CONTROL BURNING FROM AIRCRAFT

By Baxter, Packham & Peet.

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J.R. Baxter*, D.R. Packham†, and G.B. Peet+

* Human Engineering Group, Aeronautical Research Laboratories, Department of Supply, Melbourne.
† Division of Physical Chemistry, Chemical Research Laboratories, CSIRO, Melbourne.
+ Western Australian Forests Department, Western Australia.

1. Introduction

It is inevitable that as long as large forest fuel accumulations and hot dry weather occur together in Australia there will be disastrous and uncontrollable bushfires. Many foresters believe that because the weather cannot be controlled, the build-up of forest fuels must be prevented if damaging fires are to be avoided: the cheapest way to limit this fuel build-up is by burning the forest when the weather is mild.

Controlled or prescription burning is of little use unless it is carried out over very large areas. It is over-optimistic to hope that strips of burnt forest 5-20 chains wide will ever do very much to slow down or stop a severe wild fire — although they may help to control milder fires. In bad conditions spotting distances of 2-5 miles are common and instances of fires throwing burning embers distances of up to 20 miles are known. Thus, it would appear that, where bad fire conditions exist, large scale prescribed burning is the only adequate answer to the forest fire problem. To give some protection from large and damaging fires roughly 12-25% of total forest areas must be burnt each year, and it is essential that this burning be of such an intensity as to cause minimum damage to trees or to degrade the forest in any way.

A mild fire will not travel fast, and any fire that does travel faster than about 3 feet per minute is generally much too hot for the purposes of control burning: thus to obtain a complete burn throughout a given area in a relatively short period, many small fires must be lit. To meet this requirement the grid system of lighting has been adopted wherever large scale, high quality controlled burning is practised.*

Grid ignition systems imply that the burning be done within well-defined boundaries, that fairly complete burnout is aimed for and that there is accessibility to the area to enable ignition sources to be placed accurately within the forest.

Unfortunately there are large areas in the southern forest regions of Australia where thick scrub, mixtures of forest types and sparse roading has prevented the implementation of a controlled burning programme, and where grid lighting is impossible, or at best, costly, difficult and dangerous. It has long

* A forester obtains a successful control burn if he is able to achieve a grid pattern of a size appropriate to the prevailing weather conditions: in this way the fires produced are of an intensity that the forest will tolerate.

been considered by West Australian foresters that the lighting of the forest with small incendiaries dropped from low-flying light aircraft might overcome some or all of these difficulties.

After some laboratory experimentation an incendiary that appeared suitable and safe for use from aircraft was designed, together with an attendant ejection apparatus. The details of both the incendiary and apparatus are given below.

2. Nature of Incendiary

The incendiary found most suitable for igniting forest areas is a plastic (polystyrene) capsule 2" x 1" in diameter, containing approximately 4 grams of potassium permanganate and 3 safety fusees.* The capsules are sealed with cellulose tape. To prime the incendiary, 1½ mls of ethylene glycol is injected through the cellulose tape with a hypodermic syringe; some 30 seconds later the exothermic oxidation of the glycol causes the glycol to boil and ignite, and the burning glycol ignites the fusees which in turn set fire to the plastic case. In the aircraft, injection of the ethylene glycol is carried out automatically with a special syringe. The incendiaries are dropped at appropriate time intervals, and shortly after each incendiary hits the ground it bursts into flames and ignites the fuel onto which it falls.

The time delay after priming the potassium permanganate with ethylene glycol varies with temperatures in the manner shown in Fig. 1. The particle size of the potassium permanganate is also very important, and should be > 28 mesh: finer particle sizes will cause much shorter time delays, which are naturally to be avoided.

3. Rate of Ejection

If an aircraft is flying at a ground speed of 100 knots, then it covers 2½ chains every second. Thus spots of 10 chains separation require an incendiary to be released every 4 seconds. With the injector used so far this rate can just be achieved; however, as spot distances of 5 chains may be required in future then an improved model of injector will be needed. This will be constructed during 1966, and a semi-automatic machine is envisaged. An injector must have ample provision for dealing with any emergency that may occur in flight.

