THE COLLEGE OF AERONAUTICS

DEPARTMENT OF FLIGHT

PILOT RELIABILITY INVESTIGATION

Final Report on
Agreement PD/28/035/ADM

- by -

I.A. ROBERTSON, D.F.C., C.Eng., A.F.R.Ae.S.

and

D. MILLS

SUMMARY

The feasibility of constructing a device to give a measure of pilot reliability has been investigated. A rig to meet the proposals made by BLEU has been designed and basic circuits constructed and tested for accuracy of operation and reliability. An estimate of the materials required and the cost of construction has been made.

The rig has been designed to be subject operated for twenty-four tests before requiring attention, and devices have been incorporated to indicate unserviceability and prevent operation if starting conditions are not correct.

Switching sequences typical of the final period of an autoland approach are demanded verbally by magnetic tape replay equipment and the performance of the subject measured. The test consists of two phases; a preparatory or "unloaded" phase, and a "loaded" phase during which the subject performs a tracking task in addition to the switching sequence. The performance of the subject is recorded on veeder counters for both phases of the test in the form of actions demanded, actions taken and actions taken during a memory period. A measure of performance of the tracking task is also given by veeder counter.

I N D E X

INTRODUCTION

An investigation into the feasibility of constructing a device to measure pilot reliability has been completed. The general requirement as stated in BLE/19/017 Ref.(1) was used as a specification and where necessary modified and amplified by discussion with BLEU staff. The main features required of the device were:-

1. To measure the reliability of a pilot in responding correctly to actions demanded of him both at the time of demand and during a memory period.

2. To measure the effect on performance of a pilot of superimposing a "loaded" or secondary task on the actions demanded in para. 1.

3. To be representative of modern aircraft practice considering the actions demanded and the interface representation of these actions.

4. To be subject operated and of the best possible degree of system integrity and serviceability.

Investigation has shown that a device can be made incorporating these features.

An enclosed cockpit type structure and a mobile equipment rack accommodates the subject, the equipment for initiating, measuring and recording performance on the primary and loaded tasks. The device is operated from mains power and is sectionalised for ease of transport. The initiation of the tasks is by magnetic tape replay equipment giving verbal and visual demands. Recording of results is by photographing veeder counter indicators giving a measure of subject performance.

Representative circuits have been constructed and tested for operation and reliability and all the required actions investigated and considered feasible using these circuits.

The cost of constructing the device has been investigated and the estimate given in Appendix 3.

GENERAL DESIGN

The functional requirements given in BLEU papers BLE/19/017 were used as a guide for the design of the test rig. In the design shown in GA form in Figs. 20-25 the main factors considered were:-

1. Layout of switches and controls in the best ergonomic manner consistent with current cockpit layouts in aircraft with autoland capability.

2. Ease of operation by the subject.

3. Ease of maintenance of electrical and measuring equipment.

LAYOUT OF SWITCHES AND CONTROLS

The switches and controls required are dictated by the tasks stated in Tables 2 and 3. The actions are typical of the actions required of a pilot during the final phase of an autoland approach.

The general layout of controls and switches is shown in Figure 20. The design follows the current practice of having flight system selection, autopilot, and radio controls, and essential system controls on a console on the pilot's right. A wheel type control column controls the "loaded" or tracking task of following the indications on a Zero Reader type instrument. An instrument panel - Figure 21 - has a Zero Reader, Heading indicator, Altimeter or distance to run indicator, Flap position, undercarriage position, and autopilot mode indication. The altimeter barometric setting scale will operate but the height pointer will not change its position with alteration of this setting. The Heading indicator selector will operate but heading will not change with control column movement. The Zero Reader will operate in response to control column movements.

For reality the switches and controls must be the same as those used on aircraft with autoland capability. This reality aspect applies especially to the autoland controller which has rotary and toggle switches, push/pull switches and digital setting knobs. It is considered that an actual controller will have to be modified to achieve this purpose as the indication of correct action as well as the type of action has to be catered for, e.g. Magnetic hold ON of engage buttons, Dolls eye indication of mode engagement. The Flight controller selections will operate the mode indicator on the instrument panel. The particular controller considered is the Smiths Flight Controller No. Z104, and inspection has shown that it could be modified for this requirement. However no particular difficulty should be experienced in using any other type of flight controller in conjunction with the rig.

The ILS controllers with no requirement for frequency change are full scale photographic reproductions with the switch position drilled out and an actual switch installed. Dummy frequency change knobs are fitted and the normal light indication of switched ON is provided.

EASE OF OPERATION BY THE SUBJECT

The cockpit is an enclosed booth type structure, easily entered and soundproofed. The test cannot be started until all the switches and controls are set in a "start test" position. This requires the subject to perform a minimum cockpit check on entering. Electrical interconnections prevent the device from functioning until these settings are made. The electrical interconnection system also provides a partial serviceability check in that any malfunction of the components on the cockpit check would prevent the test start condition being achieved. It was considered uneconomical to have automatic setting of all "start of test" conditions as the variety of controls concerned had differing mechanical actions for resetting.

Magnetic tape replay equipment gives the subject verbal instructions to make the switch and control actions given in Tables 2 and 3 and his performance on these tasks is recorded.

A veeder counter is mounted externally to be subject recorded for motivation purposes and represents the score of his performance on the tracking task. It is most unlikely that any two subjects will achieve the same score on this task.

EASE OF MAINTENANCE OF ELECTRICAL AND MEASURING EQUIPMENT

Alternative installations of electronic, magnetic tape replay and recording equipment have been considered:-

1. Installation of all the equipment in a separate cabinet on castors which is connected via plugs and sockets to the cockpit. Fig. 25.

2. Installation of the equipment in various areas of the cockpit, e.g. forward of and under the console, under the seat. Figs. 22,23 and 24.

Alternative (1) is considered the most efficient for the following reasons:-

(i) Ease of access to all electrical power supplies electronic circuits, magnetic tape and recording equipment.

(ii) Economy and simplicity in construction of the cockpit eliminating the provision of a large number of access panels.

(iii) The cockpit can be smaller.

(iv) Any noise from the equipment will be remote from the subject.

(v) It provides a segregated instrumentation pack which could be attached to other simulators.

EASE OF MAINTENANCE OF ELECTRICAL AND MEASURING EQUIPMENT (continued)

The circuits have been designed on the plug in board principle. Illustration No. 1 and the components chosen for their high reliability.

The magnetic tape replay equipment is easily accessible to allow for change of programme tapes. The photographic recorder is a simple automatic observer containing the digital counters using a 50 exposure ROBOT type single shot camera. Subject identification could be included if required. The recording is automatically completed at the end of each test run.

The system allows for flexibility of operation, easy recording of new programme tapes incorporating different switching operations within the maximum capacity of the tape recorder and the addition of other monitoring tasks, should this be required.

A suitable tape recorder giving a two-hour running duration can be obtained. Allowing five minutes per test, such a recorder would provide three sets of eight test programmes on one tape. This would allow twenty-four tests to be completed before tape rewind or recorder camera reloading was required.

SYSTEM REQUIREMENTS

The basic system requirements are to provide:-

(a) Interference free verbal instructions.

(b) Eight separate test programmes with demand, error, and corrected error recording for the 9 switch actions during the unloaded task phase (see Table 2) and for the 8 switch actions during the loaded task phase (see Table 3). These actions require 30 "switch accuracy check" circuits for the unloaded task programmes and 19 circuits for the loaded task programmes.

(c) Two tracking tasks one in pitch and one in azimuth with a subject performance indicator. These tasks provide the load element of the "loaded" phase.

(d) A pacing indicator showing progress toward the completion of the test.

MEASURING SYSTEM

A 4 track magnetic tape record/replay system provides the switching instructions and switch action checking system.

MEASURING SYSTEM (continued)

Track 1 provides the verbal switching instructions.

A one second Tone Signal recorded on one of the remaining 3 tracks 5 seconds after the verbal instruction primes the appropriate switch action checking circuit. Ten audio tones are used in a tone/track combination to provide the priming signals, each specific switch action is allocated a tone/track combination (see Tables 4 and 5).

The incoming tone signal provides the switch action demand count and an error count if the switch action is incorrect. It also primes the corrected error circuits to record any corrected action carried out during the remainder of the phase or during the memory period.

THE TRACKING TASK

The subject is required to maintain a zero reader type indicator in the zero position against deflection signals supplied in a controlled manner from the tape replay system. A mixture of two audio tones is recorded. These tones when fed to a filter/rectifier system produce a d.c. output, the amplitude and polarity of which is directly related to the relative amplitudes of the tones, and when applied to the zero reader deflects the pointer. The subject uses a control column operating potentiometers to provide signals to cancel the deflection. Track 3 provides the azimuth deflections, and Track 4 - the pitch deflections.

THE PACING INDICATOR

A d.c. supply reducing from 1 mA. to zero is produced from a recording of a frequency reducing signal from 6 kc/s. to 1 kc. on Track 3 to operate the pacing indicator. The indicator dial can be calibrated in altitude or distance as required.

AUDIO FREQUENCY RANGE

1. 90 and 150 c.p.s. are mixed for tracking tasks, equal amplitudes giving ON course indication; differing amplitudes giving fly right or left in azimuth or up or down in pitch. The choice of 90 c.p.s. and 150 c.p.s. tones allows the use of standard ILS equipment filters and rectifiers.

AUDIO FREQUENCY RANGE (continued)

2. A continuous equal amplitude signal, frequency reducing from 6 kc/s to 1 kc., which after detection provides a d.c. reducing relative to frequency from 1 mA. to zero.

3. Switch action identity tones of 1 second duration as shown in Table 1.

TABLE 1

Tone No.	Frequency c/s
1	400
2	560
3	730
4	960
5	1300
6	1700
7	2300
8	3000
9	3900
10	5400

These tones are harmonically separated and have been chosen below 6 kc/s to allow a lower tape recorder speed to be utilised.

TABLE 2

UNLOADED PHASE TONE/TRACK ALLOCATION

Task		No. of Tones	Identity of Tones	Track
A	Set Q.F.E. ..... 8 different settings	8	1 to 8	2
B	Set Runway Heading 8 different settings	8	1 to 8	3
C	Switch ILS (3 switches in series)	1	9	2
D	Select ILS on Auto	1	10	2
E	Select 15^{o} Flap	1	9	4
F	Lower undercarriage	1	10	3
G	Select I.A.S. on Auto Throttle	1	9	3
H	Engage Auto Throttle	1	10	4
J	Select I.A.S. ..... 8 different settings for descent.	8	1 to 8	4

TRACK ALLOCATION - UNLOADED PHASE

Track 1 - R/T voice only.

Track 2 - Set Q.F.E. tones 1 to 8. Switch on ILS Tone 9. Select ILS on Auto Tone 10.

Track 3 - Set runway heading tones 1 to 8. Select Flap Tone 9. Lower undercarriage Tone 10.

Track 4 - Select I.A.S. tones 1 to 8. Select I.A.S. Tone 9. Engage auto throttle. Tone 10.

Total 30 Tones shared between 3 tracks.

TABLE 3

LOADED PHASE TONE/TRACK ALLOCATION

Task		No. of Tones	Identity of Tones	Track
AL	Set Display 1 or 2	2	4 and 5	2
BL	Select Glide on Auto	1	10	2
CL	Reset I.A.S. ..... 8 different settings	1	1 to 8	4
DL	Reset Q.F.E. ..... (3 programmes only)	3	1 to 3	2
EL	Reset Flap 60°	1	9	4
FL	Prime Land	8	8	2
GL	Select Land Display	2	6 and 7	2
HL	Press cut out button	1	9	2

TRACK ALLOCATION - LOADED PHASE

Track 1 - R/T voice only.

Track 2 - Reset Q.F.E. Tones 1, 2, 3. Set Display 1 or 2, Tones 4 and 5. Select Land display Tones 6 and 7. Prime Land Tone 8. Press cut out button Tone 9. Select Glide on Auto Tone 2.

Track 3 - Mixture 90 and 150 c.p.s. Azimuth Tracking task. Frequency reducing 6 kc/s to 1000 c.p.s. to drive pacing task indicator.

Track 4 - Mixture 90 and 150 c.p.s. Pitch Tracking task. Reset I.A.S. Tones 1 to 8. Reset Flap Tone 9. Spare Tone 10.

Total - 20 Tones shared between 2 tracks.

SWITCHING GENERAL

A standard circuit comprising a Tone filter, a Relay Board type 1 and a Board type 2 has been designed and is triggered by each specific identity tone. Each correct switch action completes the path between pins X and P Relay Board type 1 (Fig. 16). These pins are connected to terminal strips to provide flexibility for thirty switch action paths available during the unloaded task phase and twenty during the loaded task phase.

SUBJECT PERFORMANCE INDICATORS

Magnetic digital counters, three to each switching task, are used to indicate Demand/Error, Corrected Error. These counters operate from pins V, N, and Y respectively on Relay Board type 1. Where more than one switch action is recorded on one set of counters, these pins are connected in parallel, (see Fig. 3). Pins V, N, and Y are connected to terminal strips to provide flexibility for the counter circuits.

FUNCTIONING OF THE STANDARD SWITCH ACTION ACCURACY CHECK AND PERFORMANCE INDICATOR CIRCUITS (Fig. 1)

In the replay condition tracks 2, 3 and 4 of the tape recorder each feed an audio transformer which in turn feeds a bank of ten band pass filters tuned to the frequencies shown in Table 1, thence to a Relay Board type 1 (Fig. 16), type 2 (Fig. 17) and via routing contacts to a set of three counters.

