the system, and 5) an autothrottle.

For safety, the system relies on the original concept (at the time) of monitoring aircraft response in relation to aircraft flight path (by detection of excessive ILS beam deviation) and aircraft movement (by measurement of attitudes, attitude rates, vertical velocity, and direction of servomotor action). All phases of landing control are automatic except rollout which is manual and visual with possible reversion to the head down flight director display.

Operational Use

This system is used with RVR's of 150m and a decision height of 50 ft on Category II or III ILS's. Since no redundancy is available it has not been necessary to fix an alert height. Only a monitoring device check is carried out at an altitude of 800 ft.

The 50-ft decision height was fixed to allow the pilot to control, as a last resort, the position of the aircraft before landing. If visual contact happens to be inadequate at 50 ft the pilot must initiate an automatic go-around. Should a warning occur, the pilot must perform a manual go-around. It must be stressed that this warning is unique, that is: 1) there is only *one* physical warning light per pilot; and 2) because of this, it removes any chance of the pilot mistaking it for another warning in the cockpit environment. The manual go-around then is carried out using the standby horizon, except when the aircraft is below the 50-ft decision height and the visual references are good enough to allow a manual landing to be carried out.

The go-around capability of Caravelle has often been stressed and the idea has spread that this autoland system was acceptable only owing to the Caravelle's exceptional handling qualities. This idea in not entirely true. To put things in the correct perspective the following facts must be considered.

As long as decision height is not zero, it will be necessary to demonstrate, and this is a requirement of the French

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regulations, that the aircraft is able to overshoot from the decision height without touching the ground. This requirement must be met whatever the type of system used: fail-passive or fail-operational (manual or automatic). As a result, it imposes a minimum standard of aircraft performance.

The go-around characteristics of most modern aircraft, Airbus and Concorde in particular, are at least as good as those of Caravelle in this part of the flight envelope.

It is desirable to attempt to decrease the number of these go-arounds and to make them automatic as far as possible.

Returning to the Caravelle, the system has been certified to allow takeoffs with RVR's down to 100 m with visual guidance and possible reversion to the head down flight director display. Furthermore, the wind limits in which the system can be used are: 10-kts tailwind, 15-kts crosswind, and 20-kts headwind.

B. Airbus A.300

Background

The Airbus autoland system has been designed with the aid of Sfena in association with Smiths and Bodenseewerk, as equipment manufacturers. It was granted its certificate of airworthiness for Category III approaches in 1974 on the basis of American regulations AC 20 57 A and AC 120 28 A. The French airline, Air-France, began using the system in Category III commercial operation during the winter of 1975/1976. FAA certification is underway at the present time.

Description

This system can be classed as a fail-operational system. It consists of: 1) two autopilots, each comprising two identical computation channels – all four channels operate simultaneously and send their signals to four voters (two per autopilot) which select the lowest median value; 2) two servo-motors, driven by the voter outputs, which operate simultaneously with priority given to one servo-motor over the other; 3) sensors – four single, two monitored, and three unmonitored, with a voting device within the autopilots; 4) indications on each instrument panel, including approach phase indications, system capability indications, mainly Land 2 or Land 3, and a master warning called "Auto-Land;" and 5) an autothrottle.

The system described is of the "double multiple" type. In the event of a failure detected by monitoring, the autopilot involved is disengaged and the system is in single-monitored configuration. Therefore survival is possible after the first failure and the system is fail-passive at the second failure. An external flight path monitoring device based on ILS beam deviation detections has been maintained. All of the landing phases including rollout down to 60 kts are automatic.

Operational Use

This system can be used with RVR's down to 200 m and, in theory, according to the American regulations, with a zero decision height. In fact, for operation within the French regulations this system would have a nonzero decision height imposed on it; the value of this has not yet been fixed but it would be in the order of 20 ft, as all of the tests carried out have shown that go-around is possible down to an altitude of 15 ft, without touching the ground, even in the event of an engine failure.

Consequently, as far as the principle of operation is concerned, there should be no difference between Caravelle and Airbus. Furthermore, as far as in-service use is concerned, the presence of two autopilots guarantees a considerably reduced number of takeovers by the pilot before touchdown and, even in the event of a warning, an automaticity of go-around which does not exist on Caravelle and the safety of which has been demonstrated down to the ground, including touchdown.

The alert height at which system capability (Land 3) should be checked has been fixed at 100 ft. The operational wind limits under which the system can be used have been fixed at 10-kts tailwind, 15-kts crosswind, and 25-kts headwind. Finally, the system remains capable of carrying out Category II autoland after failure of one of the autopilots.

C. Concorde

Background

The Concorde autoland system has been designed with the aid of equipment manufacturers Marconi-Elliott and Sfena. Category II and III certification is being obtained on the basis of regulation TSS 1-2, the spirit of which fully reflects the British regulations in this field.

