Part I—Description and Management of Systems

Chapter 10—Flying Controls

List of Contents

1 General

(*a*) Conventional aileron, elevator and rudder control surfaces are fitted and are operated by electro-hydraulic units, the elevators being hinged into the outer plane trailing edges inboard of the ailerons.

(*b*) To guard against complete loss of aileron or elevator control in the event of a power unit failure the control surfaces are divided into half sections, each operated by its own power unit. Should a unit fail, the surface half-section affected will trail or run down (see Part V, Chap 2, para 1). Duplicate control in the operation of the single rudder surface is achieved by providing two power units operating at opposite ends of the rudder actuator arm which is pivoted at the centre. Only one unit is necessary to operate the surface, the stand-by one coming into use automatically if the main unit fails.

(*c*) Dual interconnected control column handles and rudder pedals are provided in the pilots' cockpit, and artificial loading of the cockpit controls, as a function of aircraft speed, is introduced by spring-loaded feel units. Provision is made to trim these artificial loads with changes of aircraft trim.

(*d*) Both control column handles incorporate an auto-pilot cut-out switch (A/4), a press-to-transmit pushbutton (A/7), a nosewheel steering switch (A/2), a trim controller (A/5) for the ailerons and elevators which operates in the natural sense, and an aileron and elevator artificial feel relief switch (A/8). Each pair of rudder pedals incorporates a pair of toe pedals for the foot-operated brakes, and is adjustable for reach by a star-wheel (B/3) and (B/20) at the lower inboard edge of each pilot's instrument flying panel.

2 Power flying controls (PFC) units

(*a*) (i) Each unit is self-contained and consists essentially of an electric motor, a hydraulic ram and a differential lever assembly. Movement of the cockpit control operates the lever assembly to supply fluid to one side or other of the ram which, by movement of the ram rod, operates the control surface. When the control surface reaches a position relative to the displacement of the cockpit control, the fluid supply to the ram is automatically cut off and the surface ceases to move, remaining in this position until a further input movement is received by the power unit.

The power units are driven by 112-volts from three of the four 112-volt busbars. Failure of any one bus-bar therefore will affect only those power units on that bus-bar. The distribution of individual power units to bus-bars is listed at Part I, Chap. 7, Para 2(*h*). The power units are controlled from the 28-volt DC section.

(ii) If a PFC unit fails in flight, the control surface should normally " trail " in the neutral position. At high Mach numbers due to unpredictable hinge moments the control surfaces may move towards the fully down position. A decrease in Mach number should allow the control surface to return to the neutral position.

(iii) Each PFC unit is fitted with a run-down restrictor to prevent the control surface from tramping under gusty wind loads when the aircraft is parked. The run-down restrictor is in operation when a PFC unit fails or is switched off. In flight, if a PFC unit fails, any movement of the control surface towards the fully down position may be prevented or will be at a slow rate.

(*b*) *Starting controls*

Three pushbuttons (D/2), (D/1), (D/32) marked START AND ART. FEEL RESET, one each for the AILERON, RUDDER and ELEVATOR, are mounted at the rear of the central console, and are pressed in to start the units. Both the 112-volt and 28-volt bus-bars must be energised to make them work. When the aileron or elevator pushbuttons are operated the power units start automatically in the sequence, port outer, starboard outer, port inner and starboard inner, and the feel units are energised.

A delay of approximately 18 secs will occur before the last unit in each wing group starts.

NOTE: It is not possible to start the PFC motors on the ground unless a 112-volt ground supply is plugged in, or at least one engine is running, and its associated generator is connected to the bus-bar, and the 112-volt battery isolating switch is ON.

(*c*) *Stopping controls*

Ten pushbutton STOP SWITCHES (C/29) marked PFC SWITCHES, one for each power unit, are provided on the port console so that the units may be switched off independently. The push-buttons are arranged to present a plan view of their respective positions on the aircraft.

NOTE: Before leaving the aircraft and before the 28-volt isolating switch is set to OFF, all PFC STOP switches must be operated and the PFC stop indicator (C/28) must be white.

