Elevator jam on takeoff, HS748 Series 2A, G-ATMI

Micro-summary: **Takeoff rotation was prevented by an elevator jam; the takeoff was rejected after V1.**

Event Date: **1996-08-16 at 2357 UTC**

Investigative Body: **Aircraft Accident Investigation Board (AAIB), United Kingdom**

Investigative Body's Web Site: **http://www.aaib.dft.gov/uk/**

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HS748 Series 2A, G-ATMI: Main document

Aircraft Accident Report No: 1/99 (EW/C96/8/8)

Report on the accident to HS748 Series 2A, G-ATMI at Liverpool Airport on 16 August 1996

Contents

Registered Owner and Operator:	Emerald Airways Ltd
Aircraft Type:	HS748-Series 2A
Nationality:	British
Registration:	G-ATMI
Place of Accident:	Liverpool Airport, England
	Latitude: - 53° 20' N
	Longitude: - 002° 50' W
Date and Time:	16 August 1996 at 2357 hrs
	All times in this report are Local (UTC + 1 hour)

Synopsis

The accident was notified to the Air Accidents Investigation Branch (AAIB) at 0245 hrs on 17 August 1996 and an investigation began the same day. The investigation was conducted by Dr E J Trimble (Investigator in Charge), Mr R J Tydeman (Operations), Mr A N Cable (Engineering) and Mr J R James (Flight Recorders).

The accident occurred when take-off rotation of the aircraft was prevented by an elevator control circuit jam. The take-off was rejected after reaching V_1, and wheelbraking and selection of propeller ground fine pitch failed to stop the aircraft on the runway. During the overrun the aircraft collided with camera equipment mounted on a building, locally damaging the right wing.

A number of potentially serious deficiencies in the flight controls gust lock system were found, although the system passed checks intended to verify its integrity. An undemanded re-locking of the system could not be reproduced during testing, but this could not fully simulate the accident circumstances. It was concluded that the accident was probably caused by a re-engagement of the elevator gust lock induced by the carrying out of a Full and Free controls check at the start of the take-off run.

Despite a series of modifications to the flight controls gust lock system by the manufacturer, particularly following a major fatal overrun accident which occurred at Sumburgh Airport on 31 July 1979, this accident at Liverpool Airport and other possible gust lock related incidents demonstrated that associated unlocking of the flight controls on HS748 aircraft before flight is still not sufficiently reliable.

The investigation identified the following causal factors:

1. Flight control gust lock system deficiencies which probably caused the elevator lock to re-engage on completion of the crew's Full and Free check of the flight controls before the take-off.

2. Lack of any indication of a jammed elevator condition until the first officer attempted to pull the control column back at aircraft rotation speed, V_R.

3. Lack of sufficient remaining runway distance to stop the aircraft on the runway following the rejected take-off at some 8 kt above V_1 decision speed with the elevator jammed fully down.

4. Inadequacies in maintenance information and implementation that led to failure to correctly maintain a gust lock system the design of which is inherently sensitive to deficiencies.

5. Lack of fully effective modification action, following the fatal overrun accident to HS748, G-BEKF, at Sumburgh Airport on 31 July 1979 (AIB Report 1/81), to address the inherent design sensitivity of the flight controls gust lock system.

Fourteen Safety Recommendations have been made as a result of this investigation.

1. Factual information

1.1 History of the accident

It was planned for the aircraft to fly a night freight service from Liverpool to Belfast, with departure around midnight. Its previous flight had been from the Isle of Man and it had landed at Liverpool at 1759 hrs; the crew considered the aircraft to be serviceable and noted nothing unusual with the flight controls during this sector. The aircraft was refuelled and loaded with a cargo of newspapers, giving an aircraft weight close to the maximum allowable for the planned take-off conditions. The centre of gravity (CG) position was mid-to-forward.

The crew detailed to fly the sector from Liverpool to Belfast had reported for duty at 1845 hrs. They had flown another aircraft from Belfast to Leeds (Bradford) and then on to Liverpool where they landed at 2211 hrs and were allocated G-ATMI. The forecast meteorological conditions for the night flight were excellent.

The crew completed their pre-flight checks, called for taxi at 2353 hrs and were cleared to the holding point for Runway 27. As they approached the holding point at 2357 hrs, they were cleared for take-off and completed their 'before take-off checks' whilst taxiing onto the runway; this included selection of 7.5° of flap and water methanol 'ON', a system incorporated on this type of aircraft to augment the engine performance during the take-off. The flight controls gust lock lever was selected 'OFF' as they entered the runway and the first officer (FO), who was to be the handling pilot for the take-off, checked for 'Full and Free' movement of both the aileron and elevator controls whilst the commander checked for full and free movement of the rudder pedals; this was in accordance with the company Standard Operating Procedures (SOPs). The FO stated that he checked full movement of the yoke with the control in the forward position and then rotated the control column fully aft and fully forward with the yoke in the neutral position.

The take-off initially proceeded normally from the threshold of Runway 27. The FO, who had charge of the control column, applied full power, with the commander following through on the throttles and in control of the steering tiller. During the ground roll, the control column was held in the full forward position. The SOP required that at the call of '80 kt' the FO removes his left hand from the throttle and places it on the control column, the commander now has charge of the throttles in order to be ready for a rejected take-off up to the decision speed, V_1. This call was made at 80 kt and all available evidence suggested that the SOP was complied with.

The crew had correctly calculated their decision speed (V_1) and rotation speed (V_R) to be coincident at 112 KIAS (knots indicated airspeed) and at this speed the commander called "Rotate". Shortly afterwards the FO was heard on the cockpit voice recorder (CVR) to say "Jeez this is heavy", almost immediately followed by the sound of the engines winding down. The total time from the initiation of the 'Rotate' call to the start of the engine retardation was 4.7 seconds.

The FO subsequently stated that as he attempted to pull the control column aft he encountered a restriction after a pull back estimated to be about 1-2 inch. He described this 'stop' as being not an abrupt, solid, immovable one but rather one that became very stiff, very quickly, and after pulling 1-2 inches he could not pull the control column back any further. The commander, who was monitoring the position of the control column, glanced across and saw that the FO was pulling hard with no resultant movement of the control column. He realised that there was a problem and immediately initiated the aborted take-off procedure by closing the throttles, commencing braking and calling for the Flight Fine Pitch Stops (FFPS) to be removed. This abort procedure was initiated at 120 KIAS, as estimated by the commander.

The commander applied maximum force to the brake pedals but soon realised that he would not be able to stop the aircraft within the remaining runway distance. As the aircraft approached the threshold for Runway 09, he decided to manoeuvre to the right in order to avoid the steep drop into the River Mersey. The aircraft crossed the threshold lights on the right edge of the runway and ran onto the grass at a speed estimated to be about 60 kt, on a track of 280°M (Figure 1). A small building, the instrument landing system (ILS) power supply building, became visible in the aircraft lights and the commander steered to the left in an attempt to avoid a collision. The right wing passed over the building but struck the support structure of a surveillance camera and relay unit mounted on its roof. The commander tightened the turn and deliberately entered a 'ground loop' to the left in order to stop the aircraft. After the aircraft came to rest, the commander shut down the engines and notified Air Traffic Control (ATC) that he had left the runway. The FO informed the commander that they had hit something with the right wing and so the commander selected the battery switch off and the crew, who had suffered no injuries, left the aircraft.

The Airport Fire Service responded immediately to the crash alarm, which was activated by the duty ATC supervisor at 2359 hrs, and they were directed to the threshold of Runway 09. On arrival at the scene, they were met by the flight crew and duly notified ATC that both pilots were uninjured. The fire service laid down a foam blanket around the aircraft and remained at the accident site whilst the aircraft was defuelled and until it had been initially examined by the AAIB.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-

Serious	-	-	-
Minor / None	2	-	-

1.3 Damage to aircraft

Aircraft damage consisted of substantial local deformation of the right wing structure, the outboard end of the right flap and the inboard end of the right aileron. The tyre of the No 3 wheel had rolled off the wheel rim and deflated.

1.4 Other damage

Destruction of a video camera and relay unit mounted on the roof of an ILS power supply building on the airfield and minor damage to the roof.

1.5 Personnel information

1.5.1	Commander:	Male, aged 31 years
	Licence:	Airline Transport Pilot's Licence
	Instrument rating:	Renewed on 16 Nov 1995, valid to 15 Dec 1996
	Base check:	23 April 1996, valid
	Line check:	6 December 1995, valid
	Medical certificate:	Class 1, valid until 20 May 1997
	Flying experience:	Total all types - 2,504 hours
		Total on type - 1,461 hours
		Last 90 days - 98 hours
		Last 28 days - 33 hours
	Duty time:	14 hours 45 minutes rest prior to commencing duty at 1845 hours on 16 August 1996

1.5.2.	First officer:	Male, aged 35 years
	Licence:	Airline Transport Pilot's Licence
	Instrument rating:	Renewed on 12 May 1996, valid to 11 Jan 1997
	Base check:	12 May 1996, valid
	Line check:	12 May 1996, valid
	Medical certificate:	Class 1, valid until 3 February 1997
	Flying experience:	Total all types - 3,040 hours
		Total on type - 125 hours
		Last 90 days - 125 hours
		Last 28 days - 40 hours
	Duty time:	14 hours 25 minutes rest prior to commencing duty at 1845 hours on 16 August 1996

1.6 Aircraft information

1.6.1 General information

Manufacturer:	Hawker Siddeley Aviation Ltd (now British Aerospace Regional Aircraft)
Type:	HS748 - Series 2A
Aircraft Serial No:	159
Year of manufacture:	1966
Certificate of Registration:	G-ATMI/R6 Issued on 3 August 1992
Certificate of Airworthiness:	Valid until 6 October 1996
Engines:	2 Rolls Royce Dart 534-2 turboprop engines
Total airframe hours:	52,033

1.6.2 Weight, balance and fuel

Maximum Take-off Weight:	19,995 kg
Zero Fuel Weight used:	17,463 kg (see below)
Total fuel at take-off:	2,470 kg
Actual Take-off Weight:	19,933 kg (see below)

The limiting weight for the take-off from Runway 27 at Liverpool in the reported meteorological conditions was based on the maximum take-off weight of 19,995 kg. The weight of the aircraft for take-off, derived from the load sheet calculations, was 19,933 kg with a CG index of -17.92. These calculations used a cargo weight of 6,282 kg as stated on the Cargo Manifest issued to the crew and the CG index was derived by assuming an even distribution of the cargo within the freight compartment. After the accident, the cargo in each freight bay was weighed; the total weight of the cargo was then found to be 6,132 kg (ie 150 kg less than that previously calculated) and the CG index was determined to be -23.02, which represented a mid-to-forward CG position.

1.6.3 Manufacture

The aircraft type is of conventional layout (Figure 2), powered by two Rolls Royce Dart 534-2 gas turbine engines each driving a 4 bladed propeller. Air Registration Board approval for the type was granted in 1962. The original manufacturer was Hawker Siddeley Aviation Ltd, which later became part of British Aerospace after manufacture of the type ceased in 1984. Design authority subsequently passed to Jetstream Aircraft Ltd (JAL) and then to British Aerospace Regional Aircraft. At the time of the accident there were approximately 260 aircraft of the type in service in various parts of the world, including 14 in the UK, carrying passengers and/or freight.

1.6.4 Flight controls

The primary flight controls consist of an aileron on each wing, two joined elevators and a single rudder. Aileron and elevator surfaces are directly manually operated, with balance tab assistance; the rudder is controlled by a manually operated tab. Flight deck control motion in each channel is transmitted by a system of rods and bellcranks to a cable quadrant mounted beneath the aft part of the flight deck floor and thence by a cable/pulley system (or by tie rods in the case of the central part of the elevator control run) to a rod and lever system driving the respective control surface. Each control is provided with a trim tab that is also intended to act as a standby system for the primary control. The trim tab systems are cable operated.

The flight control and trim tab operating cables (or tie rods) pass along the fuselage through cut-outs in the cabin floor beams. Each cable run is made up of a number of cable lengths and adjustment is provided by the turnbuckles connecting them. Where the cables penetrate the pressure hull into unpressurised areas, they pass through pressure seals, consisting of a polytetrafluoroethylene (PTFE) coated cable sleeve running within a PTFE lined tube secured to the structure by a rubber moulding. These seals are provided at the cabin rear pressure bulkhead in the case of the rudder and elevator primary and trim tab runs, and at the wing root in the case of the aileron runs.

The elevator control run is shown in Figure 2. The cable run terminates in the tailcone at a cable tension regulator, which is intended to maintain a constant cable/tie rod tension irrespective of fuselage deformation as a result of loading or temperature changes. A spring load unit acting on the elevators biases them to the trailing edge fully down position.

1.6.5 Gust lock system

1.6.5.1 General system description

The three primary flight control runs can be locked by a gust lock system, intended to be engaged while the aircraft is taxiing or parked to prevent possible damage to the control surfaces due to these being 'slammed over' by wind loads. A lock plate in each primary control run pivots when the run is moved and can be locked by a gust lock system roller lever (Figure 3). Each lock plate is driven by the rod and lever system driving the respective control surface (at the left aileron, in the case of this system). The roller lever is oriented with the roller in the wide part of the lock plate cam slot when the lock is 'OFF', thus allowing unrestricted control run movement, and pivots to position the roller in the narrow portion of the slot in order to lock the run. The roller levers are manually operated by a lever assembly in the flight deck centre console via a rod and bellcrank/cable system. The system is 'ON' with the flight deck lever assembly at the aft end of its slot, and 'OFF' with it at the forward end. When engaged, the gust lock system locks the elevators in the trailing edge fully down position (ie control column fully forward) and the ailerons and the rudder at neutral.

1.6.5.2 Flight deck lever

The console lever assembly (Figure 4) consists of a pilot's lever [A] that can slide telescopically in a housing lever [B] to which is bolted an output lever [C]. Lever B pivots within the slot of a fixed gate plate bolted to the flight deck centre console. The slot has cut-out detents at its forward and aft ends to accommodate a baulk block attached to Lever A. Thus Lever A can only be stowed within

Lever B when the lever assembly is positioned at 'ON' or 'OFF', providing a lock for the system. The increased extension of the lever from the console at intermediate positions between 'ON' and 'OFF' provides a visual warning that the lever assembly is not stowed in either of the detents (Figure 5). Approximately 3.5 inch of telescopic movement is required to unstow Lever A, which is spring-loaded down into B. The lever assembly is mechanically interlocked with the propeller flight fine pitch stop (FFPS) levers and the throttle levers, such that both throttles cannot be fully advanced without the FFPS lever engaged, which in turn requires the gust lock lever assembly to be at, or near, the 'OFF' position.

1.6.5.3 Mechanical linkage

Lever C is connected by a series of rods and bellcranks to a cable quadrant mounted underfloor near the aft left corner of the flight deck. Two cables attached to the quadrant pass through cabin floor beam cut-outs to forward differential pulleys mounted in sliders located between floor beams in the forward cabin (Figure 3). A cable loop passing over these pulleys connects to the elevator and aileron gust lock roller levers. This second loop also passes over two aft differential pulleys in the tailcone which drive the rudder gust lock roller lever via a third cable loop. The spindle for each aft differential pulley is mounted on an idler lever, consisting of a U-section channel member riveted to two sideplates. The two idler levers are located side-by-side on a common pivot pin mounted to the aircraft structure (Figure 6). A carrier assembly, consisting of two sideplates attached together by bolts and spacers, connects each pulley spindle to the respective end of the third cable loop. The idler levers pivot in opposite directions when the gust lock system is operated, with pulleys travelling a nominal ±1 inch from a horizontal datum through the pivot pin.

1.6.5.4 Locks

Each of the three roller levers is spring-loaded towards 'OFF'. The aileron lock lever mechanism is provided with an adjustable stop to limit travel in the 'OFF' direction; 'OFF' stops for the elevator and rudder locks are effectively provided by contact of the roller with the 'OFF' side of the cam.

1.6.5.5 Function

As the rudder is the control surface most likely to be subjected to gusting side winds and thus the most difficult to lock, the system has been designed to provide the rudder lock with greater mechanical advantage. The arrangement of the forward and aft differential pulleys thus allows for half of the gust lock flight deck lever travel to be applied to the rudder lock, and a quarter each to be applied to the aileron and elevator locks. The sequence in which the locks engage or disengage can be varied by applying a control movement, or force, in one or two of the runs which has the effect of allowing preferential movement of the lock in the other run(s).

1.6.5.6 Means of inspection

The components in the flight deck console can be viewed via the lever assembly gate slot by pushing aside a bristle seal, and accessed via a small removable console side panel. Removal of left floor panels in the flight deck and cabin provide ready access to the linkage between the console and the aft pressure bulkhead, with the exception of an area at the rear of the flight deck. Aileron, rudder and elevator lock assemblies are accessed by removable panels under the left wing, in the side of the fin and under the tailcone, respectively. The tailcone panel also provides access to the aft differential assemblies.

1.6.5.7 Maintenance requirements

Gust lock system rigging procedures were given in the BAe HS748 Aircraft Maintenance Manual (AMM), Chapter 27-7-0, Pages 501 to 504. They required the setting up in turn of:

The run from the pilot's flight deck lever to the cable quadrant.

The run from the quadrant to the forward differential pulleys.

The run from the aft differential pulleys to the rudder lock.

The aileron 'OFF' stop.

The elevator/aileron cable loop tension.

The procedures required the sequential setting up of the system components, generally by orienting various levers and bellcranks to particular angles, by adjusting various adjustable rods to specified lengths and/or by measuring the distance between parts of the system and the aircraft structure. Rigging pin facilities were not provided because of a perception, during the design, of the potential danger of their non-removal after maintenance.

Procedures for testing the system after rigging were given in the AMM, Chapter 27-7-0, Pages 505 to 506. They consisted of a Full and Free control check; a sequencing check, ie measuring the pilot's lever displacement from 'OFF' at which each control channel locks when a particular engagement sequence was induced; and a check of the interlock between the pilot's lever and the FFPS lever. The procedure concentrated on the locking performance of the system and no check on the state of the system when unlocked was specified, other than the Full and Free operation.

Procedures for checking the system were given in the AMM, Chapter 27-7-0, Pages 601 to 608. These consisted of checks of the flight deck lever assembly and the console gate, checks of the interlock between the gust lock, FFPS and throttle levers, and a Pull-Down Check on the elevator lock roller lever.

A Pull-Down Check was introduced by Mandatory Service Bulletin 27/76 to check the overall slackness and rigging of a gust lock circuit, but only in regard to its ability to travel fully to the 'OFF' position and remain there. It required an initial check that the roller lever was fully off when the system had been selected 'OFF' and the controls exercised. With the gust locks selected 'OFF', a downward load was applied to the elevator gust lock roller lever, at the roller end. A feature of the system is that any slackness that has developed in the aileron or rudder parts of the gust lock circuit will be transferred by this test to the elevator part of the circuit. The manufacturer noted that the value of the weight applied to the roller lever, 11 lb, was intended to cover the worst possible dynamic loading case that the circuit could experience. After the weight had been applied, the separation of the roller centre from the 'ON' point of the lock plate cam was measured. If the separation (defined here as Dimension d) were less than 2.20 inch (56 mm) a check of the rigging of the complete system was specified. In practice this measurement could not conveniently be made; the corresponding separation of the roller surface from the 'ON' point of the cam (Dimension e) was 1.85 inch (47 mm). The manufacturer reported that the nature of the Pull-Down Check and the parameters specified for it had been determined empirically.