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* It has been brought to our attention that matches are not necessarily stable enough for their inclusion in the incendiary. Although the risk of spontaneous ignition is very small the authors consider that a safer material should be used and work is going on to find a suitable alternative.

4. Problems of Incendiary Manufacture

So far all the vials have been hand filled and capped but design of a machine to fill and cap the incendiaries automatically is in progress. Such a machine must deliver a set mass of chemical and a set number of pellets of match head composition to each vial; then it has to cap the vial.

5. Cost of Incendiaries

The cost of the components (hand filled) is approximately:

	cents per capsule
Vial	2.5
$KMnO_4$	1.5
Match Head Composition	0.5
Labour	1.5
	6.0 cents

Machine filling will lower the labour costs. Of course if some 200,000 acres are to be burnt each year, then between 20-40,000 capsules will be required, necessitating quite a large filling effort.

6. Deficiencies of Incendiary

(a) Reliability

It is not known at this stage how reliable the incendiaries are, but there are indications that more than 90% perform satisfactorily. It is clearly desirable to have close to 100% success; nevertheless single incendiaries which fall into puddles of water, or onto bare ground can never be expected to function properly.

(b) Hazard

There is no doubt that the presence of the incendiaries would add to any fire that occurs in an aircraft. The unprimed incendiaries are particularly safe and can be lit only with extreme difficulty, but if a complete load of incendiaries were accidentally ignited at one time, the results could be catastrophic.

(c) Incendiary Time Delay

With the present incendiaries, the time delay of 30 sec. is not sufficient to allow an aircraft to seed a large area and be away before any smoke forms; this restricts the seeding area to about 8,000-10,000 acres at a time. With areas larger than this, visibility during flight may be substantially reduced.

7. Future Development of the Incendiary

As indicated already, future improvements will be to simplify manufacturing procedures, and improve the reliability of the incendiaries. At this stage of the project it would be unwise to attempt any major alterations in the present technique.

8. Storage of Incendiaries

The proper storage of incendiaries is vital, and essential to the safety of the aircraft and the smooth running of the operation. The best storage found so far was a six-drawer stationery cabinet, with wood walled compartments within the trays, to limit the number of incendiaries in contact with each other to eight. The maximum number of incendiaries which could be carried in this way was 700.

It is hoped to arrange individual compartments within a similar cabinet for future operations, and to increase the storage capacity to 2,000. It is essential that any cabinet be retained firmly in the aircraft. Loose incendiaries, or incendiaries in cardboard boxes must never be carried.

9. The Injector - Design

The present priming device for injecting ethylene glycol into the capsules is shown in Plate 1. It consists of a crash-proof container (A) capable of holding 2 litres of glycol and an automatic syringe (B) which pumps the liquid through a plastic tube (C). The operator pulls the lever (D), causing the hypodermic needle to puncture the top of the vial and to deliver the liquid charge (1.5 ml) into the capsule. After a short interval, the operator feels a pulse from a variable electric timer transmitted through the plate (E) upon which each incendiary is placed; the operator then drops the incendiary out through the pipe (F) projecting through a hole in the floor of the aircraft. This outlet pipe is designed to operate under suction.

The whole assembly is firmly mounted on the seat rails of the aircraft.

10. Deficiencies of the Injecting System

a. The injector can be fatiguing to operate over long periods.
b. Small glycol leaks can occur.
c. The equipment contains protrusions and sharp edges which can be dangerous in rough flying conditions.
d. It is possible to drop a primed incendiary; however, in 5,000 primings not one primed incendiary was dropped, though about 5 unprimed ones were.
e. Priming is not completely reproducible, since the pressure head for pumping glycol is too great, and the hypodermic occasionally fails to fill with liquid..
f. The apparatus was designed for operation on the R.H.S. on the aircraft and was in fact, used on the L.H.S.: this was due to an unexpected change in aircraft type.
g. The liquid container was difficult to fill.

11. Future Development of Injector

The faults listed above will be rectified and the machine made fully or semi-automatic in operation. Safety features will be incorporated where required.

12. West Australian Experiments: 1965

A Cessna 337 twin-engined push-pull aircraft was modified to carry the equipment and operations were based on Manjimup, using airstrips at Busselton (85 miles north-west) and Shannon (50 miles south).

