PART I

SUMMARIES OF AIRCRAFT ACCIDENT REPORTS AS PREPARED BY ICAO

No. 1

British Midland Airways Limited, Argonaut, G-ALHG accident at Stockport, Cheshire, England, on 4 June 1967. Report, not dated, released by the Board of Trade, United Kingdom. C.A.P. 302 on 22 August 1968

1.- Investigation

1.1 History of the flight

The aircraft was on a non-scheduled international flight from Manchester to Palma and return. It landed at Palma at 0220 hours GMT, was refuelled and took off for Manchester at 0406 hours GMT. The co-pilot was flying the aircraft from the right-hand seat and the flight was uneventful - between 0856 hours and 0900 hours the aircraft was descending for approach and landing and was being vectored towards the ILS localizer. At 0901:30 hours the flight was informed that it was 9 miles from touchdown and well left of the centre line and it was asked if it was receiving the ILS. The pilot-in-command replied that he was and would turn right a little. Shortly thereafter one engine, most probably No. 4, ceased to deliver power, followed some 15 seconds later by the other engine on the same side. The pilot-in-command took over the controls and just after 0903 hours the Controller told the flight that it was 6 miles from touchdown and asked if it was established on the ILS localizer. This message was not acknowledged by the flight and 7 seconds later the Controller asked if it was still receiving. The pilot-in-command then replied "Hotel Golf is overshooting, we've got a little bit of trouble with rpm". The aircraft's indicated air speed was then only 116 kt and its height 1 838 ft AMSL. The Controller then ordered the pilot-in-command to turn left on to 160°M and climb to 2 500 ft QNH. He then asked the reason for overshooting and was told "We've a little bit of trouble with rpm, will advise you".

At 0903:51 hours the pilot-in-command asked what the left turn was on to. The Controller noted that the aircraft had already turned through 25° to the right instead of to the left, so he ordered the pilot to continue turning right on to 020° and climb to 2 500 ft on QNH. This was acknowledged by the co-pilot. At 0904:41 hours the Controller asked the flight to advise when ready to recommence the approach. By this time the aircraft's IAS had dropped to 111 kt, its height to 1 287 ft QNH, and it had broken cloud and was seen by an eyewitness. Thereafter it flew below cloud in conditions of reasonable visibility. At 0905:26 hours the Controller told the flight that it was 7 miles from the airfield on a bearing of 040° and requested its height. The flight reported at 1 000 ft. This was the first indication to the Controller that the aircraft was faced with an emergency and after checking that the height given was correct he put full emergency procedure into operation at the airfield and ordered the aircraft to turn right on to 180°M, so that it would close the ILS localizer.

At 0905:47 hours the Controller asked the flight if it could maintain height. The pilot-in-command now at 981 ft AMSL and only some 800 ft above the ground replied "just about". He was told he was 8 miles from touchdown and should continue his right turn on to 200°M and maintain as much height as possible. At this point 341 ft of height were lost in 10 seconds after the IAS had fallen to 100 kt and the pilot-in-command said he was not able to maintain height at the moment. The Controller told him that he was 8 miles from touchdown and closing the ILS localizer from the right. At 0907:09 hours, the Controller informed the flight that radar contact had been lost due to the aircraft's low height and asked the pilot to adjust his heading on the ILS and report when established. The co-pilot replied that they had "the lights to our right" and were at 800 ft, just maintaining height, and the pilot-in-command asked for the emergency to be laid on.

At 0907:35 hours the pilot-in-command requested his position and was told 7½ miles to run to touchdown. Half a minute later the Controller repeated that he had no radar contact, and cleared the flight for landing, the surface wind being 270°/12 kt. At this stage the PAR Controller, who had overheard that the Approach Controller had lost radar contact, saw a contact at the bottom of his elevation display, and told the flight that it was 6 miles from touchdown. The co-pilot then gave their altitude as being 500 ft. The terrain clearance was only 300 ft and the IAS was below 105 kt and falling. The aircraft was approximately on the line of the ILS localizer and heading for the very centre of the built up area of Stockport.

A few seconds after 0909 hours the aircraft struck the ground more or less level in pitch, slightly right wing down, and slightly yawed to the right. From the evidence of two eyewitnesses who saw the aircraft just before the crash it was clear the pilot-in-command deliberately cut the power very shortly before impact and deliberately put the aircraft down on what was the only pocket handkerchief of relatively open space available, immediately before tall blocks of flats, the town hall, the police station, and Stockport Infirmary.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	3	69	
Non-fatal	2	10	
None			

1.3 Damage to aircraft

The aircraft was destroyed by impact and subsequent fire.

1.4 Other damage

Several buildings were damaged either by the impact of the aircraft or by the subsequent fire.

1.5 Crew information

The pilot-in-command, aged 41, held a valid air transport pilot's licence with ratings in the Argonauts, Viscounts, Dakota C-47s and DHC1s and an instrument rating renewed on 3 March 1967. He also held a flight radio telephony operator's licence. His last medical examination was on 18 April 1967. He had passed all his pilots' mandatory checks, including an instrument approach proficiency check on 11 January 1967, a route competence check on 15 January 1967 and a line check on 15 April 1967. He had been checked in asymmetric flying, including three engine take-offs and two engine landings on four occasions during 1966. On the last occasion, on 25 October, his base check on the Argonaut included take-off, instrument approach, instrument overshoot and approach and landing, all with No. 4 engine shut down and cross feed drill.

He had flown a total of 10 197 hours including 2 009 hours in Argonaut aircraft of which 1 900 hours were flown as pilot-in-command.

The co-pilot, aged 21, held a valid commercial pilot's licence with ratings in the Dakotas, Argonauts and Viscounts and an instrument rating. He also held a flight radio telephony licence. He passed his last medical examination on 15 December 1966. He had performed all his mandatory flying checks, and had flown with this pilot-in-command on 21 flights for a total of 30 hours 25 minutes. He was tested for asymmetric flying on the Argonaut on 20 October 1966 with No. 2 engine shut down and on 12 April 1967 with No. 4 shut down. He had flown a total of 1 001 hours, including 136 hours in Argonaut aircraft since October 1966.

Also on the flight deck was a supernumerary engineer who was an experienced although not certificated ground engineer. He was flying on the subject flight in order to perform ground engineer's duties when the aircraft was away from its home station. He had no duties to perform in the air, but used to help out by filling in instrument readings in the technical log and instrument and fuel logs, and, if asked to do so by the pilot-in-command or co-pilot, he would move control levers or switches in flight, for example the radiator shutter controls, and the fuel booster pump switches during the approach check.

Also aboard were a cabin steward and a stewardess.

The period of duty performed by the flight crew on the night of 3 - 4 June was slightly in excess of the new flight time limitations then under discussion and now in force, but was well within the then existing limitations. There was no evidence that the pilots were unduly tired after what had been, up to the time of the emergency, a normal and uneventful tour of night duty performed in good weather.

1.6 Aircraft information

The aircraft's certificate of airworthiness was valid until 20 December 1967. The aircraft had been maintained according to the approved maintenance schedule and its latest maintenance certificate was issued on completion of a Check 1 inspection on 19 May 1967 and signed by the appropriate and duly certificated engineers, was valid for 42 days or a further 250 flying hours.

At all times on the flight the aircraft was within its total permitted load and the centre of gravity was also within limits. There was no question of the loading having caused or contributed to the accident.

The type of fuel being used was not stated in the report.

1.7 Meteorological information

At 0856 hours GMT the following weather conditions for Manchester were broadcast to aircraft: visibility 1 600 m in rain and drizzle, 3/8 cloud at 300 ft, 7/8 at 400 ft and 8/8 at 5 000 ft.

1.8 Aids to navigation

The Instrument Landing System was available on the runway in use at Manchester, runway 24. Because of an improvement in the weather at Manchester at about 0900 hours the Precision Approach Radar which had been in use earlier that morning was put out of service for a short time for a minor technical adjustment. Approach Radar Control was in operation throughout.

1.9 Communications

Communications were normal until the time of the accident.

1.10 Aerodrome and ground facilities

Not relevant to the accident.

1.11 Flight recorders

The aircraft was equipped with a Midas Type CMM Flight Data Recorder designed to record the indicated airspeed, pressure altitude, heading and normal acceleration simultaneously on two magnetic tapes, one housed in an armoured and fireproof container sited in the tail and the other located on the cockpit floor. Both tapes were recovered and were perfectly readable; however, for an unknown reason the normal acceleration was not recorded.