The required scheduling of the above operations is given in section 1.18.3.

1.7 Meteorological information

A large anti-cyclone positioned over the Irish Sea was producing warm, dry, stable conditions over all of the United Kingdom. A routine weather report was issued for Liverpool Airport 9 minutes prior to the accident. The surface wind was reported as 360°/03 kt and the weather was CAVOK (visibility 10 km or more with no cloud below 5,000 feet and no significant weather phenomena). The surface temperature was +16°C with a dewpoint of +12°C and the QNH was 1019 mb.

1.8 Aids to navigation

No aids to navigation were in use at the time of the accident.

1.9 Communications

VHF communications were satisfactory. Tape recordings were available of transmissions on the Liverpool Tower frequency.

1.10 Aerodrome and approved facilities

1.10.1 Runway physical characteristics

Runway 27 at Liverpool is 2,286 metres (7,500 feet) in length and 46 metres (150 feet) wide, with a published overall slope of 0.25% down. The full length was declared as available for the take-off run (TORA). The runway surface was asphalt with a 7.6 metres (25 feet) paved shoulder on either side and was dry at the time of the accident.

1.10.2 Runway lighting

The lighting for Runway 27 consisted of high intensity bi-directional white edge lights with low intensity omni-directional lights at every 60 metres. The centre-line was marked by high intensity bi-directional white lights which changed to alternate red/white lights 900 metres from the Runway 09 threshold and became all red lighting within the last 300 metres of runway. The far extremity of the runway surface was marked by a bar of red runway end lights. All of the runway lights were illuminated at the time of the accident.

The approach lights to Runway 09 (ie the lights in the overrun area for Runway 27) consisted of a five bar approach lighting system with the closest bar 150 metres from the paved surface.

1.10.3 Runway slope

From the threshold, at 77 feet above mean sea level (amsl), Runway 27 rose imperceptibly to 81 feet amsl in the first 500 metres (1,640 feet). It then sloped down at 0.39% for the remaining 1,786 metres (5,860 feet) to the end of the runway, which was at 58 feet amsl, giving an overall down slope of 0.25%. The overrun area relevant to the accident continued the slight downslope.

1.10.4 Runway friction

Runway friction classification analysis of Runway 27/09 at Liverpool Airport was carried out by the Aircraft Ground Operations Group of the Cranfield Institute of Technology in January 1989 following resurfacing of the runway. Since then the friction tests had been carried out by the Air Traffic engineers on a monthly basis. The last friction test carried out prior to the accident was on 6 August 1996. No significant change in the runway friction had been identified since the initial classification.

1.11 Flight recorders

The aircraft was fitted with a CVR and a MIDAS Flight Data Recorder (FDR). The CVR contained a recording, from the two crew channels and the cockpit area microphone, which covered the pre-flight checks and the rejected take-off. The five parameter FDR had failed prior to these events and so was of no use to the investigation.

1.11.1 Cockpit voice recorder

The recording indicated that the crew had disengaged the gust lock lever and performed a Full and Free check of the flight controls prior to the take-off roll; the first officer checked movement of the control column and the commander checked the rudder pedals.

During the take-off roll, the commander called out "80 kt" as a speed cross-check. As the aircraft was approaching the briefed rotate speed of 112 kt, the FO uttered a muted exclamation. 3.6 seconds after the commander's call of "V_1, rotate" the FO said "Jeez this is heavy". The commander immediately closed both throttles, asked for the flight fine pitch stops to be withdrawn and began braking.

The aircraft continued for a further 15 seconds before it ran off the end of the runway. The FO called "heavy braking" and also alerted the commander to the presence of a hut which was in their path. 16 seconds after leaving the runway the aircraft came to a halt. The FO advised the commander that the right wing had been hit. The commander asked if the FO could see any flames. When told "No, but I think we ought to get out", the commander informed ATC that they had left the runway. He then ordered evacuation of the aircraft, during which he switched off the aircraft batteries, thus stopping the CVR.

1.11.2 Flight data recorder installation

The FDR installation fitted on the aircraft consisted of three main components; a flight deck mounted control panel, a primary data acquisition unit and a crash-protected tape transport unit. The control panel was mounted on the right-hand side of the entry passage to the flight deck, behind the FO. Provision was made on the panel to enter flight number and date details by means of thumbwheel switches. Also on the panel was a mechanical indicator to show the current mode of operation of the FDR system (off, standby and run) and a red lamp which illuminated if the system Built-In Test Equipment (BITE) detected a fault. The design of the BITE was such that a fault had to be present for two minutes before the indicator would illuminate.

During normal operation of the system, when aircraft power was applied, the tape transport would run for 1 minute without recording data to enable different flight sectors to be separated upon replay. The system would then enter standby mode with no tape motion and the mechanical indicator on the control panel indicating 'STBY'. Once the crew had started both engines, as part of the startup procedure, they would select the aircraft generators to 'ON'. This action would switch the tape transport on, initiating the recording of data and setting the control panel indicator to 'RUN'. From this point a further 2 minute period was required to allow the BITE to detect and indicate a system fault. A later item in the checklist required the crew to ensure that the control panel mechanical indicator was showing 'RUN' and that the BITE fault indication was extinguished.

A fault in the track change sensing of the tape transport of G-ATMI's recorder had allowed the tape to run off the end of one reel, become stuck to the tape drive capstan and then wind backwards around the capstan until it had jammed. Following the engine starts, prior to the accident take-off, the crew had selected the generators to 'ON', thus setting the FDR system to 'RUN'. However, the CVR recording showed that the checklist item to ensure normal operation of the FDR system had been carried out within 1 minute of switching the generators, which did not allow sufficient time for the system BITE to detect and indicate the fault in the tape transport. The position of the control panel on the flight deck was such that neither crew member would have been able to see the fault indication without turning to look over their shoulder. The system BITE was later tested by the equipment manufacturer and found to be working to the design specification.

The FDR tape was replayed by the manufacturer and, from the recorded date and flight number information, it was determined that the tape transport fault had occurred several flight sectors before the accident, but had remained undetected by pilots and maintenance personnel.

Replay of the data also revealed that aircraft airspeed was not being recorded correctly. The operator had previously been notified of this fault by the FDR maintenance organisation during a routine replay of the recorder in June 1996 and had replaced the airspeed transducer on the aircraft. Following this change the operator was unable to check correct operation of airspeed recording as they did not possess a suitable test set. Assessment of the primary data acquisition unit and the FDR by the equipment manufacturer after the accident revealed no anomaly in the airspeed recording circuitry and so the fault was most likely to have occurred in the aircraft wiring. The previous routine replay, conducted in February 1996, revealed no such faults.

Proposed Joint Aviation Authority (JAA) requirements adopted in March 1995 concerning flight recorders for aircraft in the weight category up to 27,000 kg will prohibit the use of non-digital recording systems, such as MIDAS, from the year 2000.

1.12 Aircraft and site examination

1.12.1 Overrun area

The overrun took place within the boundaries of Liverpool Airport. Ground marks showed that the aircraft had run off the end of Runway 27 near its right edge and had continued on a track somewhat to the right of the runway heading, running on firm ground with short, dry grass cover (Photo 1.1). After an initial fairly straight run, the aircraft had begun a large radius turn to its left, shortly before it struck the ILS power supply building. The latter was a small, unmanned, single storey building, 8 feet high, with a flat roof. An intruder video surveillance camera and an associated relay unit were located together above the building, each attached to the building by means of robust steel mounts. Both units were substantial pieces of equipment; their tops were approximately 11 feet above ground level. It was clear that the aircraft's right wing had struck the video camera, relay unit and associated mountings causing their detachment from the building. The tyre ground tracks showed that aircraft had continued in a tightening left turn, crossing an airfield track. The ground marks did not indicate that the final turn had greatly reduced the stopping distance. The aircraft came to rest approximately 250 metres (820 feet) beyond the end of Runway 27 and 61 metres (200 feet) to the right of the runway extended centreline, heading 200°M.

1.12.2 General

Initial examination of the aircraft, before it had been moved, showed that the flight deck lever for the flight control gust lock system (Photo 1.2) was in its 'OFF' detent and the control column was rotatable over its full travel by apparently normal loads. All primary control trim settings were found close to neutral, flaps were at the selected position of 7.5° and the FFPS levers were at the withdrawn position. In situ calibration of the pitot-static system showed no major errors in the indication of either pilot's airspeed indicator.

1.12.3 Elevator control system

A detailed examination was made to find the cause of the elevator jam, including close inspection of all parts of the elevator run for evidence of interference by contact with parts of the aircraft, or with foreign objects. Detailed examination of the elevator trim system and the flight control gust lock system was also made and all relevant parts of the aircraft searched for foreign objects. Comprehensive inspection of all parts of the systems, except those in the regions beneath the radio racks at the aft corners of the flight deck, was possible. The control runs in these areas comprise cable runs only, with no turnbuckles, pulleys or rigid components present; the probability of an abnormality in this area having caused a jam was considered very low.

No signs of disconnection, severe binding or interference were found, with the exception of the elevator gust lock (see section 1.12.5). A number of areas were found in the region beneath the flight deck floor where the clearance between moveable parts of the elevator control run and static components was extremely small, or zero, including areas where rubbing had occurred. The characteristics of the associated markings and the type of contacts that had produced them indicated that it was not possible that contact in these areas could have strongly restricted column rotation. Elevator surface clearance from surrounding fixed structure was also tight, but signs of contact consistent with the accident events was not apparent. The cable tension regulator appeared to function normally.

Foreign objects were found in the flight deck underfloor region, in the tailcone, in the fin, in the tailplanes and, in large quantities, throughout the cabin underfloor region (Photo 2). They included numbers of nuts, bolts and washers, hundreds of portions of drilled-out rivets, three drills (one 2.5 inch long, 0.125 inch diameter), a 2 inch long riveting clamp and a 6 inch long, 0.1 inch diameter steel file. The most significant items found were a 1.7 x 0.9 inch rectangle of 0.13 inch thick steel lying on the lower boom of the floor beam at Frame 252FS, close beneath the elevator control cables; and a 0.9 inch long, 0.175 inch diameter bolt and a large rivet fragment both lying on the lower boom of the floor beam at Frame 180AS, close beneath the elevator control cable twin pulley mounted from this beam. However, close inspection revealed no evidence that any foreign object had interfered with the elevator control run. Flight deck and cabin floor panels were generally tight fitting, albeit with small gaps adjacent to the fuselage sidewalls.

1.12.4 Elevator trim system

Elevator trim was found set at 0.2 units aircraft nose down. No signs of significant anomaly in the trim system were found.

1.12.5 Gust lock system

The gust lock system was examined in detail (the elevator gust lock system is shown in Photo 3.1). Numerous measurements of the system performance characteristics were made (see section 1.16.1), initially with the system unaltered (referred to as Configuration 1) and subsequently after adjustment and component changes had been made. Displacements of various components described below were measured as follows:

Cockpit Lever Assembly	-Lever B measured along the arc of the lever gate plate at the plate top surface.
Cockpit Lever Percent Travel	-Lever B position as percentage of travel from 'ON' to 'Max OFF' (defined in section 1.12.5.4).
Left Forward Differential Pulley	-Roller surface separation from aft end of slot.
Right Forward Differential Pulley	-Roller surface separation from forward end of slot.
Aft Differential Pulleys	-Vertical distance of pulley centre above a horizontal datum from the idler lever pivot.
Gust Lock Roller	-Roller surface separation from lock end of cam slot.

1.12.5.1 Gust lock system rigging

The rigging of the control system was found to differ substantially from the AMM requirements in four places in the flight deck region, at the forward differential pulleys and at the aft differential pulley idler levers. In the latter case, this resulted in a foul of the right pulley carrier against a fixed bracket when the system approached 'ON' (see section 1.12.5.5.2). At least some features of the misrigging, including that resulting in the aft differential pulley foul, could not have been caused by wear in the system. The observed misrigging did not cause the gust lock system to fail during subsequent testing (section 1.16.1).

1.12.5.2 Gust lock system cable tension

Measured tension in the three cable loops with the aircraft under cover and at a stable temperature was low at approximately 70 to 80% of the required value (requirement of 24 lb for the elevator/aileron lock loop at the ambient temperature measured).

1.12.5.3 Gust lock system backlash

Substantial backlash was found in the flight deck gust lock lever assembly, consisting of fore and aft relative motion between both A and B and between B and C (section 1.6.5.2). As the 'ON' and 'OFF' selections were determined by contact of Lever A with the ends of the gate detents, both sources of backlash caused a loss of motion of the gust lock system. The effects of the lost motion on the behaviour of the system were assessed by replacement of the lever assembly (section 1.16.1). The following dimensions were measured along the arc of the lever gate plate (as defined earlier in section 1.12.5).

Fore and aft relative play of 0.04 inch (1 mm) present between A and B appeared normal. However, slack between B and C of approximately 0.24 inch (6 mm) was significant and, with the two effects in combination, Lever A moved 0.28 inch (7 mm), out of a travel between detents of 2.4 inch (60 mm), without motion of the output linkage. Levers B and C should have been rigidly fastened together by 6 bolts (5/32 inch diameter) and nuts (Figure 4). However, these were found loose within the pilot's lever and/or the output lever, and the holes had worn oval. The joint could be seen, without disassembly, through the slot in the gust lock lever assembly gate plate.

1.12.5.4 System travel

No major anomalies with the flight deck lever gate plate were found; the separation of the 'ON' and 'OFF' detents was 1.97 inch, against a requirement of 1.95 inch minimum. However, an appreciable range of movement of the flight deck lever assembly, and hence of the gust lock control run, was available with Lever A stowed in the 'OFF' detent. No evidence was found to suggest that this was abnormal. The position achieved by moving Lever A forward and stowing it in the 'OFF' detent at the aftmost position possible (ie without overtravel and with the Lever A baulk block against the aft end of the 'OFF' detent slot) is defined for this report as the 'Min OFF' position; the position achieved by pushing the lever fully forward until the forward edge of Lever A contacted the forward edge of the slot is defined as the 'Max OFF' position. While the range of lever movement between 'Min OFF' and 'Max OFF' was only 0.12 inch (3 mm), moving Lever A between these positions produced considerable additional movements of parts of the system, see Diagram 1:

1.12.5.5 System fouling

1.12.5.5.1 Aft differential pulley idler levers

The two aft differential idler levers were found to contact each other at mid-travel of the system and witness marks were found showing that prolonged rubbing had occurred (Photo 4.1). The right lever (Part No obliterated) was found with the web of its U-section component oriented downwards, ie not in accordance with the BAe Aircraft Illustrated Parts Catalogue (IPC), which illustrated both levers with the web upwards, but no evidence was found to indicate that this feature, of itself, had contributed to the fouling. However, the left lever appeared to have been constructed 'out of true', such that it canted out of the perpendicular and towards the right lever when both were installed on the pivot pin. The effect was somewhat diminished by a bend in both sideplates near the pulley end; the cause of the bend was not apparent. A contribution to the lever contact may have been made by appreciable play that was present between the right lever pivot holes and the pivot pin. Modification No 6897 (Service Bulletin (SB) No 27/83) 'Introduction of Improved Differential Lever Assemblies on Rear Pressure Bulkhead' listed the reason for the modification as:

'Instances have been reported of signs of rubbing between the differential levers . .'

This SB had not been incorporated on G-ATMI. It was categorised by the aircraft manufacturer as Optional and was not mandated by the CAA (Civil Aviation Authority).

It was apparent that the contact increased the friction in this part of the circuit. Evidence from operating the system suggested it was unlikely that this was sufficient to cause the idler levers to jam, but the possibility could not be dismissed. In the event of an idler lever hang-up and sudden release, it appeared possible for displacement of lock roller lever(s) to occur.

1.12.5.5.2 Aft differential pulleys

When the flight deck lever approached 'ON', the travel of the right aft differential pulley idler lever was stopped by fouling of the pulley carrier assembly on part of the fixed elevator gust lock mounting bracket in the tailcone (Photo 3.2 and 5.1). This was evidenced by clear witness marks. Because of this the rudder lock roller remained 0.47 inch (12 mm) from the locked end of the cam with the flight deck lever 'ON'.

A note in the Aircraft Maintenance Manual (Chapter 27-70-0, page 504, Para C, Amendment August 27/82) appeared to be an attempt to warn of this possibility:

'It is important that the setting of the idler levers (op. C.(3)) is accurately achieved by correct adjustment of the turnbuckle within the torsion box in order to preclude any possibility that the pulley assembly cannot foul the structure adjacent to the underside of the torsion box when the lever is pulled fully upwards as the rudder lock is selected to 'ON'.'

Information from the aircraft manufacturer indicated that the double negative in this note was an inadvertent miswording and that the intention was to ensure that the assembly did not foul the structure.

The contact occurred in two places; firstly between the pulley carrier assembly right sideplate (Figure 6) and the vertical web of the bracket; and secondly between the nut fitted on a bolt connecting the two sideplates of the carrier assembly and the horizontal flange of the bracket. It appeared that the former contact could have tended to cause the differential pulley to hang-up at the locked end of its travel when the pilot's lever was put from 'ON' to 'OFF'. Observation while operating the system suggested that it was unlikely that this could jam the idler lever, but the possibility could not be dismissed.

1.12.5.5.3 Cable turnbuckle

It was noted that a turnbuckle in the right side of the elevator/aileron gust lock cable loop in the cabin passed through the cut-out in the floor beam at Frame 253AS as the pilot's lever approached 'OFF'. This appeared abnormal, with the travel of all other turnbuckles in this and the other cable systems apparently arranged to take place between floor beams and not through them. Signs of contact between the turnbuckle and the edge of the cut-out were present, but did not appear to be consistent with a jam having occurred. The minimum separation with components static was 0.08 to 0.12 inch (2 to 3 mm); it was apparent that this would be altered by the effects of loads resulting from vibration, inertia and cabin floor loading. The profiles of the turnbuckle end and the beam cut-out edge were such that a hard foul could be produced by a slight sideways push on the cable as the pilot's lever was operated from 'ON' to 'OFF'. In this case, with the lateral displacement of the cable maintained, the pilot's lever could reach 'OFF' but the elevator/aileron loop of the gust lock system jammed slightly short of its normal 'OFF' position.

A prohibition on the turnbuckle passing through the floor beam was not identified in the AMM. The manufacturer reported that the feature was the result of system malrigging.

1.12.5.5.4 Elevator gust lock

The elevator gust lock roller lever was found to be in firm contact with the side of the elevator lock plate (Figure 7.1). Extensive rubbing between the inner face of the roller lever sideplates and both side faces of the forward limb of the lock plate was apparent (Photo 4.2). This was indicative of the roller lever having operated for a prolonged period in a plane angled relative to the plane of the lock plate. On disassembly it was found that the bush for the roller lever pivot bolt intended to be fitted in the left-hand support bracket was absent (Figure 7.1, see Photo 5.2 and 5.3). This had resulted in a radial clearance of 0.05 inch between the 0.3 inch diameter bolt and the 0.4 inch diameter bracket hole on this side and it was apparent from associated witness markings that the system had operated with the left side of the bolt off-centre and in contact with the edge of the bracket hole. The IPC showed (Section 27-70, Figure 6 illustration and associated parts list at page 25) only one lever bush and one bracket bush per assembly. The BAe Aircraft Overhaul Manual (Section 27-70-1, Figure 2) showed two bushes per assembly.