The incoming one second duration tone is coupled to the tone detector circuit on Board 2 (Fig. 17). The output from Board 2, a one second pulse of d.c. is connected via pin X Board 2 to pin T Board 1 (Fig. 16) to operate relay B and relay B.B. These relays are locked in the ON position by contacts B10-B6, D10-D2. Relay B.B contacts are used to connect the magnetic counters to the specific Board 1 which has received the detected tone pulse (allowing one set of counters to be used for the tasks demanding several switch settings e.g. task A, set O.F.F.). Contacts B9, B5 prime relay A to receive a switch action signal. The incoming one second detected tone operates the demand counter - recording one demand. Further action of the circuits depend on whether:

(i) a correct switch action is made,

(ii) an incorrect switch action is made, and

(iii) an incorrect switch action is subsequently corrected.

(i) A Correct Switch Action

This provides a short circuit between pins X and P Board 1, supplying a d.c. positive to Relay A coil, the negative side of the relay coil having been connected to d.c. negative by the incoming tone signal. Relay A energises, contacts A9 A1 open to disconnect the error counting circuits.

(ii) An Incorrect Switch Action

When no short circuit occurs between pins X and P Board 1, i.e. incorrect switch action taken, Relay A is not energised, contacts A9-A1 connect the 1 sec. d.c. detected tone pulse via C1-C9 to the error counter counting one error, and to the 2 second delay switch unit on Board 2 (Fig. 17). The output of this unit (24 v. positive) is fed via contacts C3-C11 D4-D12 to energise relay C. Contacts C1-C9 open to prevent a further error count, contacts C10-C6 close and form a series path with B11-B7, A6-A10 to the corrected error counter.

(iii) A Corrected Switch Action

Correction of the switch action i.e. action taken during memory period, short circuits pins X and P Board 1, and energises relay A. Contacts B11-B7 and C10-C6 are already closed, contacts A6-A10 close and connect d.c. to the relay D switch unit Board 2. This unit is used to ensure a positive action of relay D. Relay D energises counting one corrected error. Contacts D1-D9 D12-D4 open to de-energise relay C. Contacts D10-D2 open to de-energise relay B. These actions prevent any further counts being recorded on this channel until a further tone input pulse is received.

TABLE 4

ACTION TIME HISTORY UNLOADED PHASE
TRACK/TONE ALLOCATIONS AND TIMING SEQUENCE

Task Identity	Allow Time S		Programme 1	2	3	4	5	6	7	8	Test Running Time (s
A	5	SET Q.F.E.	0923	1027	0943	1047	1023	0924	1043	0947	5
	5	Op. Switch									10
	1	TRACK 2 TONE	1	6	3	8	5	2	7	4	11
	1	Space									12
B	5	SET RUNWAY HEADING	143 etc. as chosen								
	5	Op. Switch									22
	1	TRACK 3 TONE	Tones 1 to 8 as appropriate								23
		Space									24
C	3	SWITCH ON ILS	—	—	—	ALL	—	—	—	—	27
	5	Op. Switch									32
	1	TRACK 2 TONE	9	9	9	9	9	9	9	9	33
	1	Space									34
D	3	SELECT ILS ON AUTO	—	—	—	ALL	—	—	—	—	37
	5	Op. Switch									42
	1	TRACK 2 TONE	10	10	10	10	10	10	10	10	46
	1	Space									47
E	2	SELECT 15° FLAP	—	—	—	ALL	—	—	—	—	49
	5	Op. Switch									54
	1	TRACK 4 TONE	9	9	9	9	9	9	9	9	55
	1	Space									56
F	3	LOWER UNDERCARRIAGE	—	—	—	ALL	—	—	—	—	59
	5	Op. Switch									64
	1	TRACK 3 TONE	10	10	10	10	10	10	10	10	65
	1	Space									66
G	3	SELECT I.A.S. ON AUTO THROTTLE	—	—	—	ALL	—	—	—	—	69
	5	Op. Switch									74
	1	TRACK 3 TONE	9	9	9	9	9	9	9	9	75
	1	Space									76
H	2	ENGAGE AUTO THROTTLE	—	—	—	ALL	—	—	—	—	78
	5	Op. Switch									83
	1	TRACK 4 TONE	10	10	10	10	10	10	10	10	84
	1	Space									85
J	5	SELECT I.A.S.	218	210	215	218	160	165	218	165	89
	5	Op. Switch									94
	1	TRACK 4 TONE	3	1	2	3	7	8	3	8	95
	1	Space									96
	9	Allow 9 secs. memory period before loaded phase.									105
	1	Change counters to loaded phase.									106

TABLE 5

ACTION TIME HISTORY LOADED PHASE
TRACK/TONE ALLOCATIONS AND TIMING SEQUENCE

Task Identity	Allow Time S		Programme 1	2	3	4	5	6	7	8	Test Running Time (secs
AL	4	SET DISPLAY (1 or 2)	1	2	1	2	1	2	1	2	110
	5	Operate Switch									115
	1	TRACK 2 TONE	4	5	4	5	4	5	4	5	116
	1	Space									117
BL	4	SELECT GLIDE ON AUTO				ALL					121
	5	Operate Switch									126
	1	TRACK 2 TONE	10	10	10	10	10	10	10	10	127
	1	Space									128
CL	5	RESET I.A.S. TO ...	165	148	160	145	148	140	210	140	133
	5	Operate Switch									138
	1	TRACK 4 TONE	8	6	7	5	6	4	1	4	139
	1	Space									140
DL	5	RESET Q.F.E. TO ... (3 Programmes only)	0924	-	-	-	0923	-	-	0943	145
	5	Operate Switch									150
	1	TRACK 2 TONE	2	-	-	-	1	-	-	3	151
	1	Space									152
EL	3	RESET FLAP 60°				ALL					143 155
	5	Operate Switch									148 160
	1	TRACK 4 TONE	9	9	9	9	9	9	9	9	149 161
	1	Space									150 162
FL	2	PRIME LAND				ALL					152 164
	5	Operate Switch									157 169
	1	TRACK 2 TONE	8	8	8	8	8	8	8	8	158 170
	1	Space									159 171
GL	3	SELECT LAND DISPLAY	Port	Stbd.	Port	Stbd	Port	Stbd.	Port	Stbd.	162 174
	5	Operate Switxh									167 179
	1	TRACK 2 TONE	6	7	6	7	6	7	6	7	168 180
	1	Space									169 181
HL	3	PRESS CUT OUT BUTTON									172 184
	5	Operate Switch									177 189
	1	TRACK 2 TONE	9	9	9	9	9	9	9	9	178 190
	1	Space									179 191

SWITCH ACTION CANCELLING

Certain switches e.g. flap and engage buttons have solenoid operated hold "on" devices. The circuits have been arranged to remove the hold on power from these circuits at the completion of each run, thus allowing their return to the "OFF" position. Other switch actions e.g. task AL (Set display 1 or 2), alternate between tests and will always be in a position requiring their setting to be altered. For all other switches, a pre-flight checking circuit has been designed (Fig. 2). This will only allow the power to be connected to the main circuits when all switches have been switched to the "OFF" or "START OF TEST" position. Pre-flight instructions will be displayed in the cockpit.

TASK ANALYSIS

SWITCH ACTIONS AND SWITCH MODIFICATION - UNLOADED PHASE

Task A - Set Q.F.E. (Fig. 3)

To reduce the number of selections normally available from a standard Q.F.E. selector mechanism, the following eight discreet selections have been chosen:

1.	0923 mb.	2.	1024 mb.	3.	0943 mb.	4.	1044 mb.
5.	1023 mb.	6.	0924 mb.	7.	1043 mb.	8.	0944 mb.

Switch Action

The "Set Pressure" control knob gear chain, or the Q.F.E. indicating veeder counters must be modified to provide the following switch actions. A make contact when the following figures are selected:

0	Thousand
1	Thousand
0	Hundred
9	Hundred
2	Tens
4	Tens
4	Units
3	Units

The make contacts are used to energise relays (see Fig. 3) with the following contact arrangements:

0	Thousand	2 make = 1 relay
1	Thousand	1 make = 1 relay
0	Hundred	1 make = 1 relay
9	Hundred	2 make = 1 relay
2	Tens	3 make = 1 relay
4	Tens	3 make = 1 relay
4	Units	5 make = 2 relays
3	Units	6 make = 2 relays

Each of the eight programmes is routed via the selecting system comprising:

(i) The Tone Filter

(ii) The Relay panel Board 1

(iii) The switch selection relay contacts

(iv) (Relay D Switch Unit, 2 sec. delay, Tone Det.), Board 2

Thence to the three digital counters.

Tones 1 to 8 on Track 2 are used for Task A.

Tone 1	0923	Tone 5	1023
2	0924	6	1027
3	0943	7	1043
4	0947	8	1047

Task B - Set Runway Heading (Fig. 4)

Runway heading is normally selected by a small knob rotating a lubber line round a 360° dial through a gear chain. This system must be modified to drive a multiway rotary switch, the number of contacts dictating the setting spacing of the selected headings.

The contacts which should be single pole break before make will be routed via the selecting system comprising:

(i) Tone filter

(ii) Relay panel Board 1

(iii) Switch selection (Runway heading) contacts

(iv) (Relay D switch unit - 2 sec. delay - Tone Unit) Board 2.

Thence to the three digital counters.

Tones 1 to 8 on Track 3 are used for Task B.

Task C - Switch on ILS (Fig. 5)

Three ILS switches are required, these are normally associated with the ILS control unit, each switch having two make "ON" contacts and one make "OFF" contact.

The contacts are used as follows:-

(i) To make a series chain for the correct switch action counting.

(ii) To switch on the control unit dial lights, and to remove the "OFF" flags on the zero reader indicator.

(iii) To complete the pre-flight checking circuit.

Tone 9 on Track 2 is used for Task C.

Task D - Select ILS ON AUTO (Fig. 6)

This requires the movement of a rotary switch through one position on the Radio Selector Panel.

The switch must provide two single make contacts.

One contact is used to complete the chain for a correct action count, the second to complete the pre-flight checking circuit.

Tone 10 on Track 2 is used for Task C.

Task E - Select 15^{o} flap (Fig. 7)

This requires the movement of a lever through a gate with positions UP, 15^{o} and 60^{o}. The lever operates a micro switch in the UP-15^{o}-60^{o} position and drives a desynn type flap position indicator.

The flap lever will have to be manually returned to the UP position during the pre-flight checks before each run.

Tone 9 on Track 4 is used for Task E.

Task F - Lower Undercarriage (Fig. 8)

This switch action is provided by a lock-in push button which returns to the UP position when power is removed from the equipment after each run.

The switch requires a double pole make switch operating a relay with change over contacts used as follows:

(i) To complete the correct action counter path.

(ii) To lock on the relay.

(iii) To operate the undercarriage down lamps.

(iv) To complete the pre-flight checking circuit.

Tone 10 on Track 3 is used for Task F.

Task G - Select I.A.S. on Auto Throttle (Fig. 9)

This requires the movement of a rotary switch on the Flight Controller through one position.

The switch must provide one make contact used to complete the chain for a correct action count and one make contact to complete the pre-flight checking circuit.

Tone 9 on Track 3 is used for Task G.

Task H - Engage Auto Throttle (Fig. 10)

This requires the operation of the engage button on the Flight Controller.

The switch must provide one break contact used to complete the chain for a correct action count and one make contact to complete the pre-flight checking circuit. The button is provided with a hold on solenoid.

Tone 10 on Track 4 is used for Task H.

Task J - Select I.A.S. .... (Fig. 11)

The following eight programme selections have been chosen:

1.	218 kts.	5.	160 kts.
2.	210 kts.	6.	165 kts.
3.	215 kts.	7.	218 kts.
4.	218 kts.	8.	165 kts.

To provide reality the I.A.S. selected during the unloaded phase is greater than that selected during the loaded phase.

Switch Action

The speed control knob rotates a veeder counter on the Flight Controller which must be modified to provide the following switch operations.

A make contact when the following numbers are selected:-

1 - Hundred = 1 make

2 - Hundred = 1 make

1 - Tens = 1 make

4 - Tens = 1 make

6 - Tens = 1 make

0 - Units = 3 contacts = 1 relay

5 - Units = 3 contacts = 1 relay

8 - Units = 3 contacts = 1 relay

The Hundreds and Tens contacts are used as direct series links; the unit contacts operate relays to provide the correct action path.

Tones 1 to 8 Track 4 are used for Task J.

Tone 1	210 kts.	Tone 5	145 kts.
2	215 kts.	6	148 kts.
3	218 kts.	7	160 kts.
4	140 kts.	8	165 kts.

LOADED TASKS

Task AL - Set Display 1 or 2 (Fig. 12)

The double pole two way switch is located on a separate panel mounted in the cockpit adjacent to the ILS control units.

The contacts are used as follows:-

(i) To complete a series chain for the correct switch action counting.

(ii) To operate a mode indicator.

Tones 4 and 5 on Track 2 are used for Task AL.

Task BL and Task FL - Select Glide on Auto : Select Prime Land (Fig. 13)

The three-position switch - OFF-PRIME GLIDE-PRIME LAND - is part of the Smiths Flight Controller.

Make contacts will be required as follows:-

"OFF" position - one pair to complete the pre-flight checking circuit.

"GLIDE" - 2 pairs,

"PRIME LAND" - 2 pairs.

