Aircraft Type and Registration:	Folland Gnat T Mk 1, G-BVPP
No & Type of Engines:	1 Rolls-Royce Orpheus Mk 10101 jet engine
Year of Manufacture:	1963
Date & Time (UTC):	17 September 2004 at approximately 1240 hrs
Location:	Near to the A414 road, 1 nm north-west of North Weald Airfield, Essex
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damage to underside of aircraft
Commander's Licence:	Basic Commercial Pilot's Licence
Commander's Age:	36 years
Commander's Flying Experience:	1,250 hours (of which 40 were on type) Last 90 days - 15 hours Last 28 days - 5 hours
Information Source:	AAIB Field Investigation

Synopsis

Whilst approaching the circuit to land at North Weald Airfield, the engine lost power. As the pilot considered that the aircraft had insufficient energy to complete the turn on to final approach, he elected not to order an ejection and landed the aircraft wheels up in a partially ploughed field, approximately one nautical mile to the north-west of the airfield. With a landing speed of approximately 160 kt and approximately 800 lbs of fuel on board, the aircraft touched town, bounced and then slid to a halt with minimal damage. There was no fire and both occupants made their escape unaided. No definitive technical cause could be established for the loss of power but it was considered likely that a restriction in the fuel supply to the engine had occurred late into the flight.

History of the flight

The aircraft took off from North Weald at 1147 hrs, with 3,063 lbs of Avtur fuel on board (full tanks), bound for the Royal Naval Air Station Yeovilton. The route, to be flown under the Visual

Flight Rules (VFR), was planned to take the aircraft overhead Cranfield Airfield and then direct to Yeovilton, passing to the south of Swindon. The pilot had decided that, in view of the deteriorating weather conditions to the west, he would make a decision abeam Swindon as to whether to continue on to Yeovilton or return to North Weald.

The flight proceeded as planned until the aircraft reached the decision point at Swindon. Here the pilot established that the weather at Yeovilton was unsuitable and he elected to return, routing via Cranfield Airfield's overhead and from there to North Weald. At Cranfield the aircraft descended to an altitude of 1,500 feet amsl, having previously transited at various levels below FL100. At that point the pilot observed the aircraft's fuel gauge was indicating 1,100 lbs, which, on the basis of a consumption rate of approximately 42 lb per min, gave a total endurance of about 26 minutes. The pilot also stated that the throttle was set at about 70% to give a speed of less than 250 kt.

At 1233 hrs the pilot contacted North Weald to advise them that G-BVPP was north of Luton's control zone and "inbound". North Weald radio acknowledged this call and advised the pilot that they were using Runway 20 with right hand circuits. When the aircraft reached the Visual Reference Point at Ware the pilot recalled seeing a fuel state of just below 800 lbs. With an estimated one and a half minutes to go to touchdown, he considered that the aircraft was behaving normally.

About 30 seconds after passing Ware, the amber FUEL caption, located on the secondary warning panel on the pilots instrument panels, illuminated. The passenger also observed the corresponding caption on the rear seat instrument panel and he recalled that the fuel gauge was reading between 800 and 850 lbs at that point. The pilot checked that the fuel booster pump was on, which it was, and about 15 seconds after he had first seen the caption the engine lost power and 'spooled down'. With the airfield in sight, the pilot opened the throttle but was unable to restore the power. Suspecting an engine flame out, he pressed the relight button for approximately 10 seconds but this had no effect either. By now the aircraft was at about 1,000 feet agl and a speed of approximately 240 kt. The pilot shut the high pressure fuel cock (HPC) and carried out the relight drill from memory. He recalled that on opening the throttle the engine remained at very low power and sounded as if it was idling. He could not remember what the engine gauges were indicating.

