

# Avro 146-RJ100, HB-IXP, 30 April 1996

**AAIB Bulletin No: 9/96 Ref: EW/C96/4/13 Category: 1.1**

**Aircraft Type and Registration:** Avro 146-RJ100, HB-IXP

**No & Type of Engines:** 4 Allied Signal LF507-IF turbofan engines

**Year of Manufacture:** 1996

**Date & Time (UTC):** 30 April 1996

**Location:** Woodford, Greater Manchester

**Type of Flight:** Public Transport

**Persons on Board:** Crew - 2 Passengers - None

**Injuries:** Crew - None Passengers - None

**Nature of Damage:** None

**Commander's Licence:** Not relevant

**Commander's Age:** Not relevant

**Commander's Flying Experience:** Not relevant

**Information Source:** AAIB Field Investigation

## History of the flight

The aircraft had completed final assembly and flight testing at the manufacturer's assembly plant, and was scheduled for handover to the customer on 26 April 1996. In the event, however, a delay in the provision of the customer-supplied passenger seating meant that formal delivery could not take place on schedule. Rather than have the aircraft standing idle in the interim, it was agreed that it would be handed over on a temporary basis, allowing the customer to use the aircraft for crew training pending delivery of the seats. The aircraft was duly handed over to the customer on this basis on 26 April, at which point it was formally transferred onto the Swiss register, and was operated thereafter according to the provisions of its Swiss Certificate of Airworthiness.

Late on 28 April, the aircraft was returned to the manufacturer for installation of the seats and rectification of minor snags which had arisen in the interim. This work was subsequently carried out by the manufacturer's personnel, working under the provisions of the Swiss Certificate of Airworthiness. On 30 April, on completion of the work which included a daily inspection carried out according to the customer's inspection schedule, the aircraft was handed back. Later on the same day, the aircraft was taxied out in preparation for the return flight to the customer's operating base, manned by the customer's flight crew.

Whilst carrying out the *full and free* control movement checks prior to take off, the first officer felt a restriction in the aileron controls. In his attempts to confirm this restriction, the forces he applied to the control wheel were sufficient to exceed the 60 lbf break-out force in the interconnect mechanism between the two *halves* of the roll control circuit, which on the 146 comprises a collapsible strut linking the captain's and first officer's controls. The Captain confirmed there was a restriction in his controls, and the aircraft was then taxied back to the hangar where investigation revealed that a bolt was inserted in the control wheel rigging pin hole at the base of the captain's control column.

## Background

### Manufacturing process

Prior to the primary structural elements (fuselage, wings, tail) being joined together, the various separate sections of the aircraft moved physically through the factory as work proceeded. Once these elements had been mated together, however, each aircraft moved to one of four **integrated assembly stations** (referred to subsequently as **assembly stations**) where the remaining assembly and systems installation took place. Upon completion of this work, typically 6 weeks later, each aircraft was moved out into the **finals** assembly area, where customer-specific installation work and final function checks were carried out in preparation for the flight-test phase of the production cycle. Once flight testing was complete, the aircraft was issued with a Certificate of Airworthiness, and formal handover to the customer could take place.

Each assembly station comprised a fully equipped build-station which allowed assembly to continue without need to move the aircraft physically along the production line. The production personnel responsible for assembly work across all four assembly stations were grouped into **cells**, each led by a **cell leader**. Each cell operated in a semi-autonomous manner, and comprised a mix of **approved operators** (skilled craftsmen, whose function was to carry out the assembly work) and **inspectors** (whose function was to check that each stage of the production process had been carried

out correctly, and to formally record this fact by the application of an inspector's stamp in the appropriate documentation).

The factory worked several shifts during each 24 period, each comprising several cells which together provided a skills matrix meeting the overall production requirements of all four assembly stations. The mix of skills within cells varied slightly: most were generalist in nature, spending the bulk of their time working at one assembly station; the more specialist cells, however, (for example the approved operators working mainly on flying controls and hydraulics systems) tended to *float* between assembly stations according to day-to-day production requirements.