It was also apparent that the two roller lever sideplates were bent inwards (Photo 4.3), reducing the 0.51 inch (13 mm) gap between them to 0.45 inch (11.5 mm) in places. This was clearly due to overtightening of the nut on the bolt that carried the roller lever bias spring. The bolt passed through the two sideplates and carried two spacers; in the absence of sideplate deformation the arrangement would have left a gap between the spacers as a location for the spring to freely pivot on the bolt. In fact, the spring anchor loop was found tightly clamped and unable to pivot, and the first coil of the spring had permanently distorted. The sideplate deformation increased the likelihood and severity of the contact between the roller lever and the lock plate.

It was apparent that friction forces from this contact would apply downloads on the roller lever (Figure 7.2) when the lock plate rotated in response to an aft-to-forward control column rotation on the flight deck. This would tend to pull the elevator roller towards the lock position (see section 1.16.1).

1.12.5.6 Pull-Down Checks

A number of Pull-Down Checks (section 1.6.5.7) were conducted on the system in its various configurations, both by the operator's personnel and by the AAIB in conjunction with the aircraft manufacturer's personnel. With the system unaltered (Configuration 1), the test was passed on four occasions, with values of Dimension d between 2.20 to 2.25 inch (requirement 2.20 inch minimum, section 1.6.5.7), but the results of further tests were found to be dependent on the technique employed and on some occasions a value of 2.05 inch was obtained. However, with the elevator stationary, the friction forces resulting from the contact between the elevator lock roller lever and the lock plate (section 1.12.5.5.4.) would have resisted the lever pull-down and assisted in passing the test.

1.12.5.7 Lock-load Checks

A variation of the Pull-Down Check was carried out to assess the level of robustness of the system in maintaining the elevator unlocked when the system was selected 'OFF'. The check consisted of measuring the force required to move the elevator roller lever to a position where the elevator was locked for a series of positions of the flight deck lever assembly. After setting up each condition of lever assembly position and roller lever load, the condition of the elevator lock was checked by applying a rearward force on the control column. This is referred to here as the Lock-Load Check. It was found consistently that, with the flight deck lever assembly advanced to slightly less (0.2 inch (5 mm)) than the 'Min OFF' position, a relatively low force (3 lb) on the elevator lock roller was sufficient to move the roller lever to a position where the elevator was locked, irrespective of the force then applied to the control column.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

There was no fire.

1.15 Survival aspects

The airport fire and rescue services were alerted at 2359 hrs by the duty ATC supervisor as soon as she realised that the aircraft had left the runway. Four vehicles responded; they were directed to the threshold of Runway 09 and arrived at the aircraft one minute later. They were met by the flight crew who had vacated the aircraft unaided. The senior fire officer notified ATC that both pilots were uninjured and then gave instructions for a foam blanket to be laid around the aircraft. The local fire service was notified at midnight and arrived at 0006 hrs with 7 fire appliances. All fire service units remained at the accident site whilst the aircraft was defuelled; this operation was completed at 0305 hrs at which time the local fire service was released. The airport fire service units remained in attendance until the aircraft had been towed clear at 0916 hrs.

The flight crew members, who had both been wearing full harness, were uninjured and left the aircraft using the normal exits.

1.16 Tests and research

1.16.1 Gust lock system testing

A series of measurements and tests were made on the flight control gust lock system with the system in the following configurations:

Configuration 1 -	System as found after the accident (A - outside, B - under cover).
Configuration 2 -	Configuration 1 with flight deck lever assembly changed for a unit without play between Levers B and C.
Configuration 3 -	Configuration 2 with system re-rigged approximately in accordance with the AMM (see section 1.16.2).
Configuration 4 -	Configuration 3 with system further re-rigged approximately in accordance with the AMM (see section 1.16.2).

The elevator roller lever bush which was found to be missing (section 1.12.5.5.4) was absent for the above configurations.

The position of various components of the system was measured at a series of positions of the flight deck lever assembly when the latter was cycled from 'ON' to 'Max OFF', to 'ON'. Repeat measurements showed some variation, particularly when the aircraft was outside with the flight control surfaces affected by wind, but the variation was not gross. The lock roller characteristics obtained for Configuration 1 with the aircraft under cover are shown in Figure 8. The measurements showed:

1. Hysterisis in the forward differential pulley movement equivalent to approximately 6 mm or 10% of pilot's lever movement, between forward and aft travel of the lever (not shown in Figure 8).

2. Early unlocking of the aileron lock when the pilot's lever was moved from 'ON' towards 'OFF', with full unlock at around 38% of lever travel.

3. A substantial degree of rudder lock unlocking as the pilot's lever neared 'OFF', eg 87% unlocked at 75% lever travel.

4. Late unlocking of the elevator lock when the pilot's lever was moved from 'ON' towards 'OFF', with the lock still fully engaged at around 72% lever travel.

5. Incomplete unlocking of the elevator lock with the pilot's lever at the 'Min OFF' position, ie 59% unlocked at 98% lever travel.

6. Complete unlocking of the elevator lock with the pilot's lever at the 'Max OFF' position.

It was also found that an elevator trailing edge upload (approximately 20 lb) applied during unlocking had an appreciable adverse effect on elevator lock movement towards 'OFF'.

Measurement of the gust lock system performance on another of the operator's HS748 aircraft found that the elevator lock unlocked somewhat earlier, but only marginally so, and this system also exhibited late and highly geared unlocking of the elevator lock.

Some improvement in G-ATMI's elevator lock unlocking performance was apparent from measurements made after replacing the gust lock flight deck lever assembly and after re-rigging and re-tensioning the system (Figure 9). The elevator roller achieved a somewhat greater separation from the 'ON' end of the cam slot at a given pilot's lever setting, but the system still exhibited very late elevator unlocking and very high gearing of the elevator lock.

The Pull-Down Check was performed, and repeated, for each of the different system configurations. An improvement in the results (d=2.40 inch) was apparent for Configuration 2, but the test was failed by a large margin in Configuration 3 (d=1.42-1.77 inch). Repeated performance of the check on a particular configuration of the system showed an appreciable variation in results, in part due to the technique employed.

During the course of the testing, it was found to be possible to manipulate the flight controls and column and elevator loads to leave the elevator lock roller in a position where the elevator was locked with the flight deck lever at 'Min OFF' This condition was reproduced on a number of occasions.

It was also found that, at any selected system setting, substantial free movement could be exchanged between the rudder and elevator lock roller levers. Thus a downward pull on the elevator lock roller would act via the aft differentials to drive the rudder lock roller onto the 'OFF' side of its cam and cause the elevator roller to travel towards 'ON'. The elevator roller travel was twice that of the rudder roller because of the 2:1 aft differential ratio.

Observation of the rubbing contact between the elevator lock plate and the roller lever showed a tendency for a forward movement of the control column to pivot the roller lever towards lock, although no significant movement was observed during the testing.

1.16.2 Gust lock system rigging

Attempts were made to re-rig the gust lock system using the procedure in the AMM to achieve Configurations 3 and 4 (section 1.16.1). The work was carried out with the aircraft in a hangar, with representatives from the aircraft manufacturer assisting and without substantial time pressures. It was found that the procedure was difficult to follow, in a number of areas was non-specific and in parts was impossible to accomplish realistically, for example:

1. Bellcranks that were required to be set to a particular orientation, apparently by eye, were largely hidden from view.

2. Access to enable required measurements to be made was not available.

3. The required action if certain specified check measurements were not met was not given.

4. In most cases no allowable tolerances on specified dimensions were given.

5. No definition was given of the turnbuckle lengths that were specified.

It was also found to be impossible to exactly achieve all the AMM rigging requirements simultaneously, in spite of spending a considerable number of man-hours on the process, although differences were relatively minor. It appeared that greater experience of undertaking the process would have improved the result, as would additional iterations of the process.

During the course of the investigation, mechanics familiar with HS748 operations reported that ad hoc adjustments to an individual part of the system, such as the rudder lock cable loop length, could on occasion be made in order to encourage a harder engagement of a lock that had failed to remain engaged, or to enable the system to pass a Pull-Down Check.

1.17 Organisational and management information

The design authority for the aircraft type at the time of the accident was Jetstream Aircraft Ltd (JAL), now BAe. Emerald Airways Ltd was approved to operate G-ATMI under an Air Operator's Certificate (AOC) issued by the Civil Aviation Authority (CAA). It was not a Joint Aviation Requirement (JAR) 145 approved maintenance organisation. All base maintenance was contracted to JEA Engineering, which is an approved maintenance organisation under JAR 145, and the operator could carry out line maintenance under the auspices of JEA Engineering's approval. The operator was required by the CAA to be responsible for the standard of all the maintenance conducted on its aircraft, including that carried out by JEA Engineering, but was not required, by the CAA, to nominate an individual who was responsible for related maintenance quality assurance. In this case the operator had elected to have a quality manager. The operator's Engineering Manual gave him responsibility for 'all aspects of quality within the Engineering Department, ensuring that the engineering operation conforms to the standards required by the Regulatory Authority and the contracted maintenance organisation'.

JEA Engineering's JAR 145 approval had been granted by the CAA, as a full member authority of the JAA. This approval remained valid indefinitely, subject to satisfactory recommendations from the CAA to the JAA every 2 years, based on the results of a 'rolling audit' of JEA Engineering which was conducted by surveyors from the CAA's Weston-super-Mare Office. Any 'non-compliance' identified by such sample audits was required to be addressed and rectified by the company within certain time limits, dependent upon the type of non-compliance. At the time of this accident there were reportedly no outstanding issues of non-compliance which had been identified by the previous sample audits. The CAA has relied for many years on an audit regime to monitor approved organisations; it considered that it was the responsibility of the approved organisation to remain in compliance with airworthiness codes. The system did not appear to include substantial quality assurance monitoring of the airworthiness standard achieved on actual aircraft.

Continued acceptance of the operator's AOC by the CAA was based upon the results of monitoring by personnel from the CAA's Manchester Office, in addition to recommendations from the Weston-super-Mare Office with regard to the maintenance of the operator's aircraft by JEA Engineering. Emerald Airways maintenance arrangements were monitored by a sample audit process conducted by a CAA Gatwick team ('AOC Maintenance').

JAL provided major assistance with the investigation. However, the technical personnel who had been responsible for the gust lock system design and knowledgeable on the service experience with the system were inevitably no longer with the organisation and detailed knowledge of the system was initially unavailable. An understanding of the system was, however, developed in the course of extensive and prolonged assistance by the manufacturer's engineering personnel.

The operator's and maintainer's personnel were extremely willing to assist the investigation but were prevented from providing substantial engineering assistance by apparently severe limitations on personnel and/or materiel resources due to the need to continue servicing their normal activities. In the period between April 1996 and February 1997 the CAA had judged that the maintainer had sufficient personnel. It was reported that 11 months after this accident the CAA Manchester Office had identified a lack of adequate personnel numbers within the operator's line maintenance engineering organisation. However, the operator stated in response to this that a 'Follow-up review by the CAA controlling office at Weston-super-Mare failed to confirm the findings of the CAA Manchester office who did not carry out an in-depth audit of Emerald maintenance requirements'. The available evidence indicated that both the operator and maintainer were operating in a highly commercially competitive environment (see later and section 2.6).

In addition, it was considered that there were indications that the CAA had commonly experienced considerable commercial pressure to minimise their charges. The CAA did not accept this view but noted that 'The consultation mechanism, in particular in regard to the role of SRG (Safety Regulation Group) Finance Advisory Committee, permits the Group to achieve a balance between setting effective financial control while achieving high standards in aviation safety regulation. It is also true that the Authority endeavours to manage its affairs so as to minimise the regulatory burden. In this regard, 'regulatory burden' means both the amount of regulation and the financial costs associated with SRG's regulatory activities.' Following a number of AAIB Reports in recent years highlighting inadequate maintenance in relation to public transport aircraft (AAIB Reports 1/92, 2/95 and 3/96), the CAA has recently modified their audit practices by recruiting some additional surveyors and conducting safety audits without prior notification, including visits conducted during night shift and weekend operations.

Representatives of the maintainer and the regulator agreed that a number of unsatisfactory maintenance aspects had been identified by this investigation, but felt unable to identify the associated cause(s).

CAA Paper 97011 entitled 'REPORT ON THE WORK OF THE JAR 145 QUALITY ASSURANCE REVIEW TEAM', dated December 1997, included the following recommendations to the CAA:

'*Quality Assurance Departments primary role is the airworthiness and safety of the end product - the aircraft. Active auditing of maintenance needs more emphasis.'*

and,

'All JAR 145 Quality Systems must include a route by which all staff in production, and particularly licensed aircraft maintenance engineers can report on staff resource issues. Also, the CAA Aircraft Maintenance Standards Department Surveyors should examine, record and analyse more details of resource management and any related incidents.'

Following its involvement with this investigation after the accident, the maintenance organisation supplied details of the remedial action taken:

'1. Quality Awareness Bulletins issued regarding rigging checks and FOD (foreign object debris).

2. Technical Instructions issued requiring mandatory recording of all figures for cable tensions and range of movements carried out during routine inspections and defect rectification on flying control and gust lock systems (all aircraft).

3. Review of test criteria of installed FDRs and amendment to relevant inspections/check sheets.

4. Programme of underfloor inspection for FOD and debris on all HS748 aircraft.

5. Change in emphasis on Type training and basic courses given by the Training School from 'ensuring gust locks on' to 'ensuring gust locks off' during maintenance.

6. Revised Maintenance Schedules and associated Check Sheets/Job Cards taking account of the report's findings.

7. Revised aircraft audit plan in conjunction with increased operator monitoring.'

In addition, the maintenance organisation later forwarded the following review of the actions taken:

'The maintenance organisation fully complied with the relevant (draft) safety recommendations originally issued in October 1996. It also introduced Awareness Bulletins for rigging checks and FOD, mandatory recording of rigging check figures, an under-floor inspection programme on all HS748s, a review of Training School Type and Basic courses with particular reference to gust lock systems, revised maintenance schedules and associated paper work, revised test criteria for installed FDRs and increased auditing of the operator and relevant aircraft. Additionally, the organisation reinforced its long standing review policy which ensures resources are sufficient to meet the contracted maintenance requirement.'

It was understood that, as part of the latter review of resources, the projected 'man-hours' provisioned for maintenance was significantly reduced to bring engineering staff resources more in line with future workload.

1.18 Additional information

1.18.1 Operational

1.18.1.1 Crew procedures

The take-off procedure was described in the HANDLING NORMAL section of the Emerald Airways Operations Manual (OM) where it stated that the Handling Pilot *'holds control column, with any necessary into wind aileron applied, and forward pressure to keep weight on the nosewheel.'*

The Emerald Airways OM addressed the possibility of an aborted take-off up to a speed of V_1. In the FLIGHT DECK MANAGEMENT section, under the sub heading of THROTTLE HANDLING, the OM stated that *'At 80 kt . . . . . the non-handling pilot will lift the throttle following hand to the top of the throttles to be ready for an abort up to V_1. After V_1 the non-handling pilot will continue to guard the throttles until Climb Power is called for.'*

In the HANDLING ABNORMAL section of the OM, the aborted take-off was dealt with under the heading of ENGINE FAILURE DURING TAKE OFF where it stated 'Immediately close the throttles, select 'Ground Fine' and apply maximum braking until it is certain that adequate stopping distance is available. If it is anticipated that the aircraft will leave the paved surface the Captain will take control and call for the Imminent Overrun drill. After the aircraft has stopped carry out the necessary drills.'

1.18.1.2 Crew training

During their conversion training to the HS748, crews were required to demonstrate compliance with the SOPs. An essential element of this training was verification of their ability to function as both the handling and non-handling pilot during a take-off. As part of the briefing prior to each take-off the commander was required to carry out a 'touchdrill' to demonstrate the actions required to complete an aborted take-off.

1.18.1.3 Background

During the course of the investigation, evidence obtained suggested that pilot technique in handling the HS748 control column during the take-off ground run might vary. Those pilots who were particularly aware of the Sumburgh accident (see section 1.18.4.4) tended to make it their practice to ease back on the column from the full forward position periodically during the take-off run to feel that it had remained free. There was no published requirement to do this.

1.18.2 Accelerate - Stop performance

The take-off decision speed, V_1, is the speed below which the take-off may be safely abandoned and above which the take-off may be safely continued following the failure of an engine. However, it is predicated on the basis of acceptable aircraft performance after an engine failure and does not address the possibility of a failure that makes rotation into a climbing attitude impossible and only becomes evident at a speed above V_1. In such a case, the pilot will not be able to fly the aircraft off the ground and will have no choice but to initiate the abort procedure at a speed greater than V_1, at a time when the remaining runway length is being rapidly consumed. It is notable that the runway lengths required for a take-off abort published in the Aircraft Flight Manual (AFM) for various conditions are based on the distances achieved during flight testing. These include an allowance for the degradation of engine performance with age, but use runway line-up and power setting techniques that are more expeditious than those commonly used in practice and do not include any factor on the flight test distance achieved. Thus when the take-off roll is commenced with the aircraft positioned at the start of a limiting runway and with engine power already set against the brakes, an abort due to an engine failure at V_1, with maximum braking applied, will theoretically bring the aircraft to a halt with the nosewheel at the runway end, when the accelerate-stop for the chosen V_1 is a limiting case.

For a standard take-off abort from V_1, the AFM performance tables gave a distance for the prevailing conditions of 1,585 metres and thus a stop could theoretically be expected to be achieved 701 metres from the end of the 2,286 metres runway. In the case of this accident, although no information was obtainable from the FDR, the available information indicated that the aircraft travelled for an extra 4.6 seconds, accelerating in this period from the planned V_1 of 112 KIAS to approximately 120 KIAS as estimated by the commander. The additional runway distance consumed during the acceleration from V_1 to 120 KIAS and subsequent deceleration to V_1 was thus approximately 550 metres. Theoretically, therefore, the aircraft should have stopped approximately 151 metres before the end of the runway. However, this analysis is only an approximation and, in addition, takes no account of runway usage for line-up or power setting, or of the overall reduction in braking efficiency caused by the application of the brakes with the elevators jammed fully down, which would have appreciably reduced the weight on the main wheels, and at a speed 8 kt above V_1. The aircraft overran this calculated stop point by approximately 401 metres, running partly on bitumen and partly on grass.

1.18.3 Aircraft history

After manufacture in 1966, G-ATMI had been initially operated in Antigua before returning to operation in the UK in the early 1970s. It had then been operated by Dan Air between 1975 to 1991 and by Emerald Airways since 1992. Records indicated that the aircraft had been maintained during its service with Emerald Airways in accordance with Maintenance Schedule (MS) JEA/HS748/5 (CAA reference MS/H748/39). The aircraft was 30 years old and had accumulated around 52,000 flying hours at the time of the accident. Maintenance records indicated the following relevant requirements and events: see Diagram 2.

The records did not indicate that any problems with G-ATMI's flight control systems had been experienced during the 397 hours of operation following the C Check on 20 February 1996 until the accident flight or that any problems with, or work on, the wheelbraking system had been recorded during this period, other than routine tyre changes.

During an Airworthiness Flight Test on 19 May 1997 following repair of the accident damage it was found that the aircraft felt nose heavy for the given conditions. Crews familiar with G-ATMI reportedly noted that this had always been the case. The Flight Test Certificate noted *'Aircraft handles as though nose heavy. Impossible to produce a full stall (cg 66 in AOD). Elevator force on rotation higher than normal. A lot of elevator trim required on landing flare'.* Rigging checks revealed that the tailplane incidence was approximately 0.5° leading edge up from the normal setting and compensation was made by elevator trim tab resetting, in accordance with the AMM. The previous check of elevator and trim system rigging had been on 2 December 1986. The worksheet showed that the requirement for a 'flight handling check, if applicable' after the rigging had been signed off as 'not applicable'.