Use of a twin-engined aircraft was recommended for safety reasons*. The above plane had comfortable seating for four crew members (including a Forestry observer) and additional space was available for the dropping device and bomb storage.

The Cessna 337 is actually a 6-seat aircraft, and the dropping mechanism was mounted on the left-hand seat rails behind the pilot, replacing the central left-hand seat. The chute passed through the floor and was extended down sufficiently far to ensure that the capsules could not strike the rear propeller. The central right-hand seat was removed and a chest of drawers

* Any aircraft used must be able to fly safely at a speed of 100 knots, and it must possess adequate climb performance on one engine as well as on two. VHF radio is also necessary, whilst the likelihood that ADF equipment will be used in the future leads to a further possible requirement. The aircraft must be capable of flights of long duration.

containing about 600 capsules was mounted behind the front right-hand seat, facing backwards.

The capsules, when taken aboard, had been loaded with potassium permanganate and fusee heads and had been covered with cellulose tape; all that was required to prime them was the injection of glycol.

13. Ground Marking of Areas Selected for Burning

The plan was for the pilot to sit in the front left-hand seat beside a forestry officer who carried a map and was responsible for giving instructions when to start dropping and when to stop; this officer was also primarily responsible for radio communication with the forestry staff on the ground. The bombardier sat in the rear left-hand seat behind the dropping mechanism, and beside him sat another member of the forestry staff, who was responsible for taking the unprimed capsules from the chest and passing them to the bombardier. In the unlikely event of any capsule starting to smoke, this man was also charged with the duty of calling "feather rear engine", opening the right-hand window, and casting out the offending capsule or the drawer containing it; no such emergency actually occurred.

The pilot's primary task was to fly the accurate grid pattern required, which, on long runs of up to 7 miles, called for mean tracks which were parallel within $\pm\frac{1}{2}^\circ$. Minor oscillations about the mean were of course inevitable in the turbulence experienced at low altitudes on hot days (75 to 95°F), and heading oscillations of up to $\pm 3^\circ$ about the mean were not uncommon.

To assist the pilot in this demanding task, which had to be performed while flying at 150 to 400 feet above the trees, a head-up projector, built by the Aeronautical Research Laboratories, Department of Supply, was mounted in front of the directional gyro. This displayed a magnified collimated image of the directional gyro presentation on a semi-silvered glass plate above the coaming, where it could be seen super-imposed upon the outside scene. The handling technique used was to hold the top of the glass plate parallel to the horizon with aileron and maintain the desired heading with rudder.

The aircraft was flown at 100 knots with 10° of flap and a constant altitude was chosen for each job to clear the highest ground by 150 feet. It was considered that lateral trim changes caused by climbing and descending should be avoided as far as possible, because of the requirement for particularly accurate mean tracks.

14. Development of Grid-Flying Techniques

The original thought in regard to flying technique was to fly across-wind with successive flight tracks progressing upwind - in other words to apply in the air the same burning procedure which is used on the ground. This would require a procedure turn at the end of each run, and any error in estimating the drift, or any change in drift during the runs, would produce a tendency towards criss-crossing of the flight tracks as shown in Fig. 2. Another variation considered was to fly a similar pattern up and downwind, moving progressively across the area; this could minimise drift effects but would still call for a procedure turn at the end of each run.

In either case it was envisaged that balloons would be used to mark the beginning of each run, and that forestry staff on the ground would move the balloons through measured or paced distances between successive runs. It had been shown in earlier tests at Heyfield (Victoria) that smoke canisters did not produce a clearly defined signal above tree-top height because of diffusion of smoke among the trees; in these same tests it had also been shown that, at the beginning of a particular run, the fires from the capsules dropped on the previous run were not normally visible. A supply of meteorological balloons and hydrogen cylinders was therefore taken to Manjimup.

Discussions with forestry staff after arrival at Manjimup revealed that with aerial burning it was not essential for the burn to progress across the area from one side; this was only necessary with ground burning to avoid the danger of the man on the ground being trapped between two flame fronts. It was suggested that the racecourse pattern shown in Fig. 3 could be used if desired; drift errors would then cause a convergence or divergence of the two halves of the pattern rather than a criss-crossing of successive runs.