(*d*) *Indicators*

(i) Three POWER CONTROL WARNING red warning lights (A/23) are fitted at the top of the engine instruments panel, one each for the aileron, rudder and elevator systems. If any power unit for a surface is not functioning correctly the red light for its system will come on.

When a PFC unit is switched off, the red warning light for the appropriate system will indicate some 15 seconds later, except in the case of the starboard inner unit on the aileron or elevator systems, when the red warning light will indicate immediately. This is a normal feature of the systems.

(ii) The CONTROL SURFACES indicator (A/22) on the engine instruments panel shows the position of all the control

surfaces simultaneously. It enables the pilot to check that the controls are operating fully and correctly. Two datum lines, one vertical and one horizontal, are fixed in the centre of the instrument face and represent a view of the aircraft looking forward from the tail end. If a section of an elevator or aileron surface fails, the appropriate red warning light (A/23) will come on ; the section as shown on the control surface indicator will not respond when the pilot's controls are moved. There is, however, no indication on the CSI of a failure of the main rudder motor although the rudder failure warning light comes on.

(iii) A PFC stop indicator (C/28) is fitted to the port console adjacent to the PFC unit STOP SWITCHES. The indicator will remain black until *all* the power units have been stopped, when it will go white.

3 Artificial feel system

(*a*) *General*

(i) An artificial feel system compensates for the lack of loading on the flying controls and three feel units are provided, each adapted to give the degree of feel required for its particular control.

(ii) The artificial feel is brought into operation automatically when the START AND ART. FEEL RESET buttons, (D/1), (D/2) and (D/32) are pressed.

(iii) ARTIFICIAL FEEL magnetic indicators (A/27), one for each system, are at the top of the engine instruments panel and show black when the artificial feel is operative, and white when it is inoperative or not giving the correct feel for the airspeed obtaining. A master warning indicator (A/10) on the 1st pilot's instrument panel goes white if any one of the units is inoperative or working incorrectly. The pilot must then look at the other three indicators (A/27) to determine which system is at fault.

(iv) An artificial feel relief switch (A/8) on the control column enables the aileron and elevator feel to be reduced to a fixed low speed value. A separate switch (B/27) marked RUDDER ART. FEEL RELIEF on the fuel contents gauges panel permits