1.18.4 Previous incidents and accidents

1.18.4.1 General

Information from the CAA Accident and Incident Database dating from 1976 identified 24 known previous cases of excessive control force or restriction of HS748 primary flight controls. Seven of the cases concerned G-ATMI. The limited summary information available suggested that 16 of the cases were probably attributable to icing, incorrect control column shaft shimming, inappropriate pitch trim setting, autopilot or elevator tension regulator problems. It appeared that 8 of the cases were possibly, or probably, caused by gust lock system anomalies (Figure 10). In one case (G-ATMI; section 1.18.4.2) the ailerons locked in flight; 4 of the cases concerned aborted take-offs (Nos 1, 2 and 3 in Figure 10) because of an apparent inability to rotate the aircraft for lift-off, with the aircraft stopping just before the runway end in one case and running off the runway in the other 3 cases. The aircraft manufacturer considered that one of these cases (No 7) had resulted from an incorrect elevator trim setting, but no positive evidence as to the cause appeared to be available (PK-IHN, Jakarta, 24.7.87).

Except in the case of the Sumburgh accident (see section 1.18.4.4 below), the detailed causes of these control restrictions or the aircraft modification state were unknown, or the information was unclear, and there were no indications as to whether current mandatory modifications would have positively prevented any of the cases, with the possible exception of case No 5 in Figure 10. For example, the findings in one of the take-off abort cases (No 1) was that 'despite detailed inspection no fault was found' and it was closed as an 'isolated unexplained incident'; this case occurred some 2 years before the Sumburgh accident. The manufacturer reported that the rate of instances of control restrictions caused by the gust lock system had decreased markedly following incorporation of the modification action that resulted from the Sumburgh accident (section 1.18.5).

Previous experience suggested that it was possible that other incidents in addition to the above could have occurred, particularly to overseas operators, but not come to the CAA's attention.

1.18.4.2 G-ATMI aileron lock at Berne

In one incident on 6 August 1981, believed to have occurred in the climb after take-off from Berne, G-ATMI's ailerons locked in neutral. However, they apparently freed after a 'hard push forward' on the pilot's gust lock lever.

1.18.4.3 G-ATMI pitch control incident at Liverpool

In another incident (not included in Figure 10) concerning G-ATMI at Liverpool on 22 December 1995, the crew found that an excessive column force was required for take-off rotation and that their ability to retain control of the aircraft in pitch during the subsequent circuit was marginal. However, they did manage to land the aircraft without damage. This incident was attributed to substantial slack in the elevator control cables that had not been eliminated by the cable tension regulator because of friction in the regulator as a result of inadequate lubrication.

1.18.4.4 G-BEKF accident at Sumburgh

The Sumburgh accident referenced above concerned HS748, G-BEKF, at Sumburgh Airport on 31 July 1979 which failed to become airborne while attempting to take-off and crashed into the sea. Seventeen of the 47 occupants on board the aircraft did not survive. The associated AIB Report (No 1/81), published in May 1981, concluded that:

'The accident was caused by the locked condition of the elevators which prevented the rotation of the aircraft into a flying attitude. It is likely that the elevator gust-lock became re-engaged during the pilots' pre-take-off check, and that this condition was not apparent to either pilot until the take-off was so far advanced that a successful abandonment within the overrun area could not reasonably have been made. The re-engagement of the gust-lock was made possible by the condition of the gust-lock lever gate plate and gate-stop strip.'

The Report highlighted a number of gust lock system deficiencies found during the investigation. One of the Report's Safety Recommendations (4.1) stated that:

'Serious consideration be given to the re-design of the gust-lock system so as to ensure that positive operation of the gust-locks is achieved at all times and that the possibility of the crew being misled as to the position of any lock is eliminated.'

Subsequent action taken by the manufacturer after that accident is summarised in section

1.18.5 Gust lock system modifications and maintenance changes

The aircraft manufacturer had made the following changes to the gust lock system hardware and maintenance before the above fatal accident at Sumburgh in July 1979:

AVRO Alert Service Bulletin (ASB) No 27/8 was issued on 22 March 1963 and was entitled 'Flight Controls - Engagement of Gust locks - Possibility of Incorrect Engagement'. This ASB referred to two cases of elevator control system damage when HS748 aircraft had been parked in high wind conditions and that it had been found possible to achieve inadequate elevator locking if the control column were not positioned fully forward prior to engaging the gust locks. The ASB required a check of locking performance. Compliance was recommended and it was noted that the manufacturer considered that 'the work outlined herein affects the safety of the aircraft'. However, this ASB was not made Mandatory by the Air Registration Board. It had been complied with on G-ATMI, at build. This Alert Service Bulletin was followed by SB No 27/12, issued on 10 May 1963, which was classified as Mandatory by the Air Registration Board. It required an increase in gust lock system cable pre-tensioning and replacement of the lock lever pull-off springs with weaker springs. It had been incorporated on G-ATMI, at build.

Following the Sumburgh accident, British Aerospace (BAe) SB 27/76 was issued in March 1980 and required dimensional checks on the gust lock flight deck lever gate, execution of the elevator gust lock Pull-Down Check and a check of flight deck console interlocks. BAe SB No 27/88 followed on 12 October 1982 and required the fitment of modified gust lock system lock plates in all three control channels (Modification 7103). The CAA declared both SBs Mandatory. Both had been incorporated on G-ATMI. Subsequently, BAe SB No 27/82 was issued on 31 August 1982 and introduced a Gust Lock Warning Indicator (Modification 6823). This provided a red warning light on the pilot's emergency panel that flashed when the pilot's gust lock lever was in an intermediate position between 'ON' and 'OFF'. The manufacturer categorised the SB as Optional and it was not mandated by the CAA. It had not been incorporated on G-ATMI. No further modification action was taken as a result of the Sumburgh accident.

BAe SB No 27/83, issued 31 August 1982, noted that instances had been reported of signs of rubbing between the aft differential levers. It introduced improved aft differential lever assemblies

(Modification 6897) to increase the clearance between the levers. The manufacturer categorised the SB as Optional and it was not mandated by the CAA. It had not been incorporated on G-ATMI.

BAe SB No 27/84, issued on 24 May 1982, introduced an improved facility for carrying out the elevator gust lock Pull-Down Check by adding a tab washer from which to hang a weight, and a hole in the fuselage skin for passage of a weight suspension wire (Modification 6852). The manufacturer categorised the SB as Optional and it was not mandated by the CAA. It had been incorporated on G-ATMI.

Following the incident to G-ATMI on 22 December 1995 (section 1.18.4.3), Jetstream Aircraft Ltd (JAL) issued 'Mandatory' SB 748-27-126 on 19 July 1996. This required the inspection of gust lock cable tension regulators, cable pressure seals and the gust locks. This SB was declared Mandatory by the CAA. It had been incorporated on G-ATMI.

Following this accident to G-ATMI on the 16 August 1996, JAL Mandatory ASB HS748-A27-128 was issued on 20 December 1996. It required measurement of HS748 gust lock roller positions and the carrying out of a Pull-Down Check. If the system condition were found to be outside limits, inspection of various parts of the system for wear, play or alignment and system re-rigging in accordance with a revised procedure was required. JAL also revised the AMM to reflect the changed rigging procedure.

In addition, following this accident JAL Notice to Operators (NTO) 22 was issued on 10 September 1996. It included the following:

'OPERATING INSTRUCTION

At the start of the take-off run ensure that the control column is held slightly forward of neutral with the ailerons in the appropriate position for the prevailing wind conditions. The control column should then be allowed to move back towards the neutral position at 50-60 knots IAS. If the elevator movement is not normal abandon the take-off.'

1.19 Useful or effective investigation techniques

None.

2 Analysis

It was clear from the accounts of the crew and from the CVR recording that the accident had occurred during a high speed take-off abort forced on the crew by an elevator control circuit jam that prevented take-off rotation. The investigation therefore concentrated on determining whether the accelerate-stop performance had been deficient and on establishing the cause(s) of the elevator control circuit jam.

2.1 The take-off abort

2.1.1 Crew performance

The commander and the FO had both operated frequently from Liverpool and they were properly qualified and experienced for the flight. The aircraft weight and balance were within the published limitations and the crew had correctly calculated the speeds for take-off. They had followed the published SOPs, the meteorological conditions were excellent and the aircraft was apparently serviceable as the take-off run was initiated. A jammed condition may have been apparent to the crew earlier had the control column been allowed to 'float back' from its fully forward position during the take-off ground run. However, while such a procedure was apparently followed by some crews, it was not a requirement. Following the accident, the manufacturer did publish an associated instruction NTO 22 (see sections 1.18.5 and 2.3.6.3).

Having reached their decision speed, the crew quickly realised that they could not get the aircraft airborne and their only possible course of action was to abort the take-off; this was initiated promptly and correctly. The commander then realised that the aircraft could not be stopped on the runway and he elected to steer the aircraft to the right as it ran off the end of the runway onto the grass, to minimise the risk of over-running into the River Mersey. This area of the airfield was generally clear and it was unfortunate that the track took the aircraft towards the ILS power supply building which, in the darkness, became visible to the crew too late to enable them to avoid wing contact. However, the crew then managed stop the aircraft expeditiously and damage was confined to relatively minor damage to the right wing, aileron and flap. The crew performance in reaction to the unexpected event was commendable.

However, in many other overrun situations where such an elevator jam could have occurred such a relatively benign outcome may not have been possible, as had been previously demonstrated by the Sumburgh accident in July 1979 (section 1.18.4.4).

2.1.2 Stopping performance

The overrun distance of 951 metres that occurred, when compared to AFM values for a take-off abort at V_1, exceeded the calculated additional distance of 550 metres resulting from the unavoidable exceedence of V_1. However, close correlation between these distances could not be expected as some distance would have been used for line-up and power setting, braking efficiency was likely to have been reduced by braking initiation some 8 kt above V_1, and since a large part of the deceleration took place on grass where braking effectiveness would have been lower than on the runway. Additionally, with the elevators jammed fully down, aerodynamic effects would have appreciably reduced the weight on the main landing gear wheels and hence the braking effectiveness. The overall similarity of the distances indicated that there had been no significant deficiencies in crew or aircraft performance during the deceleration. In view of this, detailed investigation of the aircraft's propeller and braking systems was not considered relevant.

2.2 Elevator control system

Although no restriction of the elevator control circuit was found on initial examination and the reported jam could not subsequently be reproduced, there was little doubt that the accident had resulted from such a jam and extensive investigation of the elevator control system was undertaken. No evidence of deficiencies was found in the elevator system itself, but three conceivable causes of a jam were identified. These were jamming of part of the run on static components or by foreign objects, and engagement of the elevator gust lock.

2.2.1 Elevator control system clearances

It was notable that there were a number of areas in the region beneath the flight deck floor where the clearance between the elevator mechanical linkage system and static components was extremely small, or absent, and in some areas rubbing had taken place. However, it did not appear possible that contact in these areas could have strongly restricted column rotation and this was dismissed as a possible cause of the jam. It was nevertheless a highly undesirable feature for a primary flight control run. It has therefore been recommended that:

The CAA should require an early check of UK registered HS748 aircraft for adequate flight control system clearances.

(Safety Recommendation No 96-69, made March 1998)

2.2.2 Foreign objects

Many foreign objects were found lying loose throughout the aircraft compartments housing the elevator control system. Two of the objects in particular, a substantial block of steel and a medium sized steel bolt, found lying just below the elevator control run in the cabin, were well placed to interfere with the run, or possibly with some of the many other mechanical flight control system runs beneath the cabin floor. Both of these objects, and any of the other numerous pieces of debris found, appeared likely to be readily moved by inertial loads during rough ground operations or turbulent flight and there appeared to be many possible ways in which they could become enmeshed in parts of the control runs. However, although considerable potential existed for a control system restriction as a result of fouling on these foreign objects, detailed examination found no signs to suggest that a jam had in fact resulted from such interference. It was therefore concluded that it was unlikely that foreign object interference had caused the elevator jam, although the possibility could not be totally dismissed.

The large quantity of foreign objects found was surprising, given the obvious and well-known hazard that such debris can pose to an aircraft and the relative ease with which it could be greatly reduced. It was clear that, on those occasions when the cabin and flight deck floor panels had been raised for overhaul work, a few manhours of work with a reasonably powerful vacuum cleaner could have removed virtually all of the debris in these areas. The restricted size of the gaps present when the floor panels were down suggested that much of the underfloor debris must in fact have entered when the panels had been removed. Maintaining the areas clear would have required a policy of debris reduction by the organisations responsible for maintaining and repairing the aircraft; it would have involved reasonable work discipline and possibly taping over any gaps in the floor. It has therefore been recommended that:

The CAA should require an early check of aircraft with an operating and maintenance background similar to G-ATMI's for foreign objects that could possibly interfere with flight control systems.

(Safety Recommendation No 96-70, made March 1998)

2.3 Flight control gust lock system

There was evidence to indicate that the crew had correctly carried out a Full and Free check of the flight controls on entering the runway. If the elevator jam discovered at rotation had been due to the gust lock system, it would have been necessary for the elevator lock to have re-engaged either during the Full and Free check as the control column was returned to its forward stop, or during the take-off ground run. The gust lock system is effectively an intrinsic part of the flight control system, both primary and standby, as the back-up function provided by trim tab systems would be ineffective in the event of a primary control jam. A considerable number of deficiencies were found in the gust lock system and in the AMM procedures for adjusting, testing and checking this system.

2.3.1 Gust lock system rigging

The rigging of the system differed significantly from the AMM requirements in seven respects. It appeared that at least some of the misrigging features must have resulted from incorrect rigging on the last occasion that the system was adjusted, rather than from changes caused by service. This was particularly so in the case of the rudder lock cable loop, where gross misrigging caused the right aft differential pulley to foul on a fixed bracket when the pilot's lever approached 'ON'. Maintenance documents indicated that the last adjustment and check of the rigging had been carried out on 12 October 1994, 1,485 flying hours before the accident, but it was possible that subsequent adjustments had been made that had not been recorded. It could therefore only be concluded that the misrigging had resulted either because the AMM procedure had not been followed correctly at the time of the last recorded rigging in October 1994, or due to unrecorded adjustment since that date. However there was no evidence that any unrecorded adjustment had occurred.

The AMM contained a specific warning against achieving a foul of the aft differential pulley of the type present, although miswording implied the reverse of what was intended. While it was likely that the intended meaning would have been apparent to a maintenance engineer involved in adjusting the system, the warning could have been misinterpreted.

The testing undertaken after the accident did not demonstrate a substantial change to the system's basic characteristics as a result of re-rigging and overall there was little evidence to indicate that the misrigging had, on its own, directly caused the gust lock system to malfunction sufficiently to cause re-engagement of the elevator lock. However, the behaviour of the system was complex and the possibility that misrigging, including the effect of the resultant aft differential foul (section 2.3.4.2), had contributed to the re-engagement of a system, the behaviour of which had been rendered marginal by other factors, could not be dismissed. It has therefore been recommended that:

The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

1. The rigging of the system.

(part of Safety Recommendation No 96-71, made March 1998)

2.3.2 Gust lock system backlash

The considerable amount of system backlash found was chiefly due to relative motion between levers B and C because of loosening of the bolted joint between them. The cause of this was not positively established; it appeared most likely to have been due to local yielding and progressive loosening of the joint components under high loads generated in the gust lock system when attempting to engage the rudder lock, known to be difficult to achieve in a crosswind at times. Although the backlash was readily apparent when operating the lever assembly, it could have been attributed to general wear in the system that was acceptable. However, the loose joint was fairly readily detectable by inspection, without disassembly.

The backlash had the effect of reducing the travel of the gust lock roller levers towards 'OFF' when the system had been selected 'OFF'. Although replacement of the lever assembly did not produce a major change in the system characteristics, there was a marginal improvement and the available evidence suggested that looseness in the lever joint had probably contributed to a re-engagement of the elevator gust lock. It has therefore been recommended that :

The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

2. Play at the joint between the flight deck lock lever assembly input and output levers.

(part of Safety Recommendation No 96-71, made March 1998)

2.3.3 Gust lock system travel

The considerable amount of extra travel of parts of the gust lock system obtained by moving the flight deck lever assembly from 'Min OFF' to 'Max OFF' was significant with regard to the possibility of elevator gust lock re-engagement in view of the basic characteristics of the system (section 2.3.5). The position reached by the lever during the accident take-off could not be established, although there was no reason to believe that it was not in the 'OFF' detent. It would have been perfectly reasonable that the crew could have put it to the 'Min OFF' end of the 'OFF' detent and not to have given it the fairly hard push forwards necessary to achieve the 'Max OFF' position. The substantial effect on the system of pushing the lever fully forwards was reportedly not known to the manufacturer, operator or maintainer at the time of the accident.

The additional flight deck lever assembly travel was small, at only 5% of total travel, but caused additional travel towards the 'OFF' condition of 24% for the aft differential pulleys and 21% for the rudder gust lock roller lever (as a percentage of their respective total travel). While no movement of the elevator lock occurred during the testing, only a relatively low force was required to interchange any free motion present in the rudder system (ie space between the lock roller and the 'OFF' side of the cam) with the elevator lock. It was considered that minimal combined travel of the gust lock roller levers associated with an apparently adequate selection of the flight deck lever assembly to 'Min OFF' may well have been a significant factor in allowing the elevator gust lock to re-engage.

2.3.4 Gust lock system fouling

2.3.4.1 Aft differential pulley idler levers

The witness marking on the aft differential pulley idler levers was clearly indicative of prolonged rubbing contact between them. This contact had resulted from a combination of deformation of the left lever resulting from poor construction and play at the right lever pivot, both effects having been alleviated by bending of the left lever sideplates, for reasons unknown. Although the marking was evident on a reasonably close inspection of the static system and the interference was apparent on observing the functioning of this part of the system, it appeared that this defect had either not been detected or that no associated action had been taken. No positive evidence was available to show whether the effect had been present at the time of the last recorded inspection. However, the deformation of the left lever should have been evident at the time that it was fitted. The manufacturer's modification 6897 (see section 1.18.5) aimed at preventing such interference had been categorised as Optional by the manufacturer, had not been mandated by the CAA and had not been implemented.

The contact clearly increased the friction in this part of the circuit. The evidence from operating the system suggested that this probably was not sufficient to cause the idler levers to jam, but the possibility could not be dismissed. Should a lever hang-up occur, it appeared possible for a sudden release to cause displacement of the lock roller lever(s). While there were no positive indications that either factor was likely to have significantly affected the behaviour of the system in this accident, the possibility could not be totally dismissed and the deficiency was not considered acceptable in a flight control system. It has therefore been recommended that:

The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

3. Contact between the two aft differential pulley idler levers.

4. Excessive play in the aft differential pulley idler lever bearings.

5. Incorrect aft differential pulley idler lever orientation.

(Safety Recommendation No 96-71, made March 1998)

It has also been recommended that:

The CAA should require measures to prevent contact between the aft differential levers of the HS748 flight control gust lock system.