Although carried out within the same factory, the *assembly station* and *finals* production phases represented two very different and separate stages in the aircraft's life, and were physically separate from one another. In effect, the move from the assembly station out into the finals assembly area marked the first stage in the transition from a *product* into an *aircraft*, and the skills and work ethos employed in the two areas differed accordingly. Although some of the production staff working on the assembly stations had experience of working in the finals area, and vice versa, for the most part personnel from the assembly stations never worked on fit-for-flight aircraft in the finals area. This difference was particularly apparent in the case of the inspectors: those working in the assembly station environment were essentially production-process inspectors whereas those in the finals area, especially those involved with *flying* aircraft, were aircraft inspectors in the conventionally accepted sense.

## Controlling documentation and procedures

The production process was governed by a document system designed to control the assembly process; to provide specific drawings, instructions and guidelines on procedures to be used, and to regulate the whole of the assembly process. The system also provided monitoring and audit functions for final certification and trouble-shooting purposes.

Each of the assembly processes to be carried out during the assembly station assembly phase were defined in detail in the **technical control manual**. This comprised a library of drawings, and a variety of other documents providing detailed instruction on how to carry out each **assembly stage operation** (the production tasks carried out in the assembly stations, referred to hereafter as **stage operations**), and also the inspections required. The series of operations to be carried out for each stage operation were detailed in a **process sheet**, and the associated inspections were recorded on an accompanying **inspection record sheet**, which was essentially a duplicate of the process sheet but with additional provision made for the approved operators to apply their stamps denoting completion of the relevant operations in accordance with the process sheet instructions, and for the inspectors to apply their stamps formally certifying that the relevant operations had been completed satisfactorily.

The process sheets and inspection record sheets were contained in folders held at the **document station** for the assembly station in question. When a given stage operation had been completed, the relevant inspection sheets were stamped up and placed in different folder at the document station, from which they were collected on a daily basis by tech. records personnel. The inspection records thus assembled comprised the audit trail which underpinned the ultimate issue of the aircraft's Certificate of Airworthiness.

In addition to the inspection record sheets and related data required for certification, various complementary data were collected during the build process and recorded on a series of **pro-forma**

**sheets.** Whereas the inspection record sheets, for example, might record that a particular control surface was rigged to within the prescribed limits, the pro-forma sheet would be used to record the actual rigging values. The data thus collected were subsequently assembled by the technical records personnel into a record book for the particular aircraft, which was presented to the customer at the time of delivery.

Procedural systems were provided which allowed stage operations to be programmed out-of-sequence, *eg* the postponement of a particular stage due to unavailability of parts or personnel. These procedures incorporated a means of *flagging* the paperwork system to prevent assembly proceeding beyond a given key stage, until the particular out-of-sequence stage had been completed. In theory, the system also incorporated facilities enabling any member of production staff to register any anomalies which they may have seen, and which the system would then flag up for attention. In practice, however, this system did not appear to be well understood by those at working level.

## **Jigs and fixtures**

For the most part, each assembly station was provided with all the jigs and fixtures required during the assembly station manufacturing phase, either integrally with the staging or on shadow boards attached to the stagings at suitable locations.

Notable exceptions were the rigging pins and rigging protractors for the flying controls, which were kept separately in a storeroom at the far end of the assembly building, some distance from the assembly stations. No systematic logging of these items in and out of the store took place, although a loose leaf record book was provided for this purpose. Only one set of rigging pins was provided and in practice pins were often found to be missing. In an effort to meet the day-to-day requirements of their work, approved operators had therefore adopted the practice of fashioning their own rigging pins, which they kept with their personal tools.

Due to the lack of any systemized tool control for the *official* rigging pins, together with the proliferation of *unofficial* pins, it was not possible either for pin usage to be monitored or for missing pins to be highlighted for investigation. Consequently, there was a significant risk of rigging pins being left in place undetected until the controls were next operated, and of pins becoming *lost* within the aircraft structure where they would present an ongoing risk to the aircraft during service.

## **History of events leading to the incident**

### **Initial rigging procedure error**

Some 5 weeks prior to the incident, whilst the aircraft was still in the assembly station assembly phase of manufacture, the flying control surfaces had been rigged as part of a routine stage operation. The first part of the process sheet instructions for this operation provided instructions relating to various standard procedures, health and safety notices, and preparatory procedures including confirmation that the controls were free of obstructions (split-pins, wire locking, rags etc.), in preparation for carrying out the rigging operations proper. These preliminary operations were stamped up by the three approved operators on 11/12/95, and by the inspectors (the stage 1 inspection) on the following day.