One to operate the mode selector or Dolls eye; one to complete the correct action chain.

Tone 10 on Track 2 is used for Task BL.

Tone 8 on Track 2 is used for Task FL.

Task CL - Reset I.A.S. (Fig. 11)

The approach I.A.S. is selected initially during the unloaded phase. This re-selection selects the final approach speed which is lower than that selected in the unloaded phase (Task J).

The following eight programme selections have been made:-

1.	165 kts.	5.	148 kts.
2.	148 kts.	6.	140 kts.
3.	160 kts.	7.	210 kts.
4.	145 kts.	8.	140 kts.

Switch Action

As unloaded phase (Task J).

Tones 1 to 8 on Track 4 are used for Task CL.

Tone	1.210 kts.	Tone	5.145 kts.
	2.215 kts.		6.148 kts.
	3.218 kts.		7.160 kts.
	4.140 kts.		8.165 kts.

Task DL - Reset Q.F.E. (Fig. 3)

Required on 3 programmes only. The reselected Q.F.E. is always within 1 mb. of the Q.F.E. selected during the unloaded phase (Task A).

The following programme selections have been chosen:

1. 0924 6. 0923 8. 0943.

Tones 1, 2 and 3 on Track 2 are used for Task DL.

Tones 1 = 0923 Tone 2 = 0924 Tone 3 = 0943.

Switch Action

As for unloaded phase (Task A).

Task EL - Reset Flap (Fig. 7)

Switch requirements covered on unloaded phase (Task E).

Tone 9 on Track 4 is used for Task EL.

Task GL - Select Land Display Port or Starboard (Fig. 14)

The Port/Starboard switch is part of the Smiths Flight Controller. 2 contacts are required on each of the positions - Port and Starboard.

The contacts are used in each case as follows:-

(i) To complete the correct switch action path.
(ii) To operate the mode selector.

Tones 6 and 7 on Track 2 are used for Task GL.

Task HL - Press cut out button (Fig. 15)

The spring loaded button operates a lock on two pole relay. These contacts are used:-

(i) To complete the correct switch action counter path.
(ii) To lock on the relay.

Tone 9 on Track 2 is used for Task HL.

CHANGE OVER FROM UNLOADED PHASE TO LOADED PHASE RECORDING

A photo electric cell mounted on the tape recorder deck is used to operate a series of relays designated (Fig. 1). A transparent window on the tape activates the cell and relays Z after the completion of a memory period.

THE TRACKING TASK

To provide a tracking task programme, tones of 150 c.p.s. and 90 c.p.s. are mixed together and recorded. Track 3 is used for the azimuth tracking task and Track 4 for the pitch tracking task.

On replay these signals are fed via an audio coupling transformer to standard ILS type filters and rectifiers, the rectified output,depending on the difference between the two tones for polarity and amplitude, is fed to the zero reader type indicator displaying pitch deflections on the horizontal needle and azimuth deflections on the vertical needle.

The control column is modified to include potentiometers in the pitch and azimuth controls. These potentiometers are connected across d.c. power supplies (power units 4 and 5 Fig. 2) and when operated correctly cancel the deflecting signals. The tracking task error counter, Board 3 (Fig. 18) is connected in series with the zero reader indicator movements. This counter records two error counts per second per channel for the period the needles show one dot deflection. The counter is repeated in the cockpit and can be used in a motivation scheme.

THE PACING TASK

The pacing task indicator is a moving coil meter 1 mA Full Scale Deflection with a 270^{o} dial calibrated as required in altitude or distance. A frequency reducing from 6 kc/s to 1 kc. is recorded on the tape track 3. On replay this signal is fed to Board 4 (Fig. 19) which produces a d.c. frequency ratio of 1 mA on 6 kc/s to 0 mA on 1 kc.

TAPE PREPARATION

Preparation of the tape requires the following facilities which are embodied in a tape modulator box:-

(i) A source of 90 c.p.s.) / 150 c.p.s.) for the pitch and azimuth tracking tasks.

The frequency accuracy should be better than 1%. A mixing circuit capable of providing continuously variable mixtures of the 90 and 150 c.p.s. and an output amplitude control.

(ii) A source of tones 1 to 10 inclusive capable of being switched to tracks 2, 3 or 4 with output amplitude control and a one second output timer.

(iii) A variable frequency oscillator from 6 kc/s to 1 kc. with output amplitude control and track switching, or terminals to connect an external V.F.O. routed via the output amplitude control and track switch.

(iv) A microphone to match the tape recorder.

(v) A panel mounted stop watch.

INVESTIGATION TEST PROGRAMME

The following tests were carried out to prove the operation and reliability of the circuits designed.

A sample switch accuracy test rig was constructed comprising 3 Boards Type 1, 3 Boards Type 2, 3 Filters K55A and 3 Magnetic Counters. Q.F.E. selection was simulated using toggle switches instead of a modified altimeter barometric setting control. The selections:-

975 Tone 1

974 Tone 2

964 Tone 3,

were used to provide the task switch action. Demands/Errors and corrected errors were recorded on a set of three counters. Both the verbal instructions and one second tone key signal, were recorded on one track of a domestic stereo tape recorder, the other track being used to provide the tracking task in azimuth. 90 c.p.s. and 150 c.p.s. were recorded and replayed through the filters of an SR 14 ILS receiver, thence to an ILS cross pointer indicator, a Board Type 3 and veeder counter to record azimuth tracking errors. Correction in the tracking task was provided by a modified auto pilot control column. Illustration No. 2.

INVESTIGATION TEST PROGRAMME (continued)

Experiments to ascertain the type of tracking disturbance required were carried out and several programmes of simulated zero reader type approaches recorded and tested. It was possible to produce programmes of varying degrees of difficulty using equipment similar to the proposed tape modulator.

COMPONENTS USED IN THE EXPERIMENTAL TEST RIG

The small components used in the experimental test rig were chosen for their ready availability and are not necessarily the types which would be used in the final equipment.

Relays type 22 were used on all except one of the Boards Type 1 where the suggested final type G.P.R. 302-4C 24B relay was used. The GPR 302 relay mechanical life is 10^8 operations.

TEST PROGRAMME FINDINGS

The circuit boards used in the experimental units have been tested for more than 2000 operations without mechanical or electrical failure.

Switch actions were checked for accuracy under conditions of correct action - incorrect action - and corrected action to simulate each possible phase of a task. No wrong indications were experienced.

The K55A Filter units have been tested for 1000 operations and have been soak tested for 300 hours without deterioration in performance.

APPENDIX 1

MAJOR EQUIPMENT SPECIFICATIONS

TAPE RECORDER

The tape recorder should meet the following minimum specification:-

Mains Voltage: 240 v. 50 c/s.

Tape Speed: $3\frac{3}{4}$ inches/sec.

Frequency Fidelity: better than 1%

Tracks: 4 separate record/replay tracks.

Record input impedance 600 Ohm

Each track to have record level monitoring, ability to record without disturbing the other 3 tracks, ability to erase without disturbing the other 3 tracks (input approximately 5 MV).

Relay output impedance 600 Ohm

Each track to have a separate output with "volume" control. Output required approximately 1 watt. (All tracks will be replayed on the same machine as recorded).

Frequency response: 60 c.p.s. to 6 kc/s $\pm$3 db.

Intermodulation between tracks: better than - 30 db.

RECORD OSCILLATORS

MINIMUM SPECIFICATION

Frequency coverage: 400 to 6000 c.p.s.

Output: 10 MW. into 600 Ohm.

Frequency accuracy: $\pm$ 1%

A suitable unit is the WHITELEY P110b.

FILTERS

To allow for the tape recorder fidelity, response, and for the recording tone oscillator accuracy, the nose of the bandpass filter should be fo $\pm$ 2% at -3 db., and to keep good separation between tones, not wider than $\pm$ 10% at -30 db.

The MUIRHEAD K55A narrow band filter meets this specification.

SCHEDULE OF COMPONENTS

Task A	Quantity
Modified Select Pressure Switch	
4 pole change over relay identity Q.	10
Tone Filters (Tones 1 to 8) 1 off each	8
Relay Board Type 1	8
Relay Board Type 2	8
Counters	3
Task B	
Modified Heading selector switch	1
Tone Filter (Tones 1 to 8) 1 off each	8
Relay Board Type 1	8
Relay Board Type 2	8
Counters	3
Task C	
Modified ILS control units	
3 pole 2 way switch	3
Dial lighting	3
Relay Board Type 1	1
Relay Board Type 2	1
Tone Filter (Tone 9)	1
Counters	3
Task D	
Modified Radio Selector Panel Switch	
2 pole 3 way rotary switch	1
Relay Board Type 1	1
Relay Board Type 2	1
Tone Filter (Tone 9)	1
Counters	3
Task E	
Flap selection mechanism	1
Micro Switches	3
Desynn Transmitter / Receiver Indicator	1
Tone Filter (Tone 9)	1
Relay Board Type 1	1
Relay Board Type 2	1
Counters	3

Task F	Quantity
Undercarriage Selector	1
Relay 4 pole change over	1
Undercarriage indicator	1
Tone Filter (Tone 10)	1
Relay Board Type 1	1
Relay Board Type 2	1
Counters	3

Task G	
Modified switch autopilot control unit	1
Tone Filter (Tone 9)	1
Relay Board Type 1	1
Relay Board Type 2	1
Counters	3

Task H	
Modified switch autopilot control unit	1
Tone Filter (Tone 10)	1
Relay Board Type 1	1
Relay Board Type 2	1
Counters	3

Task J	
Modified I.A.S. Selector autopilot control unit	1
4 pole change over relay identity S.	3
Relay Board Type 1	8
Relay Board Type 2	8
Tone Filters (Tones 1 to 8) o off each	8
Counters	3

Task AL	
Modified set Display switch	1
2 way Double pole rotary	1
Relay Board Type 1	2
Relay Board Type 2	2
Counters	3

Task BL and FL	
Modified Switch autopilot control unit	1
Relay Board Type 1	2
Relay Board Type 2	2
Counters	6

Task CL	Quantity
Modified switch autopilot Control unit as for Task G.	1
Relay Board Type 1	8
Relay Board Type 2	8
Counters	3
Task DL	
Modified switch autopilot control unit as for Task A.	1
Relay Board Type 1	3
Relay Board Type 2	3
Counters	3
Task EL	
Flap selector as for Task E.	3
Relay Board Type 1	1
Relay Board Type 2	1
Counters	3
Task GL	
Modified switch autopilot control unit	1
Relay Board Type 1	2
Relay Board Type 2	2
Counters	3
Task HL	
Modified cut out button	1
2 pole change over relay	1
Relay Board Type 1	1
Relay Board Type 2	1
Counters	3

Tracking Task	Quantity
Modified Control Column	1
Zero reader indicator	1
Board Type 3	1
Power Unit type (P114 and P115) 1 off each	2
Modified Control Column	1
Filter rectifier units	2
Counter	1
Pacing Task	
Range or Altitude Indicator	1
Board Type 4	1
Change over loaded to unloaded Task	
Relays Type Z	10
Photo electric cell	1
Light source	1
General	
Tape recorder	1
Audio coupling transformer track 2	1
Audio coupling transformer track 3	1
Audio coupling transformer track 4	1
Headset	1
Delay units - 5 minutes	1
Delay units - 5 seconds	1
Veroboard mounting rails etc.	210
Power Unit (1 and 2) 2 x 24v.X1A.	1
Power Unit (3) 24v.10A.	1
Power Unit (4 and 5) 9 v.100 mA	2
Filter pre-set input controls.	30
Auto photographic observer	1
Mode Indicator	1
Tape Modulator	
Stop watch large panel mounting	
Oscillator coils 1-10	
Oscillator VFD	
Oscillator 90 c.p.s.	
Oscillator 150 c.p.s.	
Microphone	
Volume controls - switches - jack and plugs	
Mixing transformer	
1 sec. pulser	