This suggestion was welcomed and it was requested that a training range be set up to determine what track accuracy could be attained with successive runs in the same direction. A scale 100 chains long was set up with balloons and white drums at right angles to the far end of a 7 mile run across the Pingarup Plain, as shown in Fig. 4. A movable balloon was used to mark the starting point and was moved 10 chains to the left after each run.

Five runs were made on December 2nd, taking about 10 minutes each including the return and a left-hand 180° turn at each end. These were beginning to show a fanning out to the left when a sudden wind change occurred after the fourth run; the mean tracks are shown in Fig. 5(a). A fresh start was then made using a new heading, and five runs were made with left-hand turns at the ends followed by five with right-hand turns at the ends. The mean tracks are shown in Figs. 5(b) and (c) and it is evident that there was a steady fanning out to the left regardless of whether left-hand or right-hand circuits were made.

The gaps between successive runs at the far end are plotted in Fig. 6 and compared with the starting gap of 10 chains. The mean is 19.5 chains and the standard deviation is 7.8 chains, omitting the 54 chain gap caused by the sudden wind change. The fanning out effect was attributed to a steady precession of the directional gyro at a rate of about -5½ degrees per hour (-0.9 degrees per run) which is not uncommon in instruments of this quality.

On the following day ten more runs were made, feeding in a heading change of +1 degree per run (about +6 degrees per hour) and flying almost into wind instead of across-wind as on the first day. The mean tracks flown and the gaps at the far end were as shown in Fig. 7: the mean gap was 7.5 chains and with a standard deviation of 4.5 chains, and the change in mean track in this case was at a rate of about 1½ degrees per hour to the right. Allowing for the +6 degrees per hour heading change which had been applied, this suggests a gyro precession rate of -4½ degrees per hour.

The conclusions from these trials on the training range were that:

(1) A progressive correction of +5 degrees per hour should be applied to the heading flown, in order to compensate for gyro precession.
(2) The runs should be made up and downwind as far as possible to minimise the variance of mean track caused by wind changes.

15. Full-Scale Burning Trials

Three large areas totalling about 53,000 acres were burned in six flying days. In each case the racecourse pattern shown in Fig. 3 was flown (up and downwind) until the majority of the area had been covered, and finally any odd corners or areas which had been missed were filled in by visual judgment. Two balloons - see A and B in Fig. 3 - were used for guidance in establishing the racecourse pattern: left-hand circuits were preferred because the pilot, sitting in the left-hand seat, could obtain a better view of the balloon as he turned for his run over the top of it.

The initial headings to be flown on the projected directional gyro were determined by doing two or three dummy runs in each direction along one boundary of the area and finding by trial and error the headings which would make the aircraft track parallel to the boundary from each direction. These two headings were written in on the ordinate of a graph of heading against time of day, on which a line at a slope of 5 degrees per hour had previously been drawn; the time of day at which they had been determined was then written in at the corresponding point on the abscissa. The graph, looking something like that in Fig. 9, was kept by the pilot on his knee and referred to at the start of each run to ascertain the heading he should fly.

Considerable trouble was encountered with the balloons, particularly in areas where there were high trees. The balloon could burst after contact with branches, the balloon string could become entangled with the branches or the balloon could lose its buoyancy due to leakage of hydrogen. These problems were aggravated by a shortage of hydrogen cylinders and the difficulty of transporting the cylinders to the balloon sites over almost impassable roads.

On a number of occasions, when the aircraft was in the air and had partly completed the burning pattern, the last available balloon at that particular site was lost, and various emergency methods for marking the start of the run were tried. In open country the orange jeep used by the forestry staff was quite suitable, but among trees no really adequate alternative to the balloons was found; possibly the most useful of the devices tried was a mirror reflecting the sun towards the aircraft. At various stages different types of balloon were tried, and the best were white ones of 100 gram capacity, which were about 3 feet in diameter and could be seen against dark foliage from about a mile away; red ones of the same size were much less effective.

