Chapter 8

ENGINE STARTING

(Completely revised)

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LIST OF ILLUSTRATIONS

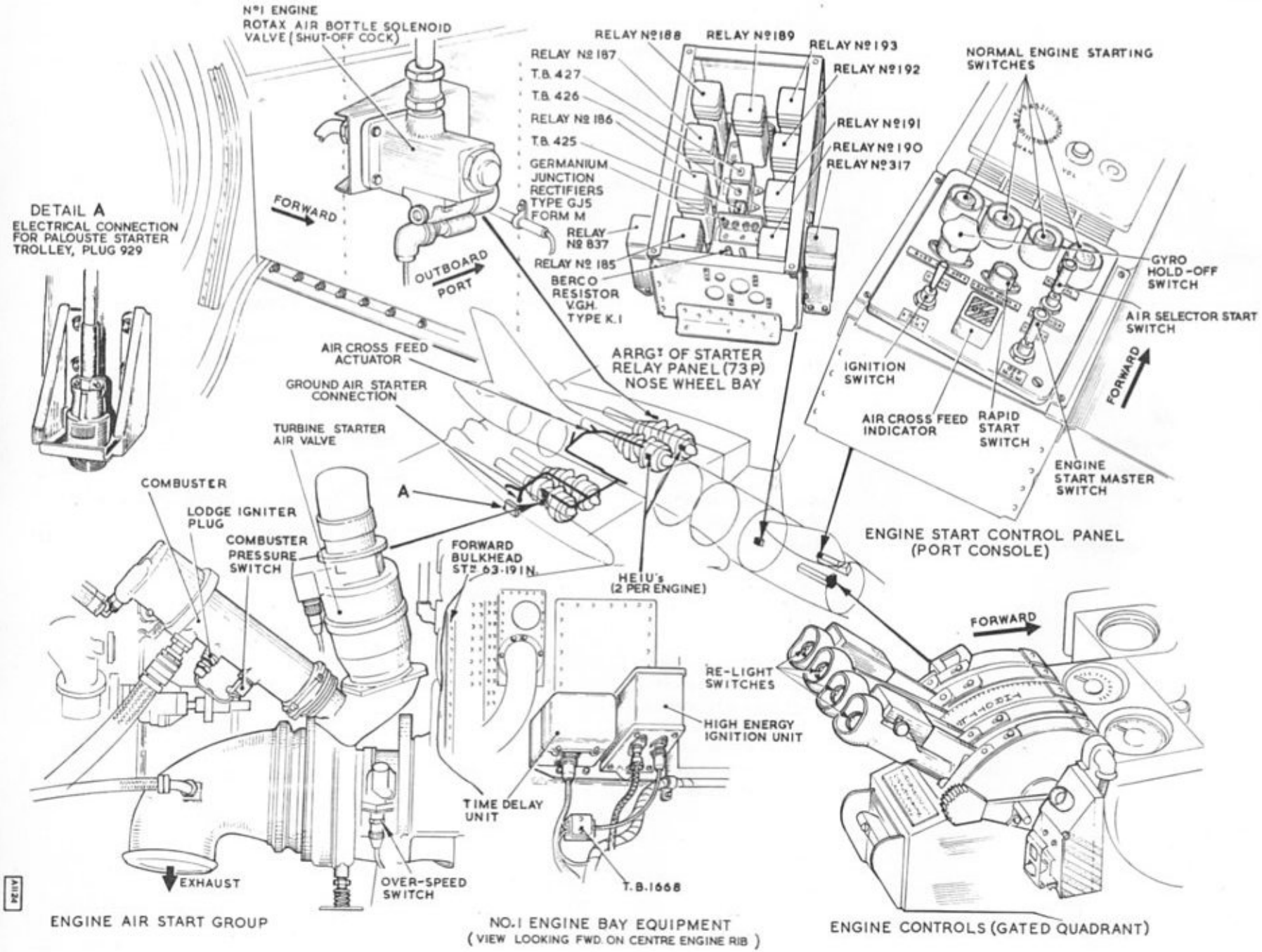

Fig.1 Location of equipment

Introduction

1. This chapter contains descriptive and servicing information on the normal and rapid engine starting systems. A general location illustration and theoretical circuit diagrams are provided with associated routing charts being included at the end of the chapter. The following modifications have been included in this chapter:-

Mod.1320 – Introduction of engine rapid starting system.

Mod.1615 – Introduction of fuel dipper valves.

Mod.1838 – Introduction of two additional air storage cylinders for rapid starting.

Mod.2235 – Introduction of a relay to render the engine fire warning systems inoperative with the aircraft in the standby configuration.

Mod.2251 Introduction of wiring changes to ensure that the MFS turn altitude system 'fast erects' when the engine start master switch is selected 'ON' following operation of the gyro hold-off pushswitch during aircraft standby conditions.

Mod.2263 – To remove the autoland leader cable and auto-throttle facility.

Mod.2376 – Introduction of individual fusing for engine HE ignition units.

Mod.2400 – Introduction of TB 1850 inside the throttle quadrant to facilitate renewal of damaged relight cables.

Mod.2418 – Introduction of a relay to isolate the rapid start circuits whilst a normal start is in progress.

Mod.2481 – Revision of wiring for CSDU oil temperature gauges (affects start circuit connections in engine bays).

DESCRIPTION AND OPERATION

General

2. The electrical power supply required for the engine start control circuits is provided from a ground electrical supply trolley or when not available from the airborne auxiliary power plant (A.A.P.P.). The engines are started by compressed air, each engine incorporating its own Lucas Aerospace air starting system, Type CT 1303, consisting basically of a combuster unit and a pneumatic starter which is geared to the engine. The air starting system is fully described in AP 103D-0218-13A7.