The aircraft had now reduced speed further to about 190 kt and was descending through 800 feet on the North Weald QFE pressure setting. Despite being close to the north-western side of the airfield, the pilot considered that the aircraft had to negotiate too large a turn to the right to enable it to reach Runway 20 so he elected to land in a large field approximately one nautical mile to the north-east of the airfield. He briefly considered ejecting but decided that a forced landing was the better option. The aircraft landed one third of the way into a partially ploughed field at a speed of about 160 kt, on a southerly heading, with full flap selected and the landing gear retracted. G-BVPP bounced and remained controllable until it landed a second time. During the subsequent ground slide the pilot jettisoned the canopy and after an estimated 200 metres the aircraft slewed to the right and slowed down rapidly over the final 100 metres, remaining upright. The Gnat came to a halt pointing 45º to the right of the direction of the ground slide. The pilot shut the engine down and he and his passenger exited the aircraft. They were uninjured and moved away to a safe distance. Seeing no signs of smoke, fire or leaking fuel, they then returned to the aircraft to make the ejection seats safe.

The pilot had not transmitted a MAYDAY on the radio before landing. Consequently it was about 10 minutes before the emergency services began to arrive at the scene after being alerted by a member of the general public.

Meteorology

The synoptic situation showed a moist south-westerly airflow covering the intended route between North Weald and RNAS Yeovilton, with a cold front lying to the north along a line from the Humber through Gloucester to Penzance. The front was moving slowly south-east.

The conditions at North Weald at the time of the accident were cloudy with the base at 2,500 to 3,000 feet above airfield level (aal). There was 30 km visibility and a surface wind from 210º/15 to 25 kt. The surface air temperature was 18ºC and the dew point was 11ºC.

Procedures

The aircraft's emergency flight reference cards (FRCs), as used when the aircraft was in service with the Royal Air Force (RAF), state that in the event of the FUEL caption illuminating:

> *'If there is a restriction in the fuel supply, max engine RPM may be reduced. There is a slight risk of flame-out, preceded by fluctuating RPM and rough running.'*

The pilot's actions are to:

> *'1. Throttle back.*
>
> *2. If light goes out, maintain power (if possible) at a setting below that at which the light comes on.*
>
> *3. If the light does not go out, keep power to the minimum possible, avoiding negative g.*
>
> *4. In either case, land as soon as possible.*
>
> *Note: If the engine runs normally, treat as booster pump failure and return to base. If the DC caption comes on, momentarily switch on ILS to check for DC failure'.*

There was no report of the DC caption illuminating.

The procedure for a belly landing is given as:

1. *Make a normal approach aiming to land gently on the runway at normal touchdown speed.*
2. *On touchdown stream brake chute and select HP OFF.*

There is no procedure given for an 'off-runway' forced landing. The FRCs also include the following warning and limitations:

> *'If a safe landing is doubtful, both crew must eject before the minimum height/speed for safe ejection, allowing at least 300 feet to regain level flight prior to ejection.'*
>
> *'Minimum height/speed for ejection. Ground level/90 knots (level or climbing)'*

Also, paragraph 5.2 of Chapter 7 of CAP 632, *Operation of 'Permit-to-Fly' ex-military aircraft on the UK Register*, issued by the CAA, states:

> *'Forced landings should only be carried out in jet aircraft as a last resort, unless they can be made onto a suitable airfield. If ejection or abandonment is inevitable, every effort must be made to ensure that the aircraft falls into an unpopulated area. ……..'*

Aircraft description and history

The Gnat is a two seat (tandem) aircraft, powered by a single Bristol Siddeley Orpheus jet engine, and is equipped with a tri-cycle retractable landing gear. It was originally designed by the Folland company, but built by a division of Hawker Siddeley Aviation for the RAF. Production of the type in the UK ceased before 1970 and all examples had been withdrawn from military service in the UK by 1984. The original agreement of sale for the engines incorporated a contract for the engine manufacturer to provide technical support whilst the type remained in service with the original operators. All UK manufactured examples of the engine were withdrawn from service approximately 20 years ago, once the Gnat and the Fiat G91, the other type to use this engine, ceased to be operated by the British and Italian air forces respectively.