The actual task of carrying out the rigging adjustments and readings, and the associated inspection stages, were defined in the process sheet by a series of 9 instructions which can be summarised as follows:

- 1) Ensure that control input circuits are correctly rigged.
- 2) Fit protractor plate and pointer to control column and aileron handwheel respectively.
- 3) Insert rigging pin at base of control column, and ensure that pointer aligns with zero-degree position on protractor. Remove rigging pin.
- 4) Position first person at right hand spoiler trailing edge.
- 5) Position second person at control column, ready to apply handwheel inputs.
- 6) Move handwheel anti-clockwise by approximately  $5^\circ$ , then move handwheel slowly clockwise in half degree increments, calling out the protractor reading at each increment to person at spoiler.
- 7) Person at spoiler to watch control surface for spoiler initiation, and note handwheel protractor reading when this occurs.
- 8) Adjust as necessary.
- 9) Repeat for left hand spoiler (handwheel rotations reversed).

Upon completion of these nine operations, for both left and rightspoilers, the process sheet states,

"With hydraulic power on, adjust and function roll spoilers to drawing requirements. Record figures on pro-forma No: 17".

Three approved operator's stamps in the inspection record sheet testify that these instructions were carried out fully, including transfer of the readings to the pro-forma sheet. In fact however, the roll spoiler readings had been omitted from the pro-forma in error. The *first* and *duplicate* independent inspections (inspection stages 2A and 2B) were also stamped up, on 12/12/95 and 13/12/95 respectively, despite the fact that the pro-forma sheet was incomplete.

The process sheet instructions for the final stage in the rigging operation covered torque tightening of the roll spoiler adjustable rod-end nuts and associated wire locking. This work was stamped up by

the three approved operators on 11/12/95, and the *first* stand *duplicate* inspections (inspection stages 3A and 3B) were stamped up by the inspectors on 12/12/95 and 13/12/95 respectively.

In summary, upon completion of the spoiler rigging stage operation, the inspection record (including a *duplicate* independent inspection) certified completion of all relevant work, whereas in fact the pro-forma sheet was incomplete.

### **Discovery that data was missing**

Unlike the inspection record sheets, which were routinely collected by the technical records department, the completed pro-forma for a given aircraft were held in a separate folder which stayed with the aircraft until about 3 to 4 weeks prior to delivery, when they were collected in preparation for making up the aircraft's record book. As a result, the missing roll spoiler data on pro-forma 17 was not detected until technical records staff began transcribing the data some 3 weeks before delivery of the aircraft was due. By this time the aircraft had already moved into the final assembly area and was part way through the final assembly phase.

### **Subsequent activity relating to the roll spoilers**

#### **The perceived problem**

The technical records supervisor saw the problem simply in terms of *missing data*: the validity of the inspection record sheet in relation to the actual spoiler rigging operations carried out on the aircraft, and *stamped up* alongside the pro-forma operation, was not questioned. This (simplistic) perception of what was required to redeem the situation seems never to have been questioned at any stage subsequently, either by the technical records supervisor himself or by anyone else involved.

#### **Attempts to remedy the situation**

According to senior management in charge of production, any one of three separate and distinct procedures could have been used to by the technical records supervisor to request that a task be programmed to obtain the missing data. These were:

- i) Raising of an additional stage operation: effectively, the insertion of a special (one-off) stage operation into the assembly station production schedule.
- ii) Entry onto a document known as an **observation snag sheet**, a process designed to provide a means whereby any member of staff could draw attention to any safety or quality issue affecting a given aircraft; for example, to report observed damage.
- iii) Re-issue of the stage operation: effectively requiring a repeat of the original stage operation to be programmed.

It was evident, however, that these procedures were not well understood in practice. Certainly, the technical records staff who discovered the pro-forma shortfall were not familiar with them, and so

As the technical records supervisor was concerned there existed no formalised procedures by which he could recover his missing data. He therefore went down personally to the assembly station and spoke to the cell leader whose team had created the problem in the first place, asking him to arrange for the missing data to be obtained. Despite the informal nature of this request and the absence of paperwork, the cell leader evidently did not consider the implications of what he was being asked to do, neither did he implement any of the formalised procedures outlined above; instead, he simply undertook to have the readings taken again.