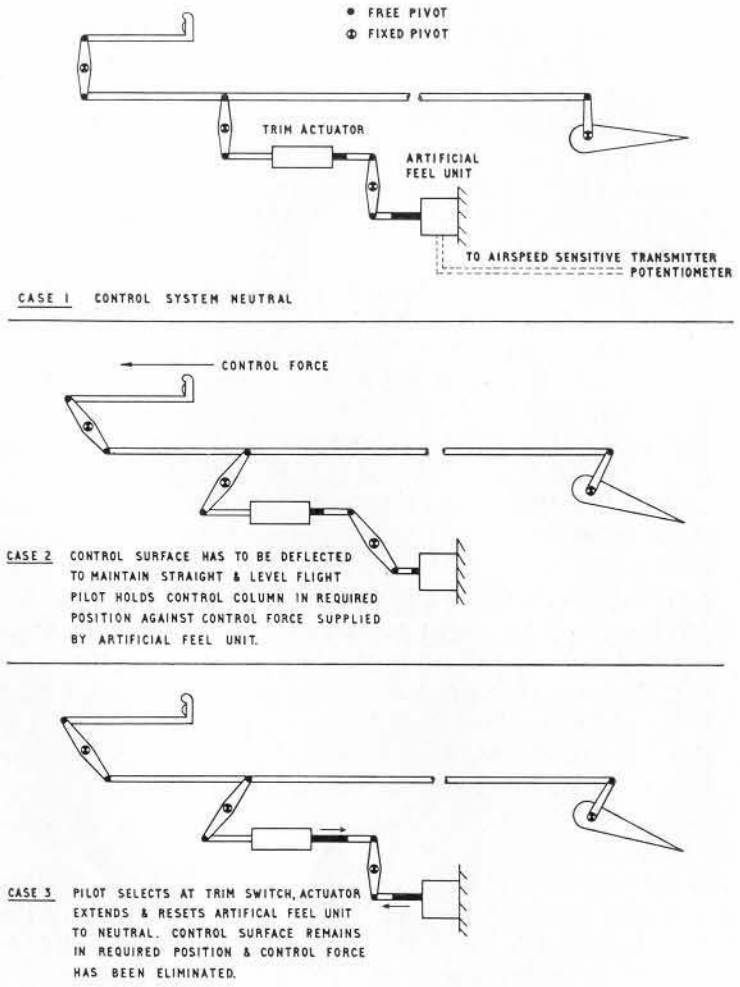

Fig. 1 Artificial Feel System

the rudder artificial feel to be reduced to a fixed low speed value. To re-engage normal artificial feel the appropriate START AND ART. FEEL RESET switch (D/1), (D/2) or (D/32) should be pressed in when the aircraft is in trim.

(v) Mod. 1927 introduces a guarded FEEL-LOCK switch marked NORMAL-LOCK with an associated green indicator light on the port console. The light comes on when the switch is set to LOCK and the appropriate feel relays have operated, locking the artificial feel and feel relief actuators of all three channels.

(vi) In order to prevent a feel failure causing the feel to run down to the low speed value when flying at speeds above 250 knots at low altitudes, the switch should be set to LOCK when the desired speed is reached and a check made to ensure that the light comes on.

(vii) If the airspeed is changed by more than about 30 knots from the speed at which the lock is engaged, artificial feel warning is indicated on all three channels, the master indicator shows white and, if speed has been reduced, the out-of-trim and manoeuvring forces are higher than normal.

(viii) Before unlocking the feel, speed should be reduced to below 250 knots and the control forces trimmed out. After unlocking, ensure that the feel warnings disappear and the green light goes out. Ensure that the feel forces are at the appropriate level before making any large control movements.

(ix) The artificial feel lock, if fitted, should always be operated before opening the bomb doors at low level.

(*b*) *Elevators*

The artificial feel is fed back as a stick force applied as a function of elevator angle and airspeed in the ratio " the square of the indicated airspeed ". When the feel is relieved only a small fixed pre-set degree of feel is retained (appropriate to 80 knots) ; stick forces therefore will be very much lighter than normal, particularly at high speeds.

(*c*) *Ailerons*

The artificial feel system provides simple spring feel to give approximately 11 ± 2 lb. stick force at the maximum aileron and stick deflection which can be applied at any airspeed. Full aileron stick force is possible up to approximately 310 knots ; above this speed the range of aileron angular movement is progressively reduced by variable stops in the artificial feel mechanism. Since the stick forces are not a function of airspeed the pilot will have no indication, from feel alone, of failure in the system and must rely, therefore, on magnetic indicators. Failure or malfunction of the variable stops will permit application of excessive aileron angles at speeds above approximately 310 knots but it is unlikely that the pilot will notice that he is able to displace the control column over a greater arc than normally.

(*d*) *Rudder*

The artificial feel is fed back as a foot-force applied as a function of rudder angle and airspeed in the ratio " the cube of the indicated airspeed ". When the feel is relieved only a small pre-set degree of feel is retained (appropriate to 140 knots) ; foot-forces therefore will be very much lighter than normal, particularly at high speeds.

4 Trimming

(*a*) *General*

(i) As the flying control system is irreversible, aerodynamic loads are not transmitted to the control column or rudder pedals. Control forces felt by the pilot in flight are produced by compression or extension of the feel mechanism in response to control movement, or change in airspeed. Trim adjustment is made by varying the length of the control run between the pilot's control and the artificial feel units by means of an electrically-operated actuator which removes the load by re-setting the spring feel mechanism.

(ii) Each actuator is a single unit containing two motors, one for normal trim operation, and the other as a stand-by for emergency use.

(*b*) *Normal trimming—ailerons and elevators*

(i) A two-axis trimming switch (A/5) spring-loaded to the central off position, is fitted on each pilot's control handle, and operates in the natural sense.