The Orpheus engine type was also built under licence in India and installed in a number of aircraft types, including the licenced produced Gnat, and these engines continued in service after the withdrawl of the UK produced engines. Thereafter, Rolls Royce, the inheritor of the Bristol Siddeley company, sold the Orpheus project to India and relinquished any responsibility for further development, production, product-support or flight safety involvement with the engine type. Consequently, some two decades later, little manufacturer's expertise specific to the Orpheus engine remains. BAE Systems, the inheritor of the airframe manufacturer, similarly no longer retains in-house specific knowledge of the aircraft. Thus, the support of such aircraft is difficult to provide and, together with the lack of newly manufactured spares, is likely to become increasingly so in the future.

Engine history

The engine was released to service with zero hours from overhaul in 1975 and returned for repair in 1976, having run for 69 hours. It was returned again in 1978 with a total running time of 269 hours for the replacement of some bevel gears. It was fitted to G-BVPP at 3,550 airframe hours, on 6 February 1987, with a total running time of around 403 hours, and inhibited in May 1993 after which it was not used for some two years. At the time of the accident some 3,670 airframe hours were recorded, indicating that the engine total running time was around 522 hours in the 29 years since it had been overhauled.

Fuel system description

At the time of the accident, G-BVPP was fitted with two under-wing slipper tanks and eight airframe fuel tanks were in use, Figures 1 and 2. (The two rearmost fuselage tanks were reportedly isolated.) Pneumatic pressure, bled from the engine compressor, is supplied to each slipper tank and causes the fuel to be transferred to the associated wing tank, from where it subsequently transfers into two pannier tanks, one located each side of the fuselage. From there, the fuel transfers to the fuselage centre tank group. All fuel tanks on the aircraft eventually feed into the No 1 centre tank in the fuselage, which contains a boost pump, from where the engine is supplied via the low pressure fuel cock (LPC). A flow proportioner ensures that equal volumes of fuel are taken from each tank group (left and right) to prevent any imbalance across the aircraft. A fuel low pressure switch, downstream of the engine low pressure filter, operates the FUEL warning light on both pilots instrument panels should the boost pump pressure be lost or the filter become blocked. Additionally, a fuel low level float switch triggers a warning light when the contents of the No 1 centre tank become depleted to a level that only assures sufficient fuel for a missed approach, a go-around and a landing.

A single fuel gauge in each cockpit indicates the total amount of fuel on the aircraft, and fuel levels (full/empty) in the slipper tanks are indicated by a pair of 'dolls-eyes'. Should pneumatic pressure be lost to the slipper tanks, any remaining fuel would not transfer to the fuselage tanks and would be unavailable for use. Similarly, some of the wing fuel would not transfer. Under such conditions a sensor in the pneumatic line, downstream of a pressure reducing valve between the engine compressor and the slipper tanks, should cause a fuel transfer (FTR) warning light to illuminate in both cockpits, and the fuel gauge would then only indicate the remaining available fuel on board.

The engine fuel control system consists of a low pressure fuel filter, a high pressure fuel pump, a combined control unit (CCU), a pressure ratio limiter (PRL), and an air-fuel ratio controller (AFRC). The CCU, PRL and AFRC are separate units connected to the high pressure fuel pump by a network of pipes, all of which provide fuel pressure signals to control the output of the pump, and hence engine speed.

Aircraft examination

General

Little physical examination of the aircraft could be carried out in the field whilst the aircraft remained on its belly so the aircraft was salvaged by the operator's maintenance organisation and returned to its base at North Weald Airfield. As the circumstances of the accident appeared to indicate a problem with the fuel system, the airframe and engine fuel systems were examined in detail, albeit some time after the accident.

With the aircraft standing on its landing gear, an examination of the underside showed that although most of the fuselage skins had been destroyed in the ground slide, the bottom of the No 1 tank and piping to the engine mounted fuel components remained intact. A small crack in the main fuel gallery between the boost pump and the engine main fuel filter, however, allowed a very slow weep of fuel to occur. With the batteries installed and power selected to ON, the fuel contents gauge indicated in excess of 700 lb of fuel remained on the aircraft.