Description

This system also can be classified in the category of fail-operational systems. It consists of: 1) two autopilots each containing its own monitoring devices, 2) a double-body servo-control relay jack which receives its orders from the two autopilots, 3) indications on each instrument panel, which are essentially the same as on the Airbus, and 4) two autothrottles.

This system is the duplicated monitored type. If the first system fails and this failure is detected by internal system monitoring, automatic changeover to the standby autopilot takes place. As on the Airbus, there is an external monitoring system based on excessive ILS beam deviations, and all landing phases are automatic except rollout.

Operational Use

It, therefore, should be possible to use this system with RVR's down to 200 m, with or without a decision height according to the operational regulations with which it has to comply. If a nonzero decision height is imposed, the tests carried out also would enable a decision height of about 20 ft to be chosen.

Alert height has been fixed at 300 ft and the operational wind limits are identical to those of the Airbus. Here again the system is based on a reduction of pilot intervention at low altitude and a high degree of availability of automatic go-around.

III. Operation

The only aircraft which can be discussed for the time being at operational level in Aerospatiale's experience is Caravelle. The discussion will therefore be limited to this aircraft. The means implemented are separated from the results.

A. Means Implemented

Airfield Equipment

Airfield equipment included: 1) a complete Category II performance ILS (ICAO); 2) ground lighting comprised of high-intensity runway threshold marking, high-intensity runway edge lighting, and centerline lighting system (it is to be noted that the touchdown zone lighting and centerline color coding are not mandatory for Air Inter operations); and 3) a continuous RVR measurement system with two transmissometers.

Crew Training

Crew training and qualification are provided by Air Inter. The Air Inter instructors have been delegated by the French authorities to grant the crew minima authorizations themselves.

Airline training courses. Category II and Category III autoland courses are provided for crews who already have several months' experience of Caravelle and of using the system in Category I minima. They are organized as follows:

7 sessions (21 hr) of classroom instruction, 3 sessions (10 hr) of simulator training, 1 session of flight instruction, and 1 session of in-flight crew training supervised by an instructor.

Crew qualification. After this training course the crews receive their autoland qualification. They are authorized to use the autoland system with passengers on board in the following meteorological conditions: DH – 200 ft and RVR – 400 m.

Granting of minima. The minima evolve as follows, as far as the Captain is concerned: 1) qualification plus 200-hr experience of the aircraft (150 ft/400 m), 2) twenty successful automatic landings in airline service with minima equal to 150 ft/400 m or more, plus one landing supervised by an instructor (100 ft/300 m), and 3) one landing under actual fog conditions supervised by an instructor (50 ft/150 m).

It is interesting to note how the crew's confidence in the system increases as the training period progresses. Before the training period, crews are generally fairly skeptical about the efficiency of the autoland system. After qualification, now helped by their knowledge and initial experience, most crews believe in it; however, a slight doubt still remains. It is only after seeing the system operate in actual bad visibility conditions that the pilots are convinced of the value of the system and the safety which it provides. It should be noted here that *one* landing in real conditions (50 ft/150 m) is considered *indispensable* before giving pilot authorization at these minima. This landing is intended mainly to remove the psychological doubt of the pilot faced with an unknown situation.

Operational Procedures

Without going into all of the details of flight manual procedures, the basic rules followed by Air Inter are described. All of the crews use the *same* method of control. The distribution of tasks between the various members of the crew is *strictly* defined and must be respected *scrupulously*. The workload of the two pilots has been arranged to allow the Captain to devote himself mainly to active supervision of the landing process and to make the decisions required by the circumstances, in particular the decision to pursue landing or interrupt the approach.

The procedure which Air Inter requires of its crews can be outlined as follows: 1) as soon as the horizontal visibility is less that 400 m, autoland is *mandatory*; 2) from 300 ft down, only the Captain carries out external supervision and the copilot instrument supervision; and 3) the decision height must be observed strictly, at this height a) the Captain has acquired sufficient external references to be able to control (or carry out) decrab and rollout, in which case he pursues the landing in automatic mode, or b) the external visual references have not been acquired, in which case the instructions are to carry out an automatic go-around.

If a failure occurs below 200 ft, *only one* warning per pilot is provided – Flash. The pilot must react to this warning without trying to analyze the failure. When this Flash warning light comes on, the mandatory instructions are to revert to manual mode and: 1) if the RVR is < 300 m, the Captain must go around on the standby horizon (even below decision height); 2) if the RVR is > 300 m, it is up to the Captain to decide to land or to go around according to whether or not sufficient visual references have been acquired.