(ii) The circuit is designed to guard against a " runaway " trim. If the trimmer " runs away ", the switch must be moved in the reverse direction (either for the elevator or the ailerons). This breaks the normal trimming circuit (either elevator or ailerons) and trimming must then be carried out on the emergency trimming control. This safety device can be tested by operating the trimming switches on the 1st and co-pilot's control column handles in opposite directions simultaneously. This will cause the normal trimming circuit to be cut out and the TRIM indicator (A/26) at the top of the engine instruments panel, which is normally black, will go white. The normal trimming circuit can be regained by pressing and releasing the TRIM reset switch (D/19) on the central console.

(*c*) *Normal trimming—rudder*

Twin guarded three-position switches (B/25) marked RUDDER TRIM PORT—STBD, spring-loaded to the central off position, on the fuel contents gauges panel, control the rudder trim in the natural sense. The switches are designed to prevent a " runaway " trim by the fact that both the positive and negative lines of the circuit are disconnected when the switches are released to the off position. Both switches must be selected before the trimmer will operate.

(*d*) *Emergency trimming*

(i) If any of the normal trimming circuits fail, the EMERGENCY TRIM control (D/17) on the central console may be used (irrespective of the indication given by the TRIM indicator (A/26)) to operate any of the three trimmers. The emergency trim control operates in the natural sense but the central button must be held in while the control is being used, so as to energise the emergency trim circuit.

(ii) In the case of a " runaway " aileron or elevator trimmer which has been corrected on the pilot's normal trimming control, the aileron and elevator TRIM indicator (A/26) will show white. In this case no attempt should be made to regain the normal trimming circuit but the emergency trimmer should be used. If there is a fault other than a " runaway ", the normal trim will be inoperative but the TRIM indicator (A/26) may not turn white, and an attempt should be made to regain the normal trimming circuit by operating the aileron/elevator normal trim RESET switch (D/19).

(iii) In the case of the rudder, if the normal trimmer fails to function the emergency trimmer control must be used.

5 Starting the powered flying controls

(*a*) Before starting any of the PFC units check that all ground personnel are clear of the controls and that either an external 112-volt supply is connected or the engine generators are on line. The engines must be run at the minimum speed at which the generators are effective on full load, i.e. 32%, before starting the PFC units. Check that the PFC stop indicator on the port console is white and that the PFC red warning lights are on.

(*b*) Bring the PFC motors into operation by pressing the three START—ART FEEL RESET buttons. Select each button in turn with a delay between each selection until the appropriate PFC red warning light for the surface has gone out and the feel indicator has gone black. When all units for all surfaces are functioning, the three PFC red warning lights should be out and the three feel indicators and the master feel indicator should be black. The PFC stop indicator should be black when any of the units are running.

NOTE: Pending modification action, before switching on the rudder PFC motors, apply and maintain full port rudder until the power control warning light goes out, which should occur immediately after switching

on. Starboard rudder should not be applied until the warning light is out. Otherwise oil pressure build-up in the tail cone of the rudder stand-by PFC can result, with possible damage to the end cap of the damper valve assembly.

6 Testing the controls

(*a*) Test the flying controls for full, free and correct movement over full range of travel. Compare movement of control surfaces with the CONTROL SURFACES indicator.

(*b*) Press the main rudder PFC unit stop button; test operation of the standby unit ; then re-engage the main unit by pressing the rudder START—ART FEEL RESET button.

(*c*) Press the elevator/aileron and rudder artificial feel relief buttons, and check that the individual artificial feel indicators and the master artificial feel indicator are white. Re-engage artificial feel by pressing the START—ART FEEL RESET pushbuttons and check that all artificial feel indicators are black.

7 Testing the trims

(*a*) Select opposite aileron trim on the two control column switches thus tripping the main motor. Check that the TRIM indicator goes white and that the normal trim switches are inoperative ; press the trim reset switch and check that the indicator returns to black. Then select opposite elevator trim on the two switches and check that the TRIM indicator goes white and that the normal trim switches are inoperative.