A reconstruction of the last 15 minutes (900 seconds) of the flight was made from the read-out of the recording. Subject to the aircraft track being plotted about half a statute mile to the SE of its actual track this reconstruction conformed closely with the eyewitnesses' evidence (see Fig. 1-1 and 1-2).

A plot of the aircraft total energy derived from the flight recorder speed and height data against time was drawn (see Fig. 1-3). The plot showed that 900 sec before the crash (-900) the total energy level was corresponding to cruising flight at a fairly constant speed and height. After 150 sec (-750) this was followed by a somewhat variable energy loss as height and later speed were reduced in the initial stages of the approach. At -340 sec there was a sharp reduction in the slope of the curve followed by a further reduction at about -215 sec. The period from -550 sec to the crash was plotted on a larger scale in Figures 1-4 and 1-5, and these changes show more clearly on Figure 1-4. Energy continued to be lost at a steady rate without any sustained increase until the end.

The increase in slope at around -495 sec (see Fig. 1-5) was consistent with the extension of some 10° of flaps, followed by a decrease consistent with a small increase in power. Beyond this point the increase in slope at -430 sec suggested the failure of an engine, followed at -410 sec by the failure of a second engine at about the same time as the feathering of the propeller on the first. At -340 sec the decreased slope was consistent with increase of power on the live engines at 2 650 rpm and 48.2 in. manifold pressure, no doubt when the pilot decided to overshoot and go round again, with a further increase at -215 sec, shown on Figure 1-4, to 2 850 rpm and 58.4 in.

The rate of energy loss for the final 215 sec of flight corresponded to a descent at 200 ft/min with the aircraft in the configuration in which it was found after the crash, i.e. landing gear retracted and flaps extended at 10°. Furthermore, the only sensible power situation which could be drawn from the slope of the total energy curve and the configuration of the aircraft after the crash was two engines at maximum continuous power, i.e. 2 850 rpm and 58.4 in. manifold pressure, one engine feathered and the other windmilling. This was consistent with the fact that the pilot was able to maintain his heading approximately constant over the last 80 sec of flight at a speed of less than 110 kt, which would not have been possible with two engines on one side at take-off power.

Figure 1-6 shows the parameters of indicated airspeed, height and magnetic heading plotted to show their relation to the 3° slope of the ILS glide path, 1.1 x stalling speed at 0°, 10° and 15° flap, the key R/T messages and the eyewitness statements. The sudden loss of height at the rate of 2 000 ft/min with a corresponding increase in airspeed from 126 to 140 kt between -415 and -405 sec bears out the inference from the total energy plot that two engines failed within a very short time of each other very shortly before. By -375 sec the airspeed had decayed to 110 kt and the aircraft had started to turn right, continuing to do so although vectored to the left on to 160° 50 sec later. All its behaviour as indicated on the plot was consistent only with the pilot being faced at about that time with a major emergency involving severe control difficulties, which were never overcome.

1.12 Wreckage

At the time the aircraft struck the ground, the left wing complete with engines was torn off by a three storey building which it partly demolished. The fuselage and right wing and engines were brought to a stop within 15 yards of the first point of contact by a low concrete garage building. The cockpit was largely broken away clear forward of the fuselage, and the tail was left projecting in the air over the edge of the building. A gaping hole was torn in the left side of the fuselage near the wing leading edge.

Detailed examination of the engines and their propellers after the accident revealed that Nos. 1 and 2 engines were rotating at the time of the accident and that Nos. 1, 2 and 3 propellers were within a 27° to 28° pitch angle band corresponding to the flight fine position, whereas No. 4 propeller was at a 94° pitch angle corresponding to the feathered position.

No evidence of malfunction or failure of the engines or propellers prior to the accident was found.

1.13 Fire

At first there was no fuel fire, only small flames here and there which were not sufficient to disturb rescue operations. However, some 10 minutes after impact there was an explosion as the fuel in the ruptured tanks of the right wing took fire.

Fire started in the fuselage where the dead and injured were still trapped at the forward end of the cabin and quickly beat the rescuers back. It spread very quickly and strongly aft to where the passengers from the rear of the cabin were trapped. Ultimately, as a result of the fire the tail section of the aircraft subsided to the ground.

The Manchester Airport Fire Service crash crews were alerted at 0908 hours when the Approach Controller initiated the emergency procedure, but the first call to the fire service itself came at 0912 hours, some 3 minutes after the crash. The first appliance, a water tender, arrived at the crash site at 0917 hours and by 0925 hours local resources had been reinforced from the Cheshire County Council brigade and from the Manchester brigade, and foam tenders were arriving from the airport.

In addition to the major fire in the aircraft itself the fire services had to deal with fire in two transformers in an electricity substation which had been struck, with fires in other buildings involved, and with the exploding petrol tanks of the burning garage. They prevented two 500 gallon petrol tanks in the garage forecourt, which were nearly full, from becoming involved. A number of firemen joined the police, Civil Defence workers and ordinary civilians in the rescue efforts. The fire services functioned promptly and efficiently, and it was in no way through any delay on their part that more of the passengers were not rescued.

1.14 Survival aspects

The aircraft crashed about 100 yards from the Stockport police headquarters and police officers and other rescuers arrived at the scene within seconds. Rescue started at once through the rent in the left side of the fuselage near the wing leading edge and no attempt was made to use the emergency exits located further aft. As a result the rescue was concentrated on the forward part of the cabin where a confused heap of passengers were found, still strapped in their seats which had come away from their securing points when the cabin floor was shattered by the impact. Most of these passengers were dead, some were still alive but unable to move because of severe leg injuries caused by impact against the strengthening metal bars across between the uprights of the seat immediately in front of them. Difficulties were encountered by the rescuers in undoing the seat belts because of unfamiliarity with the operation of the belt release. After some 10 minutes from impact ten injured passengers had been rescued, nine out of those ten were seated on the right side of the cabin and five out of ten had fractures of the lower leg. At that time the fire became so fierce that the rescuers were beaten back from the cabin. They then set about the cockpit which was clear forward of the flames and with great difficulty managed to extricate both pilots from the shattered cockpit. The pilot-in-command who had moderate head injuries, including a broken jaw, survived but the co-pilot was found to be dead on arrival in hospital. Evidence indicated that the crash forces in the rear part of the aircraft were less than those further forward and were potentially survivable. Most of the passengers there died because they were unable to escape and could not be rescued before the fire took hold. The main disintegrating forces appeared to have been vertical deceleration, considerably greater than 9g, rather than fore and aft deceleration.

1.15 Test and research

Post-accident examination did not reveal any evidence of ill health or abnormality which could suggest that physical incapacitation of one of the pilots could have contributed to the accident.

In September 1967 flight tests were carried out on another Argonaut to establish minimum control speeds with the aircraft in the configuration suggested by the flight recorder readout and to assess qualitatively the baulked landing qualities in that configuration. With one or more engines inoperative the Argonaut's control characteristics were such that, though acceptable for transport aircraft at the time the Argonaut was certificated, they would not be accepted any more for a modern transport aircraft.

It was found that with the landing gear retracted, flap extended 0° to 15°, No. 3 engine windmilling and No. 4 engine feathered, the minimum control speeds at various power settings on the port engines were severely compromised by the extremely high rudder control forces involved, and that while full rudder trim significantly reduced the foot forces down to fairly low speeds it did not help much at absolute minimum control speeds. Full rudder trim was required at low speeds with only one failed engine. It was not possible to maintain height with the flaps up even at full power on the two operative engines. In an emergency such as that, the pilot-in-command would be fully occupied, because of the poor performance and handling qualities, in controlling the flight path and the remaining work load, navigation, communications, lookout and engineering would greatly exceed the capability of the second pilot. A short pilot with his seat correctly placed for view could not apply and hold full rudder in an emergency, and unless the shoulder harnesses of both pilots were undone, the altimeter millibar setting knob, some of the fuel cocks, and some of the fire extinguishers were difficult if not impossible to reach.

In October 1967 following an analysis of fuel logs by the airline's Flight Safety Officer, tests were carried out in an Argonaut on the ground to determine whether inadvertent transfer might have something to do with the subject accident.

The Argonaut fuel system comprises four main tanks and four auxiliary tanks:

in the left wing	No. 1 main tank and No. 1 auxiliary tank normally supplying No. 1 engine No. 2 main tank and No. 2 auxiliary tank normally supplying No. 2 engine
in the right wing	No. 3 main tank and No. 3 auxiliary tank normally supplying No. 3 engine No. 4 main tank and No. 4 auxiliary tank normally supplying No. 4 engine.