(Safety Recommendation No 96-72, made March 1998)

2.3.4.2 Aft differential pulley

The foul of the right aft differential pulley on the fixed structure when the gust lock system approached 'ON' was clearly the result of system maladjustment. The foul was readily apparent on inspecting this part of the system while it was functioned. The testing suggested that it was possible that the contact could have tended to cause the differential pulley to hang-up at the locked end of its travel when the pilot's lever was put from 'ON' to 'OFF'. Observation while operating the system suggested that it was unlikely that this could jam the idler lever, or result in an input to the system as it released, but the possibility could not be totally dismissed. It has therefore been recommended that:

The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

6. Contact of the aft differential pulley assemblies with the structure.

(part of Safety Recommendation No 96-71, made March 1998)

It has also been recommended that:

British Aerospace Regional Aircraft should . . . . revise the HS748 Aircraft Maintenance Manual to ensure that:

1. The warning against the aft differential pulley fouling the structure is clear.

(part of Safety Recommendation No 96-73, made March 1998)

2.3.4.3 Cable turnbuckle

The passage of the turnbuckle forming part of the aileron/elevator cable loop through the cut-out in a cabin floor beam as the pilot's lever approached 'OFF' brought the turnbuckle very close to the fixed structure. The cause of the inadequate clearance was not identified; it may have been due to the misrigging present. It appeared possible that a foul could have resulted under the influence of the effects of vibration, inertia and cabin floor loading. Such a foul could possibly stop the turnbuckle, and downstream parts of the system, including the lock roller levers, from travelling any further towards 'OFF', while still allowing the pilot's lever to be selected 'OFF'. The evidence did not indicate that this had occurred on G-ATMI. However, it represented a potential hazard that was apparently not addressed by the AMM. It has therefore been recommended that:

The CAA should require British Aerospace Regional Aircraft to introduce measures to preclude the possibility of any HS748 gust lock system cable turnbuckles jamming against floor beam aperture edges.

(Safety Recommendation No 96-74, made to BARA March 1998)

2.3.4.4 Elevator gust lock

The firm contact between the elevator lock plate and the roller lever was primarily the result of a missing bush at the roller lever pivot. This had clearly been omitted on the last occasion on which the roller lever had been fitted. While the reasons for this omission could not be positively established, it was considered that an error in the IPC, where the illustration and listing incorrectly showed only one bush per assembly, may have been a major factor. It would not have been appropriate for the IPC to have been used as the source of information for the assembly as it is not an approved document. However, in practice it is possible that this was not generally known and that it could have been used to assist reassembly. It has therefore been recommended that:

British Aerospace Regional Aircraft should revise the HS748 Illustrated Parts Catalogue to correctly show all detail parts of the elevator gust lock assembly.

(Safety Recommendation No 96-75, made October 1996 under earlier No)

A contributing factor to this contact was the appreciable distortion of the elevator roller lever due to overtightening of its spring carrier bolt. This had also caused seizure of the end of the spring and permanent deformation of the spring. All of these effects would have been readily apparent with the lever removed from the aircraft, but somewhat difficult to detect with it installed. The evidence suggested that the overtightening had occurred on the last occasion on which the spring had been fitted. The rub marks resulting from system operation with the roller lever and lock plate in firm contact were readily apparent in situ.

It was notable that friction forces from this contact would apply downloads on the roller lever from the lock plate when the latter pivoted in the direction corresponding to the control column being pivoted forwards, and thus would tend to pull the elevator roller lever towards the lock position. While the testing did not produce significant roller lever movement, there was a clear tendency in this direction, in circumstances that could not fully simulate those of the accident. It was concluded from the available evidence that it may have been possible for the contact friction forces to have dragged the elevator lock roller towards its lock position as the control column was pivoted forwards at the completion of the pitch channel Full and Free check. It has therefore been recommended that:

The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

7. Contact between the roller lever and lock plate of elevator, aileron and rudder gust locks.

8. Absence of any of the bushes at the pivot of the elevator gust lock roller lever.

9. Distortion of the elevator gust lock roller lever.

(parts of Safety Recommendation No 96-71, made March 1998)

2.3.5 Gust lock system function characteristics

Notable features of the system functioning characteristics revealed by the testing (section 1.16.1) were the lateness of the elevator lock to begin unlocking when the pilot's lever was moved from 'ON' to 'OFF' with the first 72% of the selection having no effect at all; the incomplete unlocking of the elevator lock with the pilot's lever at the 'Min OFF' position, ie only 59% unlocked at 98% lever travel; and the highly geared relationship between elevator lock and the pilot's lever movement near the 'OFF' positions. The results of the Lock-Load Checks were also significant in showing that, with the pilot's lever very nearly at 'Min OFF', only a relatively low force on the elevator lock roller was required to re-engage the lock. Furthermore, it was seen that only a relatively low force was needed to interchange any free motion present in the rudder lock system into the elevator lock system, at a ratio of 1:2. These effects did not greatly change after the relevant system deficiencies had been corrected (section 1.16.1).

It was also relevant that, while the above results were generally repeatable, considerable differences in the performance of the system could be produced by variation in the test conditions, such as applying a relatively small upload to the elevator trailing edge. It was even found to be possible by manipulation of the flight deck controls and elevator loads to select the pilot's lever to 'Min OFF' while leaving the elevator locked. While this condition was not directly relevant to the circumstances of the accident, it did demonstrate the system's lack of positive operation, both before and after correction of the relevant system deficiencies.

It was also notable that the gust lock system performance of another of the operator's HS748 aircraft, while somewhat better than G-ATMI, was qualitatively similar. Although many deficiencies with G-ATMI's system were apparent, the elimination of the most crucial of these by replacing the gust lock flight deck lever assembly and re-rigging and re-tensioning the system provided some improvement in the elevator lock unlocking performance, but still left complete unlocking relatively late. It was therefore clear that the above characteristics, while made somewhat worse by the system deficiencies found, were intrinsic features of the system.

The inability to achieve movement of the elevator lock to the point where it re-engaged during the testing was not considered to have ruled out this possibility. If a re-engagement had in fact occurred during the take-off run, then it could not have been the result of a sudden change in the gust lock system condition, as no sudden failure or recent disturbance had occurred. The system had apparently operated without a re-engagement for an extended period. Any re-engagement would therefore necessarily have been due to a particular set of conditions having caused a slight, but crucial, change in the behaviour of a system the performance of which was clearly very marginal. Relevant factors could have included the combined effects of vibration, slipstream, crew technique, cabin loading, manoeuvre loads, etc. It was concluded that the failure to achieve a re-engagement during the testing may have reflected an inability to reproduce the necessary set of conditions.

2.3.6 Gust lock system design features

2.3.6.1 System travel

The system was evidently designed such that the roller levers should reach the 'ON' and 'OFF' states coincident with the pilot's lever reaching the 'ON' and 'OFF' detents. In the absence of provision for overtravel of the pilot's lever with respect to the roller levers, one or more of the locks inevitably will engage or disengage late in the locking or unlocking sequence and the final state of the locks will be sensitive to lost motion in the system. The lock state will also be sensitive to any variation in the pilot's lever travel, as demonstrated by the effects of moving the lever between the 'Min OFF' and 'Max OFF' positions. It has therefore been recommended that:

The CAA should require modification of the HS748 gust lock system to provide substantial overtravel of the mechanism with respect to the flight deck selector lever assembly.

(Safety Recommendation No 97-49, made March 1998)

2.3.6.2 System free motion

It was apparent that the roller levers are fixed when the flight deck lever is at its 'OFF' position only if all three locks are positioned against their 'OFF' stops at this point (ie elevator and rudder rollers contacting the 'OFF' faces of their respective lock plate cams and aileron lock mechanism against its 'OFF' stop). Any separation of one or more locks from its 'OFF' stop represents free motion which can be transferred from one lock to another without appreciable resistance. The bias springs on the locks, apparently intended to cater for a cable break, act to oppose each other with the system intact. The system geometry is such that any free motion fed from the rudder lock equates to twice the movement of either the aileron or elevator lock. It has therefore been recommended that:

The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

10. Excessive separation of any gust lock roller from its 'OFF' stop with the flight deck lever assembly at its 'Minimum OFF' position, with limits to be supplied by the manufacturer.

(part of Safety Recommendation No 96-71, made March 1998)

2.3.6.3 System indication

The only available indication of the state of the gust locks for a given selection of the pilot's lever, without removing external bolted access panels, is that obtained from a Full and Free check of the primary flight controls. While this verifies that the lock rollers are not engaged in their respective lock slots, it provides no indication that all rollers are fully, or even substantially, 'OFF'. The position of the pilot's lever provides an indication only of the selection, but no information on the state of the locks, or of the remainder of the system, unless the system is functioning exactly as intended. The assumption of a system state being necessarily determined by the setting of the selector is particularly inappropriate in this case, where the motion of a vital component, the elevator lock, is ill-conditioned with respect to movement of the pilot's selector. The optional modification available to provide a gust lock warning light (section 1.18.5) merely monitors the pilot's lever position. It appears unlikely that the system would reliably differentiate between the 'Min OFF' and 'Max OFF' positions of the lever.

A system that continuously monitored gust lock roller positions and alerted the crew to an anomaly would ensure that any divergence of the gust locks from the fully 'OFF' state would be instantly apparent and be likely to prompt maintenance action. Although the remedial actions available to the crew on ascertaining an anomaly in the gust lock system are limited in some circumstances, this cannot be considered reasonable grounds for withholding the information. The argument that hazards could be increased by an indication system because of the crew reaction it could promote, such as a take-off abort or diversion, presupposes an inadequate reliability level for the gust lock and/or indication systems, which cannot be considered acceptable. It appears likely that an indication system would, in the vast majority of cases, detect a fault long before it became hazardous.

The manufacturer has stated 'There *is* a secondary indication that the elevator gust lock has not re-engaged, initiated by pilot action during the take off roll by allowing the control column to float back as recommended in NTO 22. With the elevator off its lower stop, the gust lock cannot operate; since the in flight application of full down elevator is not a control input normally associated with the operation of commercial transport aircraft, this must provide sound assurance that a re-engagement will not occur.' While this is correct and the technique may provide a last check before rotation is commenced, it would not provide any indication of the state of the gust lock system. It would show that the elevator is not actually locked but would not indicate if the elevator, rudder or aileron locks were almost engaged and cannot be considered a satisfactory procedure for ensuring flight control system operation, relying as it does upon such a final and critical assessment of elevator response during the actual take-off run of a public transport aircraft.

The current system indication detects only that the system is not locked, not that it is unlocked. Given the current inability to determine the gust lock system state, the limitations of the system uncovered during this investigation, the age of such aircraft, possible deficiencies in the associated general maintenance standards and the known previous accidents and incidents apparently generated by the system, there would seem little grounds for confidence that HS748 operation with the gust lock system in an anomalous, or even potentially hazardous state, has been eliminated. It has therefore been recommended that:

The CAA should require for UK registered HS748 aircraft the development and fitment of a system to continuously monitor the position of each of the three gust lock rollers and to provide an associated flight deck indication of a potentially unsafe condition.

(Safety Recommendation No 97-50, made March 1998)

2.3.7 Gust lock system maintenance considerations

2.3.7.1 Rigging

A number of features of the rigging procedure made it a difficult process (section 1.16.2). Experience during the investigation found that the procedure was not clearly presented, was non-specific or ambiguous in a number of areas and was impossible to accomplish realistically in parts. It was also notable that at no point in the procedure was the appropriate position of the elevator and rudder gust lock rollers specified in relation to the pilot's lever position, or required to be checked. The approach taken during the investigation of attempting to follow the procedure as precisely as possible expended a large number of manhours and would have been difficult to follow in a commercial operation. While experience would have undoubtedly reduced the time required and possibly improved the accuracy of the results, it could not be expected that such experience would always be available. It has therefore been recommended that:

British Aerospace Regional Aircraft should expedite the generation of flight control gust lock system adjustment . . . . . procedures and revision of the HS748 Aircraft Maintenance Manual to ensure that:

2. The adjustment procedure is clear, specific and practical.

3. The adjustment procedure achieves optimal unlocking performance.

(parts of Safety Recommendation No 96-73, made March 1998)

2.3.7.2 Test procedures

The notable feature of the AMM procedure for testing the gust lock system after rigging was the concentration on the locking performance of the system and the absence of any check on the state of the system when unlocked, other than Full and Free operation. This check confirms the absence of lock, not the presence of an unlocked condition. It has therefore been recommended that:

British Aerospace Regional Aircraft should expedite the generation of flight control gust lock system test procedures and revision of the HS748 Aircraft Maintenance Manual to ensure that:

4. Test procedures verify that optimal unlocking performance is achieved.

(part of Safety Recommendation No 96-73, made March 1998)

2.3.7.3 Check procedures

Most of the AMM check procedures for the gust lock system concerned the flight deck lever assembly, gate plate, the FFPS and throttle lever interlocks. The only check specified for verifying the performance of the remainder of the gust lock system was the Pull-Down Check. The passing of this check had been widely considered, in the absence of other specified methods, to confirm a satisfactory system state and, by inference, satisfactory performance. It was regarded as an 'Overall Confidence Check', to the point where some operators apparently may have adjusted parts of the system to achieve a satisfactory Pull-Down Check. However, it was readily apparent that the specified dimension was difficult to measure accurately and that results varied considerably with technique and conditions. The minor modification 6852 (section 1.18.5) that was available to facilitate the check was Optional, but had been embodied on G-ATMI.

It was also apparent that the check would be invalidated by certain deficiencies in the system. Two of the system fouls found on G-ATMI would not have been detected by the check. The third, the contact between the elevator lock roller lever and the lock plate, that was probably a major contributor to re-engagement of the elevator gust lock, would have generated friction forces that resisted the lever pull-down and actually assisted in passing the test. While these faults should have been detected by inspection, an inspection coincident with the check was not automatically specified. It also appeared that the manufacturer, maintainers and operators may have felt that the need to adjust and inspect was reduced by the apparent confirmation of integrity provided by the Pull-Down Check. The check appeared in fact to have become an 'Over-Confidence Check'. It has therefore been recommended that:

British Aerospace Regional Aircraft should expedite the development and introduction of a repetitive check procedure for the HS748 gust lock system that adequately verifies system integrity.

(Safety Recommendation No 97-51, made March 1998)

2.4 Flight controls summary

The elevator control run had minimal clearance from structure in places, but this did not result in a jam. Foreign objects present in considerable quantities had the potential for interference with the run, but it was unlikely that this had occurred, although the possibility could not be totally dismissed. The evidence therefore suggested that the gust lock had re-engaged. The system exhibited multiple rigging faults and seven other potentially serious deficiencies. It was also found that the basic characteristics of the system could make its behaviour susceptible to the effects of wear, small deficiencies, environment and operating technique, particularly in the case of the elevator gust lock. On G-ATMI this lock was found to have marginal unlocking performance. The tight turnbuckle clearance in the aileron/elevator cable loop did not cause a gust lock malfunction, but possibly had the potential for so doing.

The misrigging and the two fouls of the aft differential pulley assemblies were unlikely to have caused an elevator lock re-engagement, but the possibility that they had contributed could not be dismissed. The effects on system travel of the loose joint in the flight deck lever assembly and of the variable position of the assembly within the 'OFF' detent probably contributed significantly to the possibility of a re-engagement. The contact between the elevator gust lock plate and the roller lever, due to omission of a bush and overtightening of a bolt, imposed friction forces which tended to move the roller lever towards the lock position when the control column travelled forwards. It was concluded from the available evidence that this effect, with the gust lock system significantly degraded by the other deficiencies, probably caused the elevator lock to re-engage as the control column travelled fully forward on completion of the pitch channel Full and Free check. This contact may also have assisted in falsely passing the Pull-Down Check.

The specified procedures for inspecting, adjusting, testing and checking the gust lock system were inadequate. Neither they, nor the maintenance standards evident, reflected an awareness of the importance of the gust lock system as a vital part of the flight control system, in spite of a number of previous related incidents and accidents, including the Sumburgh fatal accident. The action taken after the latter accident addressed the specific deficiencies identified; it did not appear to have led to an examination of the integrity of the system more generally and to have fully responded to the relevant AIB Safety Recommendation 4.1 (see section 1.18.4.4).

2.5 Flight recorders

It was likely that a valid FDR recording would have assisted in the investigation of this accident, and thereby in the prevention of a recurrence, but an FDR failure prevented the recording of any information on the accident flight. It was fortunate that in this case the essential facts could be gathered from the CVR recording and from accounts by the crew. Although there are, by modern standards, shortcomings in this FDR BITE and recording system, the proposed JAA requirements concerning flight recorders for aircraft in the weight category up to 27,000 kg will eventually prohibit the use of non-digital recording systems such as MIDAS from the year 2000. To ensure that the inadequacies of the type of data recording system fitted to G-ATMI do not hinder investigations before that time, it has been recommended that:

The CAA should prohibit the use of flight data recording systems that use a non-digital method of recording data.

(Safety Recommendation No 98-2, made March 1998)

Although the FDR failure had occurred several flights before the accident flight, it had remained undetected by aircrew and maintenance procedures. Even if the tape transport had not failed, the airspeed would not have been recorded correctly, because of a second undetected fault. While action to rectify an airspeed recording problem had been taken, it had not been followed by a check that this had been effective.

2.6 Maintenance standards and regulation

Inadequate maintenance standards of the flight control and gust lock systems were evident in a number of areas. These included the tight elevator control run clearances, the many foreign objects found adjacent to control runs, the gust lock system misrigging and the seven gust lock system deficiencies. Some of the deficiencies were concealed to a degree, but a reasonably detailed inspection would have made most of them apparent, such as the tight clearances, the aft differential pulley assembly fouls and the elevator gust lock contact; and some were readily apparent, such as the foreign objects, given the necessary access. All cabin floor panels are lifted during each P Check at 1500 hour or 2 year intervals; the rear hatch access to the tail area is opened at 250 hour intervals, ie every 3 to 4 months, to remove the FDR for replay. It appeared that considerable reliance had been placed on the Pull-Down Check to verify gust lock system integrity, without its severe limitations having been appreciated.

While the AMM procedures were deficient in a number of areas, the deficiencies were generally fairly obvious and could have been expected to promote an operator/maintainer regime of close inspection for possible system anomalies. However, while no grounds were found to doubt the commitment of the individuals involved in the design support, operation and maintenance of the aircraft to achieving an adequate level of airworthiness, it was considered that resources were limited by commercial pressures in a highly competitive environment. It was considered likely that this had a significant adverse effect on the standard of airworthiness achieved. The operator stated that it did not accept these observations regarding the effects of commercial pressures on the standard of airworthiness achieved, and responded to these comments as follows:

' Given the inevitable limitations of resources as a result of commercial pressures which exist in the highly competitive environment of airline operations, any deficiency in the promulgated AMM procedures is prone to inhibit implementation of a closer inspection to detect possible system anomalies thereby generated.'

CAA Paper 97011 (section 1.17) made recommendations to the CAA relating to the need for more active auditing of maintenance by Quality Assurance Departments to ensure airworthiness and safety as the end product, in addition to the provision of means by which all production staff, particularly licensed aircraft maintenance engineers, can report on staff resource issues. A recommendation was also made that the CAA Aircraft Maintenance Standards Department Surveyors should examine, record and analyse more details of resource management and any related incidents.