(*b*) Test operation of the emergency trimmer over full range of movement in each of the three control surfaces, ensuring that the emergency trim system does not operate unless the central button is first depressed, then return to neutral. Then press the trim reset switch and check that the TRIM indicator goes black.

(*c*) Test normal trim for ailerons and elevators over full travel and return to neutral. Check movement with CONTROL SURFACES indicator and leave control column neutral.

(*d*) Ensure that the halves of the RUDDER TRIM switch do not operate rudder trim when moved independently. Test by moving both halves together over full range of travel and return to neutral. Check movement with CONTROL SURFACES indicator and leave rudder bar centralised.

8 In flight

(*a*) If any PFC unit is deliberately stopped in flight it must not be left off for a period longer than 15 minutes if it is intended to restart it in flight ; damage may occur to a unit if it is switched off for longer periods under low temperature conditions, allowed to cool and then restarted. The unit may be restarted by pressing the START AND ART FEEL RESET button for the appropriate surface, but account should be taken of a possible delay of up to 18 secs due to the time sequence starting circuits. To minimise this delay and thus avoid unpleasant characteristics during an overshoot, the port outer aileron or elevator PFC only should be stopped for practice landings.

(*b*) After switching on a PFC unit an interval of 15 seconds must must elapse before an adjacent PFC it switched off, otherwise wing flutter may result. Not more than one PFC may be switched off at the same time.

(*c*) Any of the PFC failure warning lights may flicker momentarily or come on for a few seconds, especially when manœuvring at high altitude. This does not necessarily mean that a PFC unit has failed ; if doubt exists checks should be made on the control surfaces indicator.

(*d*) (i) If an aileron or elevator PFC unit fails in flight it will be indicated by the red failure warning light illuminating. Determine which unit has failed by reference to the CSI. Press its stop button and attempt to restart the surface by pressing the appropriate START AND ART FEEL RESET button.

(ii) In the event of the rudder PFC failure warning light becoming illuminated the STANDBY rudder motor must first

be stopped until it is established which unit has failed. If the main rudder unit is stopped first a runaway may occur. Having stopped the standby unit if the rudder operates normally then the standby unit is unserviceable and must remain stopped. If, however, the rudder is inoperative the main unit is unserviceable and it must be stopped and the standby unit restarted.

(*e*) In the event of certain combinations of generators, bus-bar or battery failure some of the PFC units may fail or will have to be switched off. Detailed cases of failure are listed at Part V, Chap 2, para 13. If all the generators fail in flight, the 96-volt battery will provide sufficient power to operate the PFC units for a period of time depending on the state of the battery and the amount of load-shedding which has been carried out. (See Part V, Chap 2, para 14.)

9 Stopping the powered flying control units

(*a*) The PFC units must be stopped before the aircraft engines are closed down, by pressing the 10 stop-buttons on the port console. When all units have ben shut down check that the PFC stop indicator shows white.

(*b*) When stopping a PFC motor it is necessary to give each stop button a deliberate push for about two seconds to ensure that both the engage relay and the full speed relay has been tripped. If the stop button is merely jabbed it is possible for the stop indicator to show white with a full speed relay still latched on.

10 Pitch damper system

(*a*) *General*

This system is basically a Mk 2 autostabiliser installation (see AP 129) its purpose being to improve the natural damping of any pitching oscillations of the aircraft at high mach numbers.
The equipment has two channels to provide separate operation of the outboard elevator surfaces, the servo actuators forming part of the mechanical feed-back linkage of the outboard elevator PFC's. The stabilising system is operated by AC supply at 115-volts 400 CPS from the No. 3 inverter (port pitch damper) and the No. 1 inverter (starboard pitch damper), with an alternative supply available for either channel from the No. 2 inverter. The actuator motors are operated by a 28-volt DC supply.

When Mod 458 is embodied the pitch damper servo actuators are equipped with thermostatically controlled heaters to prevent the servo motors icing up at altitude. The contacts of the thermostats are set to close at temperature below 0°C.