Since the Cessna 337 was fitted with A.D.F., it was suggested that a small radio beacon might provide a more convenient means of marking the start of the run. Unfortunately a transmitter of suitable frequency was not available locally, but plans have been made to construct one for future evaluation of the A.D.F. technique.

Apart from avoiding all the balloon problems mentioned above, a radio beacon with A.D.F. would have another important advantage; it would not be blotted out by smoke. Smoke becomes a very real problem towards the end of a large burn of say 8,000 to 10,000 acres, which might take about 2 hours flying time. As the corridor between the two halves of the burning pattern is narrowed down, a smoke pall closes over the top of it and becomes progressively thicker and lower. This is true even when working directly up and downwind, particularly at the downwind end of the run, and if there is a crosswind component difficulty is encountered at an earlier stage.

In these conditions the pilot finds himself searching for the balloon with only a few hundred feet of forward visibility, and, having found it, he often has to do a timed orbit away from the burning area in the hope of coming in over the top of it again on the correct heading. This is both time-consuming and difficult. With a radio beacon and A.D.F. it should be possible to develop a technique for starting the run, which is much less dependent on outside visibility.

The grid-flying technique described above was judged to be quite successful except that on the last day a fanning of the runs to the left became apparent, even after the 5 degree/hour correction had been applied to the gyro headings. It was estimated that a correction of about 8 degrees/hour would have restored the desired accuracy. The aircraft had been flying in particularly heavy smoke on the previous day, during a post-burning inspection by senior forestry officers. It is thought that smoke particles drawn into the directional gyro had probably increased bearing friction. These particles, which are of the order of one micron in diameter, would pass through most filters.

It is now considered that, if a vacuum operated directional gyro is used for this work, a training range of the type shown in Fig. 4 should be kept available and used to make regular checks on rate of precession. It would be preferable for this work to use a sealed electrically driven gyro.

16. Control Burning Results

The incendiary apparatus worked extremely well and there appeared to be a better than 80% take of spot fires. The accuracy of the grid pattern was superior to that generally obtained by ground crews on area controlled burning (see Plate 2) and any failure to obtain clean burns was due to fuel quantity and type variation, which prevented some spot fires from burning over the required area.

As cost of lighting with aircraft has been very reasonable (quoted as 2.5-3.5 cents per acre), two burns are suggested for such areas, one in spring and one in autumn. Repeat burns will be well warranted if fuel can be evened in quantity if not in type.

A possible disadvantage of the new technique is the inability to place a fire at the most suitable point for lighting, and some failure in lighting must be attributed to incendiaries landing in bare or wet spots. However, it is considered that the operation was sufficiently successful to justify a major aerial-controlled burning programme in the spring of 1966. It should be possible with normal weather conditions to cover an area of about 250,000 acres with one aircraft.

17. Conclusions and Recommendations

(a) Advantages of Aircraft

Aircraft have no accessibility problems; they can fly at low levels over rough and mountainous country, almost as well as over level cleared land. Providing enough landing strips are available (say 100-120 miles apart), there should be no part of any forest more than 30 minutes flying time from a base of operations.

Aircraft are the fastest means of transport available to the forester and, using the incendiary techniques described, he can cover large areas of country and burn them out in times that are now considered impossible. Using only one aircraft it should in fact be possible to treat areas of 10,000 acres in one day, as a purely routine matter.

The aeroplane also offers a unique vantage point for observing fires. From above the intensity of a burn can be seen, and changes in the lighting pattern made as required; "hop-overs" can be detected and ground crews directed to them so quickly that suppression becomes very much easier. A single aircraft can often do the work of many men, and the effects of any manpower shortages which may exist from time to time are thereby minimised.

Finally, aircraft are very mobile and can be used on consecutive days in places separated by 200-400 miles, without serious loss of efficiency. It is also worth noting that modern light aircraft are comfortable, and 4 or 5 hours can be spent in them each day without any real fatigue setting in.

(b) Disadvantages of Aircraft

An aircraft has high unit cost; most new light aeroplanes fall into the $10,000-$60,000 bracket, with those types suitable for control burning costing about $40,000. Running expenses are also high, and as a result charter costs can be around $50 per flying hour.