In this case the CAA had followed their normal system of considering the operator as an approved organisation which was responsible for the maintenance airworthiness standards achieved, and undertook a process of auditing the operator and maintainer. The JAR 145 regulatory system relies upon the combined and effective efforts of the manufacture, maintainer, operator and regulator to deliver the requisite safety assurance of the end product. If any or all of these parties does not operate to the required standard, the system output is likely to suffer. The regulatory system does not appear to include sufficient monitoring of actual aircraft. While no specific deficiencies in the regulatory system were identified, it appeared that the CAA was also operating under considerable commercial pressures, although the CAA disagreed with this view (section 1.17). The substantial number of flight control system deficiencies found in the course of this investigation clearly demonstrated that the regulatory system had failed by a large margin to detect the inadequate airworthiness standard achieved. It has therefore been recommended that:

The CAA should take additional measures aimed at ensuring that adequate standards of maintenance are achieved on UK registered aircraft and undertake more extensive monitoring of actual aircraft maintenance standards achieved, with effective enforcement action where these are found to be inadequate.

(Safety Recommendation No 98-3, made March 1998)

In addition, it has been recommended that:

The CAA should inform Foreign Airworthiness Authorities with responsibility for HS748 aircraft operations of the findings arising from this investigation and the associated Safety Recommendations.

(Safety Recommendation No 98-4, made March 1998)

It has also been recommended that:

The CAA should re-assess its response to Safety Recommendation 4.1 in AIB Aircraft Accident Report 1/81, 'Report on the Accident to BAe HS748 G-BEKF at Sumburgh Airport, Shetland Islands, on 31 July 1979', in the light of the subsequent occurrence of the accident to G-ATMI at Liverpool Airport on 16 August 1996 and other possible instances of inadvertent gust lock engagement on HS748 aircraft.

(Safety Recommendation No 98-5, made March 1998)

3 Conclusions

(a) Findings

1. The crew members were properly licensed and medically fit to conduct the flight, and were experienced on the aircraft.
2. The aircraft was below the maximum permissible weight and within centre of gravity limits.
3. The crew actions during the night take-off run were in accordance with standard procedures.
4. A take-off abort from a speed above V_1 was forced by a control column jam discovered at the point of rotation.
5. The crew reacted expeditiously to the unexpected flight control failure and throughout the deceleration.
6. The high speed at which the take-off was aborted made a significant overrun of the paved runway inevitable, particularly as the full down position of the elevators reduced the weight on the main wheels and reduced the braking efficiency.

7. During the overrun deceleration the aircraft was steered to the left to avoid an ILS building but collided with equipment mounted upon the building, locally damaging the right wing.

8. The commander deliberately 'ground-looped' the aircraft to the left to avoid the River Mersey and managed to stop the aircraft some 250 metres beyond the end of the runway, within the airport boundaries.

9. The Air Traffic Controller and the Airport Fire Service responded expeditiously following the commander's RT call declaring the overrun.

10. All flight control systems were found to operate freely after the accident.

11. The crew had correctly operated the flight controls gust lock lever and performed a Full and Free flight controls check before the take-off.

12. The elevator control run had inadequate clearance from structure and numerous foreign objects present hazarded the flight control systems but neither feature was likely to have caused the control column jam.

13. Multiple rigging faults and seven other potentially serious deficiencies were found within the flight controls gust lock system.

14. Abnormal contact between components of the elevator gust lock caused by the omission of a pivot bush and the overtightening of a bolt tended to move the lock towards engagement when the control column pivoted forwards.

15. The elevator gust lock probably re-engaged during the final part of the pre take-off Full and Free check because of the combined effects of reduced system travel and the abnormal contact between components of the elevator lock. Some of the other deficiencies may have contributed.

16. Service experience had led to emphasis having been placed on the need to achieve effective locking performance of the gust lock system; the unlocking performance of the elevator gust lock was marginal, even after substantial rectification of the deficiencies found, and the system was inherently susceptible to anomalies and external influences.

17. No reliable flight deck indication of the positions of the flight control gust locks was available.

18. The Flight Data Recorder had failed several flights before the accident and at the time of failure also had an airspeed recording fault.

19. The specified procedures for maintaining and checking the flight controls gust lock system were inadequate.

20. The maintenance standard achieved on the aircraft was inadequate.

21. An adequate airworthiness standard was not achieved on this aircraft and this was not detected by the regulatory system.

22. The AIB Safety Recommendation made following the fatal overrun accident to another HS748 at Sumburgh Airport in July 1979 caused by elevator gust lock system malfunction had not been adequately addressed to develop a less sensitive, more maintenance tolerant

design and gust lock system malfunctions have continued to affect HS748 public transport operations.

(b) Causes

The investigation identified the following causal factors:

1. Flight control gust lock system deficiencies which probably caused the elevator lock to re-engage on completion of the crew's Full and Free check of the flight controls before the take-off.
2. Lack of any indication of a jammed elevator condition until the first officer attempted to pull the control column back at aircraft rotation speed, V_R.
3. Lack of sufficient remaining runway distance to stop the aircraft on the runway following the rejected take-off at some 8 kt above V_1 decision speed with the elevator jammed fully down.
4. Inadequacies in maintenance information and implementation that led to failure to correctly maintain a gust lock system the design of which is inherently sensitive to deficiencies.
5. Lack of fully effective modification action, following the fatal overrun accident to HS748, G-BEKF, at Sumburgh Airport on 31 July 1979 (AIB Report 1/81), to address the inherent design sensitivity of the flight controls gust lock system.

4 Safety recommendations

It was recommended during the investigation that:

4.1 The CAA should require an early check of UK registered HS748 aircraft for adequate flight control system clearances.

(Safety Recommendation No 96-69, made March 1998)

4.2 The CAA should require an early check of aircraft with an operating and maintenance background similar to G-ATMI's for foreign objects that could possibly interfere with flight control systems.

(Safety Recommendation No 96-70, made March 1998)

4.3 The CAA should require an early check of the complete gust lock system on UK registered HS748 aircraft, with particular attention to:

1. The rigging of the system.
2. Play at the joint between the flight deck lock lever assembly input and output levers.
3. Contact between the two aft differential pulley idler levers.
4. Excessive play in the aft differential pulley idler lever bearings.
5. Incorrect aft differential pulley idler lever orientation.
6. Contact of the aft differential pulley assemblies with the structure.
7. Contact between the roller lever and lock plate of elevator, aileron and rudder gust locks.
8. Absence of any of the bushes at the pivot of the elevator gust lock roller lever.
9. Distortion of the elevator gust lock roller lever.
10. Excessive separation of any gust lock roller from its 'OFF' stop with the flight deck lever assembly at its 'Minimum OFF' position, with limits to be supplied by the manufacturer.

(Safety Recommendation No 96-71, made March 1998)

4.4 The CAA should require measures to prevent contact between the aft differential levers of the HS748 flight control gust lock system.

(Safety Recommendation No 96-72, made March 1998)

4.5 British Aerospace Regional Aircraft should expedite the generation of flight control gust lock system adjustment, test and check procedures and revision of the HS748 Aircraft Maintenance Manual to ensure that :

1. The warning against the aft differential pulley fouling the structure is clear.
2. The adjustment procedure is clear, specific and practical.
3. The adjustment procedure achieves optimal unlocking performance.
4. Test procedures verify that optimal unlocking performance is achieved.

(Safety Recommendation No. 96-73, made March 1998)

4.6 The CAA should require British Aerospace Regional Aircraft to introduce measures to preclude the possibility of any HS748 gust lock system cable turnbuckles jamming against floor beam aperture edges.

(Safety Recommendation No 96-74, made to BARA March 1998)

4.7 British Aerospace Regional Aircraft should revise the HS748 Illustrated Parts Catalogue to correctly show all detail parts of the elevator gust lock assembly.

(Safety Recommendation No 96-75; made March 1998)

4.8 The CAA should require modification of the HS748 gust lock system to provide substantial overtravel of the mechanism with respect to the flight deck selector lever assembly.

(Safety Recommendation No 97-49, made March 1998)

4.9 The CAA should require for UK registered HS748 aircraft the development and fitment of a system to continuously monitor the position of each of the three gust lock rollers and to provide an associated flight deck indication of a potentially unsafe condition.

(Safety Recommendation No 97-50, made March 1998)

4.10 British Aerospace Regional Aircraft should expedite the development and introduction of a repetitive check procedure for the HS748 gust lock system that adequately verifies system integrity.

(Safety Recommendation No 97-51, made March 1998)

4.11 The CAA should prohibit the use of flight data recording systems that use a non-digital method of recording data.

(Safety Recommendation No 98-2, made March 1998)

4.12 The CAA should take additional measures aimed at ensuring that adequate standards of maintenance are achieved on UK registered aircraft and undertake more extensive monitoring of actual aircraft maintenance standards achieved, with effective enforcement action where these are found to be inadequate.

(Safety Recommendation No 98-3, made March 1998)

4.13 The CAA should inform Foreign Airworthiness Authorities with responsibility for HS748 aircraft operations of the findings arising from this investigation and the associated Safety Recommendations.

(Safety Recommendation No 98-4, made March 1998)

4.14 The CAA should re-assess its response to Safety Recommendation 4.1 in AIB Aircraft Accident Report 1/81, 'Report on the Accident to BAe HS748 G-BEKF at Sumburgh Airport, Shetland Islands, on 31 July 1979', in the light of the subsequent occurrence of the accident to G-ATMI at Liverpool Airport on 16 August 1996, and other possible instances of inadvertent gust lock engagement on HS748 aircraft.

(Safety Recommendation No 98-5, made March 1998)

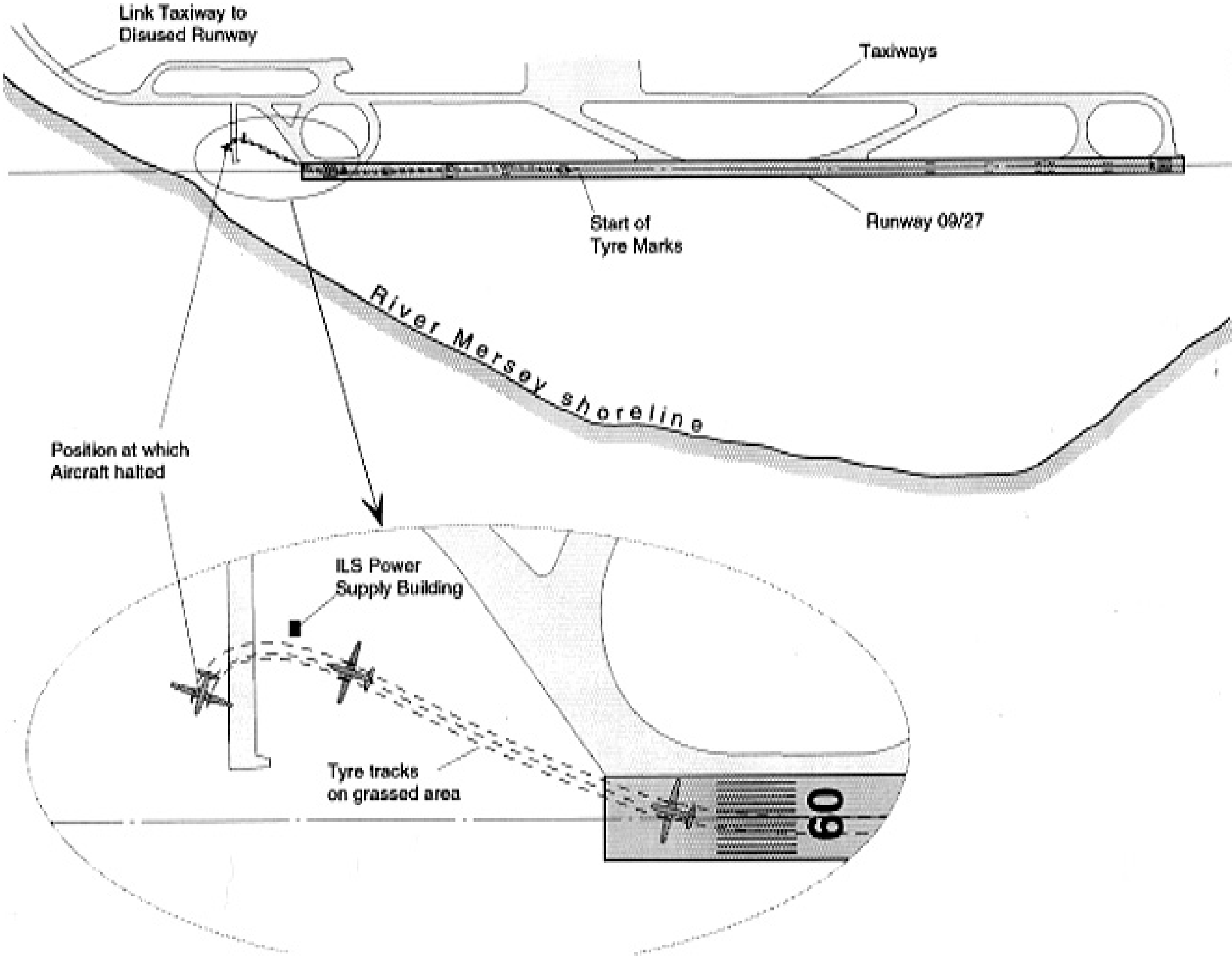
E J TRIMBLE

Inspector of Air Accidents

Air Accidents Investigation Branch

Department of the Environment, Transport and the Regions

November 1998



LIVERPOOL AIRPORT RUNWAY AND OVERRUN AREA

Fig 1

PREVIOUS HS748 ACCIDENTS AND INCIDENTS WITH PRIMARY FLIGHT CONTROL RESTRICTION POSSIBLY DUE TO GUST LOCK SYSTEM

NO	DATE	REG	LOCATION	PHASE	EVENT	SUSPECTED CAUSE
1	18-5-77	G-BEBA	Leeds	Take-Off	Column jammed full forward at Vr, abort, stop 30m from Runway end.	NFF on detailed inspection, closed as 'isolated unexplained incident'.
2	31-7-79	G-BEKF	Sumburgh	Take-Off	Take-Off abort, overran Runway end into sea, 17 killed.	Suspect gust lock re-engagement.
3	21-6-80	HS-THG	Chiang Rai	Take-Off	Unable to rotate for take-off, veered off Runway.	Gust locks engaged. SB not complied with.
4	24-9-80	G-BEKE	-	Taxy	Intermittent clunk on rudder Full & Free Check.	NFF. Similar event found due to foul by gust lock rudder lever. SB 27/20 (MOD 1016) introduced redesigned rudder stop bolt to stop slam damage.
5	6-8-81	G-ATMI	Berne	Flight	Ailerons locked in neutral.	Freed by violent gust lock lever movement. Mandatory SB 27/81(MOD 6885) fitted turnbuckle separator guards to prevent fouling of locking wires.
6	10-9-82	G-ARRW	Glasgow	Pre Take-Off	Unable to fully unlock Gust Lock Lever.	Believed due to gust lock system misrigging and crosswind.
7	24-7-87	PK-IHN	Jakarta	Take-Off	Take-Off abort at approximately 120 kt, over-run. Nose damaged.	Elevator jam possibly caused by mis-trim but no positive evidence.
8	30-10-89	C-GSXS	Canada	Approach	Violent pitch manoeuvre, elevator jammed in full down position.	NFF. Attributed possibly to misrigging of GL system.

Fig 10

HS748 FLIGHT CONTROLS

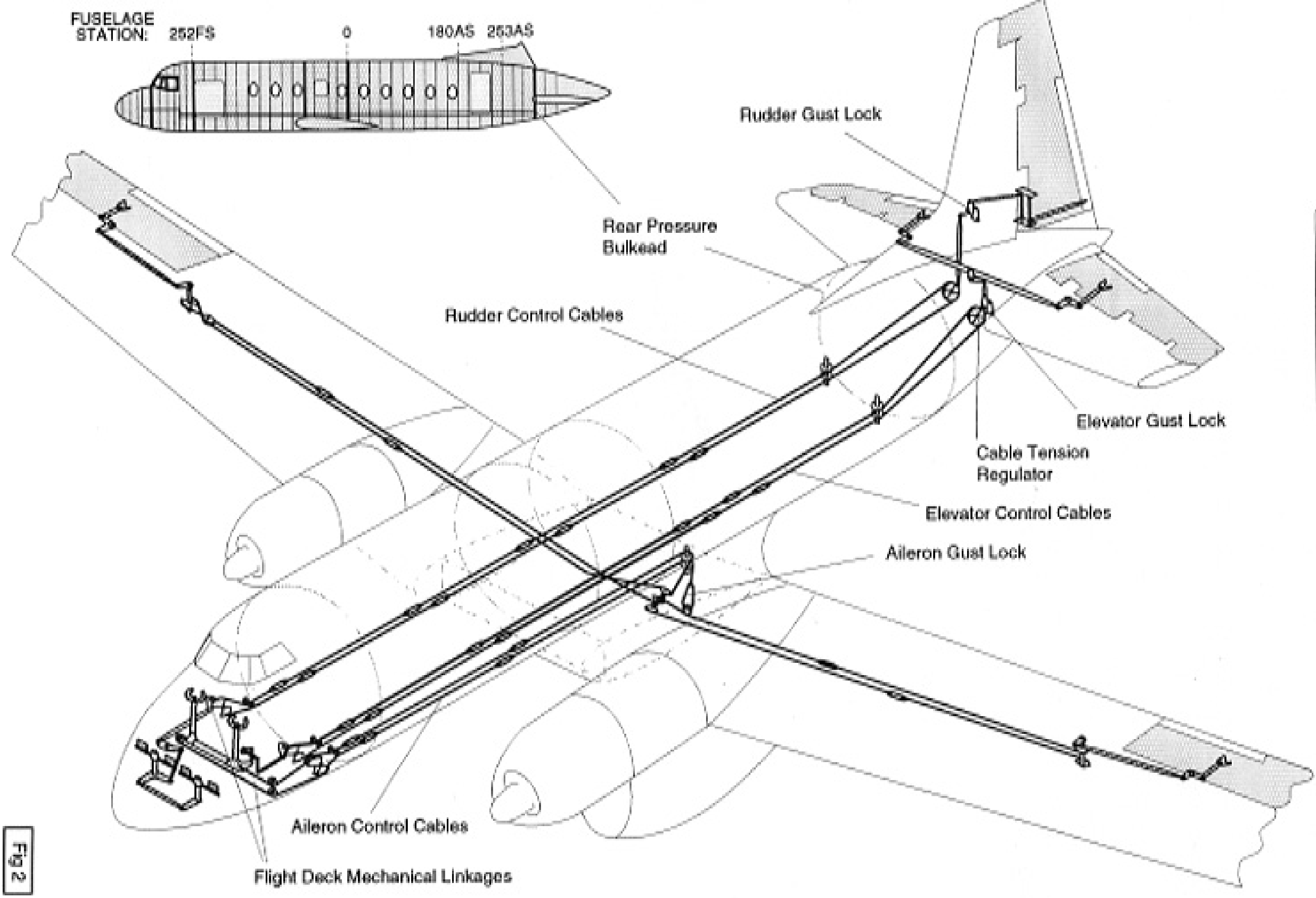
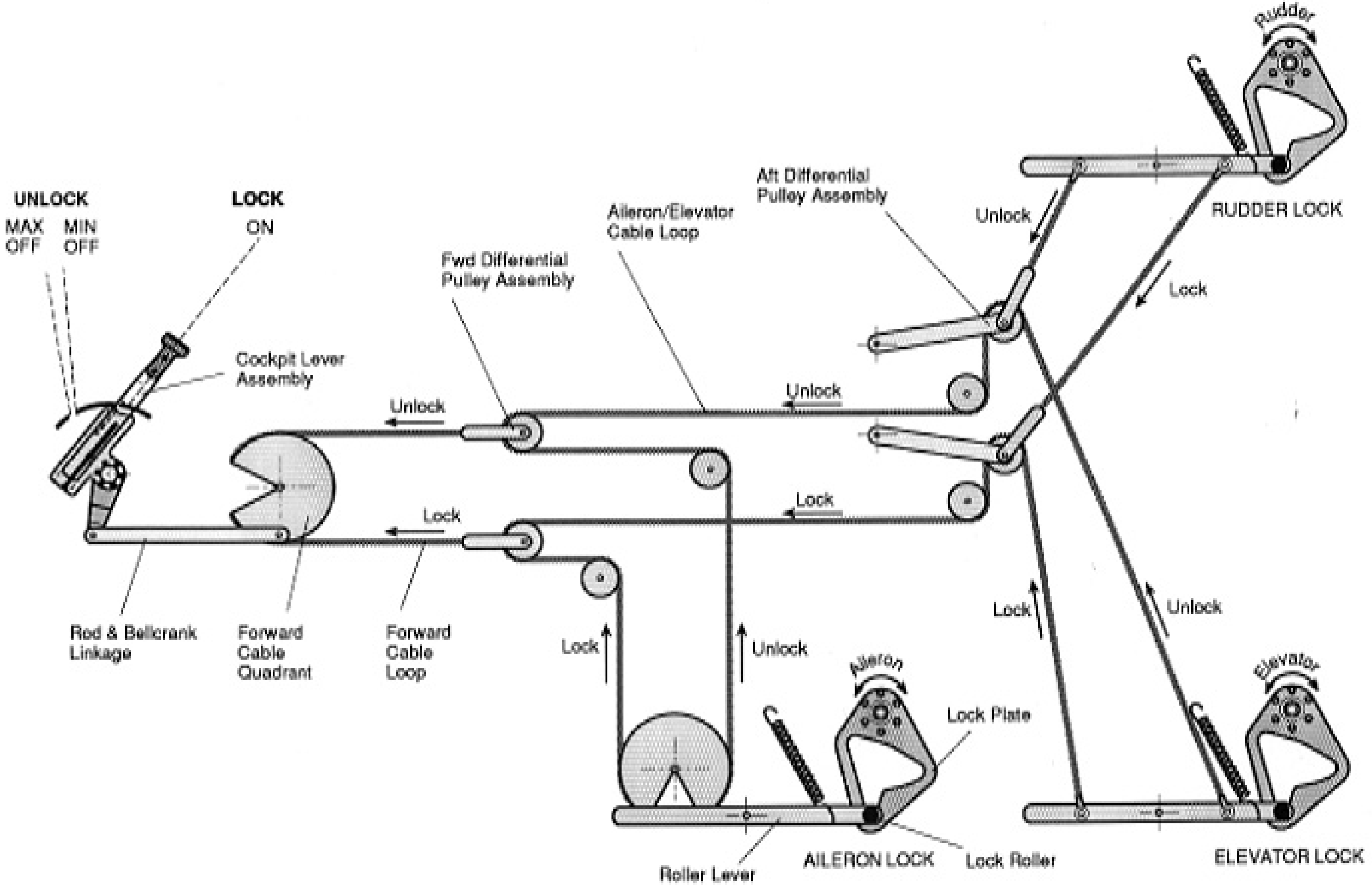