Fuel system tests

A flow test, carried out with the boost pump running and the fuel gallery disconnected at the outlet to the engine, produced a flow of fuel from the No 1 centre tank well above the minimum figure specified in the available maintenance documentation and, when re-connected, the low fuel pressure warning light extinguished. Inspection of the low pressure fuel filter revealed no major contamination.

The engine was externally examined and found to be free to turn, with no visible damage to the compressor or turbine. Temporary repairs were made to the damaged lower lips of the engine intake ducts using 'speed-tape', and a successful attempt was made to start the engine. It was found to accelerate normally to approximately 50% of full speed, at which point further thrust lever movement had no further effect. The units forming the fuel control system on the engine were then selectively disconnected and, as appropriate, their open ends blanked, prior to conducting a series of engine runs. This revealed that when the AFRC was taken out of the control loop, 100% engine speed could be achieved, but only around 50% when either the CCU or PRL were disconnected. The AFRC was then removed from the engine with the intention of conducting a performance check on a test rig. It was noted that the compressor pressure sensing connection was heavily contaminated with what appeared to be soil, most likely occasioned during the forced landing.

The AFRC was manufactured by Lucas Aerospace, now part of the Goodrich company. Their fuel system specialists were able to access archived data relating to this unit and were able to modify an existing rig to facilitate testing. The results of the test indicated that, although its performance differed from the archived figures, when allowance was made for in-service wear and tear, and possible use of available adjustments on installation, the unit was probably capable of satisfactory operation when fitted to the engine, provided the correct compressor delivery pressure could be sensed.

The operator's maintenance organisation dismantled the airframe fuel system and examined all its components. Their observations on any abnormalities were:

- Contamination of a coarse mesh strainer in the connection between the left wing tank fuel/air air transfer pipe and the left No 1 (pannier) tank, was present in the form of a small strip of white sealant.
- Failure of the No 1 centre tank float switch had occurred due to the float becoming adhered to sealant in the roof of the tank.

Additional information

An accident involving a RAF Gnat during the latter years of its service, occurred after the engine lost thrust/flamed out. The crew ejected and the aircraft crashed into a grass covered field. Evidence of fuel splashing on the ground indicated that an asymmetric fuel state existed at the time of impact. It was established that the aircraft had been refuelled in error from one side only, the refuelling crew not realising that the flow proportioner did not allow significant fuel transfer across the aircraft. Although designed to allow the system to draw equal volumes of fuel from each side of the aircraft, the proportioner apparently drew air from the 'unrefuelled' tanks once their contents were depleted. This allowed the No 1 tank to empty and the engine to run down, the consumption rate of the engine being greater than the supply from only one group of fuel tanks. The investigation into this accident reportedly found that the No 1 tank low level float switch was not functioning. It is not known if slipper tanks were fitted to this aircraft.

A former RAF instructor pilot who had flown the Gnat for a large number of hours, recalled that he had once experienced asymmetric fuel consumption from each side of a Gnat when flying with slipper tanks. On that occasion, the condition became rapidly evident as he needed to apply increasing lateral stick force/deflection to maintain wings level flight. An early landing was carried out. This characteristic is referred to in the RAF Aircrew Manual for the Gnat as a *'possibility'*.

The Defence Air Safety Centre (DASC) was requested to review any data on fuel system, fuel transfer and related engine performance problems that might have been recorded by the RAF Directorate of Flight Safety during the service life of the Gnat. No events were identified that had any bearing on the accident to G-BVPP, although the basis upon which such events might have been recorded was not established.

The Civil Aviation Authority's policy with regard to permitting the operation of ex-military aircraft is contained in both CAP 632 *Operation of 'Permit-to-Fly Ex-Military Aircraft on the UK Register* and *BCAR A – Chapter A8-20.*

Analysis

Examination of the aircraft after its recovery to North Weald Airfield failed to determine the reason for the loss of power reported by the pilot shortly before landing. The engine tests and rig test of the AFRC left little doubt that the reason for the failure of the engine to accelerate during the post-accident engine runs was the contamination by soil of the compressor delivery pressure connection on the AFRC. As the aircraft reportedly carried out most of the flight without problems, it is reasonable to assume that the contamination occurred late in the flight and probably whilst the engine was running during the ground slide.

