PART 1 : SECTION 5

CHAPTER 4

POWER-OPERATED AND POWER-ASSISTED CONTROLS

Introduction

1. Before reading this chapter it is necessary to understand the difference between power-operated and power-assisted controls. Simple definitions are :—

(*a*) *Power-Operated Controls.* The flying control surfaces in this type of system are deflected against air loads purely by the movement of hydraulic jacks, the control column serving only to govern the positions of the valves in the circuit. Some form of feel (paras. 9 and 10) must be used with this system.

(*b*) *Power-Assisted Controls.* In this system the usual stick forces applied by the pilot to deflect the control surfaces against air loads are augmented by the effort from hydraulic jacks.

The use of either method entails the provision of a standby system in case of failure of the main system. With power-operated controls the alternative can be either a separate power-operated system or a manual system. With power-assisted controls the alternative is usually to resort to manual operation. The hydraulic jacks used in both systems are also known variously as servo-control units, boosters power assisters, hydro-boosters, servodynes, sub-units, etc.

Purpose

2. The purpose of both systems is to bring the stick forces within the pilot's physical strength limitations throughout the speed and mach number range of the aircraft. Servo-control units may be hydraulically- or electrically-operated, and are controlled by either manual selectors or electrical switches from the cockpit. As most servo-control units in service use are hydraulically-operated, this chapter deals with them fully.

3. Hydraulically-operated servo-control units can be installed to provide power-operated control surfaces, which relieve the pilot of all loads on the control column, but can also be installed to provide the greater part of the effort required to move the control surface, the remaining effort being exerted manually by the pilot (power-assisted controls). Provision is made in the latter type for reverting to manual control by disconnecting the servo-control units. In this event control is maintained in the same way as in any aircraft where the controls are not power-operated or assisted, the servo unit becoming an integral part of the controls.

Hydraulic Servo-Control Units

4. One example of a hydraulic servo-control unit is illustrated. The principle of operation is as follows. Power is supplied by a hydraulic jack which extends or retracts in response to movements of the control rod of a hydraulic valve mounted on the cylinder of the jack. The principle of the valve is shown in Figs. 1, 2 and 3. Movement of the control rod into the valve body causes the jack to extend ; movement of the control rod out of the valve body causes the jack to retract. Because the effective areas on the two sides of the piston are equal, the jack exerts an equal effort in each direction. In the intermediate or neutral position of the valve (Fig. 2) the fluid in the jack is trapped and the ram is

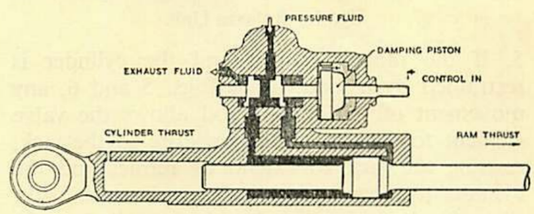


Fig. 1. Valve Action—Control Rod In

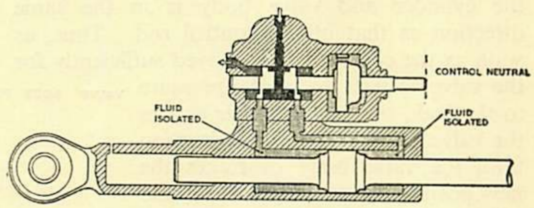


Fig. 2. Valve Action—Control Rod Neutral

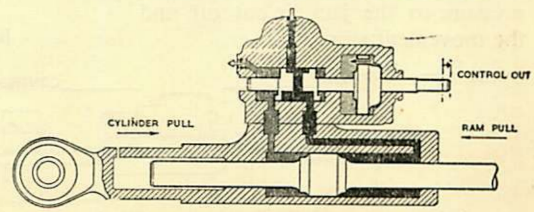


Fig. 3. Valve Action—Control Rod Out

locked hydraulically. The ram of the jack passes through a lug or a release unit incorporating a locking pawl ; the principle of the lock is shown in Fig. 4. When hydraulic pressure is supplied to the unit the piston compresses the spring and the pawl engages with a notch in the ram. When the hydraulic pressure is relieved the spring returns the piston and the pawl disengages from the ram, so disengaging power and reverting to manual control. Not all rams are fitted with a pawl release. On other systems the jack valves are designed to bypass the fluid.

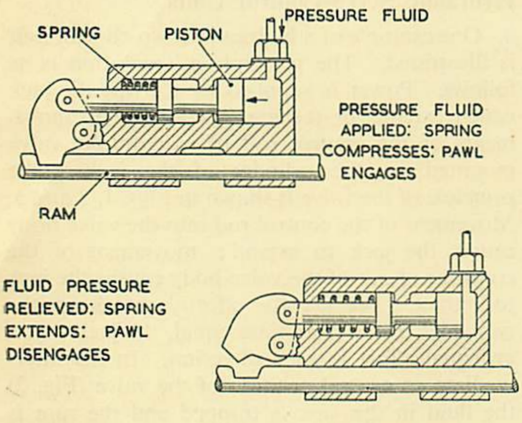


Fig. 4. Release Unit

5. If the ram is locked and the cylinder is restrained by a load, as in Figs. 5 and 6, any movement of the control rod allows the valve element to pass hydraulic pressure to the jack, causing the jack to extend or retract and the cylinder to move hydraulically against the load ; the valve body is carried with the cylinder. In both directions of cylinder travel the movement of the cylinder and valve body is in the same direction as that of the control rod. Thus, as soon as the control rod is moved sufficiently for the valve to pass hydraulic pressure to the jack, the jack cylinder carries the valve body in the same direction until the valve body overtakes the new position of the control rod and the ports in the valve body are closed, when the supply of hydraulic pressure to the jack is cut off and the movement stops.