In the weeks which followed, no information was forthcoming and with increasing concern the technical records supervisor made a number of further visits to the assembly station cell leader, each with the same outcome. Some 2 days before the aircraft was scheduled for delivery, the technical records supervisor visited the cell leader again and impressed upon him the urgency of the situation, but was told that the rigging protractor was in use elsewhere and would not become available until after the scheduled date of delivery. In the event, however, the delay due to the late delivery of the seats presented a last-chance opportunity for the missing data to be obtained, and it was agreed with the cell leader that the work should be done when the aircraft was returned for installation of the seats.

To summarise:

At no stage was any formal task programmed in relation to missing pro-forma data.

Senior management were not informed of the problem.

The wider implications of incomplete pro-forma data were never considered; in particular, it was not perceived that the assembly stage inspection record had effectively been rendered void. As a result, although it was highly probable that the rigging work had been completed satisfactorily and the control surface ranges set within limits, the aircraft was test flown and delivered to the customer without this fact having been positively confirmed, and with compromised inspection records and Certificate of Airworthiness.

## **Unprogrammed work on the aircraft**

Late on Sunday 28 April, the aircraft returned to the manufacturer for installation of the seating and rectification of a number of minor defects. This was an unusual situation for the manufacturer, insofar as the aircraft was by that stage on the Swiss register and was operating on a Swiss Certificate of Airworthiness which required all maintenance work to be carried out in accordance with the (Swiss) customer's approved procedures. Permission therefore had to be obtained from the Swiss Authorities for the manufacturer's personnel to carry out the work in accordance with the customer's procedures, including the necessary entries in the aircraft's technical log (and the associated signing off of these entries by the few personnel who held the necessary licences).

On Monday 29 April, the technical records supervisor reminded the assembly station cell leader that he was still awaiting the missing data for the pro-forma. The cell leader, in turn, instructed an

approved operator, who was a member of the assembly station rigging team, to get his team together and go out to the aircraft in the finals area 'to take a set of figures for the roll spoilers', which had been missed off the original pro-forma. The approved operator informed his colleague, and also two inspectors with whom they normally worked, and having gathered together his tools and the protractor kit, set off for the finals area in company with his (approved operator) colleague and a youth who was attached to the team as part of a work experience program.

No paperwork of any kind had been raised for the job; none was requested by the assembly station cell leader, nor did he make any attempt to liaise with the *finals* flight-line cell leader responsible for the aircraft. In addition, none of the work party realised that the aircraft was operating on a (Foreign) Certificate of Airworthiness, and no consideration was given at any stage to the implications of carrying out such work on a *live* aircraft. So far as those involved were concerned, they were simply carrying out an ad-hoc *measuring* task to obtain missing figures, not *rigging* operations per se.

Upon reaching the aircraft, the approved operator spoke to the cell leader responsible for the aircraft and told him that he needed to check the roll spoiler readings. The cell leader gave his permission but expressed surprise that this was necessary, given that the aircraft was due for return to the customer the following day: he neither asked for details of what their work would entail, nor did he question the absence of supporting paperwork or the means by which these activities were to be recorded and signed off in the technical log.

Having satisfied himself that it was safe for the work to be carried out, and in particular that it was safe for him to put hydraulic power on the aircraft, the approved operator started to install the protractor and pointer on the left hand control column, which involved the removal of cover screws on the back of the column to allow attachment of the protractor. At about this time, the two assembly station inspectors arrived carrying the inclinometer (for measuring the control surface angular deflection) and two hand radio sets to allow communication between the cockpit and spoiler locations. However, as they were about to start, the approved operator found that his rigging pin (an unofficial tool made from a steel pin with a large jubilee clip attached as a *flag*) was missing from his toolbox. Time was getting short, and rather than walking all the way back to assembly station to look for it, or trying to track down one of the official rigging pins, his colleague went off to find something else which could be used instead, and returned shortly afterwards with a (new) bolt he had found in the open-access storage area.