3. The pneumatic starter is supplied with air through either one of two annular air ducts incorporated in a manifold assembly. One supply, for normal engine starting, is provided by a Palouste ground starter trolley, the other supply, for rapid engine starting, is provided by the combuster unit fed by high pressure air storage cylinders. Normal engine starting is carried out individually but, having started one engine, bleed air from it can be used to start the remaining engines either singly or simultaneously. Using the rapid start system, engines can be started simultaneously using the rapid start push-switch, or singly by using the individual start push-switch

4. If an engine flames out whilst the aircraft is airborne, operation of the appropriate relight push-switch (one is fitted in each throttle lever) will energize the high energy ignition units associated with that engine

Components

Controls and indicators

5. The first pilot controls the engine starting from a panel fitted at the aft end of the port console (fig.1). Mounted on this panel are the engine start master switch, air selector start switch, ignition isolation switch, the four engine start push-switches, each incorporating an indicator lamp, the rapid start push-switch and a guarded gyro hold-off push-switch. A three-position magnetic indicator, showing the position of the AIR CROSS FEED COCK is also fitted to this panel. Note that prior to normal engine starting the engine air isolating cock switches, one for each engine located on the starboard console, should be placed to OPEN to admit the air to the turbine starter (para 6). The engine start master switch and air start selector switch are gated at each of their two selected positions, the switch toggles must therefore be pulled to allow selection from one position to the other. The ignition isolation switch controls the engine HE ignition units for starting only. The HEIU's remain inoperative from the re-light circuit with this switch at OFF. The HEIU's associated with the combuster units are controlled by the rapid start circuit only.

Air turbine starter

6. Each turbine starter incorporates an electrically operated air valve to control the supply of air from the ground trolley or the cross feed system, a pressure switch to monitor the starter operation, and an overspeed switch to cancel the starter operation as the engine accelerates under its own power. When air is supplied to the turbine, the build up of pressure within the unit operates the pressure switch which completes a circuit to the lamp incorporated in the appropriate start push-switch. When the turbine starter reaches a predetermined speed, the overspeed switch contacts open to de-energize the relay associated with that particular engine starting circuit. During the normal starting sequence this in turn de-energizes the air valve which closes under spring pressure to cut off the air supply.

Combuster unit

7. Each unit incorporates an air/fuel chamber, divided by a floating piston in the upper portion, and a combustion chamber with flame tube, igniter plug etc. in the lower portion. The lower portion is connected directly to the pneumatic starter. Fuel is supplied to the unit from the main low pressure fuel system whenever a fuel pump for that side of the aircraft is running. A small spring loaded valve between the air/fuel chamber and the combustion chamber retains the fuel until a rapid start sequence is initiated. Compressed air is then released from high pressure storage cylinders to enter the unit via a pressure reducing valve. The air is directed two ways; part of the supply is passed into the combustion chamber to flow over the flame tube, the remainder is passed through drillings in the unit casing to enter above the piston, in the fuel chamber. Pressure is applied to the piston and fuel is forced through a retaining valve and a calibrated orifice to enter the flame tube as a vapour. Ignition takes place and the resultant high energy gas is discharged into the turbine starter to spin the engine.

Control relays

8. The eleven control relays are fitted to panel 73P located on the port side of the nose-wheel bay (fig.1).

HE ignition units and time delay units

9. Eight high energy ignition units, Lucas Aerospace Type NB 25/3 or AEI C10TS/3 are fitted, two in each engine bay. The units are individually fused and are fed from the 28 volt dc vital busbars via the appropriate relays, when either the engine re-light push-switches are operated, or the engine start master switch and ignition isolation switches are selected ON and the engine start push-switch pressed.

10. Four further high energy ignition units, Lucas Aerospace Type NB 6103 are fitted, one in each engine bay to provide ignition for the combuster units. Each is controlled by a time delay unit Lucas Aerospace Type D 15202/1 mounted adjacent to it (fig.1).

Ignition unit stowages

11. Earthing stowages, one in each engine bay, are provided to accommodate the HT leads from the combuster ignition units during leak tests (para 45-46).

Fuel dipper valves

12. Due to the quick turnover of the engines during a rapid start cycle, it is necessary to restrict the normal intake of fuel. This is done by four fuel dipper valves, mounted one on each engine and connected into each fuel supply line. When the rapid start cycle is initiated the dipper valves are energized via the time delay units to by-pass part of the fuel supply to each engine. The valves are de-energized to admit normal fuel supplies when the starting cycle is complete

Air cross feed actuator

13. A cross feed cock is fitted into the air ducting between No 2 and 3 engines. The cock is opened or closed by means of an electrically operated actuator, controlled by the air selector switch (fig.1). With the switch selected to NORMAL the actuator moves the cross feed cock to the open position and this position is indicated on the associated magnetic indicator.

Supplies

Normal starting

14. For normal engine starting an electrical ground supply and a Palouste air supply unit are required. The air supply is fed from a turbo-compressor on the air supply unit via a delivery hose which is connected to a supply point on the aircraft air ducting system. This point is located in the AAPP compartment and access is provided through a detachable round panel on the underside of the compartment. In addition an electrical connection is made from the Palouste to plug 929 on panel 37P in the starboard main wheel bay.

Rapid starting

15. A ground electrical power trolley is required, but air for rapid starting is provided by two sets of five wire-bound high-pressure air

storage cylinders one set for the port (No 1 and 2 engines), and one set for the starboard (No 3 and 4 engines). The outputs from the cylinders are fed to the air/fuel combuster units and are controlled by electrically operated shut-off cocks and pressure reducing valves.

Ground standby

16. Rapid engine starting and take-off are normally preceded by prolonged periods of standby where certain aircraft services are switched on and held at readiness. Ground electrical supplies are connected to the aircraft (Sect.2, Chap.2) to enable the following services to be operational:-

Gold film windscreen
Air ventilated suits
AAPP heaters
UHF system
3kVA transformers (for 115 volt circuits)

The 115 volt ac is required for the following services:-

Engine instruments
Autostabilization system
MFS
Artificial horizons
U/V lighting

The 28 volt dc ground supplies are required for switching, indicators, general lighting and communications services. The total demand of the ac circuits required during standby is approximately 7.5 kW.

AAPP

17. Where no ground electrical power is available, the AAPP can be run to provide the necessary electrical supplies for either normal or rapid starting.

Operation

Normal engine starting

18. It is assumed that a Palouste air supply trolley and ground electrical supplies are connected to the aircraft, that the air isolation cocks (Chap.12) are selected to ON, and the engine controls are set for starting. Since the starting sequence for each engine is similar, and the recommended starting order is No 4-3-2-1 (Sect.4, Chap.1, para 78), the circuit operation for No 4 engine only will be described.

19. Refer to fig.2. With the engine start master switch and ignition isolation switch selected to ON and the air start selector switch selected to NORMAL a supply is fed from fuse 674 via contacts 2-3 of the master switch to prepare the circuit for normal engine starting. A supply from fuse 673 is fed via contacts 5-6 of the master switch to open the air cross feed cock, and, via the actuator limit switch, to the 'open' coil of the associated magnetic indicator.