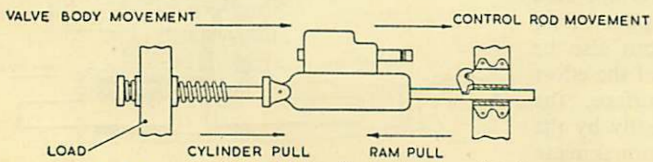


Fig. 5. Ram Locked—Hydraulic Pull against Load

6. A mechanical movement of the control rod is followed, therefore, by a corresponding hydraulic movement of the jack cylinder against the load. A limited movement on the control rod results in a corresponding limited extension or retraction of the jack. A continuous movement by pushing or pulling on the control rod keeps it ahead of the overtaking movement of the valve body and results in a full extension or retraction of the jack.

7. When the supplies of hydraulic pressure to the jack and to the release unit are discontinued, the jack becomes idle and the locking pawl disengages from the ram. If the cylinder is restrained by a load and the movement of the control rod is greater than the range of travel of the valve element, as in Figs. 7 and 8, the damping piston (Fig. 1) is brought against its stops and the excess movement of the control rod is transmitted to the valve body, which moves the jack cylinder mechanically against the load.

8. With hydraulic pressure on, therefore, the jack is powered, the ram is locked, and the manual effort on the control rod is converted to hydraulic effort on the load. With hydraulic pressure off, the jack is idle, the ram is free, and manual effort on the control rod is transmitted as manual effort

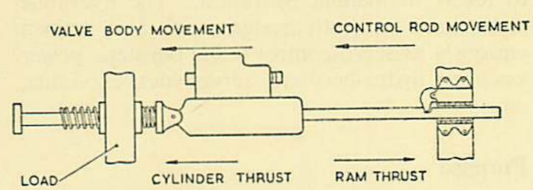


Fig. 6. Ram Locked—Hydraulic Thrust against Load

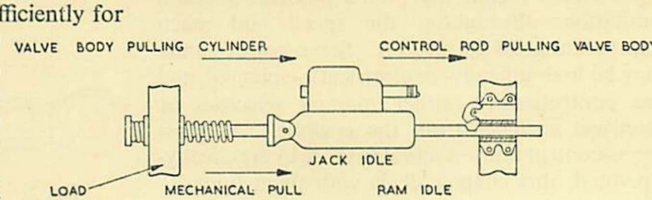


Fig. 7.
Ram Free—Mechanical Pull against Load

on the load, subject to a loss of movement while the damping piston is brought against its stops. This movement is negligible and is heavily damped by the action of the damping piston ; for practical purposes the control rod can be regarded as being connected directly to the load.

Feel

9. When the ram is locked, the magnitude of the hydraulic effort of the jack cylinder on the load depends on the pressure of the hydraulic fluid, the design of the hydraulic mechanism, and is independent of the effort on the control rod. If the control rod were connected directly to the control column, the ram locked to a part of the aircraft structure, and the cylinder loaded by being linked to a flying control surface, there would be no loading (self-centring tendency) on the control column. The effort needed to move the control column would be merely that needed to move the control rod and valve and would not vary with the load on the control surface. This would result in a flying control system in which there were no stick forces, irrespective of the air loads on the control surfaces, *i.e.* there would be no aerodynamic *feel.* It should be noted that flying controls in such an installation would be *irreversible*, in other words, if the control column were moved in any direction it would remain in the disturbed position *with no self-centring tendency* (because the control surface would be hydraulically-locked in that position).

Methods of Providing Feel

10. **Artificial Feel.** One method of simulating feel and imparting a self-centring characteristic to the control column is to install, at any point between the control column and its connection to the control rod of the servo-control unit, a device known as an *artificial feel unit* which opposes movement of the control column, according to its position and direction of motion. With such an arrangement, usually in the form of a spring or a torsion bar, the magnitude of the stick forces at any time is determined solely by the design of the device. The feel thus produced is artificial in the sense that it is not due to the air loads on the control surfaces ; artificial feel units may be of a type that simulates the normal air loads to a reduced degree, or of a type that supplies a stick force proportional only to the amount of stick movement, regardless of I.A.S.

11. **Proportional Feed-Back.** In a power-assisted control system the pilot supplies part of the force necessary to deflect the control surfaces, therefore stick forces inversely proportional to the degree of power assistance are fed back to the control column. This arrangement is termed *proportional feed-back*, and provides feel comparable to that obtained from a normal manual control.

12. Such a linkage is shown in Fig. 9. While the control rod holds the valve element in the neutral position and the jack is neither extending nor retracting, the load effort on the jack cylinder is transmitted directly as ram effort on the control lever. When the control rod is displaced relative to the valve body (so that the jack is extending or retracting) the ram effort on the control lever is opposite in direction to the movement of the control rod and equal in magnitude but opposite in direction to the cylinder effort on the load. Thus in both circumstances, the effort required to move a control column attached to the end of the control lever is proportional to the loading imposed by a control surface linked to the jack cylinder, according to the ratio between the distances "a" and "b".