The post accident examination of the aircraft showed that a reasonable amount of fuel was present in the aircraft at the time of the accident, that sufficient fuel was contained within the No 1 tank for a satisfactory flow rate test to be conducted, and that it was physically possible for the engine to produce full power, albeit with the AFRC disconnected. However, the exact distribution of fuel within the aircraft during and immediately after flight, which is dependant upon the actual rate at which fuel flows from each side of the proportioner, may have differed from that at the time of testing. This is because it is possible that fuel may have transferred into the No 1 centre tank under the influence of gravity during the intervening period. After attempting a relight, the pilot reported that the engine remained at very low power and sounded as if it were idling which, together with the observed FUEL warning, suggests that a restriction or a lack of fuel in the supply line from the No 1 centre tank to the engine (manifested as a low delivery pressure) had occurred. Also, the normal indication that its contents are low is the warning light operated by the low level float switch, but that warning was found to have been inoperative and was unlikely to have provided any such indication during the last flight. If bleed air pressure in the fuel system had failed early in the flight, then it is unlikely that fuel from one or both slipper tanks would have transferred. If such a failure had occurred but affected only one tank, the pilot should have been able to detect this as an imbalance in roll as the slipper tanks are located well outboard on the wing. None was reported. However, should such a failure have occurred later in the flight and affected either one or both sides of the aircraft, most of the fuel would have been in or close to the fuselage and roll imbalance would have been more difficult to detect. Although no evidence of a failure in the fuel transfer air system was discovered during the investigation, the possibility that the No 1 centre tank became depleted due to a failure of fuel to transfer from one or both sides of the aircraft, late in the flight, leading to the loss of power, could not be dismissed.

Until the amber FUEL caption illuminated shortly before arriving back at North Weald, the pilot considered that the aircraft had been behaving normally. At this point it was reported that some 800 lbs of fuel remained on the aircraft, a figure consistent with 700 lbs indicated when the aircraft was powered up after the accident. Thus, complete exhaustion of the fuel on board the aircraft could be dismissed as a cause of the loss of power.