Although there was no paperwork, and consequently there was no process sheet for the job, the approved operator had carried out the spoiler rigging operation many times in the assembly station and was intending to follow his usual practice on this occasion. This differed slightly, but significantly, from the strict sequences specified on the stage operation process sheet (points 1-9, summarised earlier) in that he normally re-inserted the rigging pin upon completion of each check, to confirm that the zero datum had not moved from its original position. In the event, the approved operator carried out his part of the task using his normal methods but the others involved did not. Instead of the other approved operator positioning himself at the spoiler, with the inspectors separately observing the control wheel and spoiler movements respectively before changing over and repeating the operation, on this occasion both approved operators remained on the flight deck whilst the two inspectors carried out the task of measuring and recording the spoiler movements on the wing, noting the figures on a scrap of paper for later transfer onto the pro-forma.

Upon completion of the second (final) set of readings, the approved operator replaced the bolt in the rigging hole to confirm the datum position, as was his normal practice. Under normal

circumstances he would then have withdrawn the pin, removed the protractor and pointer, replaced the cover panel screws and finally gathered his tools and equipment together before vacating the cockpit. On this occasion, however, in an effort to *involve* the work experience youth, the approved operator deviated from usual routine and invited him to remove the protractor and pointer and replace the cover plate screws, which he did. The approved operator moved across into the first officer's seat and watched whilst this was done, and his colleague then sat in the left hand seat and checked that the screws had been tightened properly. Neither of them remembered to remove the bolt from the rigging pin hole in the base of the control column.

Having reached up to turn off the electrical power to the aircraft, the approved operator was about to leave his seat and start gathering together his things when his routine was interrupted by one of the production managers, who entered the aircraft with some visitors and asked him to put the electrical power on whilst they were in the cabin. He therefore switched the power back on, and sat waiting in the first officer's seat until they had finished. When they had left, he was about to turn off the power in preparation for leaving when he was once again interrupted, this time by one of the final inspectors, who asked him to leave the power on. When he eventually managed to vacate the aircraft, it was quite late in the afternoon.

When carrying out the spoiler rigging operations in the assembly stations, the inspectors involved would normally have carried out checks in the cockpit afterwards to confirm that it was in a *clean* condition, and that the rigging pin had been removed. On this occasion, however, the whole focus of their effort was on *taking the missing readings* and neither inspector saw any need to inspect the cockpit: instead, when they had finished taking the readings, they walked back to the assembly station where they transferred the data to the pro-forma and applied their inspection stamps, without carrying out any form of *clean up* inspection in the cockpit first.

### **Rigging pin visibility**

When inserted with the red disc-flag horizontal, the *official* rigging pin was clearly visible at the base of the control column, see figures 1a and 1b. The approved operator's own *unofficial* pin with its large ring-flag would also have been highly visible. In contrast, when pushed in fully, the bolt used in this case was not only difficult to see but was effectively camouflaged by two identical bolt heads to either side, see figures 2a and 2b. This, and the fact that the cockpit in this case was fully furnished (compared with the bare cockpit of the aircraft in the assembly stations), effectively ruled out any opportunity for it to be noticed by chance.

### **Daily inspection**

Because the aircraft was being operated on a Swiss Certificate of Airworthiness requiring the use of the operator's inspection procedures, the daily inspection carried out prior to the aircraft being handed back to the customer was carried out according to the customer's own schedule. Unlike the manufacturer's daily inspection, this did not include a full and free check of the flying controls. Consequently, a final opportunity for the bolt to have been found prior to the start of the flight was missed.

### **Systematic deficiencies highlighted by this incident**

This incident has highlighted a number of shortcomings in the procedures, documentation, and facilities in use within the factory.

## Deficient process sheet instructions

The stage operation process sheet covering rigging of the rollspoilers included an instruction to ensure that the controls were free of obstructions before carrying out rigging operations. However, there was no requirement to carry out comparable checks for freedom of obstruction after completion of the task. Specifically, the process sheet contained no inspection to confirm removal of the rigging pin, or for *full and free* movement checks to be carried out.

## Inadequate differentiation between *production* and *inspection* tasks

Insufficient distinction was made between *production* task elements and *inspection* task elements listed in the process sheet covering the spoiler rigging stage operation (and possibly process sheets relating to other activities involving breakdown and/or adjustments of primary controls). Specifically, the process sheet contained no explicit *safety* inspections, as distinct from *production* inspections items designed to confirm that rigging adjustments and other production tasks had been carried out within the specified limits.