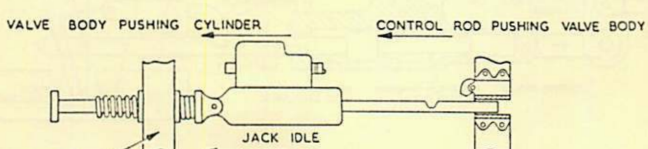


Fig. 8.
Ram Free—Mechanical Thrust against Load

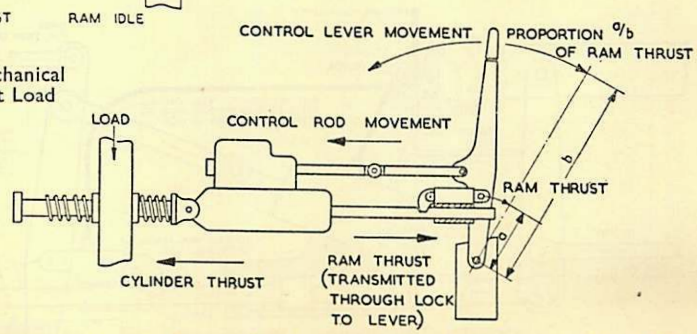


Fig. 9. Control Rod Linked to Provide Proportional Feed-Back

13. **Proportional Feel.** When the loading on the control column is proportional to the air loads on the control surfaces, the feel produced in the control column is termed *proportional feel*. The feel produced by proportional feed-back is necessarily proportional feel while that produced by an artificial feel unit varies according to the design of the unit and may not be proportional to the air loads.

Alternative Control Systems

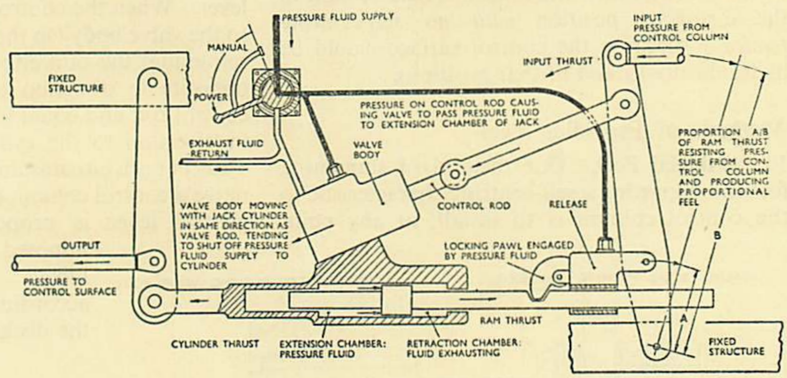
14. All aircraft having power-operated or power-assisted controls have an alternative control system for use if the main system fails. The alternative system may be either a separate hydraulically-operated system or a manually-operated system. Most installations include a selector which enables the pilot to change from the normal to the alternative system or vice versa. The selector may be either mechanical or electrical. If the alternative system is manually-operated, the change from power to manual is known as *manual reversion*. Manually-operated alternative systems have a disadvantage in that the stick forces required to manœuvre the aircraft while in manual are high. To prevent immediate reversion to manual should the hydraulic supply fail while the aircraft is at high speed, some systems have a hydraulic accumulator in the flying controls circuit. In this way the pilot can make a limited number of power-assisted control movements during the period while he is slowing down and trimming the aircraft in preparation for reversion to manual.

Representative Installation

15. The representative power-assisted installation shown in Figs. 10, 11, and 12, consists of a servo-control unit jack, valve, and pawl release assembly, installed in a system of levers, which provide a power output to a control surface and an input force from the control column, with proportional feed-back. A hydraulic pressure supply is connected to a selector in the cockpit and an exhaust return line is connected to both the selector and the exhaust union of the valve mounted on the jack. The hydraulic supply is connected to both the jack valve and release pawl as shown.

16. When the controls are powered (Figs. 10 and 11), hydraulic pressure is applied to both the jack valve and the release pawl. The pawl engages the ram, and the jack operates under hydraulic power in response to movements of the control rod relative to the valve body.