There are booster pumps in or at the outlet of each tank and cross feed lines are provided so that either engine of each pair can be fed from the tank supplying the other (inter-engine cross feed), or any tank in one wing can be used to supply engines on the other wing (cross-ship cross feed) (see Fig. 1-7). The tank selector valves and cross feed valves are similar in design. The four tank selector controls are located in front of and concealed by the throttle controls on the left side of the pedestal within reach of the pilot in the left hand seat. They have three positions: in the fully forward and down position the respective main tank is "ON" and the auxiliary tank is "OFF", in the midway position the main tank is "OFF" and the auxiliary tank is "ON". In the fully aft and up position both tanks are "OFF". The two cross feed controls are located in front of and concealed by throttle controls on the right side of the pedestal within reach of the pilot in the right-hand seat. They have also three positions: in the fully forward and down position the cross feed system is "OFF", in the midway position it provides "inter-engine cross feed" between both engines on the same wing, in the fully aft and up position it provides "cross-ship cross feed".

During the ground tests it was discovered that a very slight movement of the cross feed controls back from the closed position produced first "inter-engine cross feed" and later "cross-ship cross feed" (see Fig. 1-8). Further ground engine runs were carried out with ARB representatives present. The first runs were made with the tank selector controls of Nos. 1, 2 and 3 main and all auxiliary tanks "OFF", No. 4 main tank and booster pump "ON", and the cross feed controls cracked. In this condition all four engines ran at 30 in manifold pressure, and continued to do so when No. 4 booster pump was switched off.

Next all four engines were run off their respective main tanks with booster pump "ON" and cross feed cocks cracked. No. 4 main tank was run dry, and No. 4 engine quickly stopped. No. 3 engine was then selected to its empty No. 3 auxiliary tank, the auxiliary tank booster pump being switched "ON" and all main tank booster pumps being left "ON". All three engines continued to run at 30 in., but when the throttles were opened towards rated power at somewhere above 40 in., No. 3 engine instead of accelerating, stopped. However, with engines Nos. 1, 2 and 3 running off their own main tanks, with the cross feed cocks cracked, and with No. 4 main tank empty, all auxiliary tanks being "OFF", it proved impossible to induce No. 3 engine to fail by ingesting air from the empty No. 4 main tank.

Examination of the airline's Argonaut fuel logs in the light of the tests carried out revealed that inadvertent fuel transfer in flight had previously occurred on at least three occasions, one with another Argonaut at Abadan on 28 January 1966, the other two with the subject aircraft at Beauvais on 14 May 1967 and at Palma on 28 May 1967. None of these incidents was recognized at the time as inadvertent fuel transfer in flight. Had the pilot-in-command and co-pilot on the Palma flight immediately reported what had occurred, the facts which would have been reported were of such a striking nature that an investigation would have been made by the airline. The risk of inadvertent transfer would then have probably been discovered in June instead of in October and an immediate warning would have been given to Argonaut pilots to keep a close eye on the outer main tank fuel state. Such a warning would have put the pilot-in-command of the subject flight in a better position to avoid, or at least to cope with, the emergency with which he was faced only five days after the Palma incident.

Investigation of the Argonaut fuel logs also revealed examples of apparent fuel transfer while aircraft were standing overnight on the ground. These were ascribed by the pilots and engineers who discovered them to mishandling of the fuel controls. No one appreciated the difference between the ease of finding the detents in the fuel controls on the ground and the difficulty of doing so when strapped into the pilots' seats in the air.

There were two factors which helped to mask the possibility of inadvertent fuel transfer from both air and ground crews operating British Midland's Argonauts. The first and most important was that the fuel gauges were regarded as being highly inaccurate and therefore pilots relied primarily on the fuel flow meter readings. With the benefit of hindsight it is easy to infer that some of the extraordinary apparent anomalies in fuel consumption between engine and engine must have been due to inadvertent transfer in flight. The second was the belief of all the BMA pilots and engineers that inadvertent transfer in flight was impossible.

Further tests were conducted by the Engineering Physics Department of the Royal Aircraft Establishment, which tested the fuel system cross-feed valves and analysed the fuel records in the fuel logs of the subject aircraft and the other two Argonauts of the airline. The A&AEE Engineering Division carried out at the same time an appraisal of the fuel system, its controls and presentation, as well as some ground and flight testing on G-ALHY, one of the two Argonauts of the airline.

The RAE tests on the fuel system showed that if one postulates malpositioning of some or all of the tank selector and cross feed controls of between 5^{o} and 10^{o} an amount which it would be possible for the pilot to fail to recognize in flight, together with various combinations of booster pumps "ON" and "OFF" and different aircraft attitudes producing different relative fuel static heads, one may arrive at an infinite variety of fuel states by inadvertent transfer of fuel to tanks or engines. This could present, especially at the end of a long flight, the hazard of engine fuel starvation due to the premature emptying of the selected tank.

The RAE analysis of the fuel logs showed that on the last flights of the subject aircraft the differences between the calculated fuel states and the total recorded gauge readings exceeded $\pm$ 5 per cent, though the Boscombe recalibration of the fuel gauges in G-ALHY showed that it was possible by using a method considerably more complex than that recommended in the Argonaut maintenance manual, to set up the main tank contents gauges to read within that tolerance when quantities exceeded 1 000 lb. In all cases considered of the subject aircraft's fuel logs the fuel loaded was sufficient for the flight and the fuel burnt off corresponded to the uplift after landing, showing that no significant quantity was lost overboard. Consistent loading distribution and management procedures were followed.

On a number of flights extrapolation of the last two gauge readings suggested that one or more tanks should have run dry before landing, although in fact no engine was reported to have suffered from fuel starvation. On the Manchester to Palma flight on 28 May 1967, culminating in the 'Palma incident' extrapolation of the last two readings for No. 4 main tank showed it would have run dry shortly before landing, and of No. 1 that it was very nearly dry on landing, while extrapolation for Nos. 2 and 3 main tanks showed an excess on landing over the calculated fuel remaining. This picture is borne out by evidence that the fuel uplift at Palma showed that No. 1 main tank had only 24 or 25 gallons left after shutdown, and No. 4 had only 14.

Extrapolation of the last two fuel gauge readings on the crash flight from Palma to Manchester on 4 June 1967 shows that No. 4 main tank should have run dry 44 minutes before the crash, but the last reading had been recorded nearly 2½ hours before the crash.

The RAE expert who was in charge of the fuel log analysis pointed out the danger of drawing conclusions based on the extrapolations made from the last two gauge readings because of the possibility of inaccurate gauges and slightly inaccurate readings, and the length of time, usually some two hours, covered by the extrapolation. He was only prepared to accept the picture presented by the extrapolations as reliable if it was confirmed by some extraneous evidence, for example, the evidence of the Palma incident. He gave great weight to the fact that no engine failures due to fuel starvation had been reported on any of the occasions on which his extrapolation showed that a tank or tanks would have run dry before landing.

The ground and flight tests carried out at Boscombe Down produced results which were of the highest significance. It was found that slight malpositioning of a cross feed lever could lead to fuel starvation of an outboard engine by transfer of fuel to the benefit of the inboard engine: but failure of the outboard engine did not lead to any ill effects on the inboard engine, even with the cross feed cocks grossly open. During rig tests and engine grounding running tests no air was found to be drawn into the inboard engine fuel system either before or after the outboard main tank ran dry with any combination of the cross feed valves, main selector valve or booster pump selections made.

The tests also showed that there could be substantial transfer from a main tank to the corresponding auxiliary tank due to malpositioning of the tank selector lever. The auxiliary tanks are in each case situated 'downhill' from the main tanks so that transfer could occur even with booster pumps off.

Tests were also carried out on the effects of restoring engine power after failure through fuel starvation. Engines responded to unfeathering in approximately 3 sec, and when fuel flow was restored useful power was achieved in 12 to 15 sec and 2 250 rpm and 35 in. manifold pressure was achieved in approximately 25 sec. With booster pumps on and the cross feed valve cracked 10° open, before the engine which was being starved of fuel actually ceased to deliver power there was a period in the order of 2 to 7 minutes when it surged, the surges being accompanied by yawing noticeable even to observers on the flight deck without their feet on the controls.

On consideration of the reports on these further tests the conclusion was expressed that while it remained likely that the No. 4 engine of the subject aircraft ceased to deliver power as a result of exhaustion of fuel from No. 4 main tank by inadvertent transfer, No. 3 did not fail by reason of ingestion of air into its fuel system through a cracked cross feed cock from the empty No. 4 main tank.

2.- Analysis and Conclusions

2.1 Analysis

There was no doubt that No. 4 engine failed first, and failed due to fuel starvation from an empty No. 4 main tank due to inadvertent transfer either through one or both cracked cross feed valves or through a cracked tank selector valve or through a combination of both.