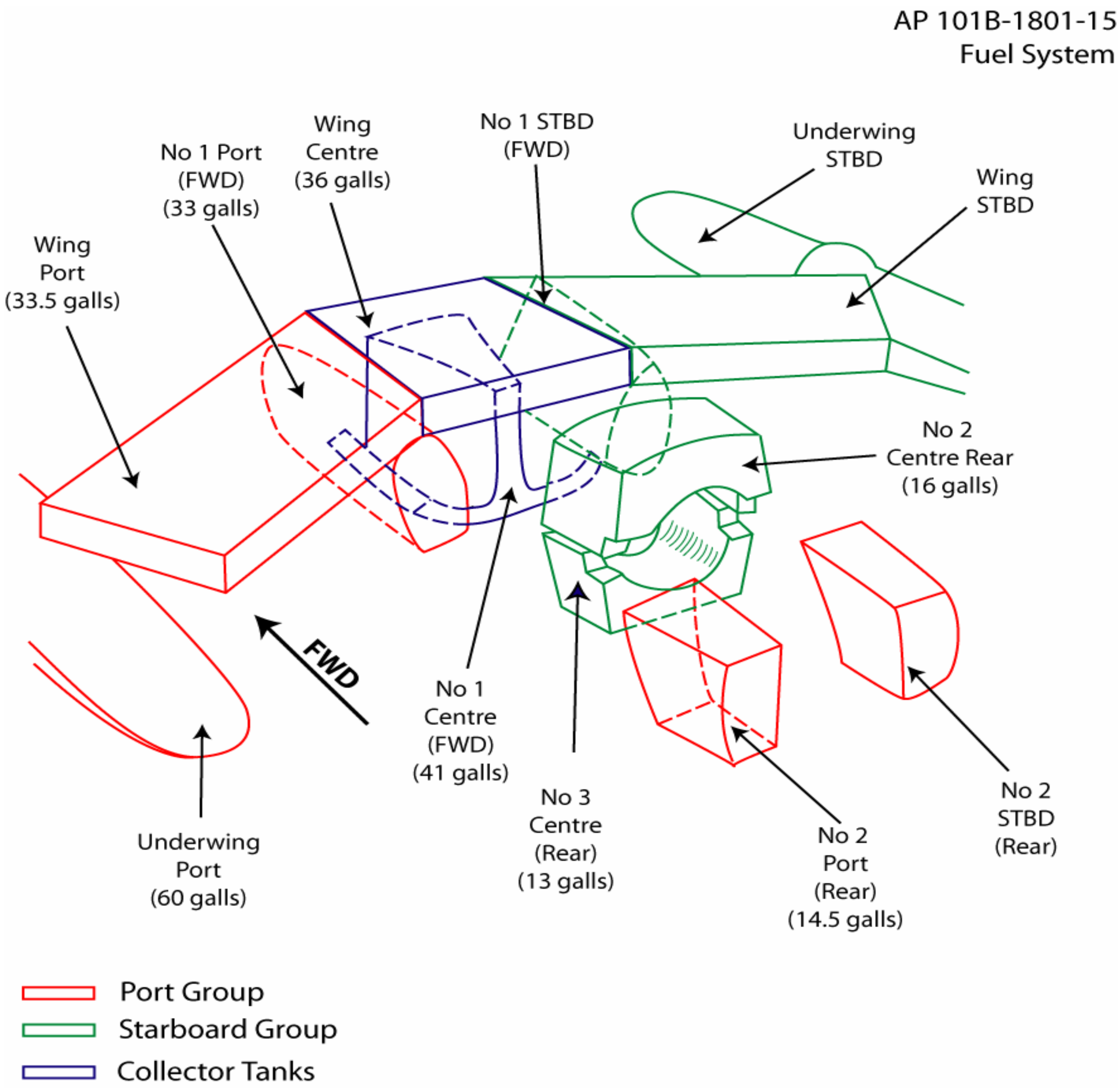
The FRCs relating to the Gnat were those published for use when the aircraft was in service with the RAF and, although information is given on the procedure for a belly landing on a runway, there is no such information for an off-runway landing. Indeed, the FRCs state that if a safe landing is doubtful then both crew members are required to eject. The aircraft was thought be have been above the minimum limits for ejection, ground level/90 kt, level or climbing, at the time the decision to land was made. Also, paragraph 5.2 of Chapter 7 of CAP 632, *Operation of 'Permit-to-Fly ex-military aircraft on the UK Register* stated that:

> *'Forced landings should only be carried out in jet aircraft as a last resort, unless they can be made onto a suitable airfield. If ejection or abandonment is inevitable, every effort must be made to ensure that the aircraft falls into an unpopulated area. ……..'*

Conclusions

In this event, a successful off-airfield forced landing was carried out at relatively high speed into a partially ploughed field, and the crew exited the aircraft uninjured. Welcome as that was, the prevailing advice indicates that ejecting would have been the preferred option and, in the circumstances, the crew were fortunate to avoid a much more serious outcome. However, had the crew ejected, then it is almost certain that the aircraft would have been destroyed, with the attendant risk that it may well have continued a short distance and crashed into an inhabited area. The investigation did not establish any definitive reason for the loss of power as the aircraft approached North Weald Airfield. It was, however, established that the engine and its control system should have been able to provide full power and so it became probable that a lack of, or a restriction in, the fuel supply to the No 1 centre tank occurred.