Fig. 10.
Power Operation under Pressure from Control Column



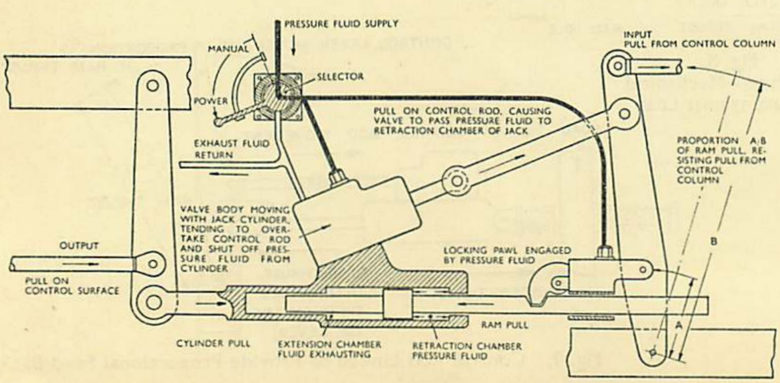


Fig. 11.
Power Operation under Pull from Control Column

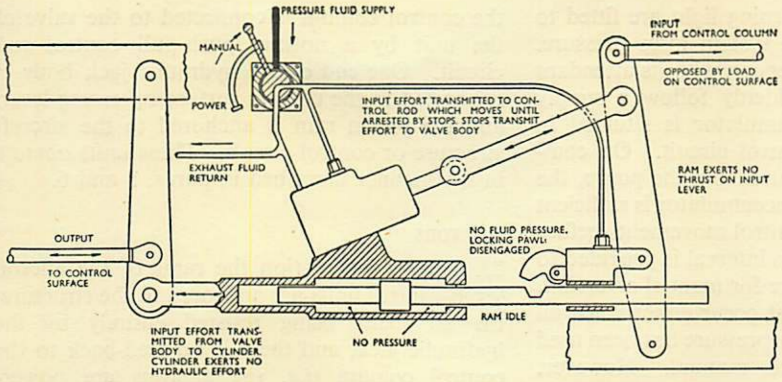


Fig. 12. Manual Operation in Emergency

17. While the input lever displaces the control rod relative to the valve body, the jack cylinder exerts hydraulic effort on the output lever in the same direction as the input effort, and at the same time the ram opposes the movement of the input lever. The pilot feels a proportion (A/B) of this opposition at the control column. While the input lever is stationary, the control surface air load on the output is transmitted through the jack to the input linkage, giving proportional feel in the control column.

18. When under manual control (Fig. 12), the hydraulic connections to both the jack valve and the release pawl are connected through the selector to the exhaust return line. Therefore the jack hydraulic circuit is idle, the release pawl is disengaged from the ram, and the power control unit is inoperative, giving the pilot manual control.

19. **Beam Assembly.** The pivots at the top of the output lever and the bottom of the input lever are fixed points and can be mounted directly onto the aircraft structure. Alternatively, the pivots can be mounted on a frame (termed a beam) which is separate from the aircraft structure. A beam assembly, consisting of the beam and assembled linkage, has the advantage that it can be removed from or installed in an aircraft as an assembled component.

DESCRIPTION OF A TYPICAL SYSTEM (HUNTER MKS. 1 TO 5)

Supply

20. The power required to operate the servo-control units in this installation is supplied by hydraulic pressure from the engine-driven hydraulic pump, which also provides pressure for other services in the aircraft. As the rudder is not normally required for manœuvring at high speed, it is not fitted with any form of assistance.

21. If, for any reason, hydraulic pressure falls, the pressure to the jacks also falls. A hydraulic

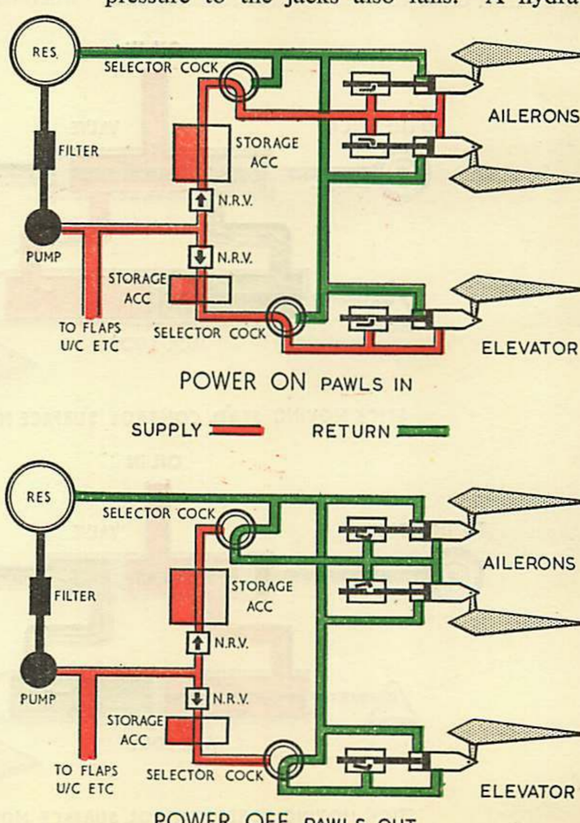


Fig. 13. Power-Operated Control Circuits (Hunter F.1)

pressure gauge and a warning light are fitted to warn the pilot when the system loses pressure. In order that manual reversion with its attendant limitations does not suddenly follow a supply failure, a hydraulic accumulator is situated in each power-operated control circuit. On complete loss of supply pressure from the pump, the pressure in the hydraulic accumulator is sufficient to permit a number of control movements before reversion to manual. This interval is provided to enable the pilot to prepare for manual reversion. Reversion to manual must occur either when all the hydraulic accumulator pressure has been used or when the pilot selects manual. However, should a hydraulic jack fail or a pipe between the hydraulic accumulator and the jack fail, immediate reversion to manual will result.

Note : The number of control movements that can be made before manual reversion takes place varies because of possible high seepage rates in the component parts of the servo-control units.

Power-Operated Controls

22. The hydraulic servo-control units are fitted in the aircraft close to each control surface, and the control column is connected to the valve of the unit by a normal push-pull control rod circuit. One end of the hydraulic jack body is connected to the control surface operating lever, and the piston ram is anchored to the aircraft structure or control circuit. These units operate in the manner described in paras. 5 and 6.