The total energy plot from the flight recorder read-out strongly suggested that at the time the first engine failed the approach check had been begun. This was consistent with the stewardess' evidence that the cabin light instructing passengers to fasten their seat belts and extinguish cigarettes was on, and that the steward had said that the flaps had been lowered and later retracted. There was no doubt that the pilot-in-command lowered the flaps to the 15° called for at the approach check, and raised them to 10° at which the rams were found to be set after the crash, when he decided to overshoot. The position of the main radiator flap actuators which were found in the fully closed position showed that the approach check was never completed, since it required the main radiator flaps to be set at between 20° and 40°.

The approach check also called for a check of the fuel controls to ensure that they were in the main tanks "ON", cross feeds "OFF" position. If that drill was carried out properly, then even if until that moment No. 4 engine with its main tank already exhausted was being fed through a cracked cross feed or main selector valve from another tank or tanks, the cracked valve would have then been properly closed and fuel starvation would have occurred almost at once without subsequent surging. It was believed that the drill was properly carried out and that this was why No. 4 engine failed when it did instead of long before the crash.

The total energy plot from the flight recorder established that a second engine, which from the position of the rudder trim must have been No. 3, ceased to deliver power some 15 sec later. The Boscombe tests disposed of the possibility that it failed as a result of ingestion of air from the empty No. 4 main tank. The flight path after the initial emergency as plotted from the flight recorder was sensibly consistent only with the configuration of one propeller feathered and another windmilling substantially throughout the whole period up to the crash. No eyewitness mentioned any propeller being feathered, but No. 4 was found to be feathered and the condition of the plugs on No. 3 engine, if of any significance, suggested that it was No. 3 rather than No. 4 which was windmilling.

It was impossible based on all the evidence to determine why the second engine failed. Following the Boscombe tests five possibilities were considered:

(i) <u>That No. 3 engine failed through icing</u>

Since there was no evidence to suggest that Nos. 1 and 2 engines were in any way affected by icing this was rejected.

(ii) That No. 3 engine failed as a result of some mechanical or electrical failure unconnected except by coincidence with the failure of No. 4

There was no evidence of any mechanical or electrical defect in No. 3 engine, and apart from the condition of the plugs to which we have already referred which would not have caused the engine to fail the evidence was that all was in order and this was rejected.

(iii) That the failure of No. 4 engine was correctly identified by the pilot-in-command but that power to No. 3 engine was cut off by error in carrying out the feathering drill, for example, by operating the fuel controls or ignition switches for No. 3 in error for No. 4

Such a mistake seemed highly improbable. Moreover, if such a mistake was made the indications would have been obvious to the crew, the mistake could have been corrected even with the high work load thrust upon the crew by the emergency, and there was ample time in which to correct it. Therefore this was rejected also.

(iv) That when No. 4 engine failed it was misidentified as No. 3 and that No. 3 was feathered and its fuel shut off; that the pilot-in-command then found not only that cleaning up No. 3 engine had not eased the handling problem, but that he was losing height which he should not have with three engines under power, and so came to the conclusion that the failure was in fact No. 4: that No. 3 was then unfeathered and No. 4 feathered, but because of the high work load power was not restored to No. 3 in time to prevent the crash

It may well have taken the pilot some time to recognize that he had misidentified the engine which had failed.
In a supercharged piston engined aeroplane with constant speed propellers it may be difficult to recognize immediately which engine has ceased to deliver power, especially if the good engines are set to deliver no more than low cruising power. The constant speed unit will ensure that the rpm on the failed engine remain at the same speed as before failure. The supercharger will continue to turn at the same speed because the propeller does, and so the manifold pressure will remain the same, although if the engine failure is due to fuel starvation what is being compressed is not the fuel air mixture but only air. The only reliable instrument indication of which engine is not delivering power is the fuel pressure gauge coupled with the flowmeter.
Dual pointer fuel pressure gauges and flowmeters may well have aggravated the problem.
Once the correct identification had been made, although ample time was in theory available to sort out the mistake, the demands upon the pilot-in-command in actually handling the controls with one engine feathered and one windmilling coupled with the consequent load on the co-pilot who had everything else to do himself make it understandable that they failed to carry out the necessary actions to restore power to No. 3 in time.
For example, No. 3 tank selector valve would have had to be opened by the co-pilot and the No. 4 closed because the pilot-in-command would have had both hands on the control column and could hardly have leaned forward to reach the tank selector controls in view of the very high loads he had to apply to the rudder pedal with his left foot. The co-pilot would have had to unstrap himself from his seat before he could reach the tank selector controls at all.

If this is what happened it would make sense of the pilot-in-command's question while under sedation in hospital on the day after the crash, 'Which engine was it?' The difficulties in the way of this explanation are that neither the stewardess nor any of the eyewitnesses mentioned either propeller being stationary, and that some 8 minutes elapsed between the failure of the second engine and the crash during which power to No. 3 might have been restored.

(v) That No. 3 main tank had also run dry because of inadvertent fuel transfer either cross ship through cracked cross feed valves or to No. 3 auxiliary tank and that when the position of the cross feed and tank selector controls was checked during the approach check fuel till then feeding No. 3 engine through the cracked valves from another tank or tanks was cut off and starvation of No. 3 followed almost immediately

If this is what happened it would explain why there was only some 15 seconds between the failure of No. 4 and No. 3 engines, and why in the 7 minutes between the failure of the second engine and the crash, power to neither engine was restored by the crew. The principal difficulty is that the fuel log readings do not suggest that No. 3 main tank was likely to run short of fuel. But the last fuel gauge readings were 2¼ hours before the emergency, and on flows previously recorded and analysed it is not impossible that No. 3 should have run dry.

The conclusion on the cause of failure of No. 3 engine accordingly must be that it was either misidentified as the failed engine, feathered and subsequently unfeathered but not got under power in time; or that it also failed through fuel starvation following upon inadvertent fuel transfer and only connected with the failure of No. 4 in that it was the check of the cross feed and tank selector controls during the approach check which finally cut off its fuel. To choose between these two possibilities would on the evidence be speculation.

At the height and position of the subject aircraft in relation to Manchester Airport at the time of the emergency it would have been possible for the pilot-in-command to reach the runway and land even with one engine feathered and the other windmilling. But it is clear from the R/T recordings that he was perplexed by what was happening and took a deliberate decision to overshoot in order to try to sort it out. Although this decision proved to be disastrous because power was never restored on either engine and control difficulties were so great that he was unable to maintain height sufficiently to reach the airfield, his decision cannot be criticized. He was faced by a wholly unexpected situation in which even the most alert crew might have been unable to combat, and it was reasonable on his part to have come to his decision to overshoot rather than to carry straight on to an emergency landing with both engines on the starboard side out.

Correspondence between BOAC and Canadair in 1953 and 1954 showed that BOAC discovered about inadvertent fuel transfer in the Argonaut the hard way, but without disaster, and after a special drive on rigging were satisfied that the problem was manageable. Correspondence from Aer Lingus showed that Aer Lingus had discovered the problem on their Carvairs, which have a similar fuel system to the Argonaut, and found it manageable. Correspondence from Invicta Airways showed that Invicta had discovered the problem on the DC-4s which they operate and that they too found it to be manageable. Provided the problem is recognized to exist, the risk of fuel starvation of an engine by inadvertent transfer is immediately minimized. It was not until after the subject disaster and after the first 12 days of public hearing that the information from BOAC, Aer Lingus, and Invicta came to light. At the time of the disaster not only did British Midland's pilots and engineers believe inadvertent fuel transfer in flight to be impossible in Argonauts, but the Accident Investigation Branch and the Air Registration Board did not know that it could occur on a significant scale.

It is obviously wrong that where an aircraft component such as the Parker valve has an inherent design characteristic which can affect flight safety, and which as in the case of the Parker valve cannot be discovered unless you take the valve to pieces or are shown drawings of how it works, users should be left to discover the possibilities for themselves. It is a design characteristic that if it is cracked 10^{o} from its correct position all three ports will be open. If British Midland had known the possibilities either from a warning in the flight manual or by any sort of notice from the manufacturers, it is doubtful whether this accident would ever have happened, and they would have found no more difficulty in managing the problem than have BOAC, Aer Lingus and Invicta. In fact, as far as the evidence went no steps were taken by anyone to inform users of this design characteristic and its implications.