20. When the No 4 engine start push-switch is pressed, the following circuit action takes place:-

(1) A supply is fed from fuse 674 via contacts 2-3 of the engine start master switch and contacts 2-2 of the push-switch to energize relay 193, the earth return for the relay being completed via poles F and C of the No 4 time delay unit and the No 4 overspeed switch contacts. Note that the TDU has no active function during normal starting.

(2) Contacts 193/6 open and 193/5 close to provide a hold-in circuit for relay 193. The push-switch can now be released.

(3) Contacts 193/4 close to energize the air delivery valve in the Palouste unit via plug 929 (C) and to energize relay 837

(4) Contacts 837/2 open to interrupt the circuit to the coils of relays 189 and 317, thus effectively isolating the rapid start circuit for all engines whilst normal starting is in progress.

(5) Contacts 837/1 close, providing a hold-in circuit for relay 837 from the engine start master switch.

(6) Contacts 193/3 close to connect a supply from fuse 674 via the engine start master switch contacts 2-3 and ignition isolation switch contacts 2-1 to energize relay 188 Contacts 188/1 and 188/2 close to supply the HE ignition units for No 4 engine from fuses 875 and 876.

(7) Contacts 193/2 open and 193/1 close to energize the turbine starter air valve solenoid. The valve will open to admit the air supply to turn the engine, and the pressure switch contacts will close to complete the earth circuit for the push-switch indicator lamp, lighting the filament.

21. As the engine starts and accelerates, the overspeed switch contacts will open to de-energize relay 193. As a result, relay 188 will be de-energized to isolate the ignition units. The Palouste and turbine starter air valve will be de-energized to close, and the pressure switch contacts will open to extinguish the push-switch indicator lamp.