## Confusion about the meaning of *duplicate inspections*

The interpretation of the term 'duplicate inspection' within the assembly station area differed from the normal interpretation of duplicate inspections as applied to *live* aircraft. Specifically, in relation to work carried out on live aircraft, duplicate inspections are intended primarily to provide independent confirmation that after disconnection or disturbance of vital systems, these systems have been fully restored to an airworthy state upon completion of the work. In the case of rigging adjustments to flying controls, for example, the main emphasis of the *duplicate* element of the inspection should therefore be to ensure that system integrity has been fully restored, and that the controls are free of restrictions.

In this case, duplicate inspections carried out as a part of assembly station build were interpreted by the inspectors to mean that the whole of the rigging process was to be repeated and independently verified: an interpretation which potentially negates the essential redundancy which underpins the value of a *duplicate inspection*. For example, in the specific case in question, the process sheet required the following sequence to be carried out for each *side* of the aircraft:

Fit protractor plate and pointer

Insert rigging pin

Ensure pointer aligns with zero-degree position

Remove rigging pin

Carry out rigging checks

Adjust as necessary

Note readings

It can be seen that a mere repetition of this sequence, *ie.* the *assembly station* interpretation of duplicate, is intrinsically incapable of meeting the requirements of a duplicate inspection as applied

to flying aircraft, insofar as the insertion of the rigging pin during the *repeat* sequence nullifies the prior inspection to confirm pin removal during the *first* sequence. In fact, since the rigging operation must be carried out for both left and right spoilers, the assembly station interpretation of duplicate inspection meant that the rigging pin removal and insertion would take place 4 times if the process sheet instructions were to be adhered to rigorously, with only the final inspection for pin removal having any validity.

It follows that a valid duplicate inspection for pin removal could not be carried out using the inspection methodology employed within the assembly station at the relevant time.

### **Cultural differences between *production* and *flight line* personnel**

Aircraft inspectors working with live (flying) aircraft invariably have a different ethos from those working in aircraft manufacture. The former are usually very much alive to the overriding need for the control systems (and other vital systems) to be restored fully after work involving disconnection, or any activity which might compromise their integrity; they also understand fully the need for effective duplicate inspections to guard against human error. Inspectors working in the factory environment, however, tend to be more focused on quality control issues pertaining to the accuracy of the work carried out. Comparable differences are invariably found between fitters working in the *manufacturing* and *flight line* environments.

These cultural differences were starkly apparent in relation to the assembly station inspectors involved in the unscheduled range checks on the roll spoilers, who not only were unaware that they were working on a *live* aircraft operating on a Certificate of Airworthiness (with all of the attendant regulatory implications), but for whom such matters were evidently perceived at the time as *not an issue*. Had they been more aware, they would not only have realised the implications of carrying out unscheduled work without proper paperwork and planning, and taken steps to remedy the situation, but at the very least would have ensured that the flight line cell leader was fully aware of what was being done.

A similar lack of awareness was displayed by the assembly station cell leader who instructed the rigging team to carry out the work, and who failed to liaise in any way with the flight line cell leader responsible for the aircraft.

### **Inadequate control of access to *live* aircraft**

It should not have been possible for workers who were not part of the *flight line* cell to gain access to the aircraft to carry out work for which no formal authorisation had been given, or documentation raised.

### **Inadequate tool control**

Full sets of rigging tools were not maintained at each assembly station, and there was no means by which the issue of rigging pins could be controlled, or their status monitored. The absence of any form of systemised tool control in relation to these items led to a proliferation of unofficial equipment, and a grave risk of these items being left in the aircraft, either still inserted at rigging points or loose in the structure.

### **Pro-forma information physically separate from process sheets**

The lack of any provision for recording *pro-forma* data on inspection record sheets prevented the missing information from coming to light at an early stage during the routine processing of the inspection records. It also potentially masked missing or anomalous data which might otherwise have drawn attention to inspection shortfalls.

### **Inadequate procedures for processing out-of-sequence tasks**

The *additional stage, observation snag sheet, and re-issue of the stage* procedures, which in theory provided a means whereby the technical records supervisor (or any member of the production staff) could have had the additional work programmed, were not understood by those intended to use these systems.

### **Recommendations**

1. It is recommended that Avro International Aerospace conduct an in-depth review of its working and inspection practices with a view to addressing the systematic deficiencies which this incident has revealed.