Failure of communication of the possibility of inadvertent fuel transfer in the air may be regarded as a major contributory cause to the subject disaster. Canadair failed to include any warning about the design implications of the Parker valve in the flight manual when the aircraft were originally sold, and failed to communicate to other operators any information about BOAC's difficulties as shown in 1953-54 correspondence. The BOAC, Aer Lingus and Invicta experience even if known to ARB inspectors in the field was never effectively communicated to the Air Registration Board or any other body connected with air safety or direct to other users of aircraft with similar fuel systems. If their experience had included an accident rather than simply incidents of fuel transfer which they were able to recognize unaccompanied by accident, no doubt things would have been otherwise.

2.2 Conclusions

(a) Findings

The crew members were satisfactorily certificated.

The aircraft had a valid certificate of airworthiness. Its gross weight and centre of gravity were within limits.

Shortly after the pilot reported receiving the ILS, No. 4 engine failed due to fuel starvation because of inadvertent fuel transfer in flight; and it was feathered. Fifteen seconds later No. 3 engine ceased to deliver power and was windmilling. The loss of power on engine No. 3 was due either to fuel starvation resulting from inadvertent fuel transfer in flight or to misidentification by the crew of which engine had failed.

(b) Cause or Probable cause(s)

The immediate cause of the accident was loss of power of both engines on the starboard side resulting in control problems which prevented the pilot from maintaining height on the available power with one propeller windmilling. The loss of power of the first engine was due to fuel starvation due to inadvertent fuel transfer in flight. The loss of power of the second engine was due either to fuel starvation resulting from inadvertent fuel transfer in flight or to misidentification by the crew of which engine had failed followed by failure to restore power in time to the engine misidentified as having failed.

Contributory causes of the accident were:

(a) The design of the fuel valves and location in the cockpit of their actuating levers, so that a failure by the pilot correctly to position the lever by an amount so small as to be easy to do and difficult to recognize would result in inadvertent fuel transfer on a scale sufficient to involve the risk after a long flight of a tank expected to contain sufficient fuel being in fact empty.

(b) Failure of those responsible for the design of the fuel system or the fuel valves to warn users that failure by a small amount to place the actuating levers in the proper position would result in inadvertent fuel transfer on a scale involving this risk after a long flight.

(c) Failure of British Midland's air crew or engineers to recognize the possibility of inadvertent fuel transfer in the air from the evidence available in previous incidents in flight and contained in the fuel logs.

(d) Failure of other operators of Argonauts who had learned by experience of the possibility of inadvertent fuel transfer in flight to inform the Air Registration Board, the Directorate of Flight Safety of the Board of Trade or its predecessors, or the United Kingdom Flight Safety Committee of the facts which they had learned so that these might be communicated to other operators of Argonauts and other aircraft equipped with similar systems and fuel cocks.

3.- Recommendation

The only recommendation made was that express warning should be given by the Air Registration Board to all operators of Argonauts and other aircraft with similar fuel systems and valves with design characteristics similar to the Parker valves of the consequences of the cracking of the fuel valves either as a result of faulty rigging or of the failure of the pilot to ensure that the selector lever is in the correct position. The warning should be contained in flight and maintenance manuals, and should be the subject of prompt action.

Note: In October 1967 there were still in operation throughout the world some 230 DC-4s, 9 Canadair or North Stars, and 19 Carvairs. There were a further 660 aircraft still in operation all over the world with fuel systems very similar to the Canadair fuel system, including DC-6s, DC-7s and Constellations.