Ailerons

23. In this installation the rams of the aileron servo-control units are anchored to the structure, the air loads being resisted entirely by the hydraulic jack, and there is no feed-back to the control column (*i.e.* the ailerons are power-operated). Artificial feel is provided by a spring fitted in the control circuit which gives a stick force for aileron deflection. The force is about 8 lb. at full travel with a 1 lb. pre-load at neutral to ensure self-centring. The ailerons are operated entirely by hydraulic power and are irreversible in that they cannot be moved by any load on the aileron unless the control column is moved first. Because of the irreversibility the trim tab fitted to the port aileron has no effect on lateral trim when the ailerons are power-operated. This trim

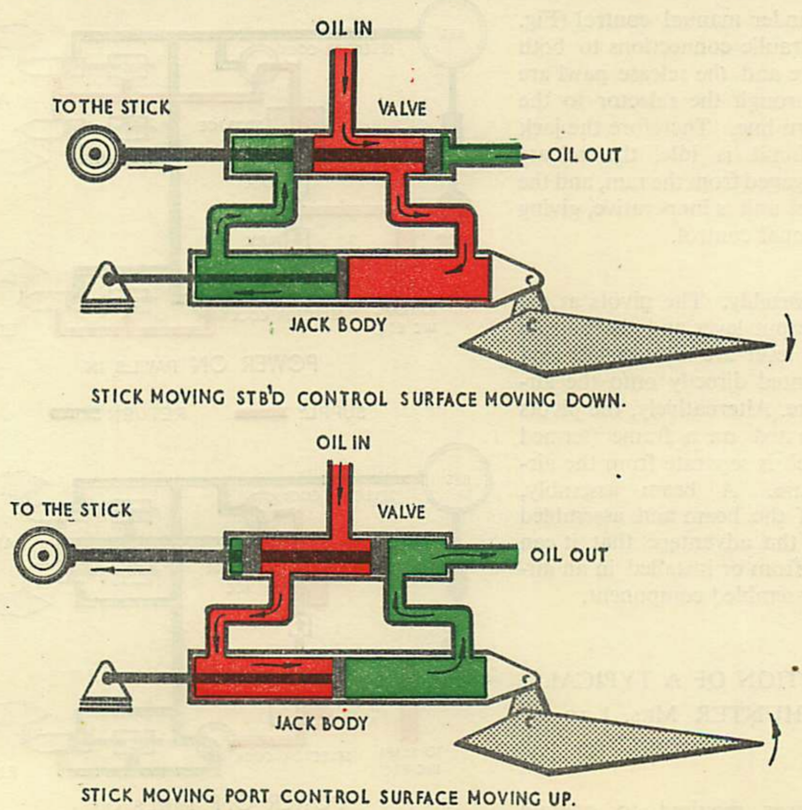


Fig. 14. Aileron Power-Operated Controls

tab is intended for use in manual only, and a guard is placed around the control to prevent inadvertent use when power operation is in use.

Elevator

24. The piston ram of the elevator servo-control unit is anchored to the control circuit itself in such a way that about a quarter of the air loads on the control surface are fed back to the control column. The elevator is therefore power-assisted in that, if the pilot applies a stick force of 10 lb., the circuit (with the hydraulic jack operating) magnifies this effort so that the elevator is moved by a force of 40 lb. Unlike the ailerons, therefore, the elevator air loads are felt by the pilot as changes of stick force (proportional feel), thus providing feel similar to that obtained from normal manual control.

Manual Reversion

25. So that, when in manual, the stick forces are not increased by the need to pump the piston to and fro with the jack full of dead oil, the ram anchorage is released by means of the spring-loaded hydraulically-operated pawl. When the hydraulic pressure to the jack, and to the locking pawl operating mechanism, falls below about 200 lb./sq. in. the spring in the mechanism pushes the pawl out of engagement with the ram thus allowing the ram to slide freely.

Selectors

26. Normally the pilot can select powered or manual control for the aileron and elevator circuits separately by means of on/off switches which control electrically-operated hydraulic cocks. These cocks require an electrical supply to select either powered control from manual control, or manual control from powered control; *i.e.* if an electrical failure occurs the cock remains at the position obtaining at the time of failure. If a hydraulic failure follows an electrical failure, reversion to manual occurs as soon as the pressure in the accumulator is exhausted (but see para. 39). (Although electrical selection is used in this particular installation, on other aircraft selection of either the normal or the standby system can be made mechanically by the pilot, thus permitting selection regardless of the electrical supply.)

Indicators

27. The locking pawls in each hydraulic release box are fitted with micro-switches which close an electrical circuit when the pawls are fully engaged with the rams, and operate magnetic indicators (dolls eyes) on the instrument panel. There are two magnetic indicators, one for the ailerons and one for the elevators. They show *black* when the