APPENDIX 3

COST ESTIMATES

Bought-out items

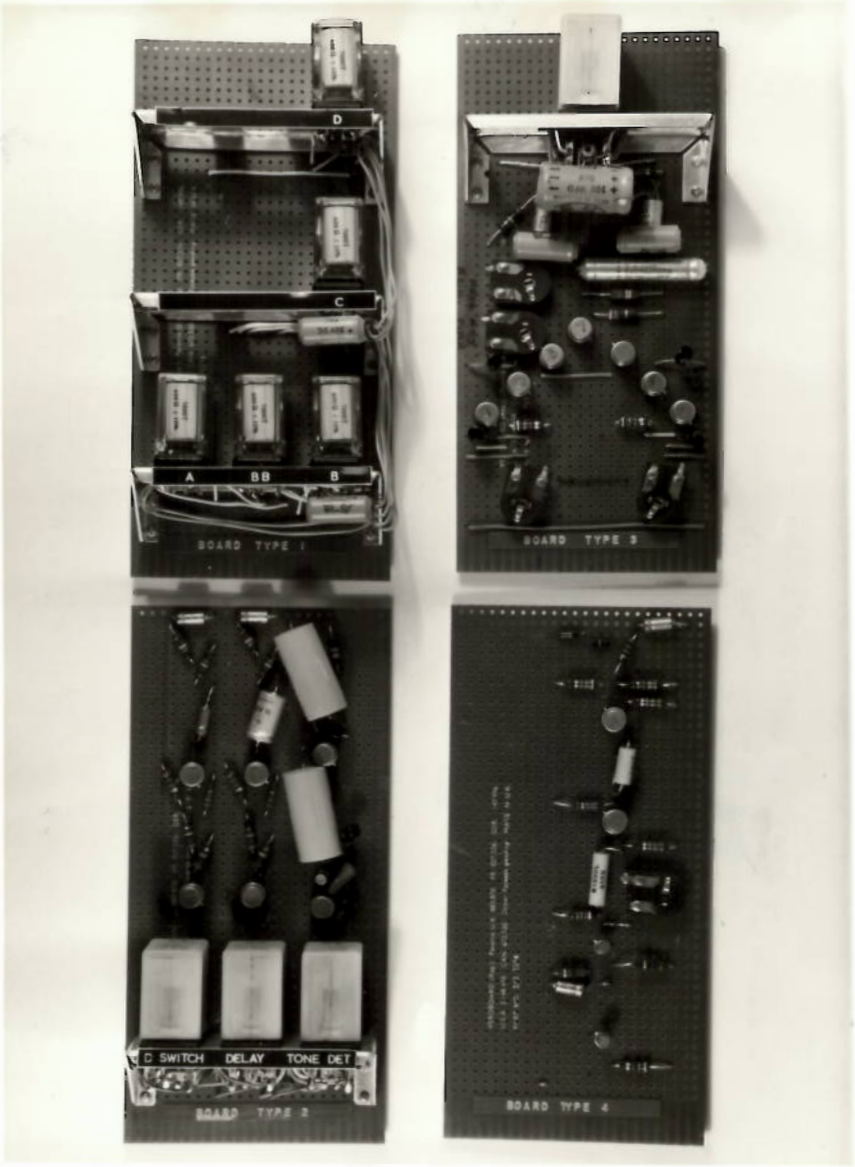
Item		Quantity	Estimate Each	Cost
			£	£
1.	Tape Recorder - Quotations for various recorders have been obtained varying from £200 to £1650. It is considered that this is the most suitable quotation to meet the specification.		510	510
2.	Filter Units K55A	30	22	660
3.	Audio Coupling Transformer Track 2 600 Ohm P.10X 500 Ohm S.	1	10	10
4.	Audio Coupling Transformer Track 3 600 ohm P.10X500 ohm S. 10K T.	1	15	15
5.	Audio Coupling Transformer Track 4 600 Ohm P. 10X 500 Ohm S. 10KOhm T.	1	15	15
6.	8-Lu-280C Filter ILS	2	30	60
7.	22-LU-77B Rectifier ILS	2	10	20
8.	Relay 4 pole change over Identity Z,Q,S.	30	1	30
9.	Boards Type 1 components (50 + 5 spare)	55	7	385
10.	Boards Type 2 components (50 + 5 spare)	55	11	605
11.	Boards Type 3 components (1 + 1 spare)	2	10	20
12.	Boards Type 4 components (1 + 1 spare)	2	5	10
13.	Filter input control pots	30	5/-	8
14.	Combined Power Unit (1+2) 2 x 24v.x1A.	1	48	48
15.	Power Unit (3) 24v. 10A	1	56	56
16.	Power Unit (4+5) 9v.100 mA	2	1	2
17.	Delay unit 5 seconds.	1	3	3
18.	Delay unit 5 minutes.	1	5	5
19.	Counters LANDIS and GYR. Type A.T.	52	6	312
20.	Photo Recorder motor lighting etc.	1	25	25
21.	Photo-electric cell and light source	1	5	5
22.	Simulated ILS control unit (triple)	1	10	10
23.	Simulated Radio Selector Panel	1	5	5
24.	Headset	1	10	10
25.	General terminal blocks, plugs, sockets. Metal, wood etc.			200
26.	Veroboard mounting components side rails etc.			100
27.	Mode Indicator			25
Tape Modulator comprising:-				
28.	Stopwatch panel mounting	1	15	15
29.	Oscillator coils 1 to 10	10	£8.5s.	83
30.	Oscillator V.F.O.	1	15	15
31.	Oscillator 90 c.p.s.	1	10	10
32.	Oscillator 150 c.p.s.	1	10	10
33.	Mixing Transformer	1	7	7
34.	Volume controls, jacks, switches			30
35.	1 Sec. Pulser	1	5	5
				£3329

ITEMS SUPPLIED FROM M.O.A. SOURCES

Indicator zero reader - Tracking Task
Flight Compass for Heading Selector
Altimeter
Mechanical section of Smiths Autoland Controller
Undercarriage selection switch
Control Column Spectacle type (Redundant item satisfactory)
Camera (Robot).

COST AND SUMMARY

Estimated cost of bought out components	£3350	
Construction of cockpit, equipment cabinet, electronic circuitry, modification of instruments, preparation of tape programme and the final tests estimated 2500 man-hours.	£3750	
Total cost		£7100


D
C
A
BB
B
BOARD TYPE 1
BOARD TYPE 3
C SWITCH
DELAY
TONE DET
BOARD TYPE 2
BOARD TYPE 4

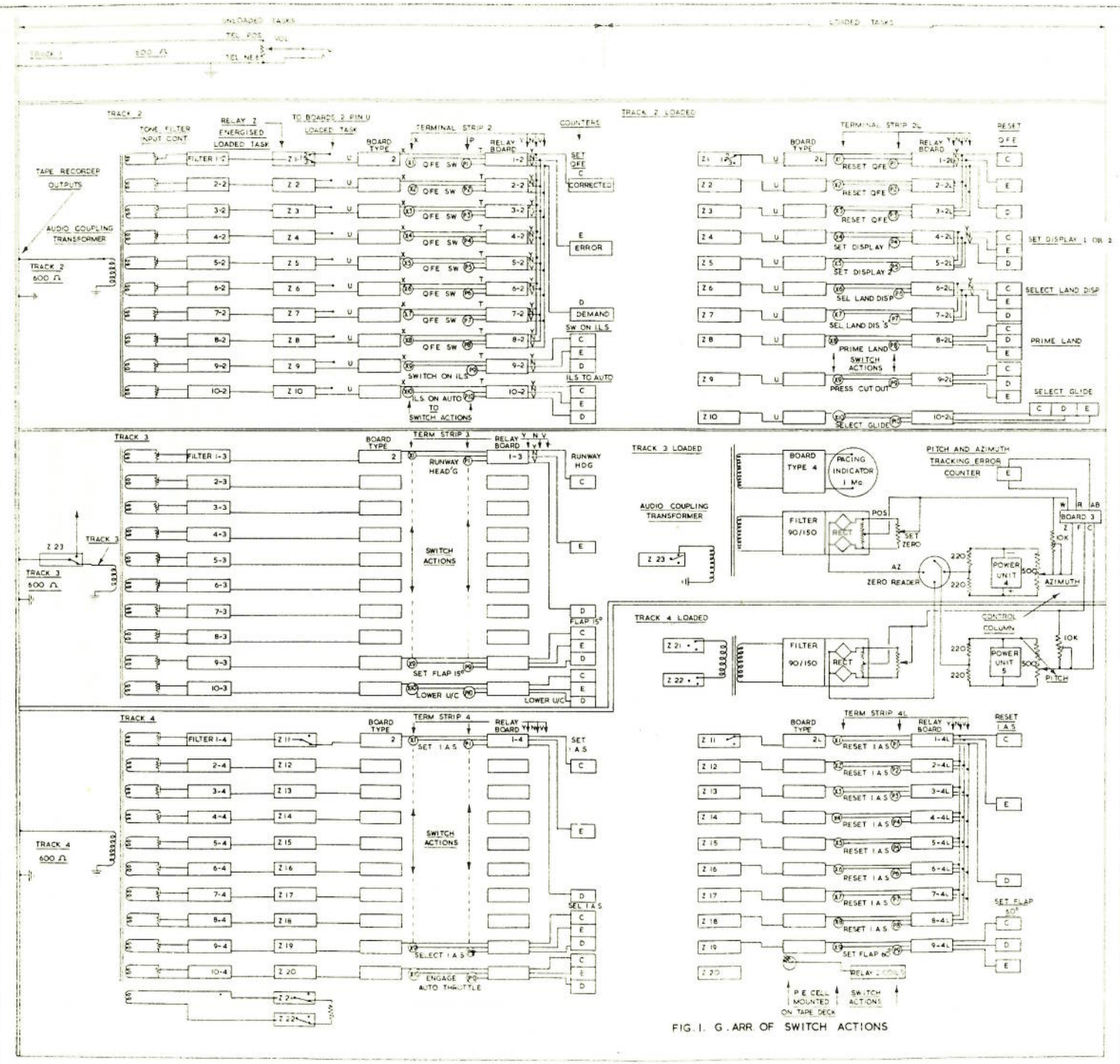


FIG. 1. GARR OF SWITCH ACTIONS

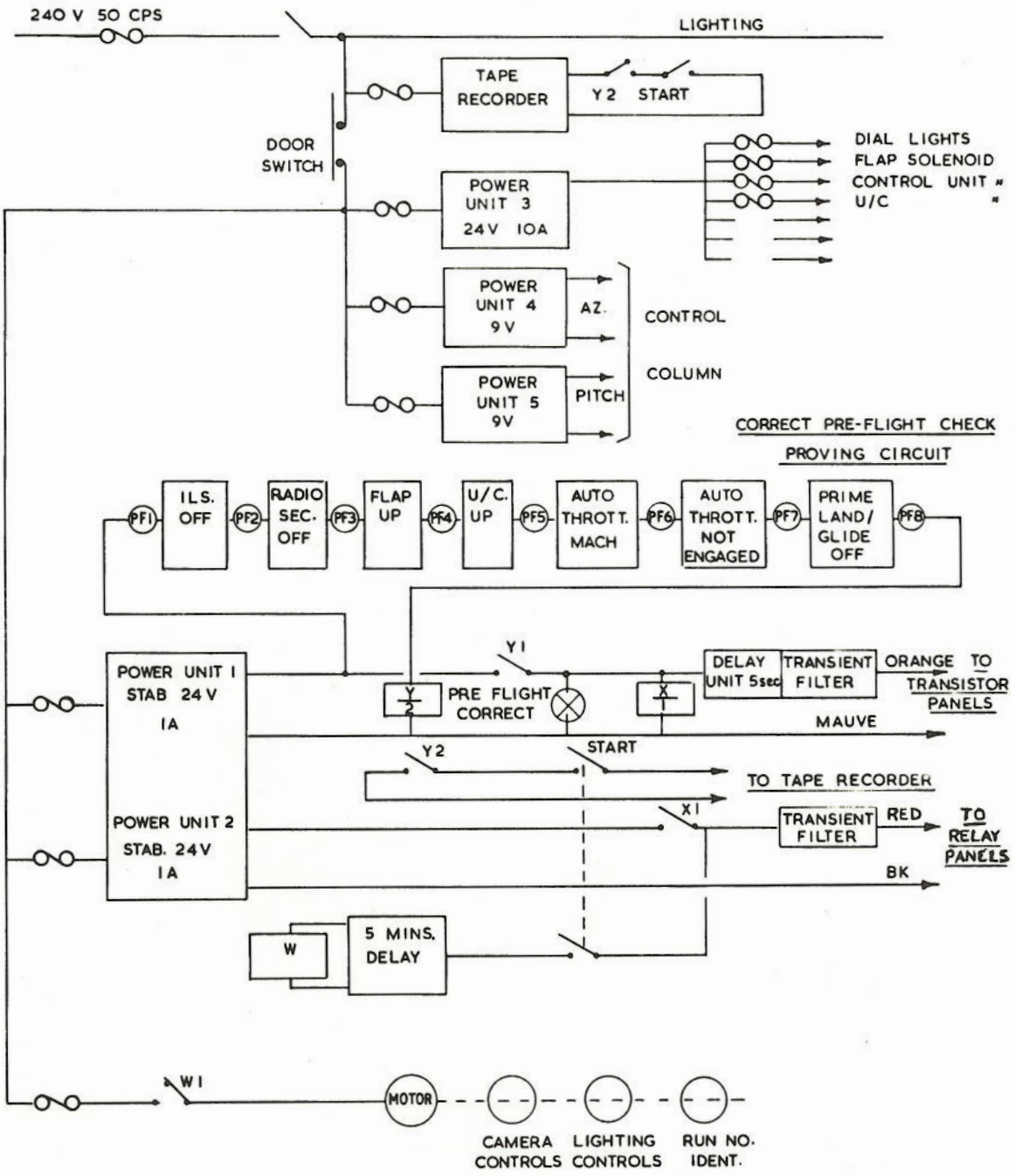
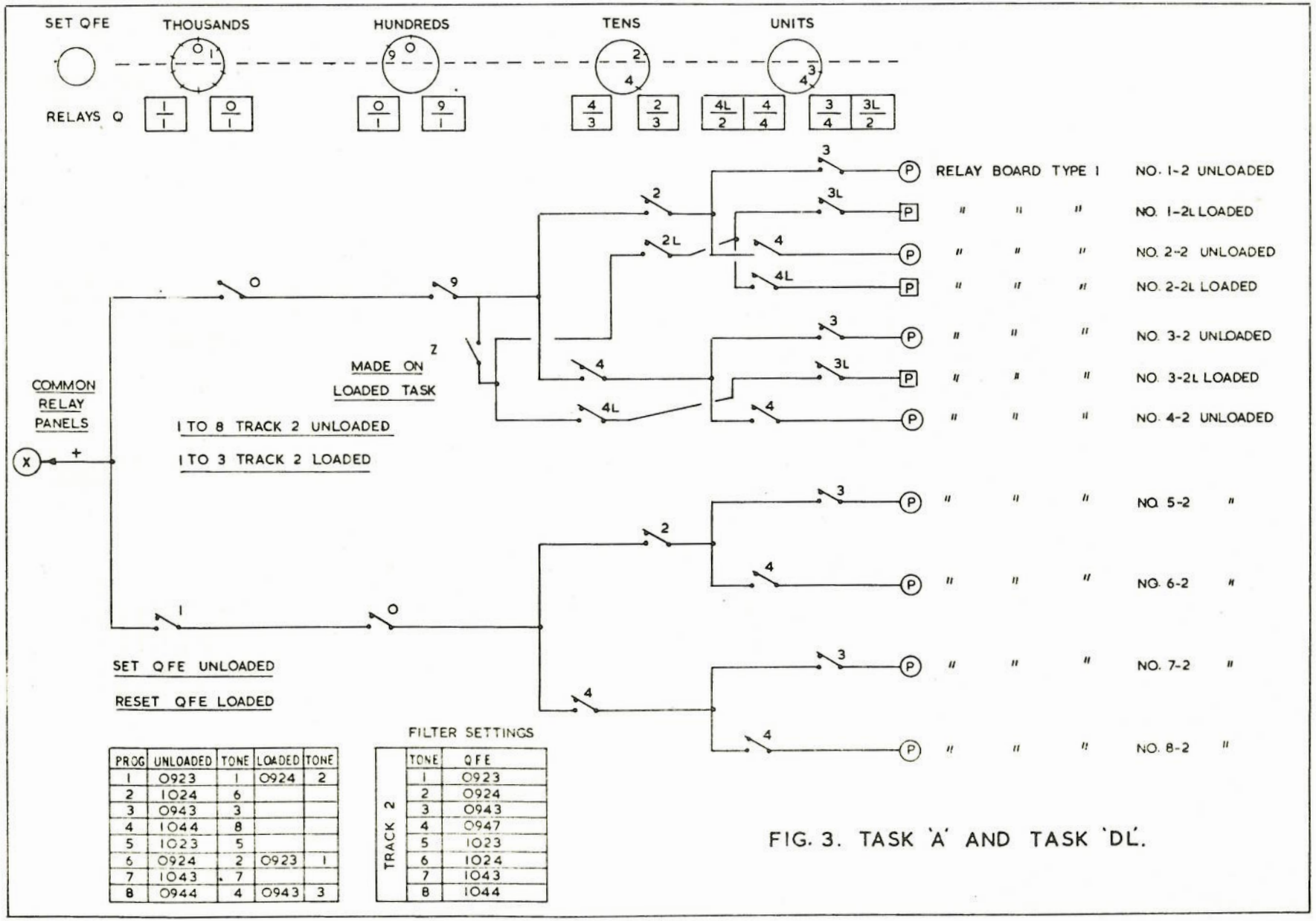