ICAO Ref: AIG/016/67

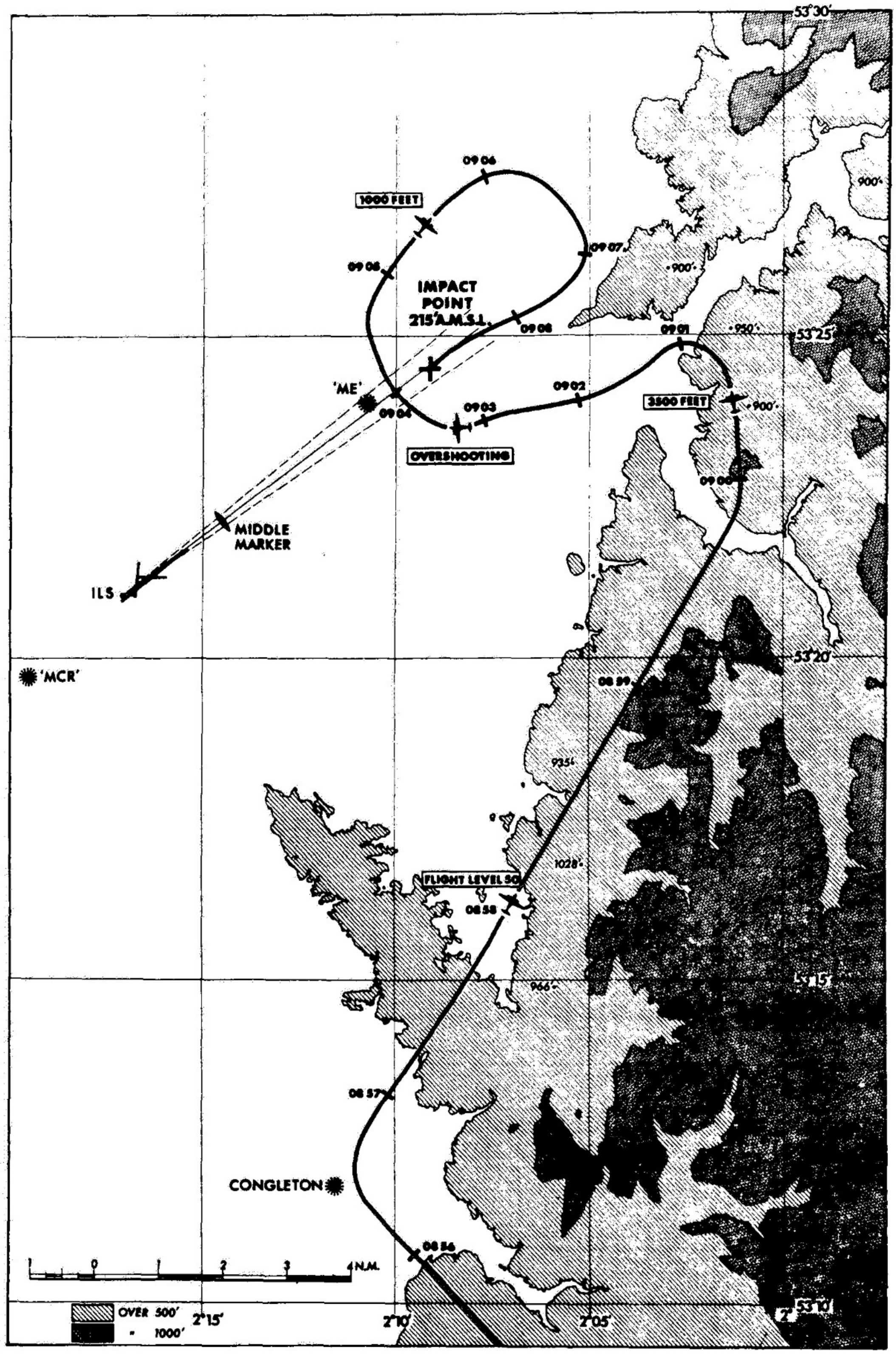

Figure 1-1. Flight Path Diagram

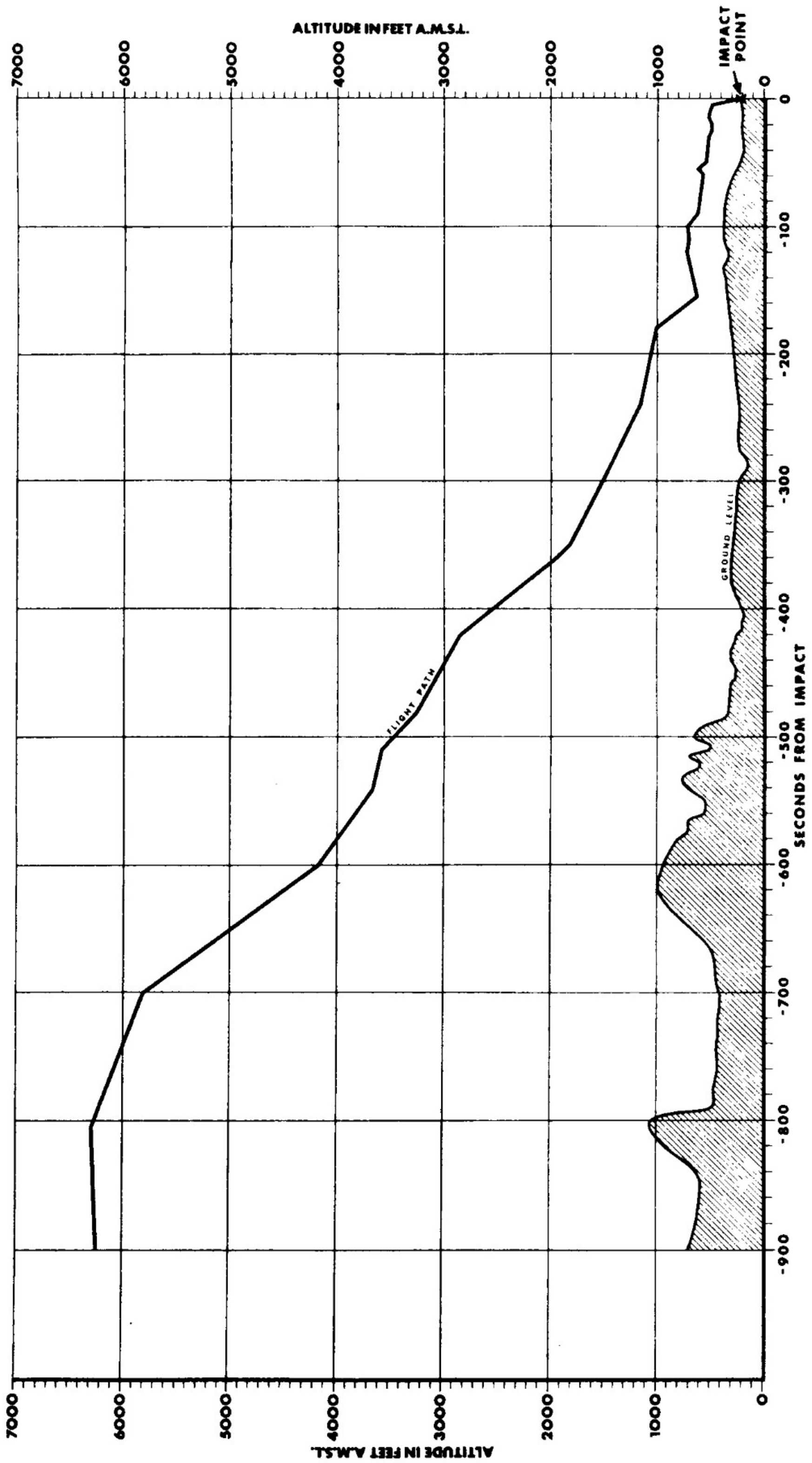

Figure 1-2. Vertical Cross Section of Last 900 Seconds of Flight of G-ALHG

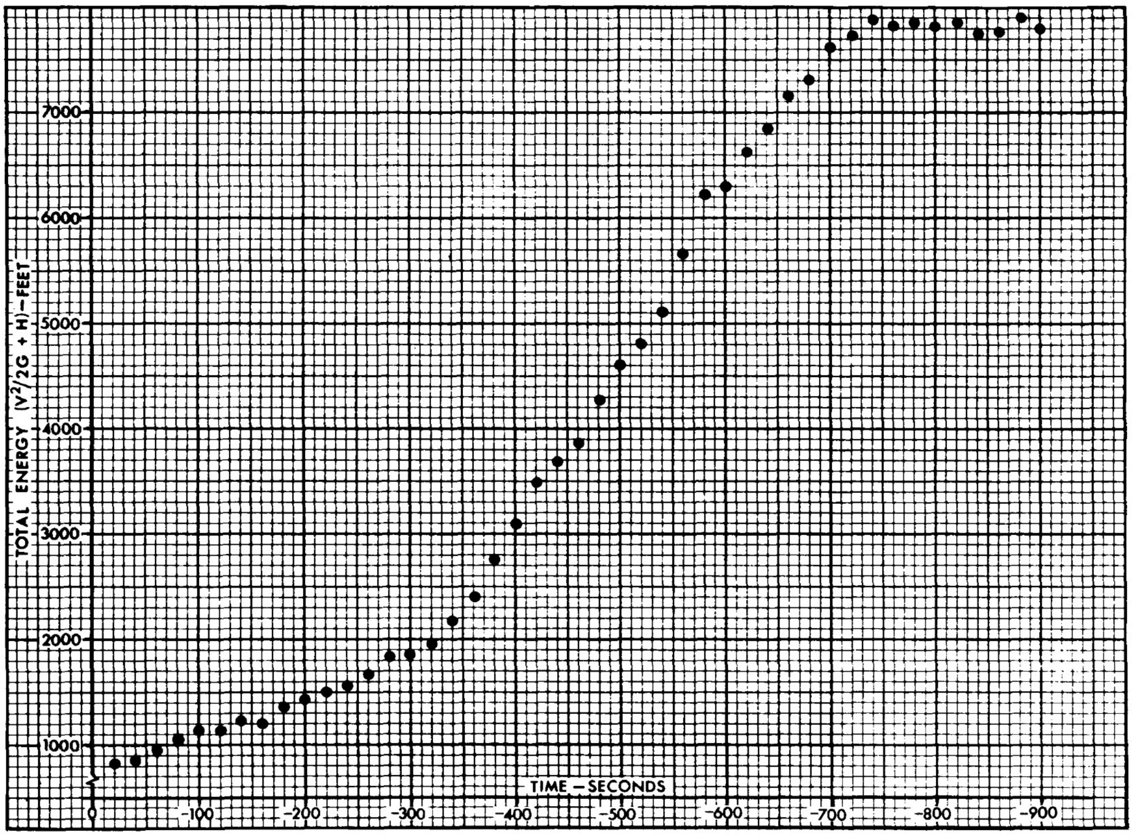