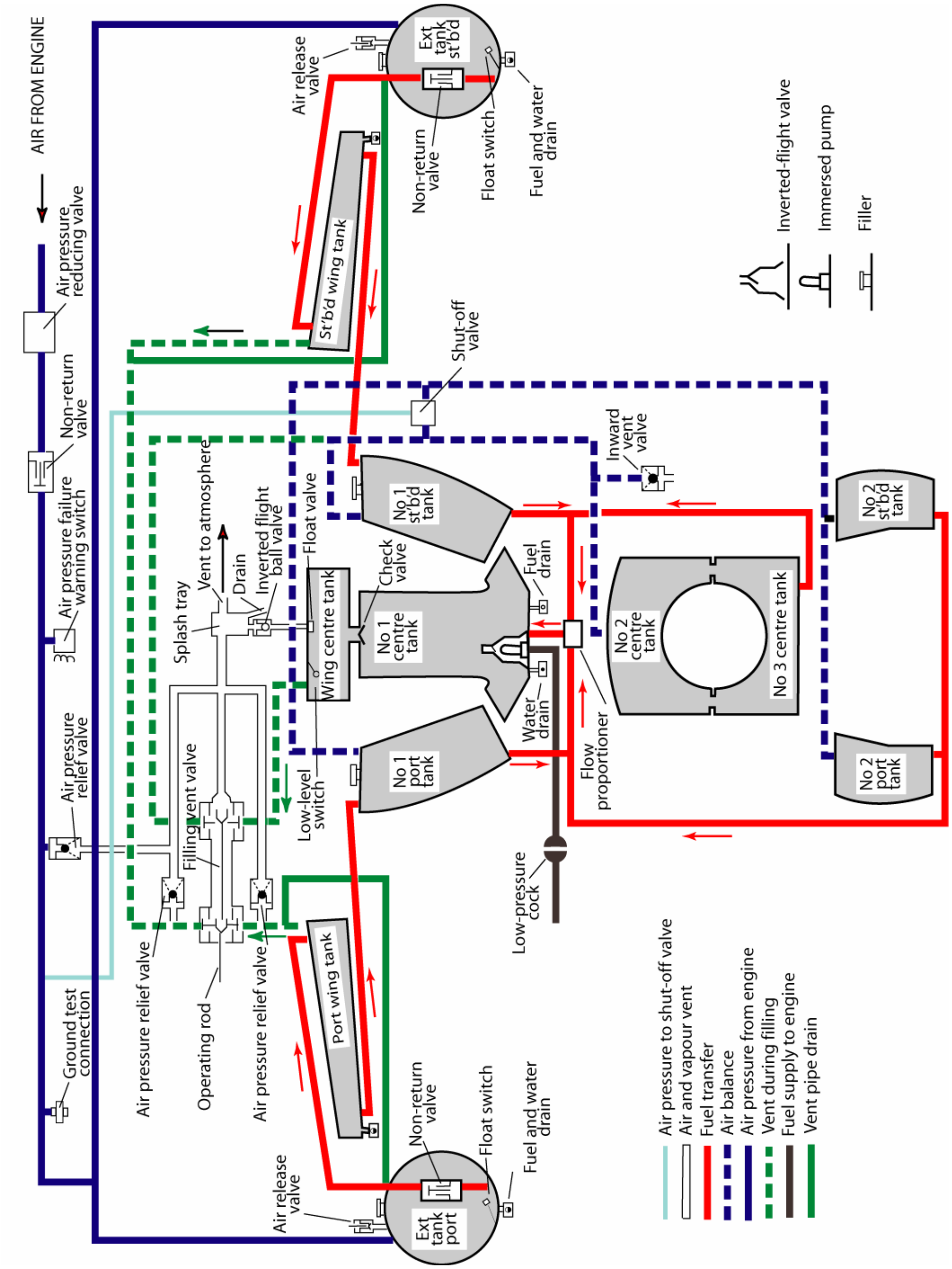
Figure 1



Fuel Tank Layout Diagram

(taken from GNAT T Mk 1 Aircrew Manual)

Figure 2



Fuel System Diagram

(taken from GNAT T Mk 1 Aircrew Manual)