FIG. 2. POWER SUPPLIES.
TAPE RECORDER.
PRE-FLIGHT PROVING.

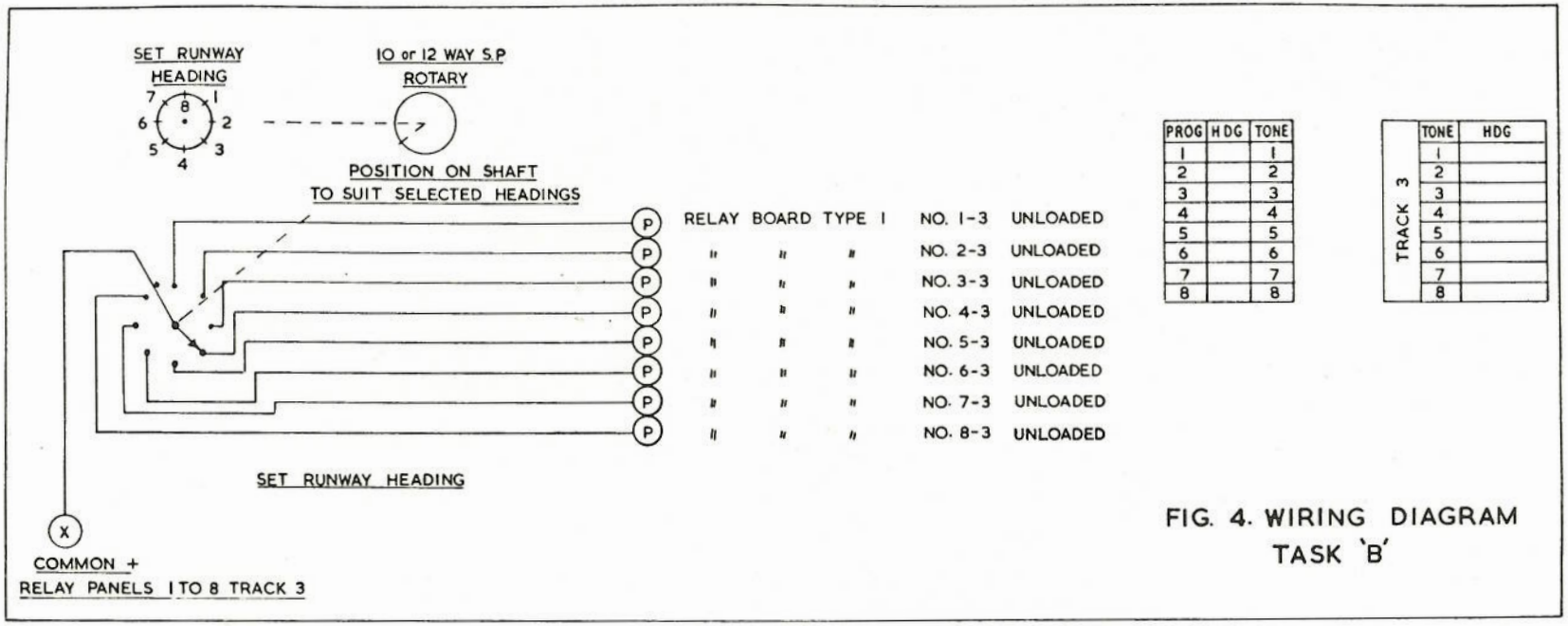


PROG	UNLOADED	TONE	LOADED	TONE
1	0923	1	0924	2
2	1024	6		
3	0943	3		
4	1044	8		
5	1023	5		
6	0924	2	0923	1
7	1043	7		
8	0944	4	0943	3

FILTER SETTINGS

TRACK 2	TONE	QFE
	1	0923
	2	0924
	3	0943
	4	0947
	5	1023
	6	1024
	7	1043
	8	1044

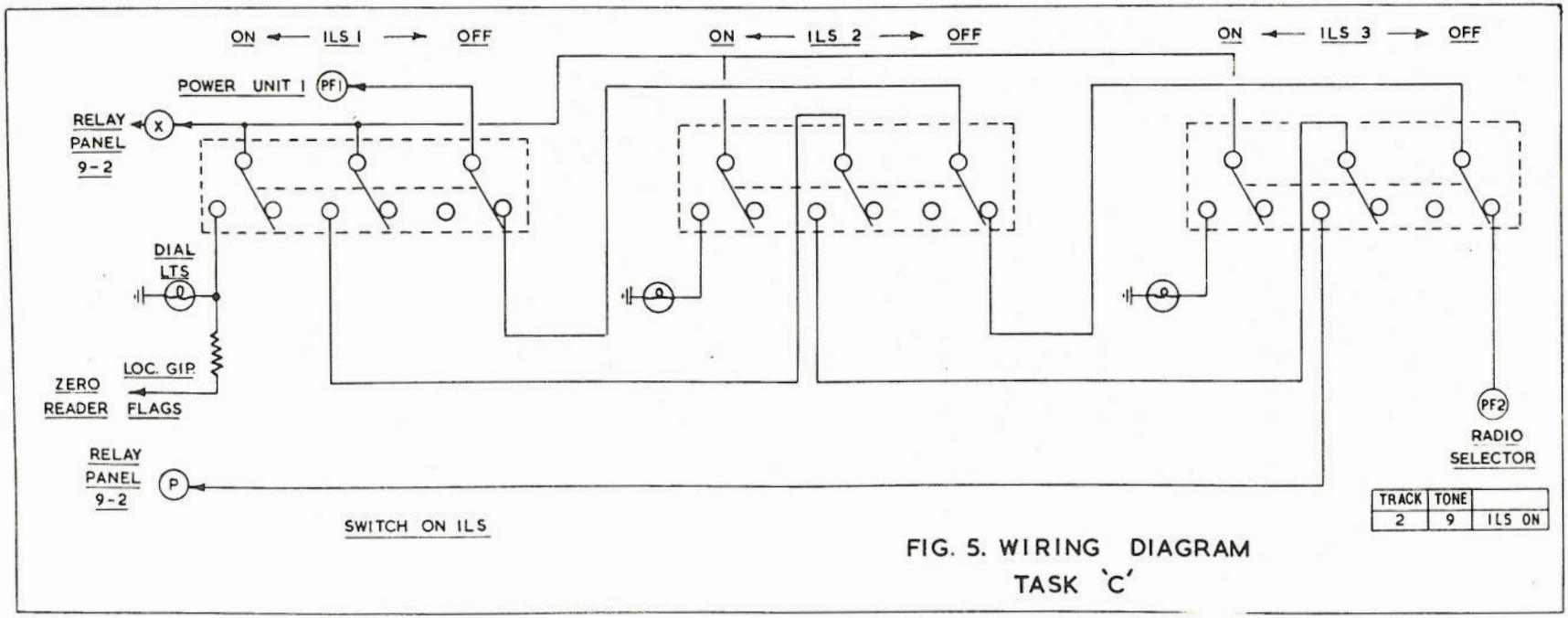
FIG. 3. TASK 'A' AND TASK 'DL'.



PROG	H DG	TONE
1		1
2		2
3		3
4		4
5		5
6		6
7		7
8		8

	TONE	HDG
TRACK 3	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	

FIG. 4. WIRING DIAGRAM TASK 'B'



TRACK	TONE	
2	9	ILS ON

FIG. 5. WIRING DIAGRAM TASK 'C'

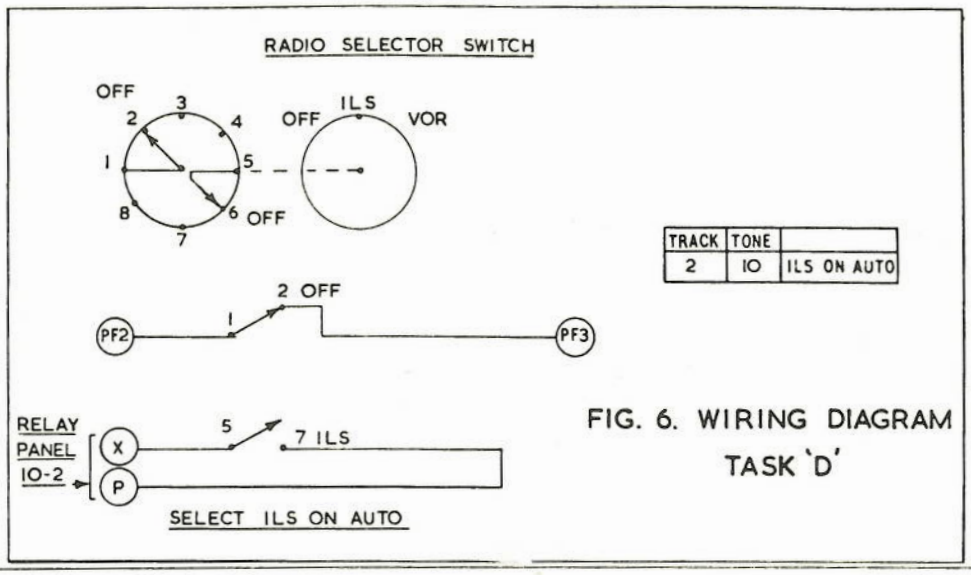


FIG. 6. WIRING DIAGRAM TASK 'D'

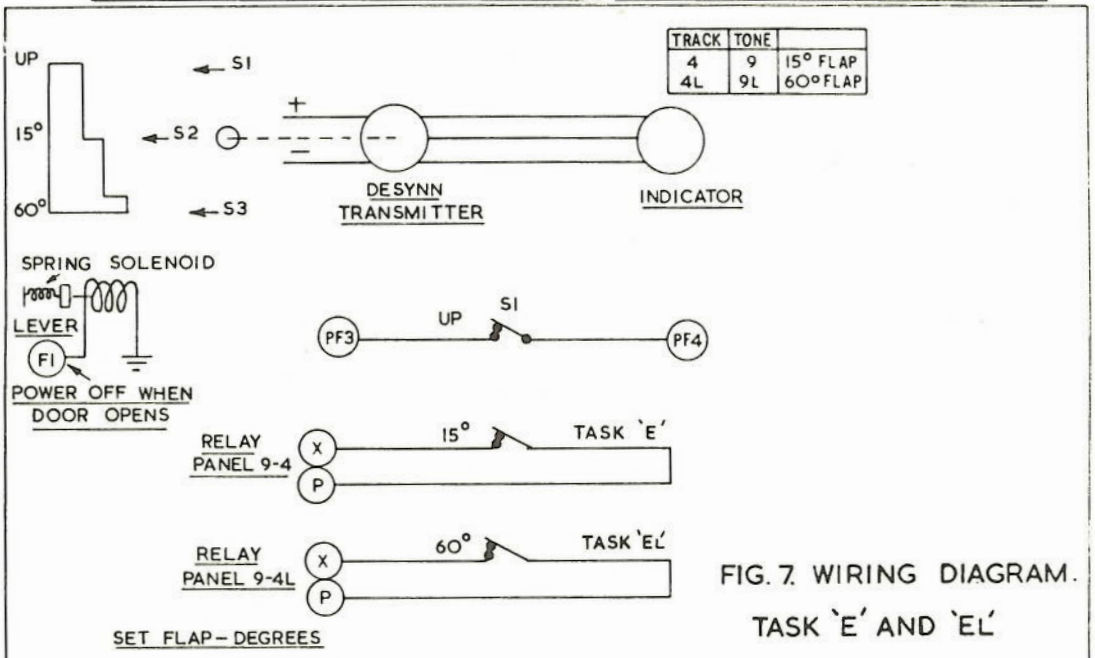


FIG. 7. WIRING DIAGRAM. TASK 'E' AND 'EL'