Figure 1-3. Total Energy Plot

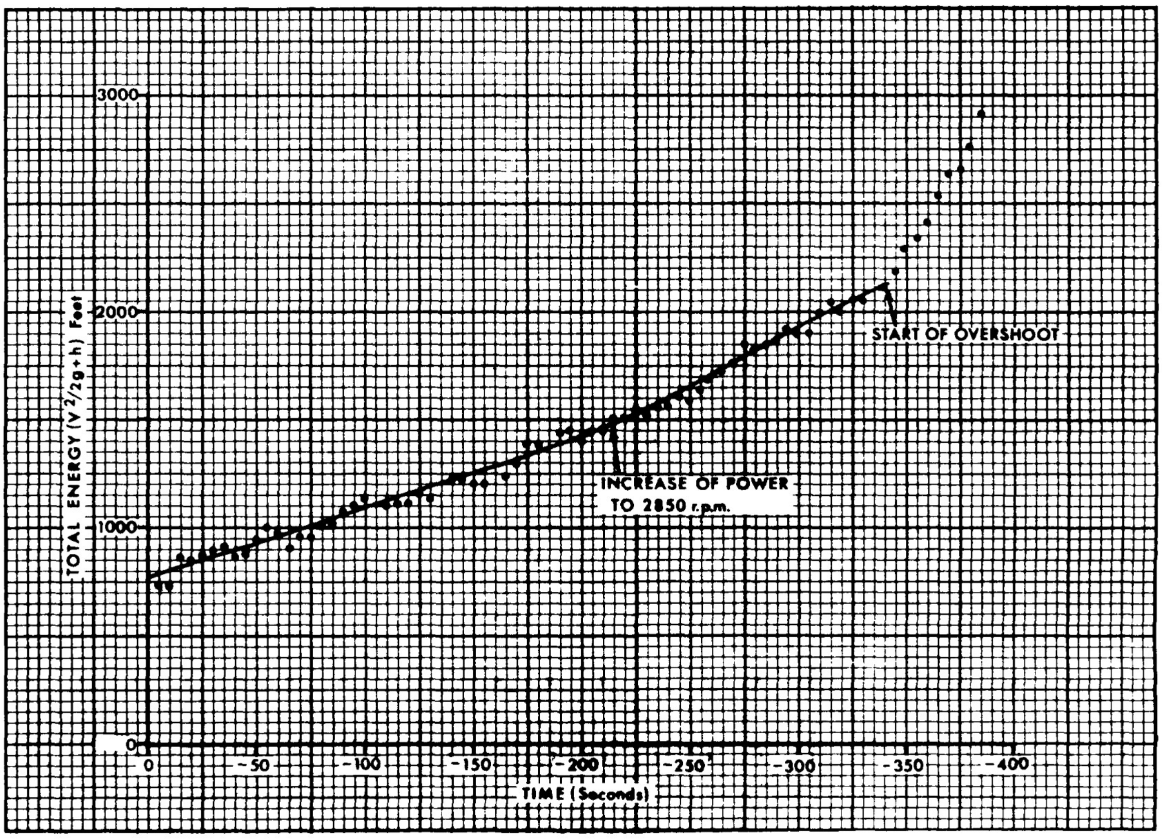

Figure 1-4. Total Energy Plot

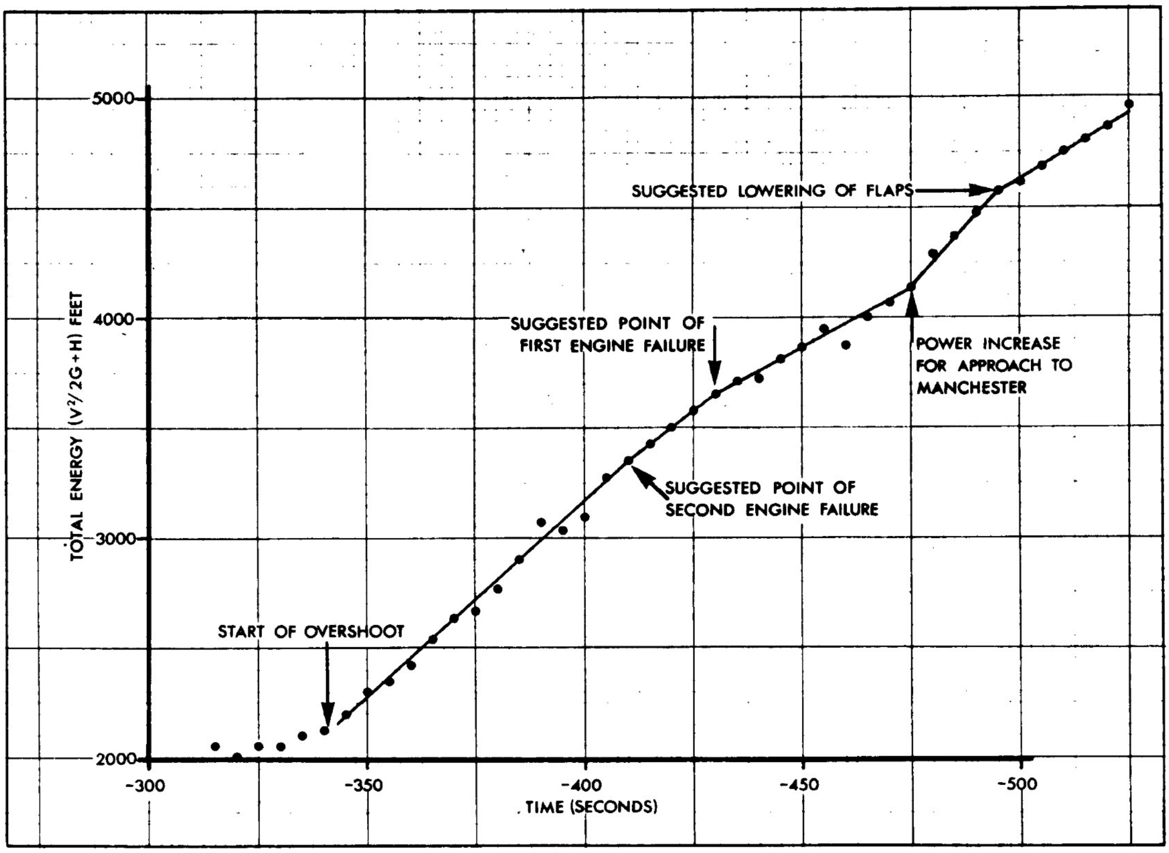

Figure 1-5. Total Energy Plot

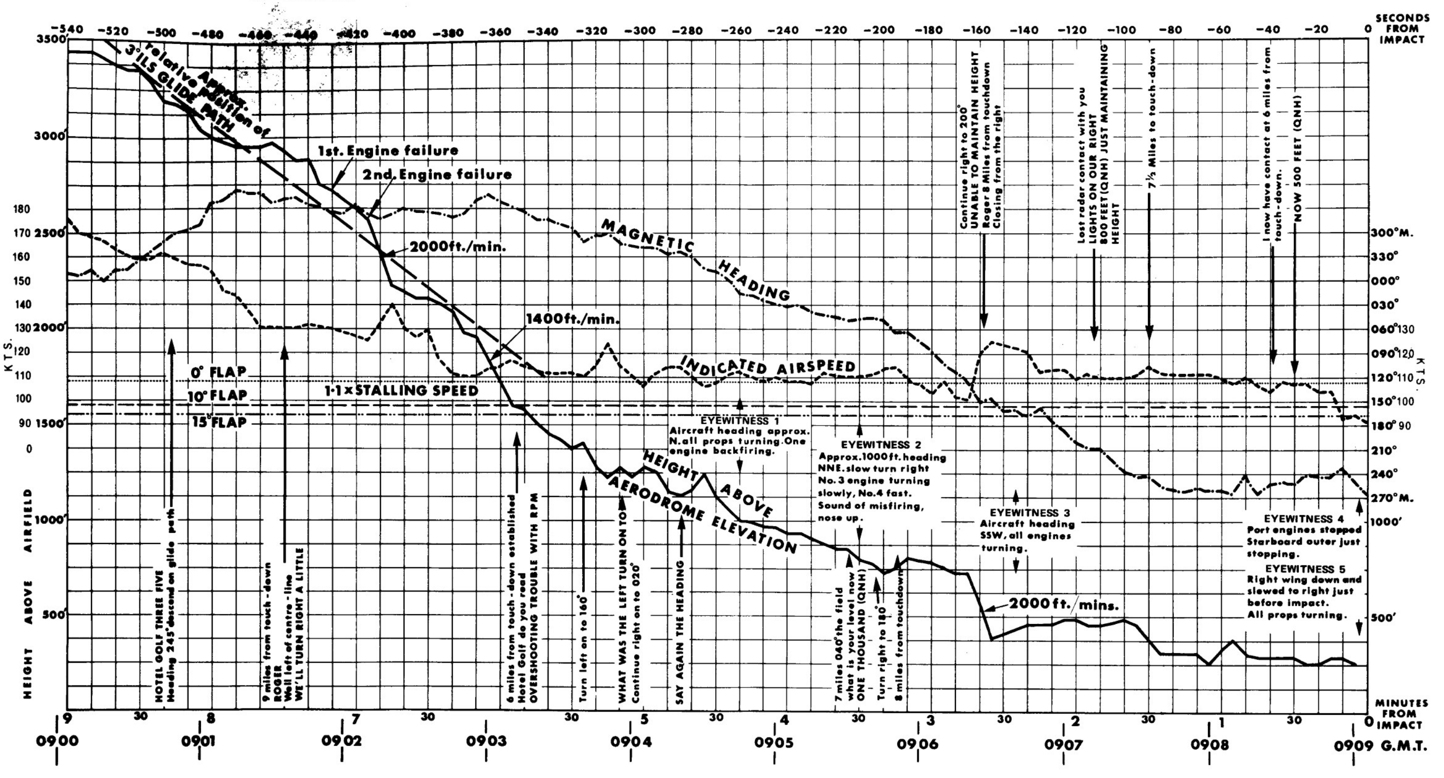

Figure 1-6. Combined Information Plot