Fig 2



HS 748 GUST LOCK SYSTEM SCHEMATIC

Fig 3

GUST LOCK SYSTEM - FLIGHT DECK LEVER ASSEMBLY

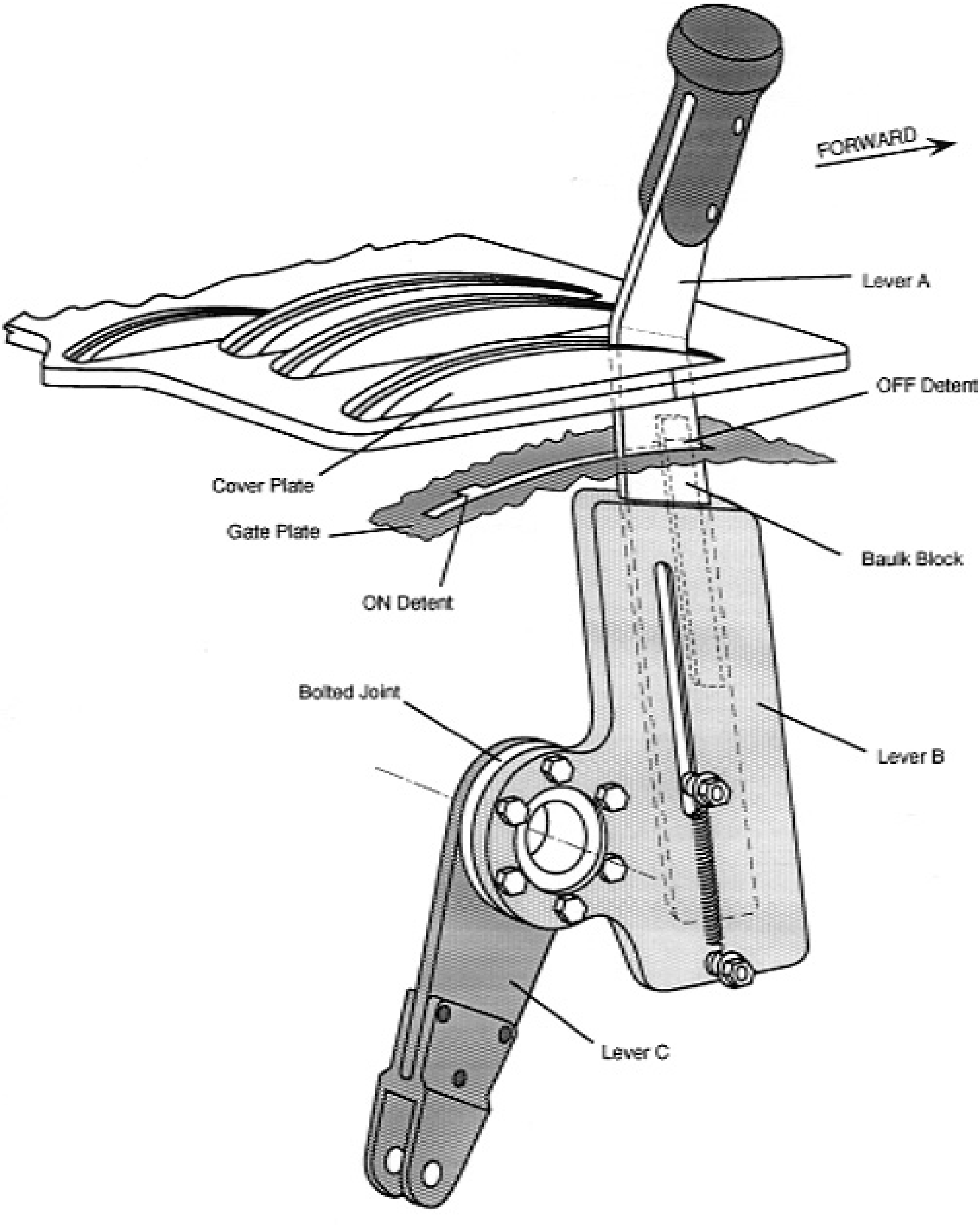


Fig 4

GUST LOCK SYSTEM - FLIGHT DECK LEVER SCHEMATIC

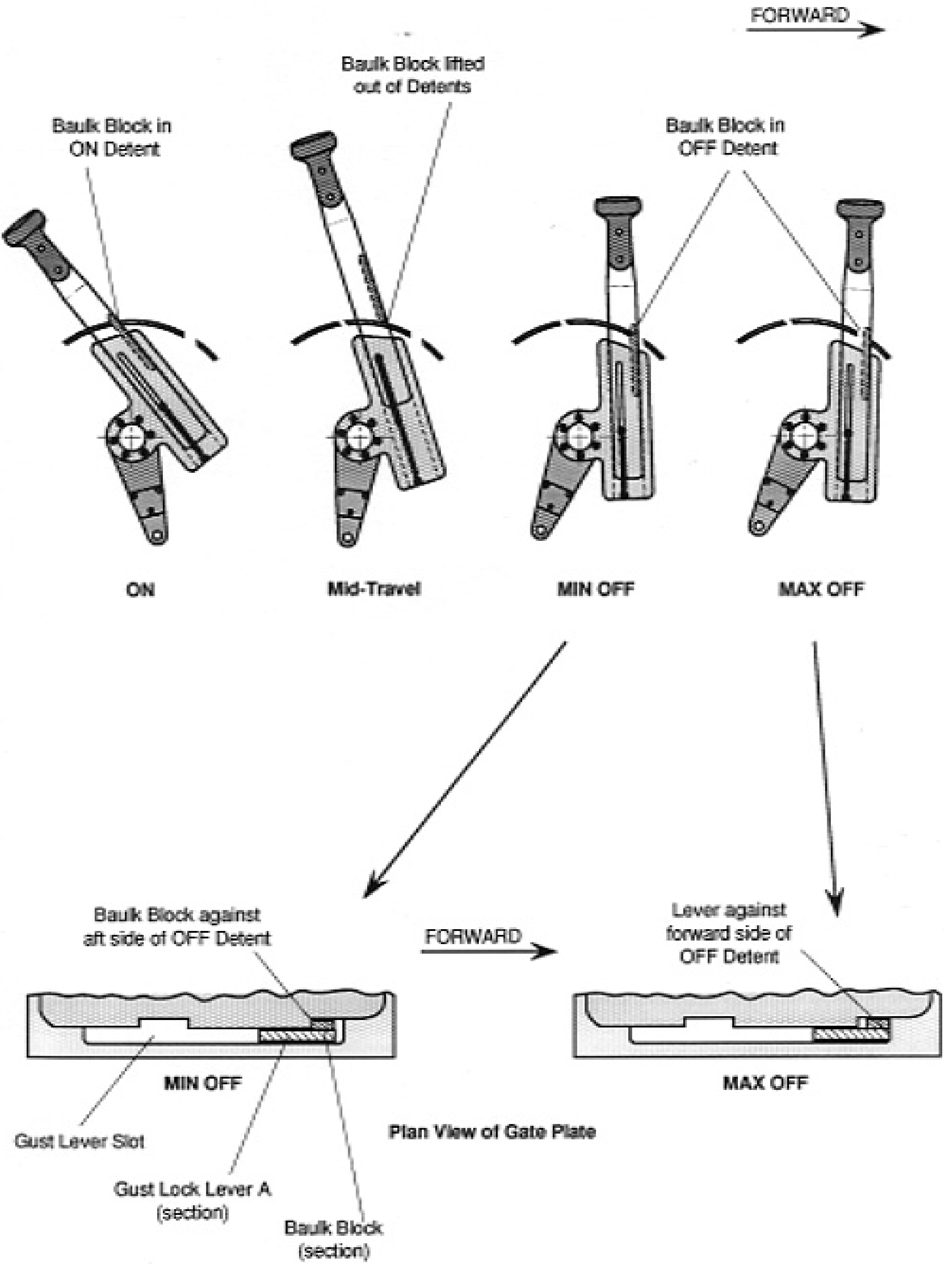


Fig 5

GUST LOCK SYSTEM - AFT DIFFERENTIAL PULLEY ASSEMBLY

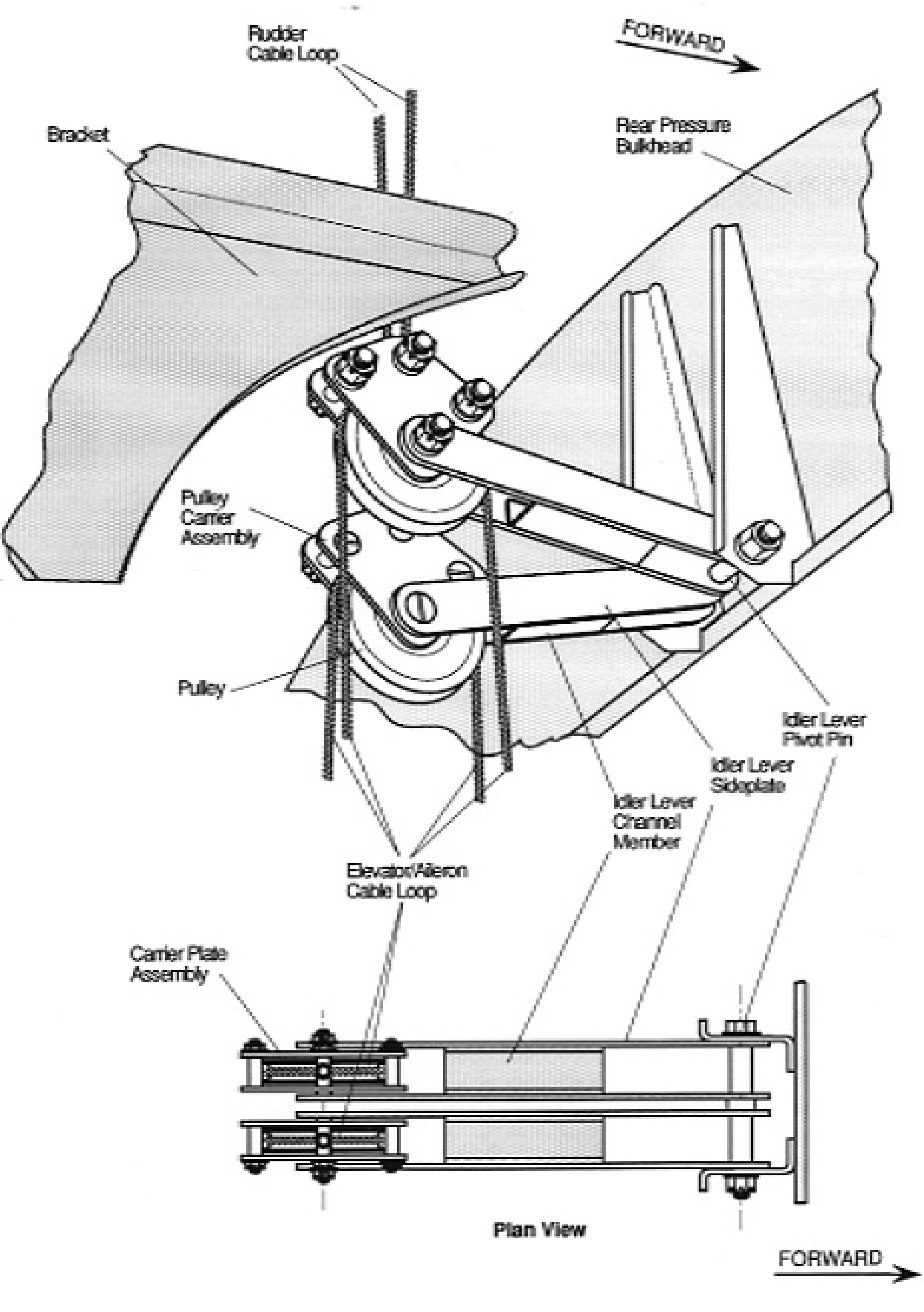


Fig 6

ELEVATOR GUST LOCK

MECHANISM

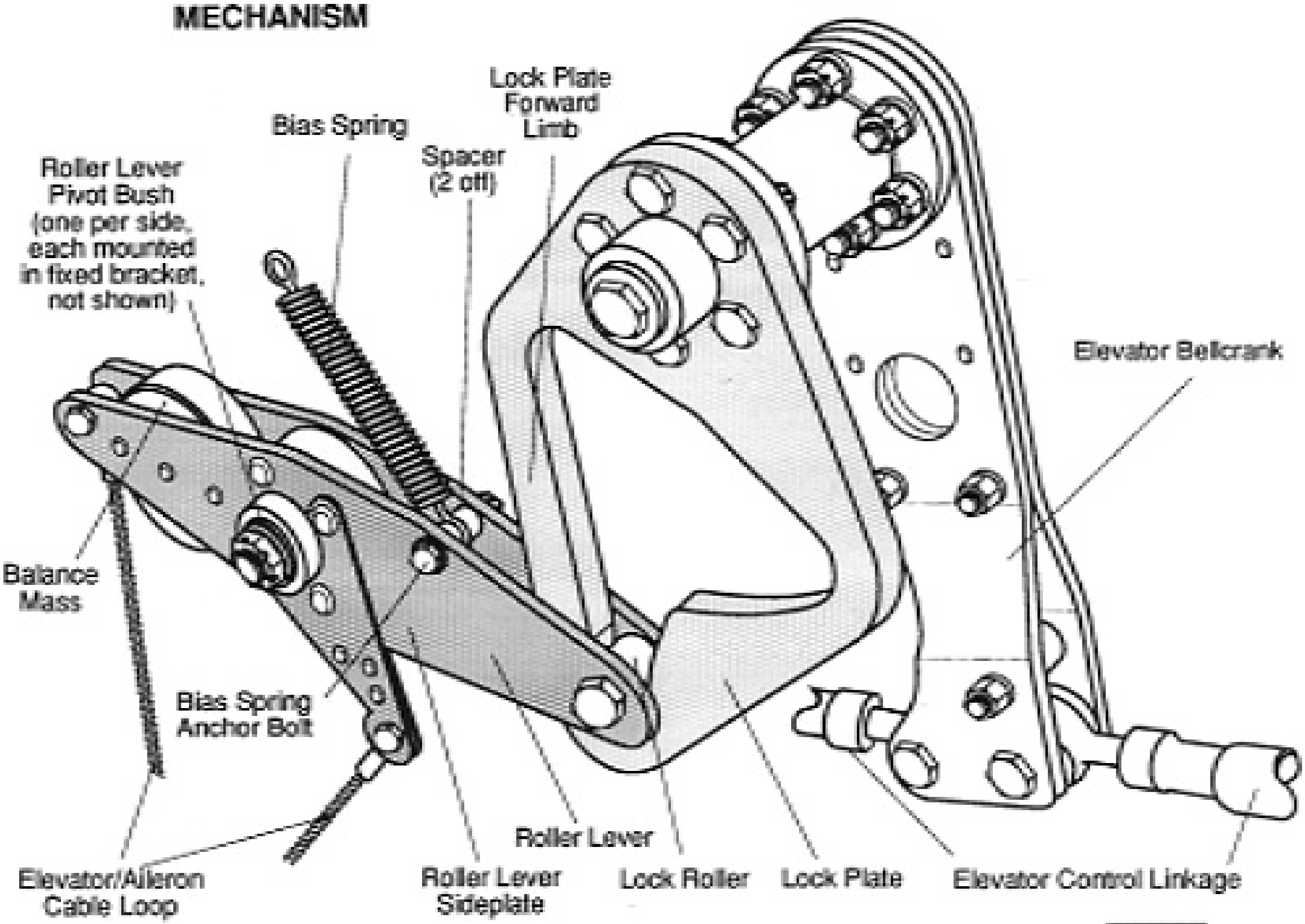


Fig 7.1

OPERATION

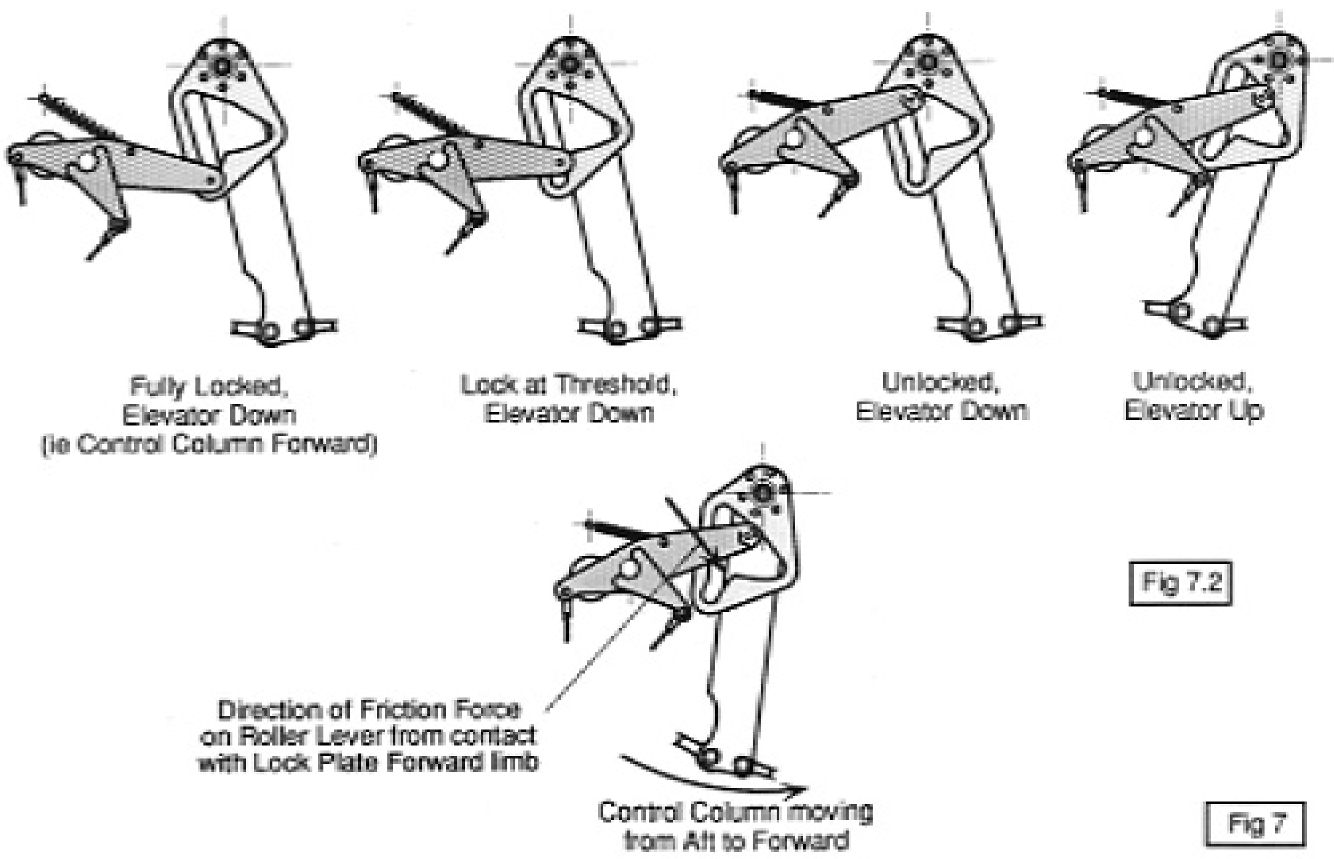
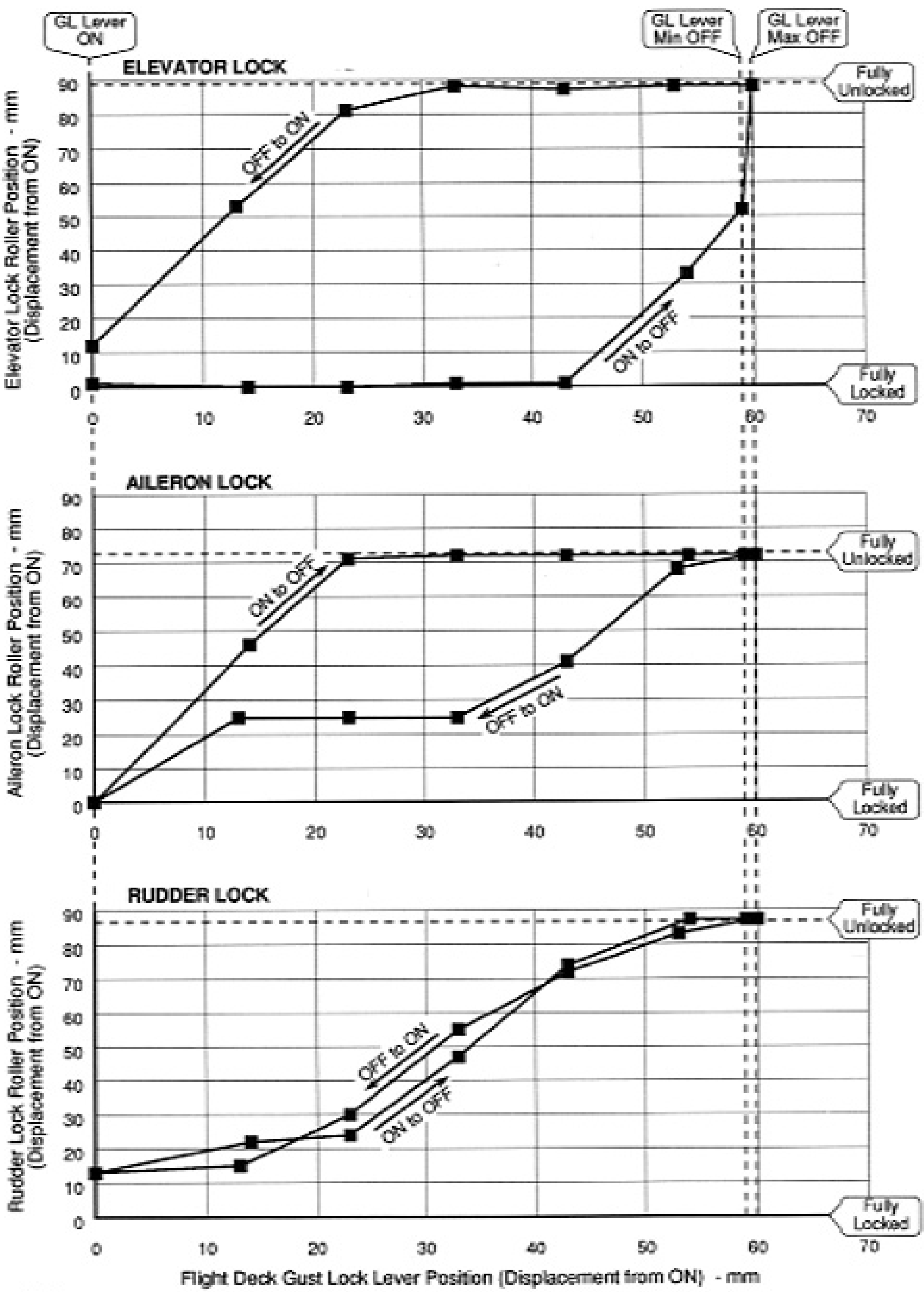


Fig 7.2

Fig 7

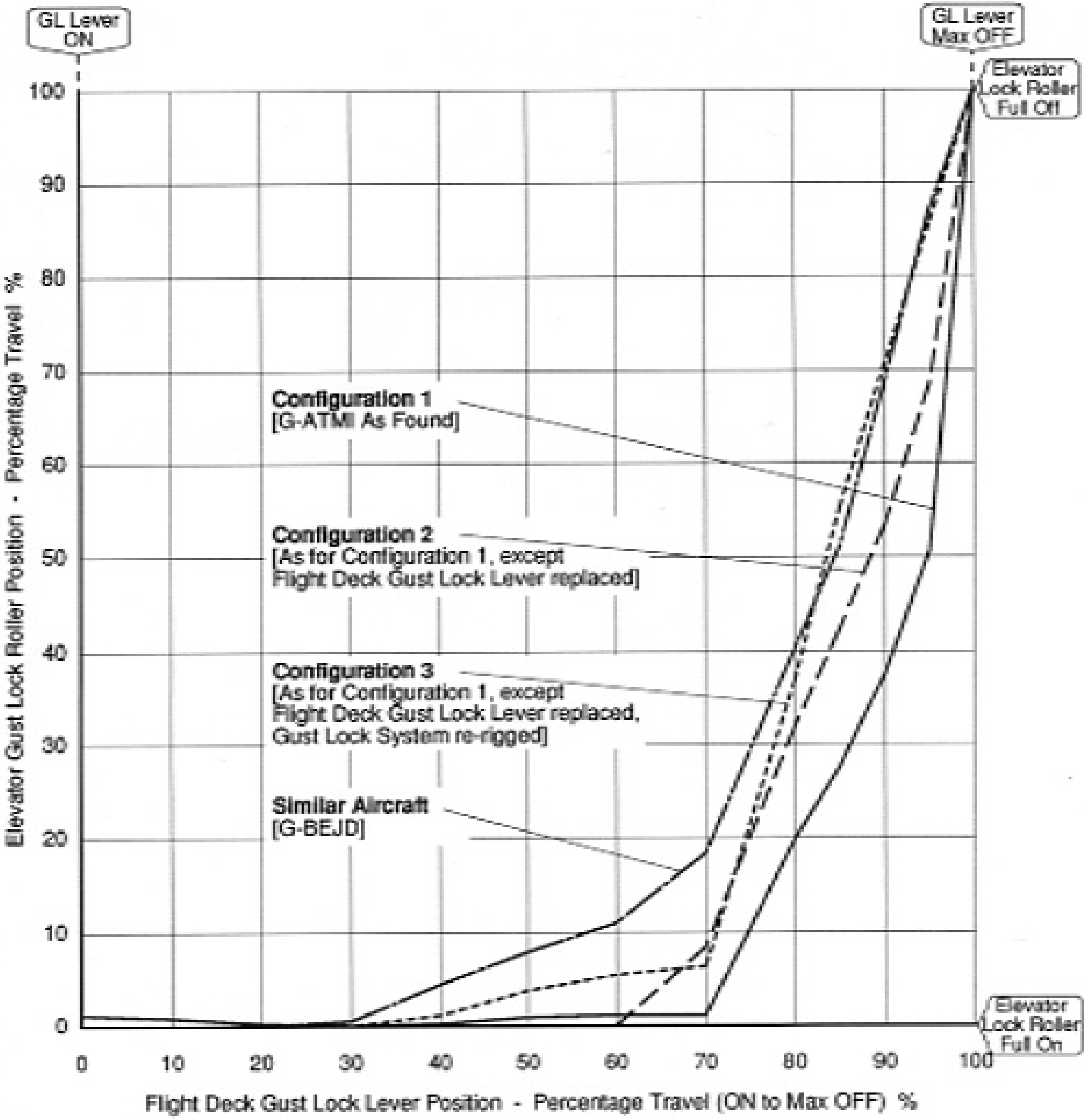
GUST LOCK SYSTEM CHARACTERISTICS



Note:
1. Measurements for G-ATMI, Configuration 1B (system as-found, under cover).
2. GL Lever - Pilot's Flight Deck Lever for Gust Lock System.

Fig 8

ELEVATOR GUST LOCK UNLOCKING CHARACTERISTICS