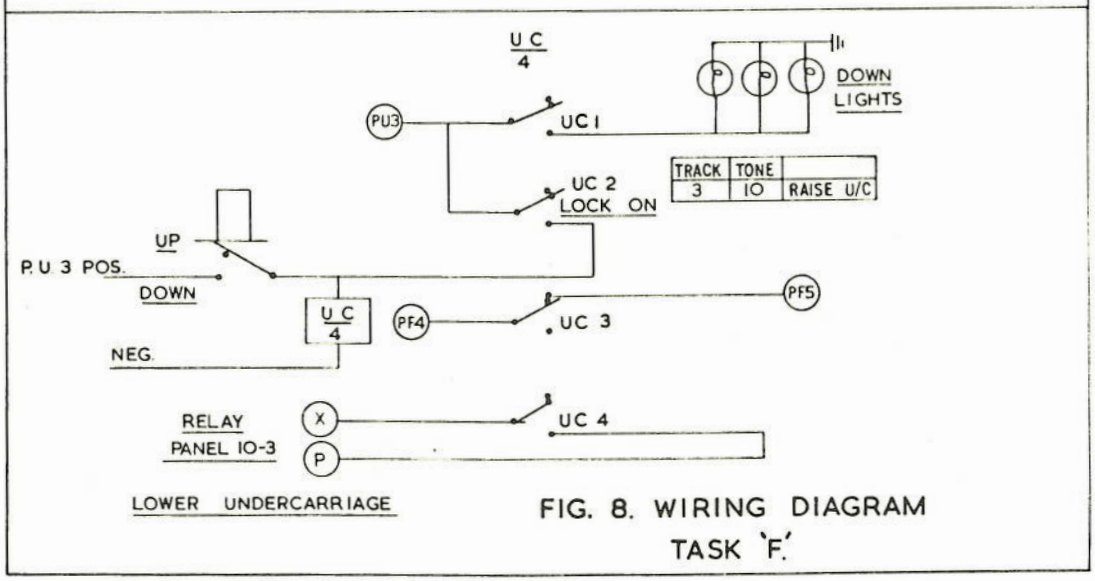


FIG. 8. WIRING DIAGRAM TASK 'F'

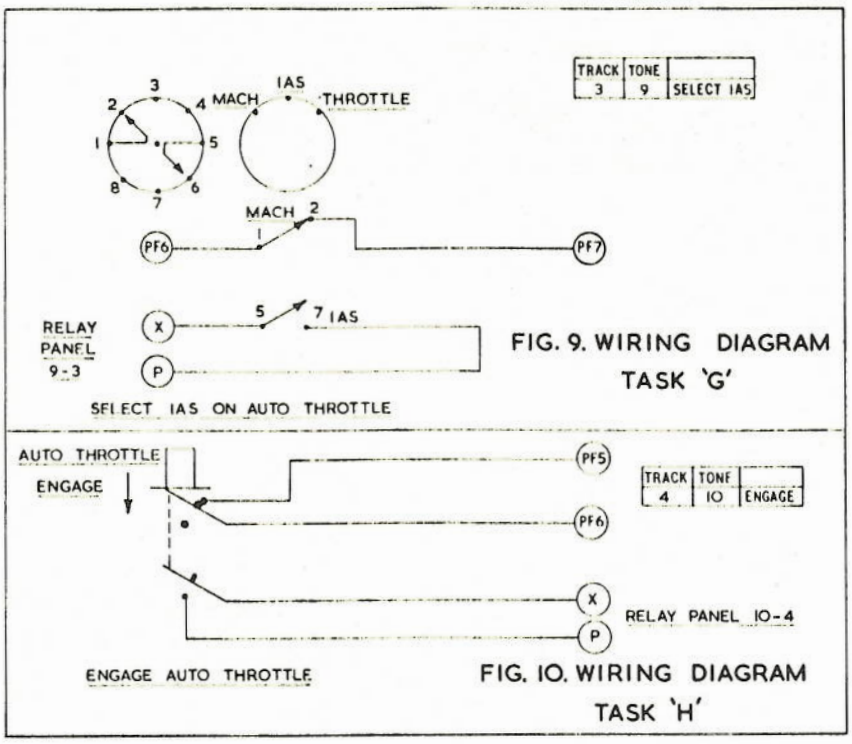
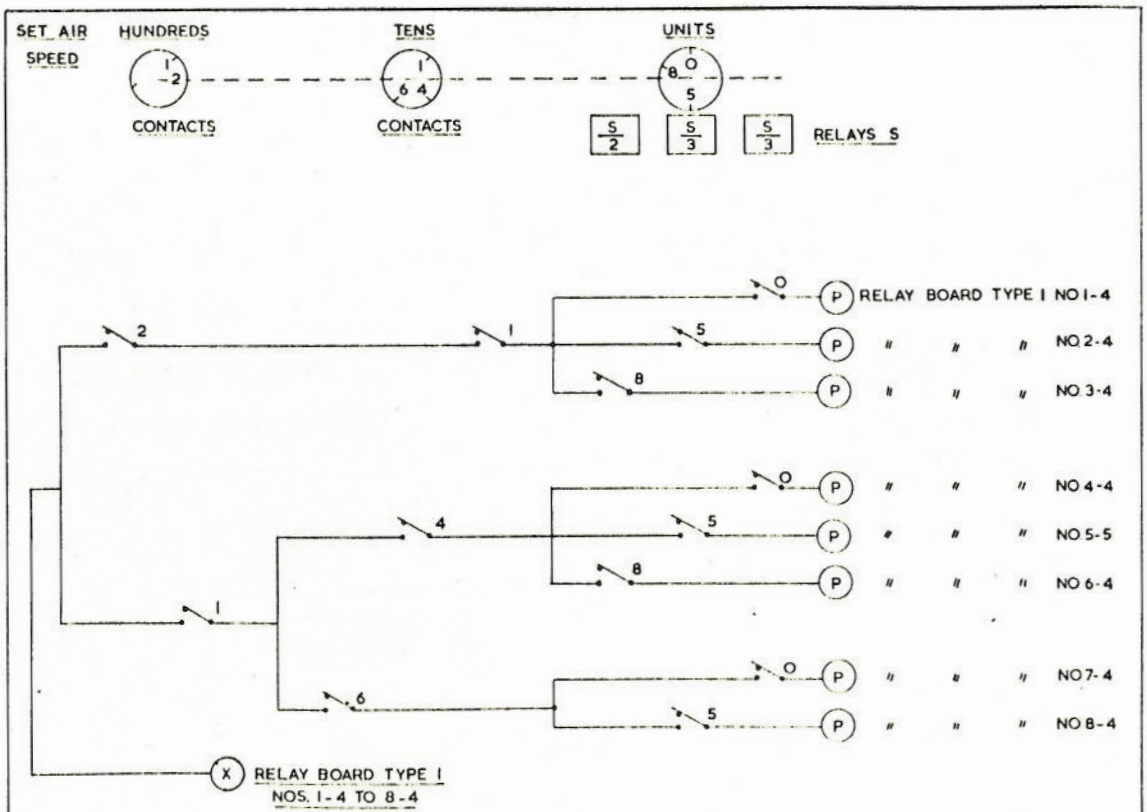


FIG. 9. WIRING DIAGRAM TASK 'G'

FIG. 10. WIRING DIAGRAM TASK 'H'



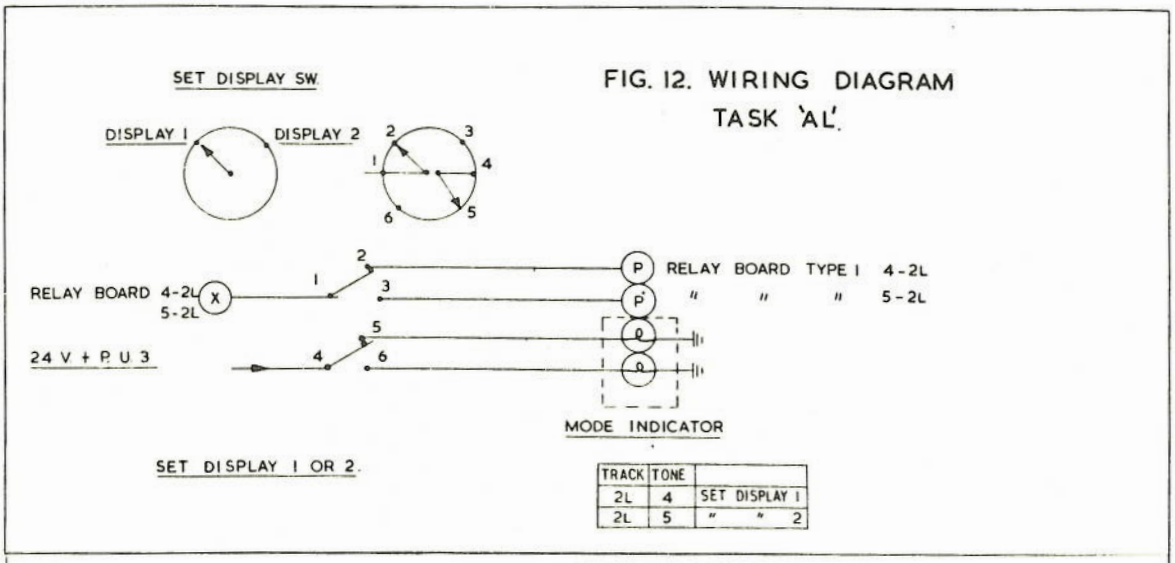
SET IAS

NOTE 1: ON LOADED TASK 'CL', THE COUNTERS WOULD BE CHANGED OVER. OTHER CIRCUITS REMAIN.

FILTER SETTING

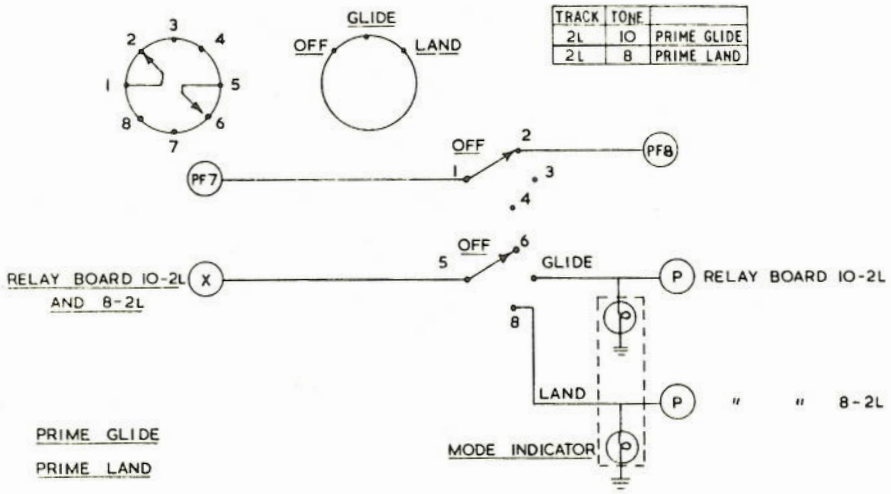
PROG	UNLOADED	TONE	LOADED	TONE		TONE
1	218	3	165	8	210	1
2	210	1	148	6	215	2
3	215	2	160	7	218	3
4	218	3	145	5	140	4
5	160	7	148	6	145	5
6	165	8	140	4	148	6
7	218	3	210	1	160	7
8	165	8	140	4	165	8

FIG. 11. WIRING DIAGRAM TASKS 'J' AND 'CL'



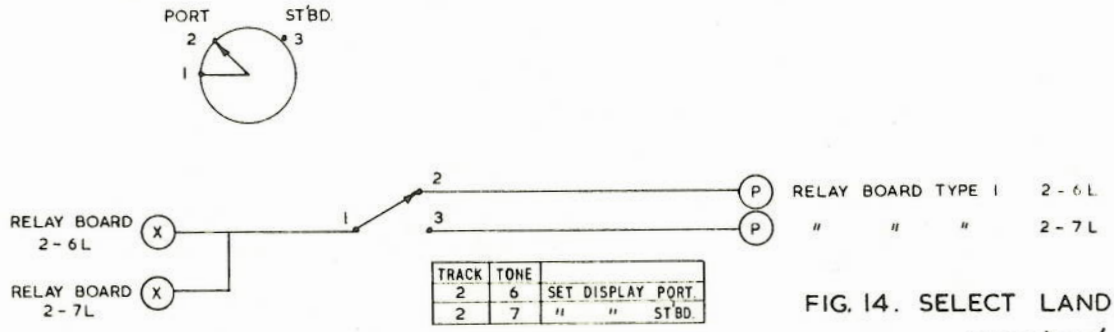
TRACK	TONE	
2L	4	SET DISPLAY 1
2L	5	" " 2

FIG. 12. WIRING DIAGRAM
TASK 'AL'.