(*b*) *Controls*

The normal switch control of the system is in effect the transmitting machmeter switch which forms part of the auto-mach trimmer (see para 12 below). This allows the circuit to operate at altitudes in excess of 20,000 feet. Two PORT—STBD ON—OFF switches (D/3) on the centre console controls the DC supply to the pitch damper servo actuators. The pitch dampers should normally be left ON whether the aircraft is flying or on the ground, the OFF position being used only if failure of a system occurs.

11 Yaw damper system

(*a*) *General*

This system is basically a Mk 2 autostabiliser installation (see AP 129) its purpose being to improve the natural damping of any yawing oscillation of the aircraft. The yaw damper is in series with the rudder control run to the PFC motors. The stabilising system is operated by AC supply at 115-volts 400 CPS from the No. 3 inverter, with an alternative supply from the No. 2 inverter. The actuator motor is operated by a 28-volt DC supply. Engagement of the rudder channel of the auto-pilot automatically isolates the yaw damper system.

(*b*) *Controls*

AN ON—OFF switch (D/29) on the centre console controls the DC supply to the yaw damper servo actuator. It should normally be left ON whether the aircraft is flying or on the ground, the OFF position being used only if failure of the system occurs.

12 Auto-mach trimming system

(*a*) *General*

The purpose of the auto-mach trimming system is to overcome static instability due to a rearward shift of the centre of pressure at mach numbers above 0·89M, by automatically trimming the elevators through a servo motor actuator. The system is operated by AC supply at 115-volts 400 and 1,600 CPS from the No. 3 inverter, with an alternative supply available from No. 2 inverter. The system is controlled by a 28-volt DC supply but is inoperative below 20,000 feet by the action of an altitude switch. The auto-mach trimmer is isolated should the elevator spring strut operate when under auto-pilot control.

(*b*) *Controls*

(i) The pilot's control is a 3-position ON—OFF—RESET switch (D/31) on the centre console, the switch being spring-loaded from RESET to OFF. An AUTO-TRIM magnetic indicator (D/30) forward of the switch goes white when the servo is in any position other than the fully retracted.

(ii) When the auto-pilot is fitted, a MACH TRIM LOCKOUT magnetic indicator (A/17) is fitted on the 1st pilot's instrument panel. The indicator shows white if the auto-mach trimmer is not switched ON, or if the auto-mach trimmer lockout relay is energised (see Part I, Chap 14, para 6).

(*c*) *Operation*

(i) The switch should normally be left in the ON position, since the system is isolated by an altitude switch below 20,000 feet. The auto-mach trimmer will begin to apply up-elevator from 0·86M and the AUTO-TRIM indicator will go white at about 0·88M. As mach number is increased the amount of up-elevator applied by the auto-mach trimmer is increased.

(ii) The RESET position of the switch can be used to return the auto-mach trimmer servo to the retracted position, should it fail to do so when mach number is reduced.

(iii) Positive and negative-G cut-outs are incorporated to prevent the servo moving if the normal acceleration of the aircraft exceeds 1·7G or is less than 0·7G.

(iv) Should the MACH TRIM LOCKOUT magnetic indicator go white, with the auto-mach trimmer switched on, the auto-mach trimmer servo will remain at the setting at the time that the indicator went white. If the reason for the magnetic indicator going white is due to the elevator spring strut disengaging the auto-pilot, the auto-mach trimmer may be made operative again by setting the auto-mach trimmer control switch OFF and then reselecting ON. However, if the auto-mach trimmer servo is extended, or if speed is above 0·88M, speed should be reduced below 0·88M and the servo retracted gradually by use of the RESET position of the control switch before switching the auto-mach trimmer ON again. This procedure will ensure correct positioning of the auto-mach trimmer servo when the lock-out relay is de-energised by selecting ON, thus avoiding unexpected trim changes.

NOTE: If the elevator spring strut disengages the auto-pilot for no definite reason attributable to the auto-pilot, it is possible that the auto-mach trimmer may be malfunctioning. In this event, care must be taken when re-selecting auto-mach trimmer ON.