Note:

1. Characteristics are approximate (based on interpolated straight-lined measurements).

Fig 9

PHOTO 1.1 - RUNWAY OVERRUN AREA

PHOTO 1.2 - FLIGHT DECK

PHOTO 2 - DEBRIS RECOVERED FROM CABIN UNDERFLOOR AREA

PHOTO 2

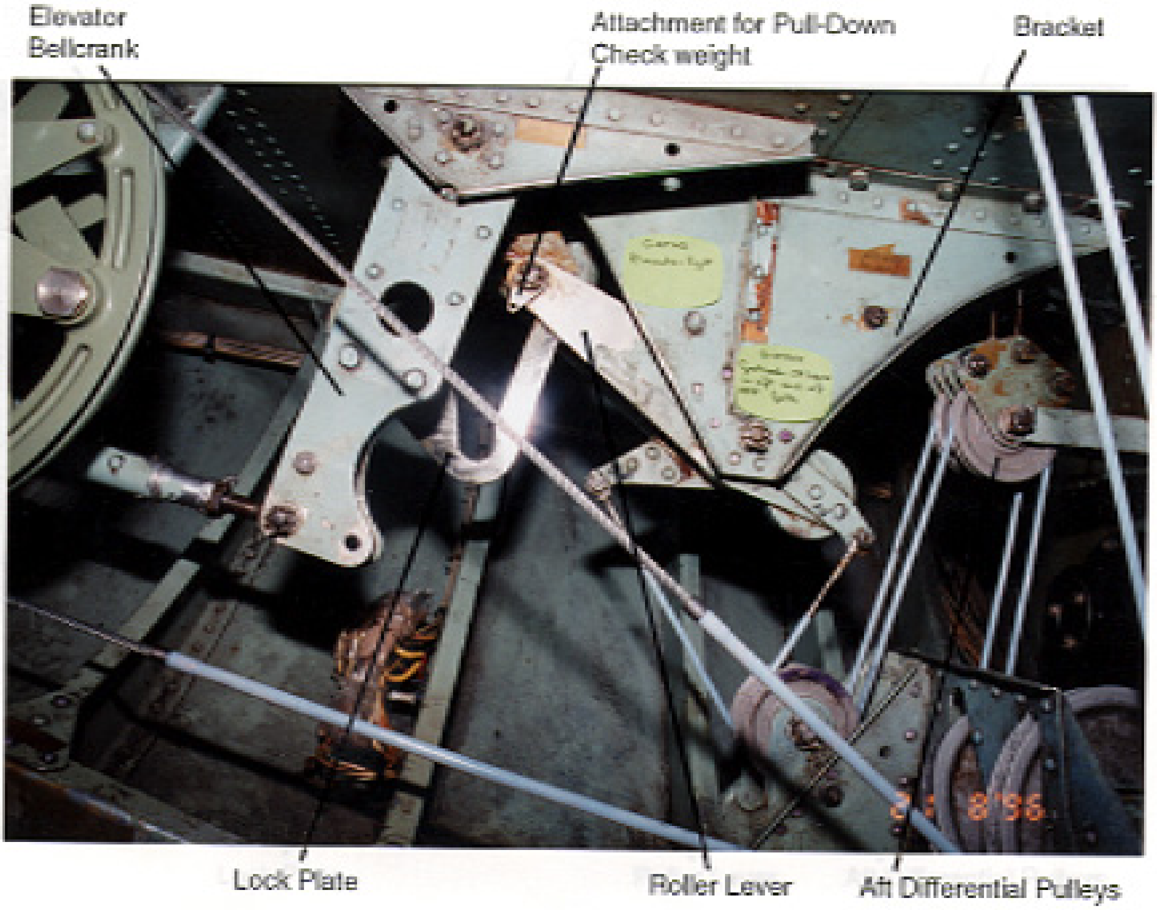


PHOTO 3.1 - ELEVATOR GUST LOCK SYSTEM IN TAILCONE

PHOTO 3.2 - AFT DIFFERENTIAL PULLEY FOUL ON BRACKET

PHOTO 4.1 - RIGHT AFT DIFFERENTIAL PULLEY LEVER

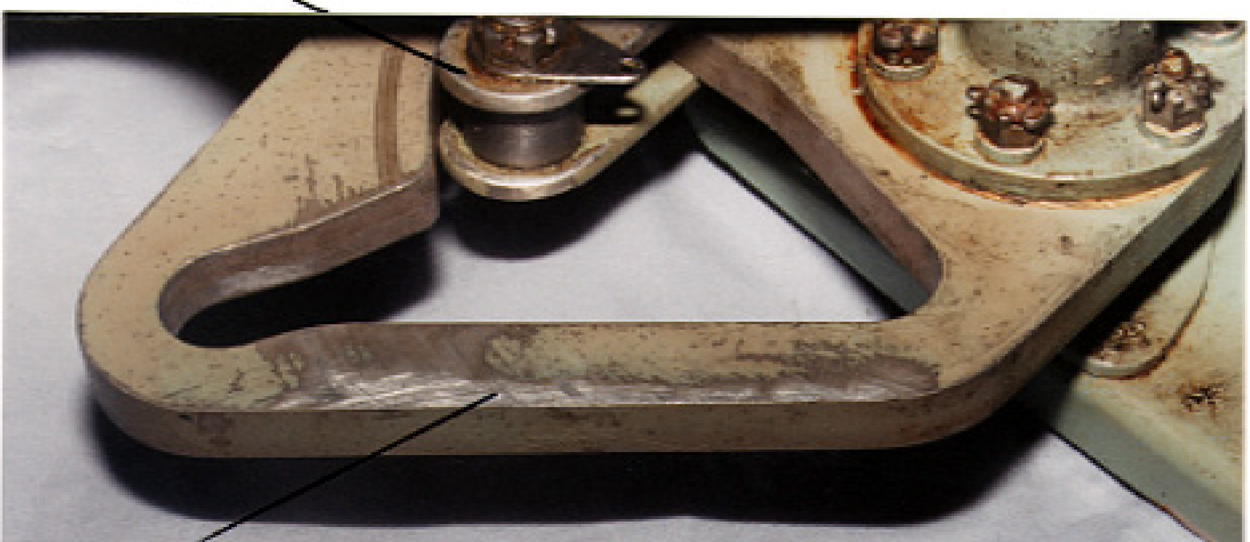


PHOTO 4.2 - ELEVATOR GUST LOCK LOCK PLATE

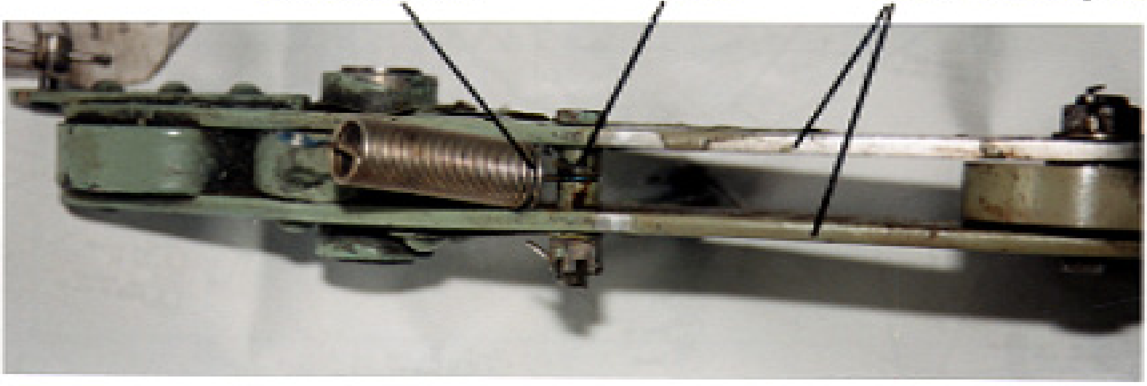


PHOTO 4.3 - ELEVATOR GUST LOCK ROLLER LEVER

PHOTO 4

PHOTO 5.1 - ELEVATOR GUST LOCK ASSEMBLY

Roller Lever
Pivot Bolt
(bush absent)

PHOTO 5.2 - ROLLER LEVER PIVOT - LEFT SIDE

Roller Lever
Pivot Bolt Bush

PHOTO 5.3 - ROLLER LEVER PIVOT - RIGHT SIDE

PHOTO 5