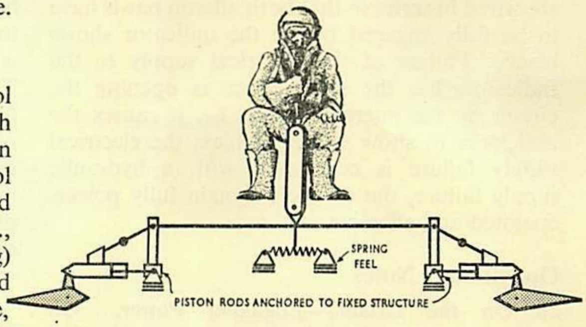


Fig. 15. Aileron Circuit

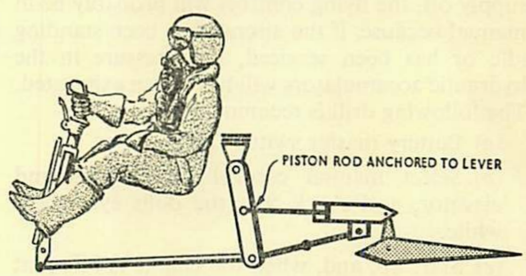


Fig. 16. Elevator Circuit

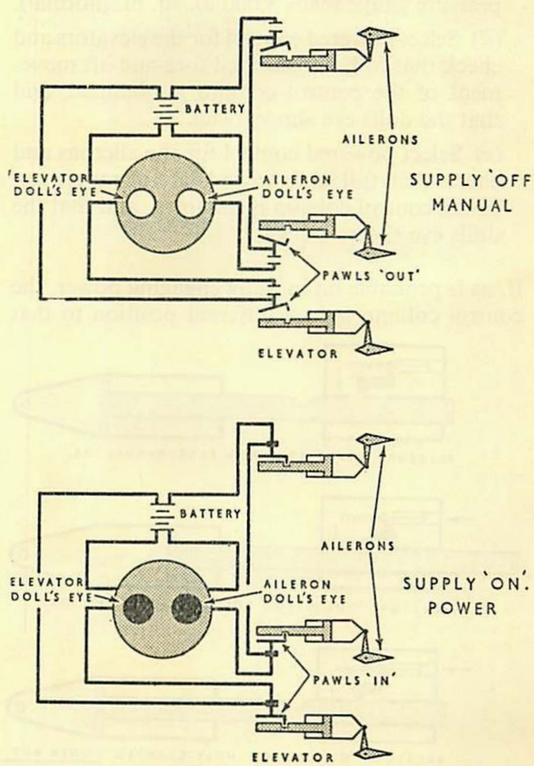


Fig. 17. Indicators—Electrical Circuits

respective circuits are correctly engaged for power operation. The aileron release box micro-switches are wired in series so that both aileron pawls have to be fully engaged before the indicator shows black. Failure of the electrical supply to the indicators has the same effect as opening the circuit by the micro-switches, *i.e.* it causes the indicators to show white. Unless the electrical supply failure is coincident with a hydraulic supply failure, the controls remain fully power-operated and effective.

Operational Notes

28. **On the Ground—Engaging Power.** On entering the cockpit, with the engine and electrical supply off, the flying controls will probably be in manual because, if the aircraft has been standing idle or has been serviced, the pressure in the hydraulic accumulators will have been exhausted. The following drill is recommended :—

(*a*) Battery master switch ON.

(*b*) Select manual control on ailerons and elevator, and check that the dolls eyes show white.

(*c*) Start up, and, when the engine is idling at the correct r.p.m., note that the hydraulic pressure gauge reads 3,000 lb./sq. in. (normal).

(*d*) Select powered control for the elevators and check that full, unrestricted fore-and-aft movement of the control column is obtained, and that the dolls eye shows black.

(*e*) Select powered control for the ailerons and check that full unrestricted lateral movement of the control column is obtained, and that the dolls eye shows black.

If, as is probable on initially engaging power, the control column is in a different position to that when power was disengaged, the locking pawls will not be opposite the slots in the rams. The hydraulic pressure operating the pawls will cause them to clamp on the ram giving a false lock that will slip when moderate jack loads are applied. The dolls eyes will show white in this event and full movement of the control column may not be obtained. To engage the pawls correctly in their slots, considerable force on the control column may be necessary to overcome the friction of the pawls clamping on the rams. Forcing the control column in the direction of the restricted travel causes the ram to slide along the release box until the pawl engages with the slot. When the pawls are properly engaged the control column can be moved freely over its full travel in all directions coming up against crisp, positive stops at the extremes of its movements.

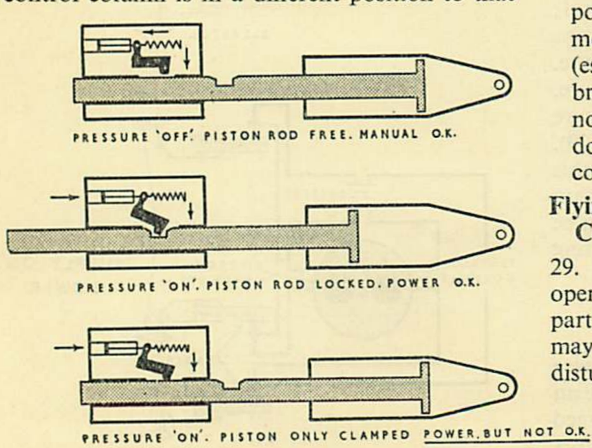


Fig. 18. Pawl Engagement with Ram

WARNING. At idling r.p.m. the hydraulic pump delivery rate is low, but is sufficient for the power controls under all conditions of flight. On the ground, however, if continuous large movements of the control column are made, the supply pressure will fall; if other hydraulic services, such as flaps and wheel brakes, are operated simultaneously the supply pressure may fall still further, and the accumulator may become exhausted. This will allow the locking pawls to become disengaged from the rams and the systems will momentarily revert to manual. When the hydraulic pressure builds up again the controls will automatically attempt to re-engage POWER ON, but it is unlikely that the ram slots will be opposite the pawls at the instant of return of pressure. A false anchorage will result, the indicators will show white, *and powered control will not be correctly engaged.* To overcome this possibility the control column should not be moved excessively when the engine is idling (especially when operating flaps and wheel brakes), and *immediately before take-off*, at not less than 4,500 r.p.m., check that the dolls eye indicators are black and that full control movement is available.