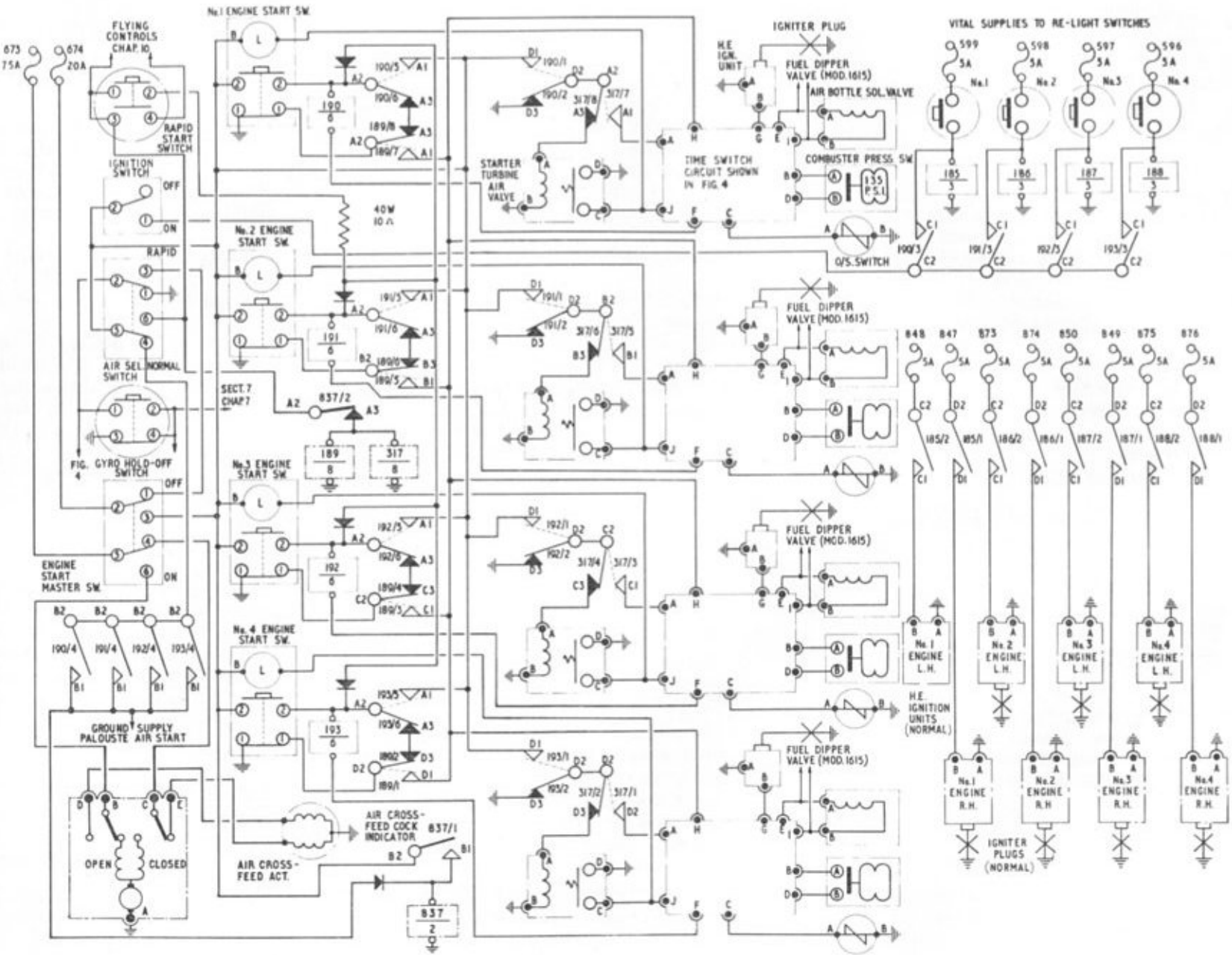

Fig 2 Engine starting circuit

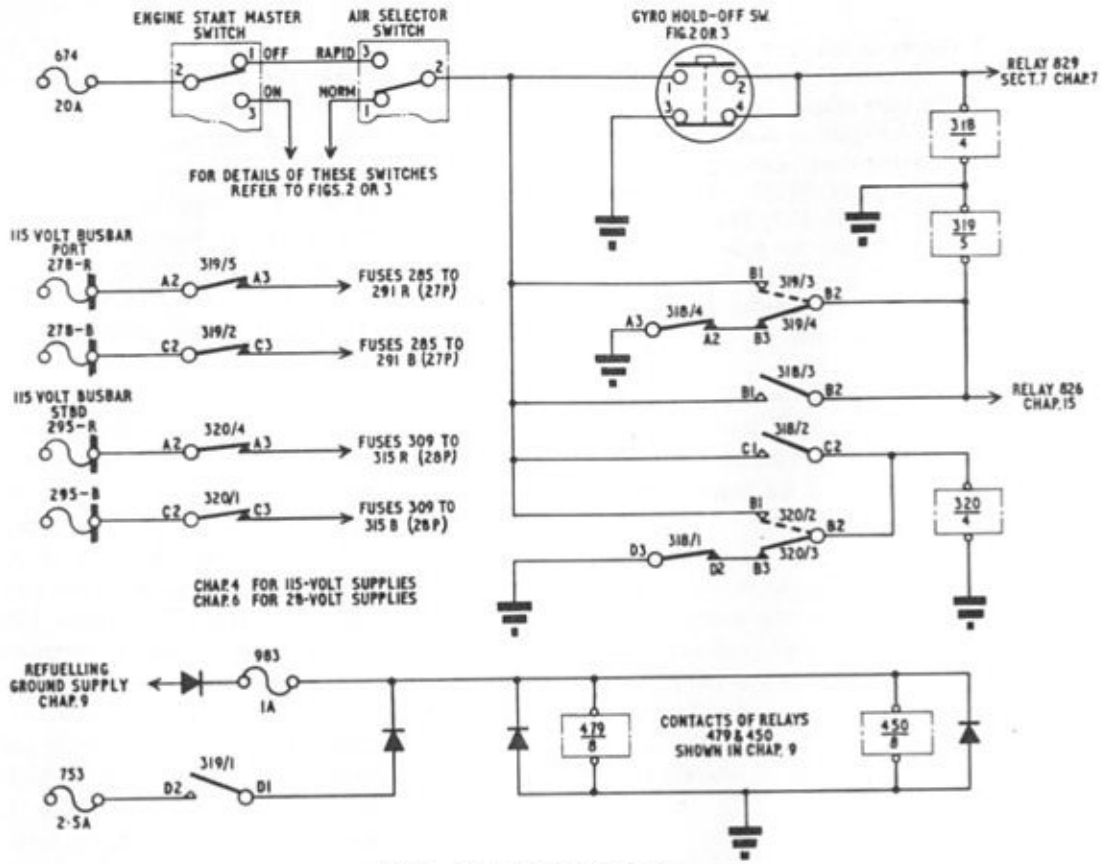

Fig.3 Gyro hold-off circuit

22. When all four engines are started and running, the engine start master switch and ignition isolation switch should be placed to OFF. A supply from fuse 673 via contacts 5-4 of the master switch to close the air cross feed cock, and energize the 'close' coil of the magnetic indicator.

Gyro hold-off

23. To prevent the instrument gyros running continuously and amplifiers being energized during extended standby periods, with consequent risk of early failure and shortened life, a hold-off circuit is incorporated. This circuit is brought into operation when the gyro hold-off push-switch is pressed whilst the engine start master switch is at OFF, and the air start selector switch selected to RAPID. A safety flap on the hold-off switch prevents inadvertent operation. Operation of the switch energizes relays 319 and 320, the contacts of which open to isolate sections of the 115 volt ac busbars, which, through appropriate fuses (fig.3) supply the MFS, artificial horizons, JPT limiters and vibrator units on the Mk.19F altimeters.

24. The hold-off circuit also includes the fuel contents amplifiers, which are isolated from the 28 volt supply when the gyro hold-off push-switch is pressed. The associated relays, 479 and 450, are energized and retained via contacts of relay 319.

25. To prevent operation of the circuit through spurious supplies, the positive side of relay 318 coil is held at earth potential by the normally closed contacts of the gyro hold-off switch, the positive side of relays 319 and 320 coils are earthed by contacts of relay 318, and the positive feed line to the gyro hold-off push-switch is earthed via contacts 201 of the air selector start switch whilst in the NORMAL position.

26. Assuming the aircraft is on stand-by with the appropriate ground supplies connected and the engine start master switch in the OFF position. Selecting the air selector start switch to RAPID, opens contacts 2-1 to remove the earth from the gyro hold-off switch and closes contacts 2-3 to complete the supply line to this switch. Pressing the gyro hold-off switch will result in the following circuit action (fig.3):-

(1) Contacts 4-3 of the hold-switch open to remove the earth from the positive side of relay 318, which is then energized by a supply from fuse 674 via contacts 2-1 of the engine start master switch, contacts 3-2 of the air start selector switch and the now closed contacts 1-2 of the gyro hold-off switch.

(2) Contacts 318/1 and 318/4 will open to remove the safety earthing from the coils of relays 319 and 320, which will then be energized by closure of contacts 318/2 and 318/3.

(3) Contacts 319/3 and 320/2 will close to provide hold-in circuits for their respective relay coils (the gyro hold-off switch can now be released and relay 318 will be de-energized).

(4) Contacts 319/5 and 319/2 will open, isolating fuses 285 to 291R and B from the 115 volt ac busbars, and contacts 320/4 and 320/1 will isolate fuses 309 to 315R and B from the 115 volt ac busbar. The associated instruments (para 24) will be isolated from the supply.

(5) Contacts 319/1 will close to connect a supply from fuse 753 to energize relays 479 and 450, the contacts of which open to isolate the fuel contents amplifiers from the 28 volt dc supply.

Rapid engine starting

27. The rapid engine starting circuit is so arranged that simultaneously with starting the engines the PFC motors will be started in sequence and the artificial feel circuits will be energized. Prior to initiation of engine starting the PFC and artificial feel failure warning lights will be illuminated. They will be extinguished in turn as the units run up.

28. With the circuits set as described in para 26, the engine starting circuits are prepared for simultaneous rapid starting of engines and for re-instatement of isolated circuits, by selecting the engine start master switch and ignition isolation switches to ON. This results in a sequence of operations as follows:-

(1) Contacts 2-1 of the engine start master switch are opened to remove the hold-in supply for relays 319 and 320. This will result in relays 319, 320, 479 and 450 being de-energized and the circuits previously isolated (para 24) will be reconnected to their supply busbars.

(2) A supply is fed from fuse 674 via the now closed contacts 2-3 of the engine start master switch, contacts 2-1 of the ignition isolation switch, air selector start contacts 5-6, and relay contacts 837/2, to energize relays 189 and 317. This supply is also connected to pole J of the rudder PFC time delay unit (Chap.10) to prepare for the starting of all PFC motors.

(3) A supply is fed from fuse 673 to open the air cross feed actuator. This action is incidental and is required as part of the normal engine starting sequence only.