When employed for control burning purposes an aircraft requires a specialized crew; this crew should be well trained and able to work as a team, with the highest co-operation and understanding between members. Again, the use of the aircraft itself should be highly organized. Because of the general variability of weather conditions it must be possible to arrange a control burn in any part of a state forest no more than 18 hours before lighting up. The aircraft is too valuable, and suitable burning days too few, to miss out on any opportunities to achieve the set control burning targets.

High unit cost and high running costs are not the only financial aspects to be considered when forest organizations start using aircraft; the cost of airfields, fuel dumps and all necessary plant and personnel may well amount to many times the unit aircraft cost.

18. Recommendations

(a) Suggested Duties of Crew

(i) Pilot - will fly aircraft and be responsible for aircraft safety in the normal way.

(ii) Co-pilot - will assist the pilot by
1. Carrying out all radio duties
2. Monitoring gyro compass drift
3. Monitoring aircraft drift
4. Monitoring engine performance, and advising pilot of engine malfunction
5. Starting and stopping the bombardier.

It is suggested that the co-pilot have a flight radio licence, and preferably be trained to about solo standard as a pilot, or have experience in some form of flying. The co-pilot should be able to assist the pilot and be knowledgeable enough to have a good understanding of a pilot's needs.

(iii) Bombardier - will operate the dropping device, and will also be responsible for its maintenance, and the loading of incendiaries into aircraft, etc.

(iv) Observer - will assist the bombardier in handling the incendiaries. He should not be a regular crew member but any available forester who can get air experience and observe how the burn is progressing, etc.

(b) Aircraft Crew Training and Experience

It is important that the first three crew members be specialists and experienced in aerial matters, as their work in the air is often rather hectic with many things happening simultaneously. All crew members should be trained to a degree whereby the pilot is satisfied that the operation can be done safely, smoothly and effectively.

(c) Aircraft Control

In the West Australian experiments two separate radio networks were used to direct the aircraft, and to control the movements of ground markers. Initial tests showed that normal forestry VHF was unsuitable within the aircraft for there was too much external traffic, and this was found to distract all crew members - furthermore some seconds might elapse before an air-ground message could be passed. The radio sets, not being designed specifically foraircraft, were deficient in terms of microphone type, and loudspeaker placement and mounting.

Air-control was then attempted by using a frequency of 119.1 Mcs (allocated by the P.M.G.) which was within the range of the multifrequency aircraft radio. While the plane was within range the system worked well, but as soon as the aircraft moved out of line of sight communication was lost. This was overcome by placing the control centre in as high a place as possible; on one occasion a fire tower was used, where radio contact was good.

Contact between the control centre and the ground markers was now established on the forestry VHF band. This was not very satisfactory because it interfered with fire control traffic, and made normal forestry operation difficult. It is suggested that in future HF be used with the aircraft's normal HF radio provided with the correct frequency. Markers and control centre should each be provided with modern high quality HF mobile sets now available (e.g. A.W.A. 60B). A stand-by frequency in the aircraft VHF band should also be used with an emergency VHF transceiver at the control centre.

The complete communications system envisaged is represented in Fig. 10. Reasons for suggesting HF for aircraft and marker control are that:

(1) There would be little line of sight problem.
(2) Ranges of 50 miles between control point and airfield could be achieved.
(3) No repeaters would be required.
(4) The independent radio network would not interfere with normal forestry operations.

During the West Australian experiments fire control at the burns was by forestry VHF. This worked very well. Fire reports from the aircraft were relayed by the control centre to the appropriate units or gangs. Wind readings from towers were relayed in a similar fashion to the aircraft.

The control centre was located at any convenient place. Positions chosen were, in fact: (1) a road junction, (2) in a shady gravel pit, and (3) in a tower. It must be pointed out that there was a feeling of remoteness about the whole control operation, as the aircraft and the fire were rarely seen by the control staff. This did not appear to hinder the operation, and it would be difficult to arrange it otherwise.

It was found useful to plot the approximate position of the aircraft by moving pencils or other markers along a map of the burning area. Detailed operational plans were seldom strictly adhered to, and the success of the operation depended upon flexibility, and a good communications system. In the later exercise this was achieved to a very high degree.