TRACK	TONE	
2L	10	PRIME GLIDE
2L	8	PRIME LAND

FIG. 13. WIRING DIAGRAM
TASKS 'BL' AND 'FL'

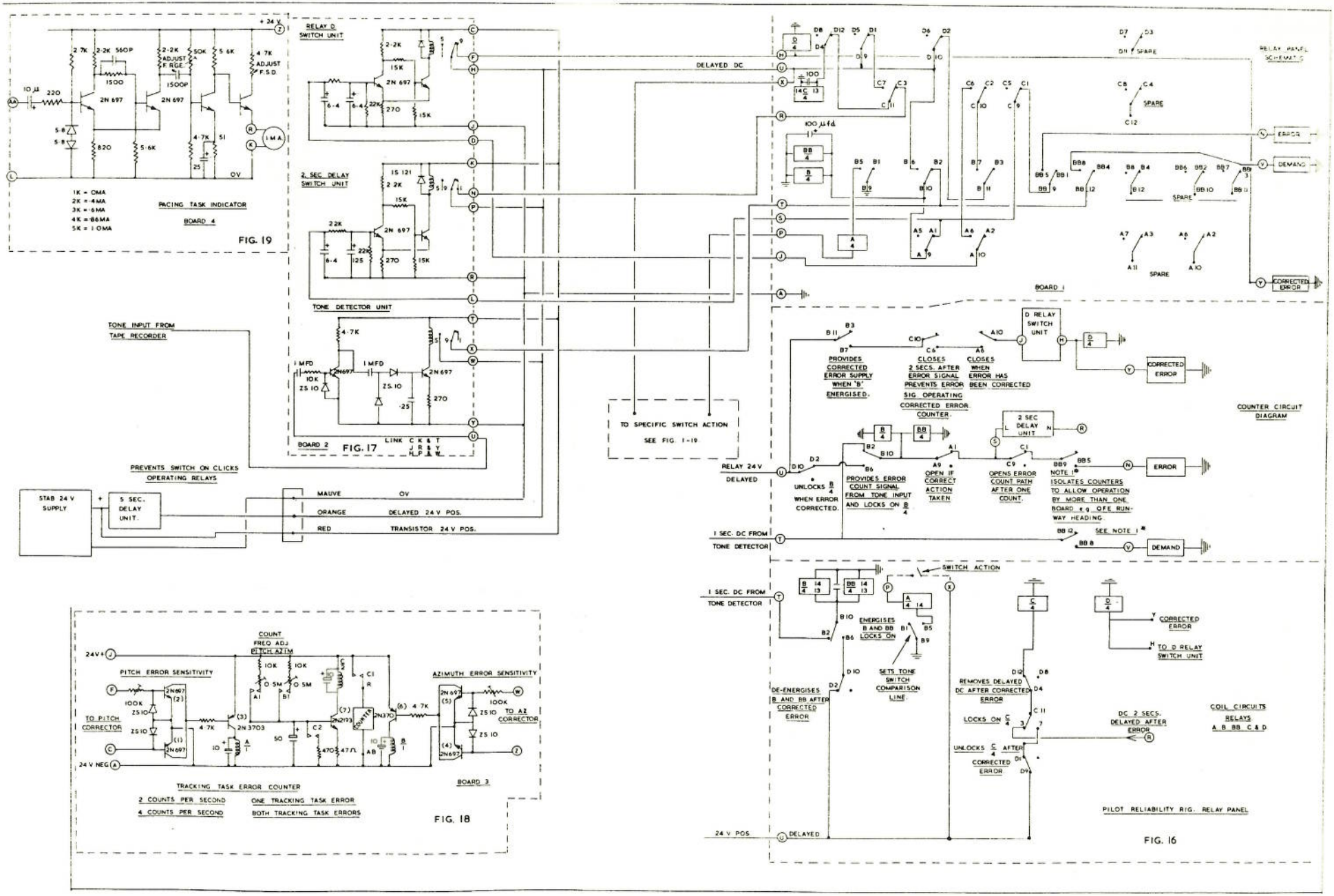


TRACK	TONE	
2	6	SET DISPLAY PORT.
2	7	" " ST'BD.

FIG. 14. SELECT LAND DISPLAY.
TASK 'G.L'.

TRACK	TONE	
2	9	PRESS C.O. BUTTON

FIG. 15. PRESS CUT OUT BUTTON.
TASK 'H.L'.


+24 V
2·7K
2·2K 560P
1500
2·2K ADJUST F. RGE.
1500P
50K
5·6K
4·7K ADJUST F.S.D
10 µf
220
2N 697
2N 697
5·6
5·6
820
5·6K
4·7K
51
25
0V
1 MA
1K = 0MA
2K = ·4MA
3K = ·6MA
4K = ·86MA
5K = 1·0MA
PACING TASK INDICATOR
BOARD 4
FIG. 19
RELAY D SWITCH UNIT
2·2K
15K
2N 697
6·4
6·4
22K
270
15K
2. SEC DELAY SWITCH UNIT
15 121
2·2K
15K
2N 697
22K
6·4
22K
125
270
15K
TONE DETECTOR UNIT
4·7K
1 MFD
1 MFD
2N697
2N 697
10K
ZS 10
ZS 10
·25
270
BOARD 2
FIG. 17
LINK C K & T
TONE INPUT FROM TAPE RECORDER
PREVENTS SWITCH ON CLICKS OPERATING RELAYS
STAB 24 V SUPPLY
5 SEC. DELAY UNIT.
MAUVE
ORANGE
RED
0V
DELAYED 24 V POS.
TRANSISTOR 24 V POS.
DELAYED DC
100 µfd.
TO SPECIFIC SWITCH ACTION
SEE FIG. 1-10
SPARE
SPARE
SPARE
ERROR
DEMAND
CORRECTED ERROR
BOARD 1
RELAY PANEL SCHEMATIC
D RELAY SWITCH UNIT
PROVIDES CORRECTED ERROR SUPPLY WHEN 'B' ENERGISED.
CLOSES 2 SECS. AFTER ERROR SIGNAL PREVENTS ERROR SIG. OPERATING CORRECTED ERROR COUNTER.
CLOSES WHEN ERROR HAS BEEN CORRECTED
CORRECTED ERROR
COUNTER CIRCUIT DIAGRAM
2 SEC DELAY UNIT
RELAY 24 V DELAYED
UNLOCKS B 4 WHEN ERROR CORRECTED.
PROVIDES ERROR COUNT SIGNAL FROM TONE INPUT AND LOCKS ON B 4
OPEN IF CORRECT ACTION TAKEN
OPENS ERROR COUNT PATH AFTER ONE COUNT.
NOTE 1* ISOLATES COUNTERS TO ALLOW OPERATION BY MORE THAN ONE BOARD e.g. OFE RUN-WAY HEADING.
ERROR
1 SEC. DC FROM TONE DETECTOR
SEE NOTE 1 *
DEMAND
SWITCH ACTION
1 SEC. DC FROM TONE DETECTOR
ENERGISES B AND BB LOCKS ON
SETS TONE SWITCH COMPARISON LINE.
DE-ENERGISES B AND BB AFTER CORRECTED ERROR
CORRECTED ERROR
TO D RELAY SWITCH UNIT
REMOVES DELAYED DC AFTER CORRECTED ERROR
LOCKS ON C 4 3
UNLOCKS C 4 AFTER CORRECTED ERROR
DC 2 SECS. DELAYED AFTER ERROR
COIL CIRCUITS RELAYS A B BB C & D
24 V POS.
DELAYED
PILOT RELIABILITY RIG. RELAY PANEL
FIG. 16
COUNT FREQ ADJ PITCH AZTM
24V+
24 V NEG
PITCH ERROR SENSITIVITY
AZIMUTH ERROR SENSITIVITY
10K
10K
0·5M
0·5M
100K
ZS10
ZS10
TO PITCH CORRECTOR
2N 697
2N 697
2N 3703
2N 3703
4·7K
4·7K
50
470
47Ω
2N 697
2N 697
100K
ZS 10
ZS 10
TO AZ CORRECTOR
TRACKING TASK ERROR COUNTER
2 COUNTS PER SECOND
4 COUNTS PER SECOND
ONE TRACKING TASK ERROR
BOTH TRACKING TASK ERRORS
BOARD 3
FIG. 18

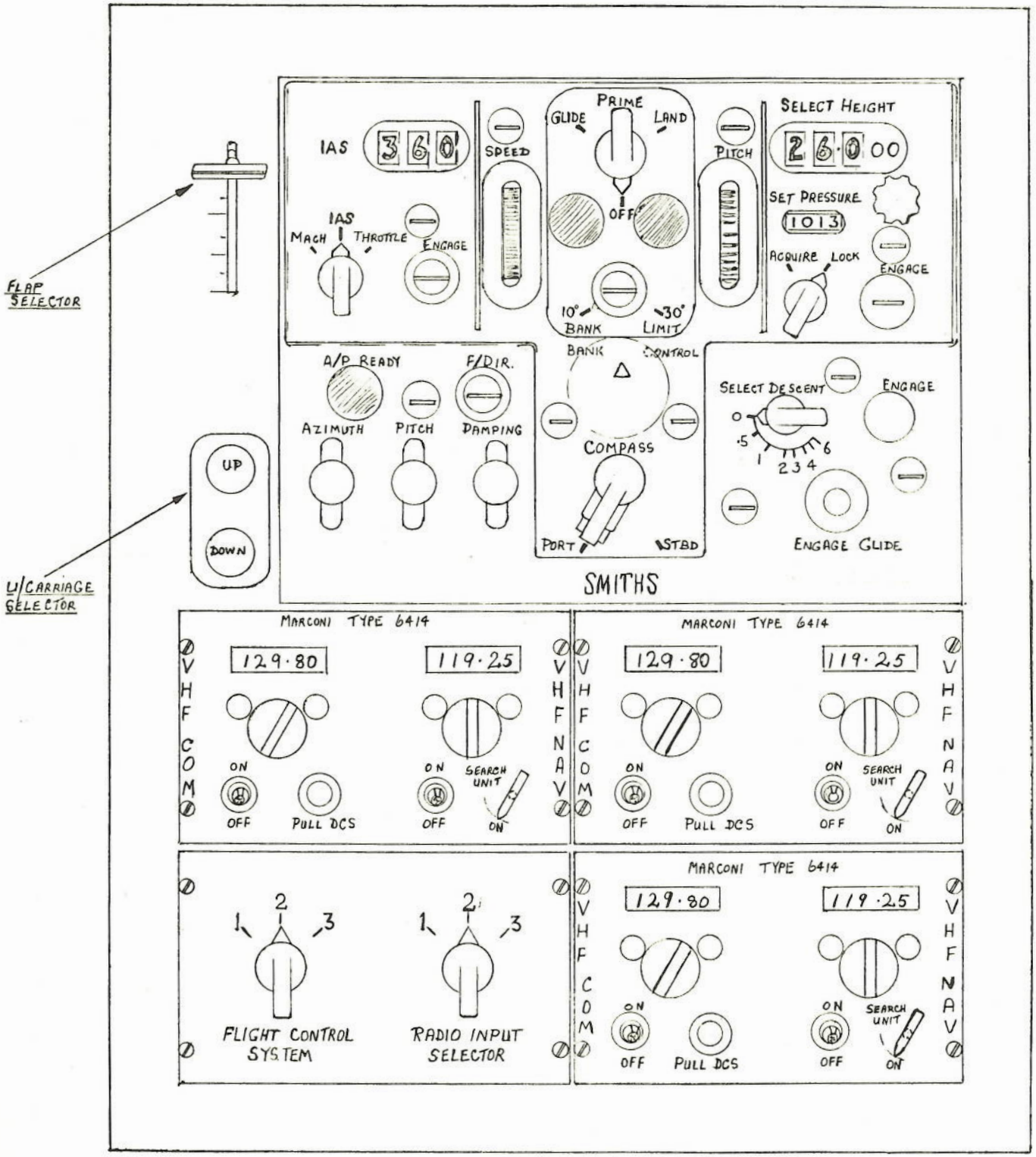


FIG. 20 GENERAL LAYOUT OF CONTROLS & SWITCHES. (IN ONE CONSOLE.)