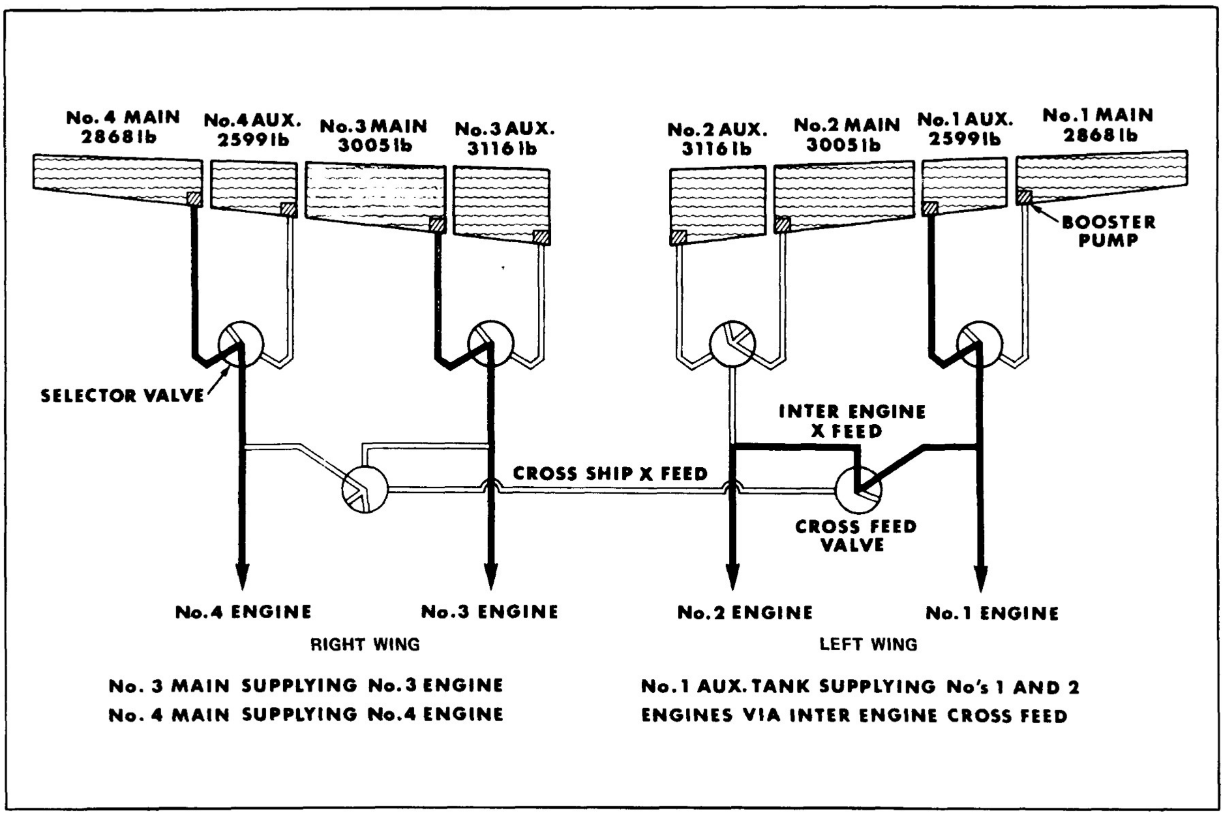

Figure 1-7. Fuel System Diagram

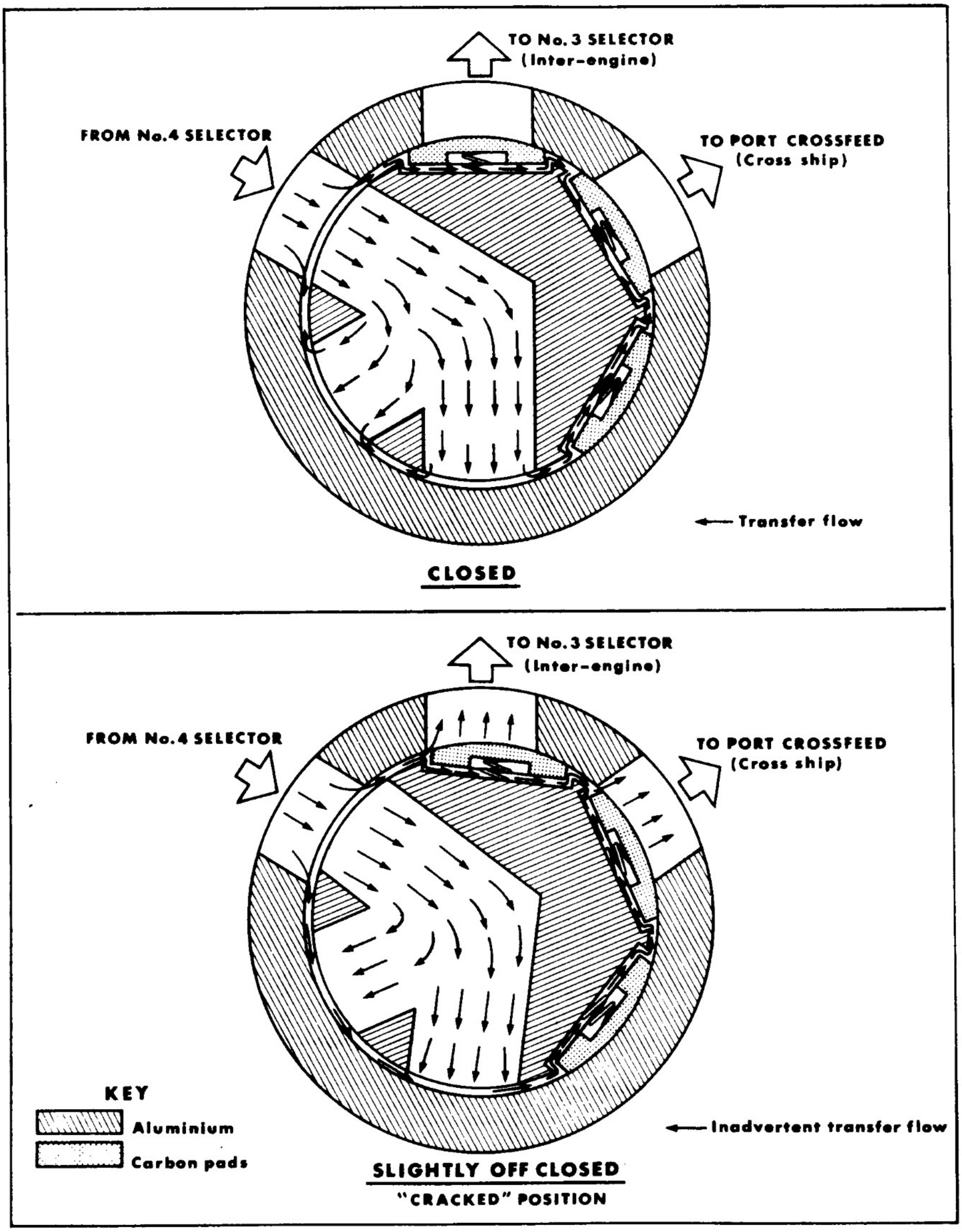

Figure 1-8. Sketch Showing Principle of Starboard Crossfeed Valve

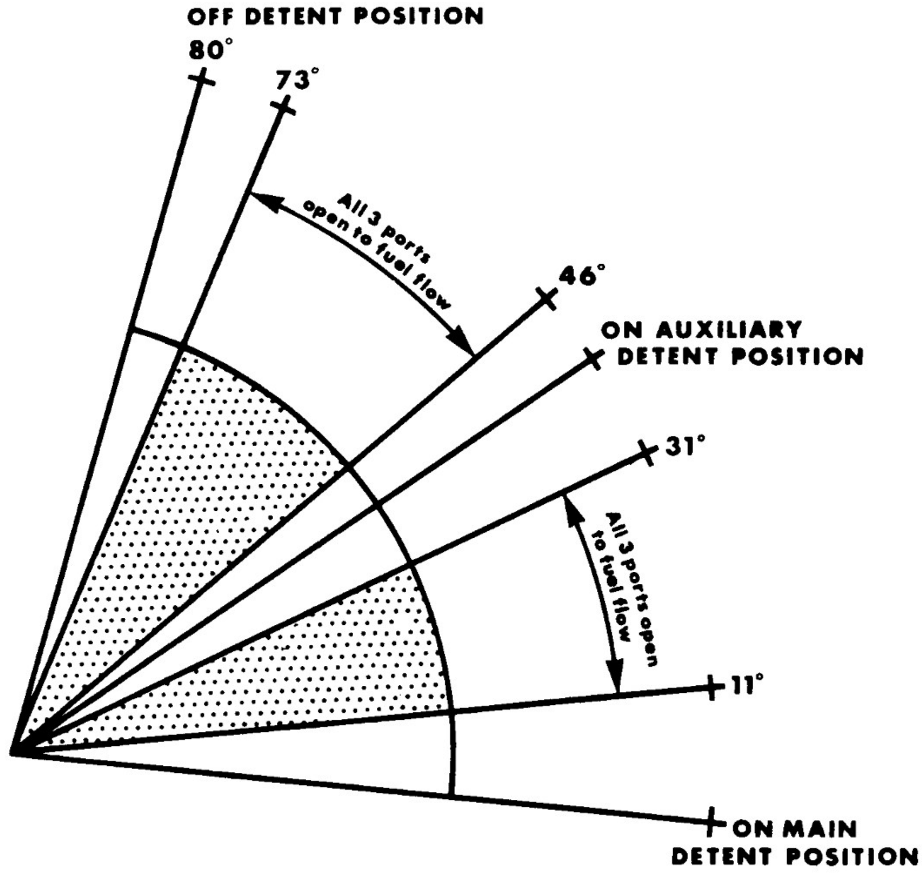

Figure 1-9. Tank Selector Cock Handle