(4) Contacts 189/8, /6, /4 and /2 will open to remove the safety earths (via the engine start push-switches) from the coils of relays 190 to 193, and contacts 189/7, /5, /3 and /1 will close to complete the same earth lines to pole H on each time delay unit.

(5) Contacts 317/8, /6, /4 and /2 will open to isolate the solenoid of each turbine starter air valve, and contacts 317/7, /5, /3 and /1 will close to prepare the energizing circuit at pole A of each time delay unit. (At the moment earthed via contacts 190/2, 191/2, 192/2 and 193/2).

29. When the rapid start push-switch is pressed the following circuit action will result:-

(1) The supply from fuse 674 is fed via the now closed contacts 3-4 of the push-switch to (a) energize relays 130, 132 and 133 (Chap.10) to engage the artificial feel units and (b) energize the rudder PFC time delay unit via pole M (Chap.10) which in turn will energize the elevons PFC time delay units, so that all PFC motors will be started up. Note that a supply is already connected to pole J of the rudder PFC time delay unit as indicated in para 28 (2)

(2) The same supply is fed via closed contacts 102 of the push-switch, the 40 ohm resistor and the respective diodes to energize relays 190 to 193, the earth side of the relays being completed via the time delay units (pole F contacts TS5 TS3 and pole C) and the overspeed switch contacts.

(3) Contacts 190/6, 191/6, 192/6 and 193/6 will open, and 190/5 191/5 192/5 and 193/5 will close to provide a hold-in supply for relays 190 to 193. The rapid start push-switch can now be released.

(4) Contacts 190/3, 191/3, 192/3 and 193/3 close to energize relays 185 to 188 respectively. The appropriate relay contacts will close to connect supplies from fuses 847 to 850 and 873 to 876 to energize the engine HE ignition units.

(5) Contacts 190/4, 191/4 192/4 and 193/4 will close but are applicable to the normal starting sequence only.

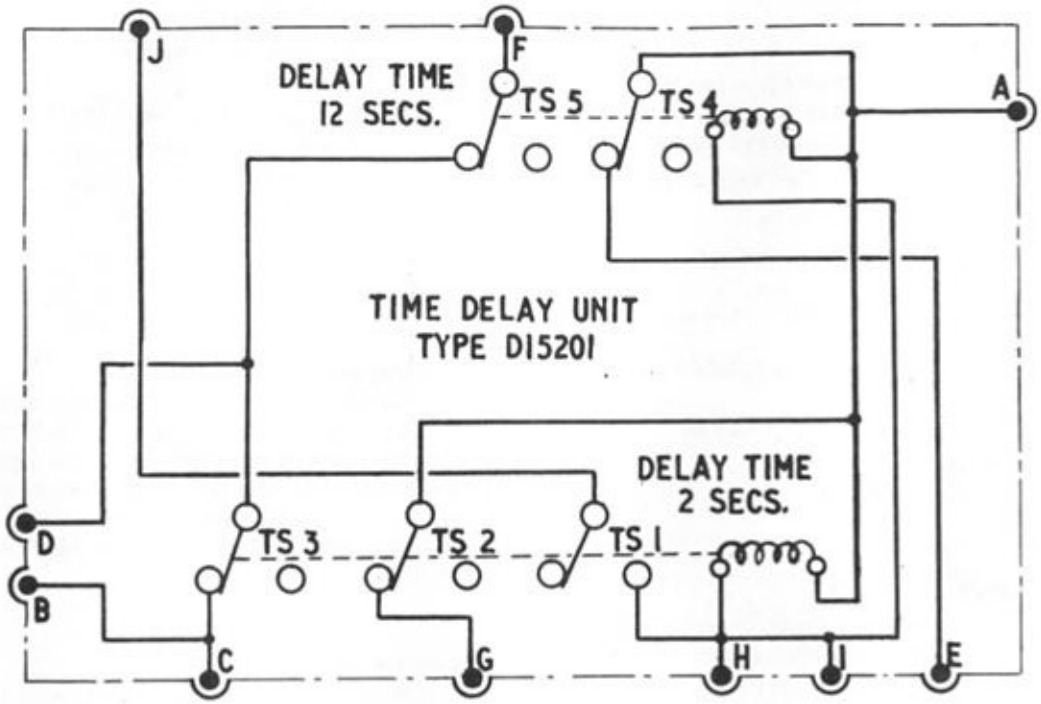

Fig.4 Time delay unit circuit

(6) Contacts 190/2, 191/2, 192/2 and 193/2 open and 190/1, 191/1, 192/1 and 193/1 close to energize the time delay units via poles A, the earth return being via pole H. The supply at pole A (fuse 674) is also fed via contacts TS4 and pole E to energize the air bottle solenoid valves, the fuel dipper valves, and via contacts TS2 and pole G, to energize the combuster HE ignition units. Rapid starting of the engines will now commence as described in para 7.

30. After 2 secs approximately contact TS1 will close to light the indicator lamp filaments in the four normal engine start push-switches, and contacts TS2, will open to break the supply to the combuster ignition units. Also contacts TS3 will open to break the earth return to relays 190 to 193 as outlined in para 29 (2). However, assuming that successful combustion has taken place, the combuster pressure switches will have closed to maintain the earth return via poles D-B-C of the time delay units, so that relays 190 to 193 will remain energized.

31. As the engines start and accelerate, the contacts of each overspeed switch will open to de-energize relays 190 to 193. As a result, the circuit will revert to the condition prior to the rapid start push-switch being pressed (para 29) Should a combuster unit fail to ignite, resulting in an abortive start, the pressure switch contacts will not close and the starting cycle for the engine will be shut down by the operation of contacts TS1. This ensures that sufficient air from the associated set of cylinders remains for a second rapid start sequence.

32. If for any reason the start cycle extends beyond 12 seconds, contacts TS4 will open to de-energize the air bottle solenoids and fuel dipper valves, and contacts TS5 will open to de-energize the relevant relay (190 to 193). After 15 seconds approximately, each time delay unit will be reset for a further starting cycle.

Restarting failed engine

33. Should an engine fail to start during a simultaneous start sequence, a second rapid start attempt is possible once the time delay unit has reset.

NOTE . . .
This must be done using the individual start push-switch for that particular engine, since further operation of the rapid start

switch would involve all engines in a start sequence when presumably three are already running.

34. Restarting an engine however can be carried out using bleed air from a running engine instead of using the rapid start facility, thus conserving the stored air supply. Should a second rapid start attempt fail, the engine can only be started by using bleed air or by connecting a ground trolley. The procedure to recharging the air storage cylinders is fully described in 1A of this publication.