Flying with Power-Operated or Assisted Controls

29. To pilots unaccustomed to flying with power-operated controls the lightness of the controls, particularly the ailerons, will be apparent. There may be a tendency to over-correct slight lateral disturbances, leading to over-controlling, but

after a few minutes the pilot quickly becomes accustomed to the feel of the controls. In the Hunter F.1 the ailerons do not heavy up with increase of speed, because of the spring-type artificial feel unit which gives constant stick forces for a given aileron angle irrespective of the speed. High rates of roll can be achieved at high speeds, and in order that the ailerons are not overstressed under these conditions the hydraulic jacks are designed to stall within a safe load. During all normal conditions this load is not reached, but a determined maximum effort can stall the jacks and so limit the aileron travel (the control column coming up against an apparent stop just short of normal full travel).

Changing from Powered to Manual Control, and vice versa, in Flight

30. Manual control is a standby system to provide sufficient control to enable a pilot to return to base and land should the hydraulic system fail. In view of this, the installation was not specifically designed for reversion from manual to power ; however, this can be done for practice purposes provided that the following points are observed.

31. **Selecting Manual Control in Flight.** First trim the aircraft, hands off, at a speed below 250 knots I.A.S. and 0·8M ; then check that the aileron trim is set at zero and remove the safety lock ; finally select manual control on the elevator, followed by the ailerons.

> *Note :* If the change-over from powered to manual control occurs with any appreciable control deflections held on, heavy and sudden out-of-trim stick forces will be experienced. Therefore while the controls are still powered pilots must always trim out any elevator stick forces and allow the aircraft to take up its own lateral (hands off) attitude before going into manual.

32. **Flying in Manual Control.** The controls are heavy while manually operated, especially the ailerons, and considerable force is necessary to carry out even gentle manœuvres. The heaviness is less noticeable after the pilot has become accustomed to flying in manual control, but care and physical effort are required on landing, especially in cross-winds and rough air. The use of rudder to aid lateral control is NOT recommended since it tends to produce lateral rocking on the approach.

33. **Reselecting Powered Controls.** Resume flight conditions identical to those when manual control was selected and check that the hydraulic pressure is normal and that the electrical supply is serviceable ; then engage the elevator power and move the control column fore and aft until the indicator shows black. Finally engage the aileron power and again move the control column laterally until the dolls-eye indicator shows black.

34. If this drill is correctly carried out the locking pawls will normally re-engage without any effort, but if during the period of flying in manual control the piston rams have crept from the position they occupied at the time when manual control was selected, the locking pawls will not immediately re-engage with the slot in the ram. The pawls will therefore clamp the ram giving a false anchorage and restricted travel.

35. If, therefore, immediate re-engagement does not occur after reselecting POWER ON for the ailerons, satisfactory engagement can usually be obtained in the following way :—

(*a*) When aileron movement is restricted in one direction only, leave the selector at POWER ON and apply rapid full stick movements in the *unrestricted* direction while flying at a moderate I.A.S. and mach number.

(*b*) When aileron movement is restricted in both directions, return the selector to POWER OFF (manual control) and reduce speed to 175 knots I.A.S. and lower full flap. Then reselect POWER ON and *force* the control column alternately in both directions until a free travel of 3 to 4 inches is obtained, then sharply exercise the control column within this range until full movement is available.

If this method fails to achieve its purpose, the selector must be returned to POWER OFF and landing made in manual control.

Emergency Conditions

36. **Electrical Failure.** In the event of electrical failure the dolls eyes show white. If the hydraulic pressure is normal the power-operated controls will continue to function normally but manual control cannot be selected *by the pilot* since the electro-hydraulic selector cock will not be capable of disengaging power.

37. **Hydraulic Supply Failure.** The pilot's action in the event of hydraulic supply failure is :—

(*a*) Reduce speed to less than 300 knots I.A.S. and 0·8M using the minimum number of control movements to conserve the accumulator pressure.

(*b*) Trim out the elevator stick forces.

(*c*) Release the safety lock on the aileron trimmer and check that the trimmer is at zero.

(*d*) Select manual control (POWER OFF) on the selector switches ; first the elevators, then the ailerons.

38. **Engine Failure.** Engine failure followed by seizure causes failure of both the hydraulic and the electrical supply. If the engine has seized (*i.e.* not windmilling) the pilot should :—

(*a*) Reduce speed to less than 300 knots I.A.S. and 0·8M.

(*b*) Switch off all unnecessary electrical equipment.

(*c*) Trim out the elevator stick forces.

(*d*) Select manual control (POWER OFF) on the selector switches.

(*e*) Set the tailplane incidence to zero.

Usually engine failure does not result in seizure and the engine continues to windmill at about 1,000 r.p.m., depending on the speed. In this event, *provided that no heavy demands are made on the hydraulic system*, the electrical supply will fail first, and with limited use of the flying controls the hydraulic supply will last until the airfield is reached. It is, however, essential to engage manual control while the electrical supply is still available to operate the electro-hydraulic cocks ; if this is not done there may be a possibility of a disconcerting change-over from powered to manual control at an inconvenient moment, *e.g.* during the final approach or the hold-off.