B. Operational Results

Availability

In addition to the Caravelle III's in use under real category III conditions since the winter of 1968, Air Inter now has been operating Caravelle XII's since 1973, under the same conditions. The French airports from which Air Inter operates and which allow 50 ft/150 m minima to be used are Paris (Orly), Roissy (Charles-de-Gaulle), Toulouse, Bordeaux, Lyon, Strasbourg, Mulhouse, Lille, and Nantes. It should be noted that fog dispersion systems are operational at Orly and Roissy. Air Inter refuses to use them as they have invested in Category III autoland on their aircraft and do not wish to pay the additional tax charged for this facility.

Commercial Landings Carried Out to Date

Caravelle III. From January 1, 1969 to May 31, 1975 there have been 12,559 landings attempted (11,639 of these were completed, i.e., a success rate of 92.84%) and 929 approaches attempted with RVR < 400 m (882 landings completed, i.e., a success rate of 94.94%). It is to be noted that 6 of the 882 landings achieved were carried out manually after a warning had occurred below decision height.

Caravelle XII. From July 1, 1973 to May 31, 1975 there have been 2,166 landings attempted (2,040 completed, i.e., a success rate of 94.17%) and 105 approaches attempted with RVR > 400 m (101 landings completed, i.e., a success rate of 96.19%). The four aborted approaches were due to warnings above the decision height.

For the whole Caravelle fleet, a total of 1034 approaches were attempted with RVR > 400 m, 983 of which were successful. It is interesting to note that 20 of the 51 aborted approaches were aborted owing to lack of visual contact at 50 ft, and that 3 of the 31 approaches which were aborted owing to warnings led to manual go-around below decision height. Finally, no incidents or accidents have been reported since the autoland system has entered service.

Figure 1 has been drawn from Air Inter's observations on the statistical correlation between RVR and the height at which the visual references are perceived. It is interesting to note that the 65 ft/200 m point has been consolidated by the studies carried out in Great Britain by the Blind Landing Experimental Unit (BLEU).

Maintenance

The tests required to insure safety and maintain a high availability level of the autoland are defined in a Sud-Aviation document approved by the French Authorities. These tests, which are carried out manually, require no special tools, and last from 15 to 30 min. They must be carried out by approved personnel 1) periodically during minor aircraft overhaul, 2) if any failure or warning has occurred during an attempted autoland, or 3) after any equipment replacement.

Financial Aspect

Operational use of Category III autoland provides the airline with two types of advantages:

Less diversions. In 1974, the mean cost of a diversion was estimated to be 8,200 French francs for a Caravelle III and 12,000 French francs for a Caravelle XII. In the same year, the Category III autoland system permitted 310 landings, which otherwise would had led to as many diversions had the aircraft involved only been equipped with a Category II system.

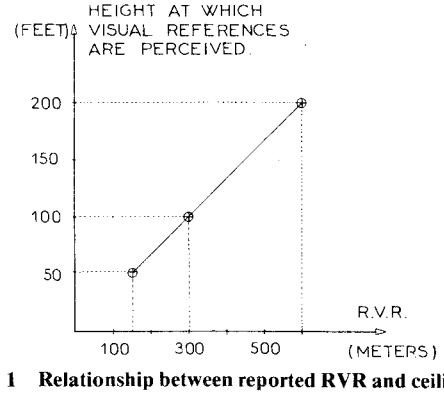

Fig. 1 Relationship between reported RVR and ceiling.

Increased returns due to better regularity. It is worth noting that Air Inter's main competitor in France is the railway system, the regularity of which is largely unaffected by meteorological conditions. Before operations using autoland, Air Inter had seen its passenger load factor decrease regularly during the winter months (November to February). This trend began to reverse during the winter of 1969 to 1970, and for the winter of 1970 to 1971 Air Inter's commercial department estimated that 48,000 more passengers (6.7%) had travelled during the same period thanks to use of the autoland facility. Considered over the whole year, the psychological effects of this improved regularity on the travelling public led to a 1.5% increase in traffic.

The combination of these two advantages leads Air Inter to consider that the autoland investment has been amortized inside four years.

IV. Conclusions and Closing Comments

Operations in Category III weather conditions have thus become common practice in France thanks to Air Inter. More advanced Airbus or Concorde type systems would undoubtedly improve "comfort" but not reduce minima much beyond the levels practiced at present. They will be limited by a nonzero decision height not through any fault of their own but because of lack of confidence in the ILS as the only means of guidance. To authorize minima less than 150 m with a zero decision height, it is considered that some other means of guidance in addition to the ILS should be used, viz., the ILM which is too vast a subject to be discussed in this paper.

One final important problem for automatic landing is system performance as far as flight path accuracy and touchdown point accuracy are concerned. This is one of the key points to the success of low visibility operations, to which Aerospatiale has paid particular attention throughout the three projects discussed above.

The problem of aircraft landings in bad visibility is progressing well throughout the world and its progress will contribute to flight regularity. On the other hand, the problem of landing safely in very turbulent weather conditions remains to be solved. Here too, autoland devices undoubtedly will have a part to play provided they are designed from the very beginning with appropriate design means.

Acknowledgment

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