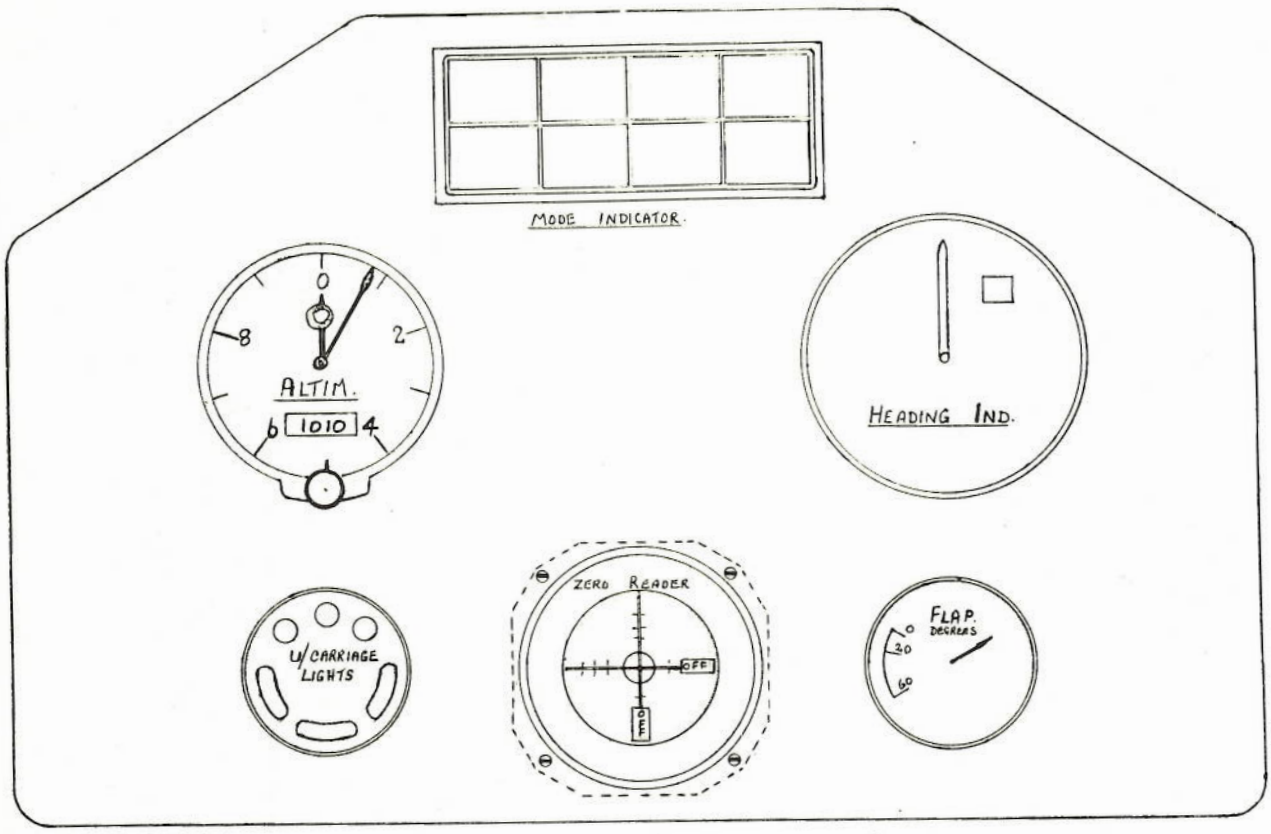
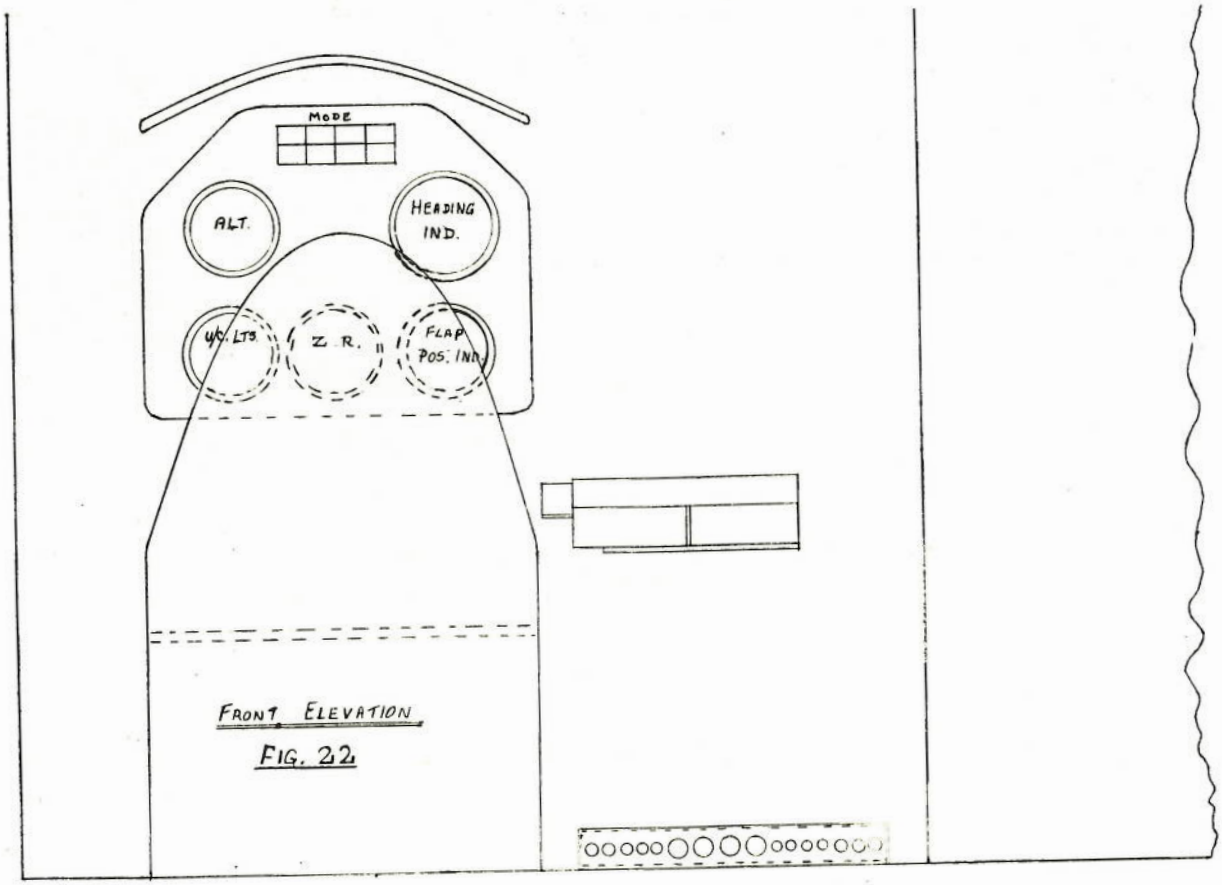


FIG. 21. GENERAL LAYOUT OF INSTRUMENT PANEL.



FRONT ELEVATION

FIG. 22.

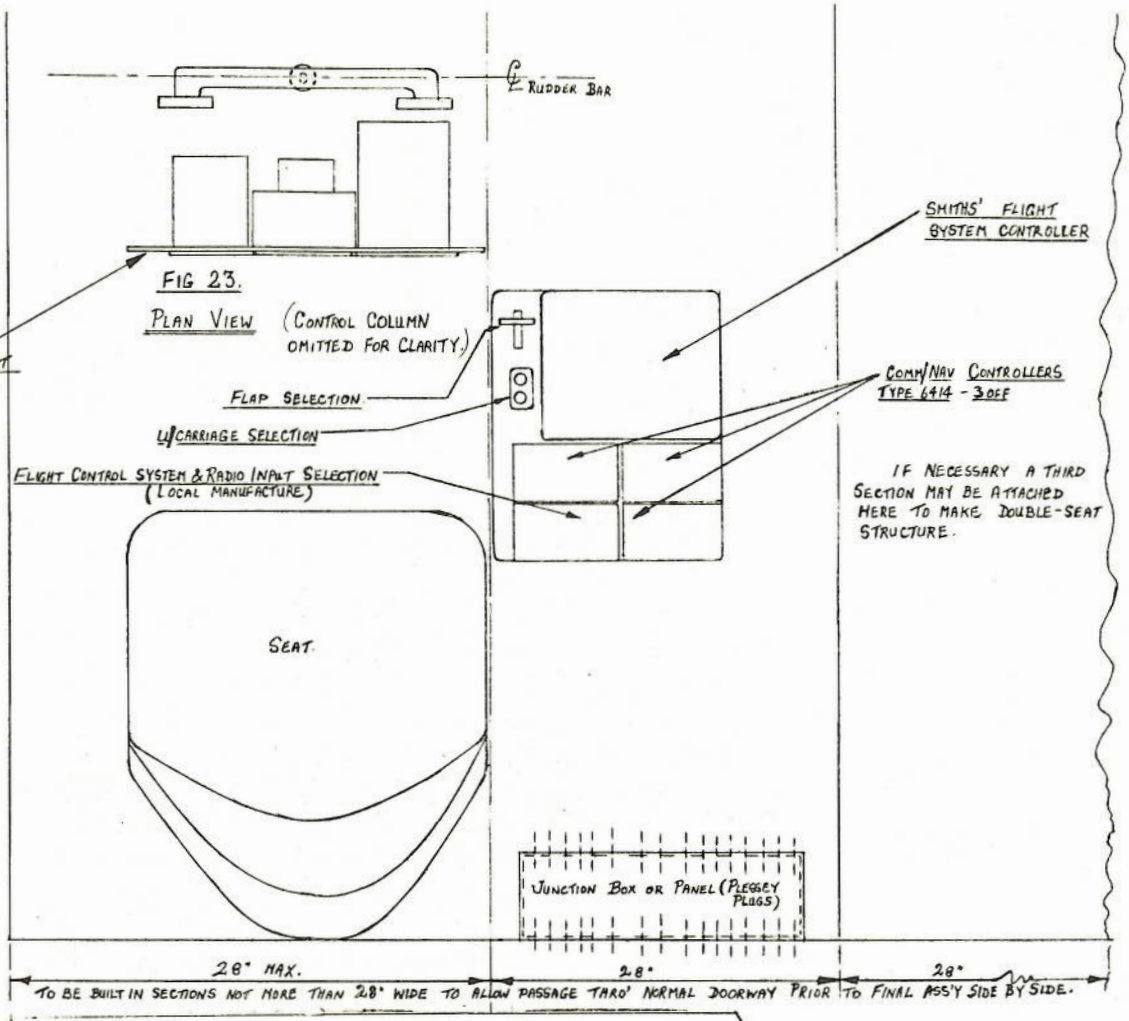
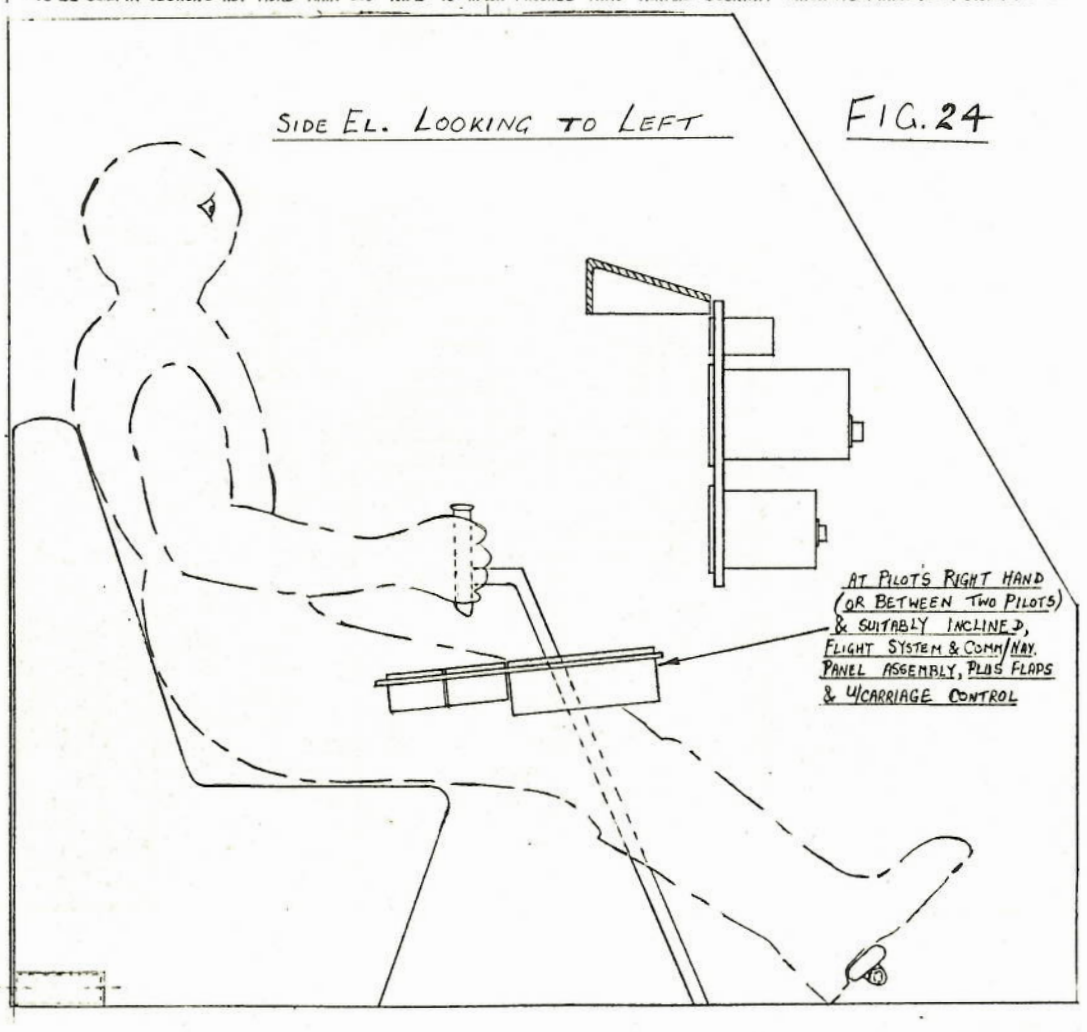


FIG 23.

PLAN VIEW (CONTROL COLUMN OMITTED FOR CLARITY)



SIDE EL. LOOKING TO LEFT

FIG. 24

FIG. 25 MOBILE EQUIPMENT RACK.