Engine relighting

35. If an engine flames out in flight, the appropriate relight push-switch is pressed, energizing the relay associated with that particular engine ignition circuit (relays 185 to 188). The windmilling effect of the engine provides sufficient air to effect a relight.

36. If the No 4 relight switch is pressed, the circuit action is as follows:

(1) A supply is fed from fuse 596 in panel 3P via the closed relight switch contacts to energize relay 188.

(2) Contacts 188/1 and 188/2 close connecting a supply from fuses 876 and 875 respectively, to the No 4 HE ignition units.

SERVICING

AEI Type C10TS/2 – AP 113L-0109-16
Lucas Aerospace
Type NB25/3 – AP 113L-0114-13A6
Lucas Aerospace
Type NB6103 – AP 113L-0120-1

Relays

37. All control relays should be examined for pitting of contacts, cracked or broken mouldings and security of connections. Testing of the relays is described in AP 113D-0013-1.

Actuators

38. The actuators used on the installation should be examined at the periods laid down in the servicing schedule. Testing is covered in AP 113E-0267-1.

High energy ignition units

WARNING . . .
The high energy ignition unit HT voltage is lethal. A period of at least one minute must be allowed to elapse after switching off before any disconnection of these units is attempted.

39. The units should be examined at the periods laid down in the servicing schedule. Particular attention should be taken to see that the metal braided cables are not damaged. Testing of the units should be carried out in accordance with:-

Igniter plugs

40. The igniter plugs should be tested at the laid down periods in accordance with AP 113L-0601-1 for the engine items, or AP 103D-0218-1 for the combuster unit.

Turbine overspeed switch

41. These switches should be examined and tested in accordance with the instructions laid down in the engine handbook.

Turbine starter air valve

42. The valves should be examined in accordance with the instructions laid down in the servicing schedule. Testing should be carried out in accordance with the instructions laid down in the appropriate engine handbook.

Time delay units

43. The time delay units which are mounted adjacent to the combuster ignition units in the engine bays should be inspected at the appropriate periods for signs of damage, security and tightness of connections. Information on testing the units will be found in AP 113D-1445-1.

Combuster units

44. Descriptive and servicing information for the combuster units and associated components is contained in AP 103D-0218-1.

Leak testing

45. In the event of mechanical breakdown of a combuster unit for the purpose of replacing components, or wherever system joints have been disturbed, it is necessary on completion to carry out a pressure test to ensure that there is no gas leakage.

NOTE . . .
Leak testing must be carried out before a rapid start sequence is attempted.

46. Prior to carrying out leak tests it is first necessary to isolate ALL ignition circuits. The ignition circuits for normal starting (but not relight function) are isolated when the ignition isolation switch is at OFF. To isolate the combuster ignition unit, however, the HT lead from each unit must be disconnected at the engine bulkhead and connected to the adjacent earthing stowage, labelled EARTHING STOWAGE FOR RAPID START HE IGNITION CABLE in the engine bay. A leak test is done by energizing the rapid start circuit, WITHOUT ignition, for the engine concerned to give a 'wet' cycle. A full description of leak test procedure is given in Sect.4, Chap.1 of this publication.

Motor cycles

47. When dry or wet motoring cycles are being carried out to test the system, a Palouste air supply trolley must be connected to the aircraft, the ignition isolation switch must be in the OFF position and the air selector start switch set to NORMAL. The motoring cycles are fully described in Sect.4, Chap.1 of this publication.

REMOVAL AND INSTALLATION

General

48. No detailed instructions are necessary for the removal or installation of the engine starting components. All cable assemblies, however, must be safely stowed when disconnected from equipment. In the case of the HE ignition units, the warning contained in the servicing text and on the label attached to the unit must be observed.