Double Emergencies

39. **Electrical Failure Followed by Hydraulic Failure.** If the pilot fails to engage manual control before the electrical supply is exhausted and a subsequent hydraulic failure occurs, reversion to manual control will occur automatically when the hydraulic accumulator is exhausted. To avoid an inadvertent change-over to manual the pilot should deliberately exhaust the hydraulic accumulators by continuous movements of the control column at a convenient time before landing.

40. **Electrical Failure Followed by Partial Hydraulic Failure.** It is possible for a partial hydraulic failure to occur owing to a leak which causes complete loss of pressure only during the use of a hydraulic service such as the flaps or air-brakes ; on completion of the operation the pressure may slowly build up again. This type of malfunction can cause the power controls to become momentarily disengaged during the period of low pressure. When the pressure builds up again there is a possibility of the pawls re-engaging on a false anchorage. This can be prevented (provided that the electrical system is functioning) by selecting manual control. However, should this type of partial hydraulic failure occur after an electrical failure, making it impossible to select manual control, the landing is likely to be extremely hazardous and the aircraft should rather be abandoned.

41. **Undercarriage and Flap Emergency Operation.** If the undercarriage or flap emergency systems are operated while the normal methods available are serviceable, the remaining hydraulic fluid in the main system will be jettisoned automatically. This will not occur if the electrical supply to the normal electro-hydraulic selector cocks for the undercarriage and flaps has failed, since these cocks are spring-turned to a neutral position blanking off both pressure and return passages. Consequently, unless a complete electrical failure has occurred, it must always be assumed that use of the emergency system for lowering the flaps and undercarriage will result in the loss of power-operated controls. Therefore manual control should be selected as early as possible before landing.

OTHER INSTALLATIONS

Victor

42. Servo-control units consisting of an electric motor, hydraulic pump, and hydraulic motor, together with valve gear, are used in Victor aircraft. The servo-control for the rudder and each aileron consists of two self-contained sub-units each comprising an electric motor, hydraulic pump, and hydraulic motor, with valve gear, etc. The hydraulic motors of both sub-units drive a single-screw jack through a bevel gear-box which operates the control surface by means of skew levers. The elevators have four sub-units, one pair on each side of the fin. Each pair moves its associated elevator through a screw jack.

43. The valves are of the piston type and when moved in either direction allow hydraulic fluid to operate the control surfaces, the direction of motion depending on the direction in which the valve is moved. When in the closed position, the valves overlap the ports through which the hydraulic fluid flows so that only a small movement of the valve is required to start the jack moving. There is no manual reversion, but the system is duplicated to cater for all likely faults.

44. **Feel.** Feel simulators are of a type in which pitot and static pressures are supplied to the inside and outside respectively of a pair of bellows so that the difference in pressure across the bellows is the dynamic pressure, $\frac{1}{2}\rho V^2$. Movement of the pilot's control compresses the bellows so that the force transmitted to the pilot is proportional to $\frac{1}{2}\rho V^2$ and the displacement of the control, thus simulating the feel of a conventional aircraft. In addition each feel simulator contains a spring which gives forces proportional to the control displacement only. This type of feel system is known as a "q" feel system, since "q" is the symbol used for $\frac{1}{2}\rho V^2$.

Valiant

45. The power controls in the Valiant are operated by four electrically-driven hydraulic pumps : two for the aileron, and two for the rudder and elevators. The systems are arranged so that if one aileron pump motor fails the ailerons will still operate, but at only half rate, the rudder and elevators not being affected. If one of the rudder and elevator pump motors fails, the rudder and elevators will operate at half rate, ailerons not being affected. Any further failure will cause the affected control to revert automatically to manual.

46. **Feel.** Feel is provided by three units in a similar manner to that described for the Victor. The feel produced is a function of speed and control deflection, and thus, although artificial, is similar to that obtained on a manually-controlled aircraft. The feel units for the rudder and ailerons may be trimmed to relieve the foot and hand loads, by operating trimming switches. The elevator feel unit cannot be trimmed. If any feel unit should jam or be damaged, or if the power controls fail, they can be disconnected by the pilot, but cannot be reconnected in flight.

Whirlwind

47. The principles and methods described in paras. 1 to 14 apply to the power-operated controls in the Whirlwind helicopter. The rams of the jacks are not provided with pawl releases, but are linked to the controls to provide feel.

48. A switch marked SERVO/MANUAL in the cockpit energizes a solenoid-operated control valve which governs the supply of hydraulic pressure to the servo-controls. In the manual position the switch closes the pressure line from the supply system, and the lack of pressure causes a spring-loaded shuttle-valve in the jack valve to move, opening both sides of the jack to the return line. Failure of the hydraulic system also causes the shuttle-valve to open both sides of the jack to the return line, and thus revert control to manual.

49. Modified aircraft have an emergency power-operated lateral cyclic pitch control system to prevent sudden reversion to full manual control should the hydraulic supply fail. The emergency control consists of a separate jack, which is automatically supplied with engine oil under pressure on failure of the hydraulic pressure supply, or when manual control is selected. It provides power assistance only on the lateral cyclic pitch control.

50. The whole control system reverts to manual only if both the hydraulic and engine oil supplies fail. If manual control is selected under normal conditions, only the emergency power-operated lateral cyclic pitch control is brought into operation.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