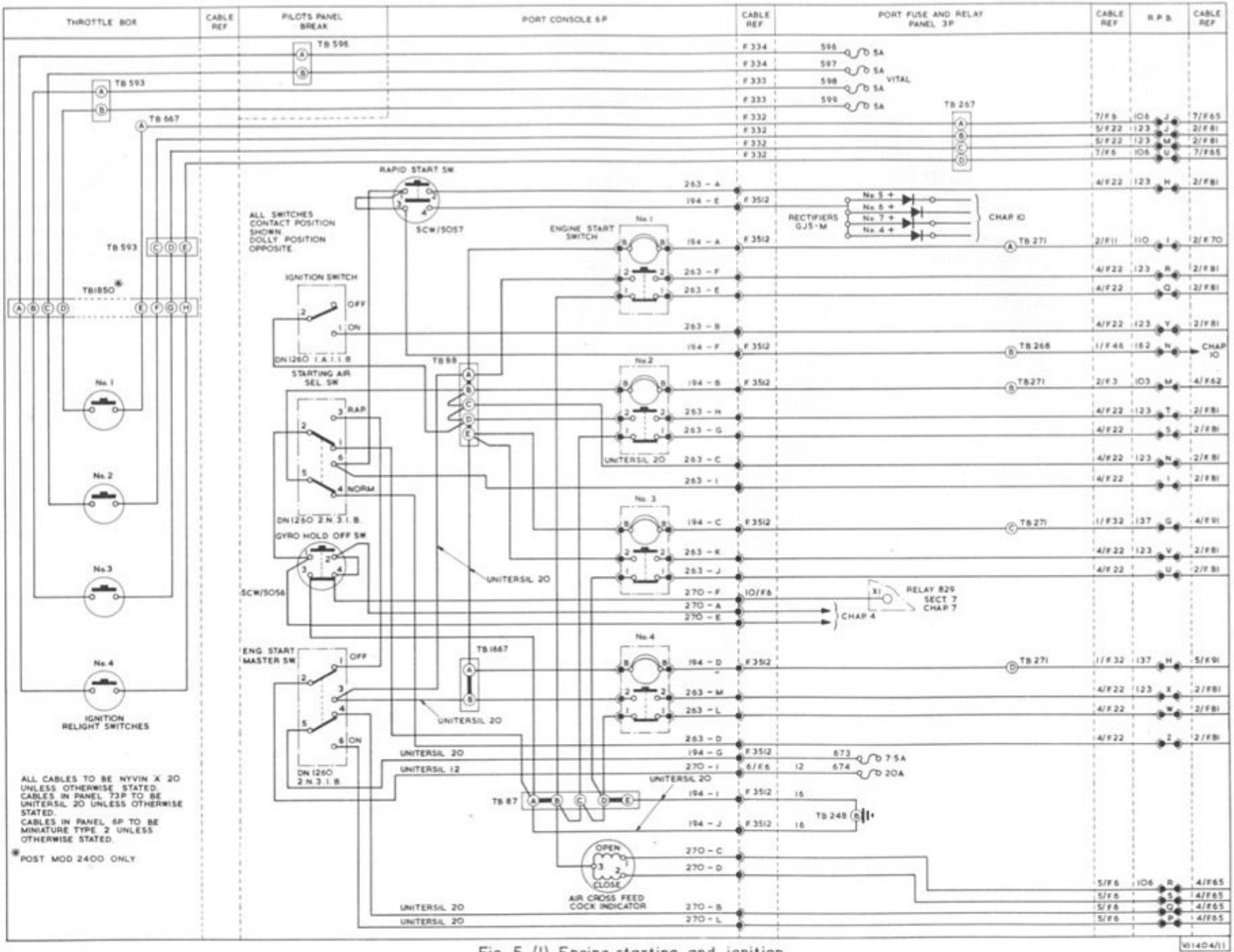

Fig 5 (1) Engine starting and ignition.

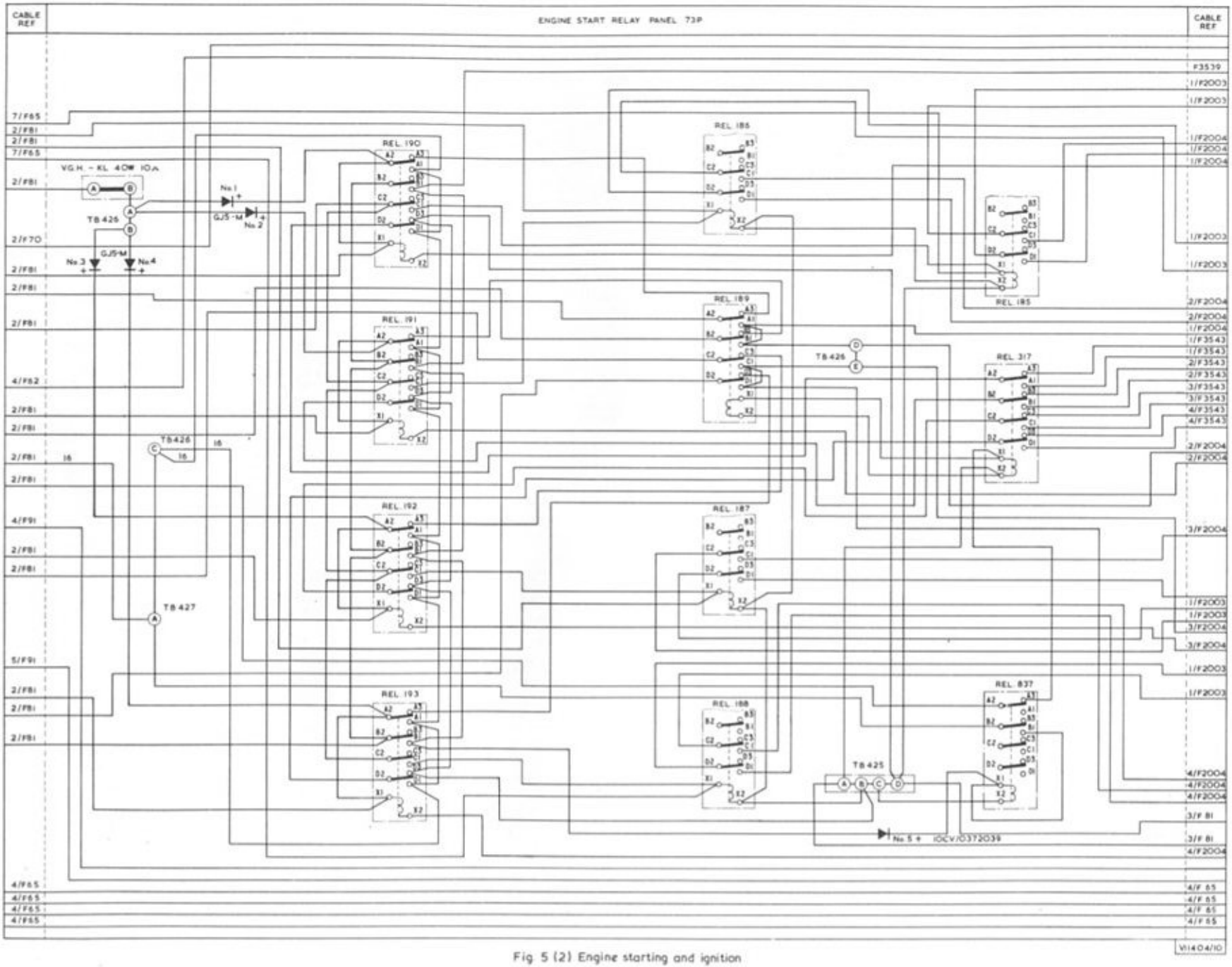

Fig. 5 (2) Engine starting and ignition

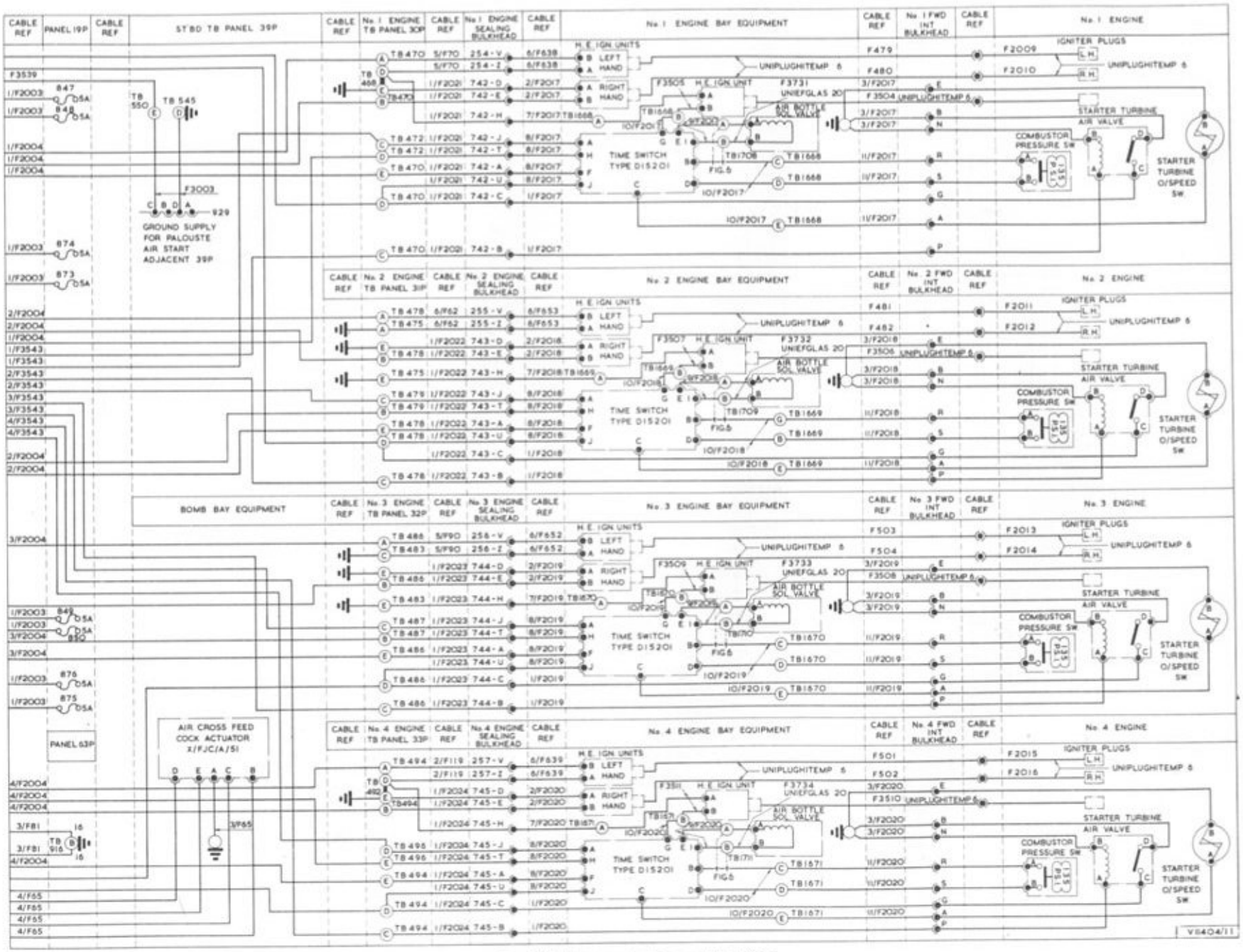

Fig. 5 (3) Engine starting and ignition

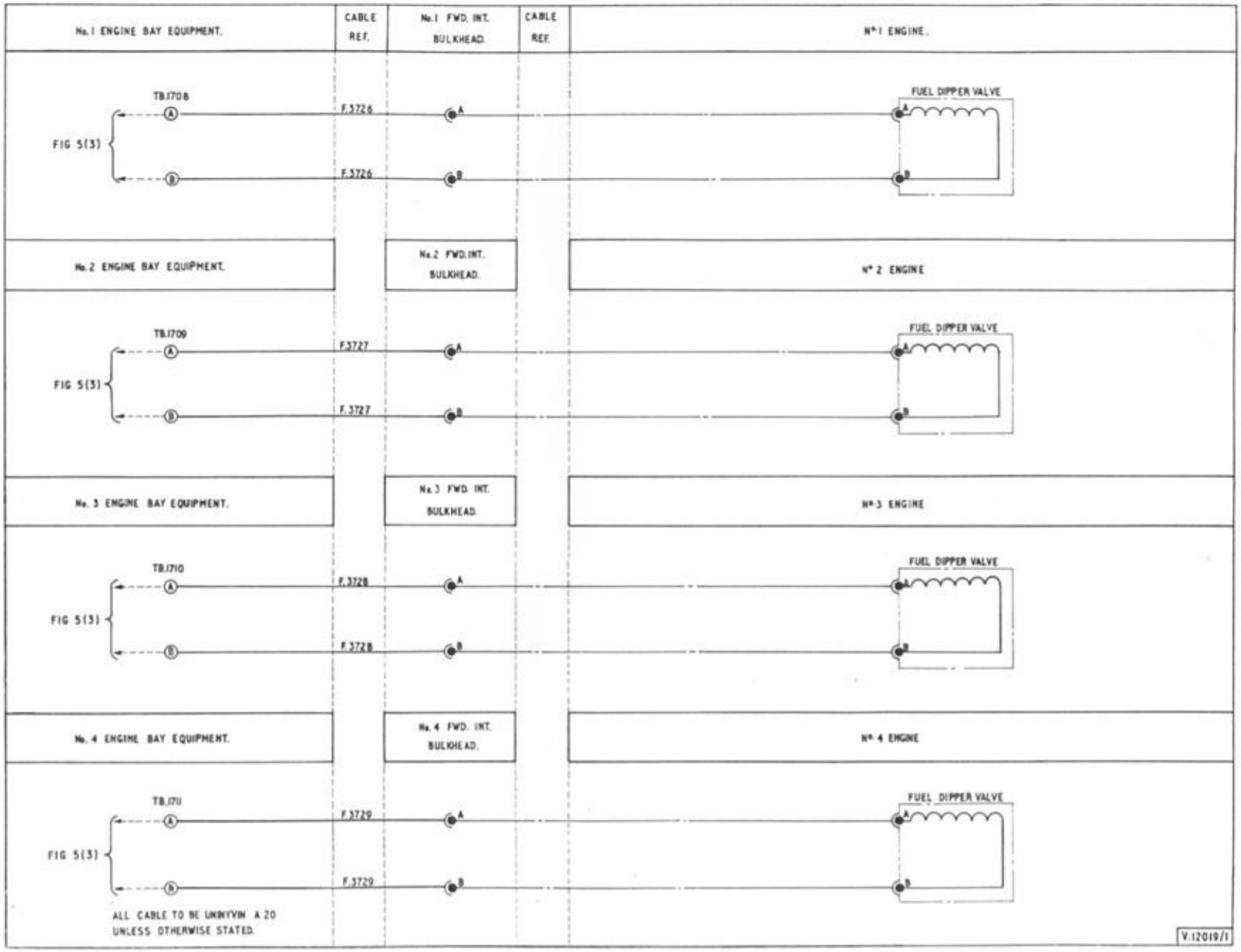

Fig 6 Fuel dipper valves