(d) Ground Marking Control

When marker crews had obtained experience there was little confusion and little need for radio contact except to confirm that the markers had been moved into their allotted places.

In future operations it is suggested that marker crews be members of the aerial burning team. There is no reason why a swap around of jobs, with the exception of the pilot and perhaps the co-pilot, should not be done, and it would make the work more interesting. Similarly all crew members including the pilot (if an alternative can be arranged for a day) should take part in ground control, marking, etc. to give an appreciation of the difficulties experienced by the "other fellow".

Aerial burning operations require team effort and co-operation probably far beyond that needed in normal situations; the co-operative effort can, in effect, make or break a particular operation.

(e) Detection of the Fire Edge

Experience showed that observation from the aircraft was the best method of detecting any hop-overs that had occurred.

At the control centre it was always pleasant to hear that the area was clear and that there were no hop-overs or escapes. This the aircraft reported before leaving the area, after making a careful reconnaissance of the fire edge. It must be remembered that an area of 8,000 - 10,000 acres means a perimeter of about 16 miles which is a lot of perimeter for a few gangs to patrol, especially when the men can see into the bush about 200 yards at the most.

With quick detection from an aircraft, there is no reason (except lack of roads) why a suppression crew cannot be directed to a hop-over within 15 minutes. Even with smoke cover, quick and rapid detection of spot fires is possible with the aid of an infra-red detector (Packham, 1966)*.

It is concluded that continual observation from the dropping aircraft is an absolute necessity. In any possible "bad situation" it is well to remember that, while a small section of the edge may be difficult to handle because of uneven fuel, the entire picture might be very different: to those at the hot edge the situation seems very bad (as well it may be) but elsewhere the area could be very safe, with extremely mild fire intensities. Clearly, the observer in the aircraft is in the most ideal situation to report on the overall condition of the fire, and he should be able to give concise and reliable information to the Forest Officer in charge of the burn.

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* Packham, D.R., 1966, CSIRO, Division of Physical Chemistry Report, "Mapping of Forest Fires through Smoke Cover".

In an extreme situation the observer in the aircraft might have to suggest that ignition be discontinued. However, to stop the aircraft lighting the area is a serious step, because it is possibly wiser to have a hot fire than to leave live uncontained edges in unburnt country. Nevertheless situations vary, and where further ignition makes control impossible then the Forest Officer should consider the decision to halt the burn - particularly if the weather forecast for the next day is unfavourable. In this respect such a situation is, of course, no different from those encountered in normal, hand-stripping operations.

(f) Pre-Burning

(i) Fuel Inspection

An even fuel is needed if an even burn is to be obtained, for the aircraft cannot alter its lighting pattern with every change in fuel concentration. Since the success of the burn will depend upon the uniformity of the fuel, a proper inspection is essential.

(ii) Edging

Edging makes control easier. It is also a safeguard against dropping incendiaries over the boundary of a compartment, as a burnt edge is more visible than roads from the air, and gives the co-pilot good warning of the closeness of the boundary. Edging also facilitates the pre-burning reconnaissance of the area, especially if unmapped roads and tracks exist within the block to be burnt; the aircraft crew are left in little doubt of the boundary when it has 1-5 chains of burnt edge marking it.

(iii) Accessibility to Boundaries

The boundaries must be fully accessible to the ground marking crew, as well as to the fire suppression forces.

(g) Flying Aspects

While the D.C.A. Flying Operations Instructions are considered very reasonable and appropriate, it is recommended that Forestry Departments, for their own protection, should accept two additional limitations:

(i) For operations at low altitude over forest country such as that around Manjimup, where a safe forced landing would be virtually impossible, a twin-engined aircraft should always be used.

(ii) The pilot in charge should be proficient at instrument flying; ideally he should hold or have held an instrument rating. While the operation is cleared as a V.F.R. one, it is impossible in practice to avoid flying through smoke which impedes visibility considerably and blots out the horizon completely.

It is recommended that work on radio beacons for use in conjunction with A.D.F. should be continued with some priority, and that considerations should be given to the development of capsules with a much greater time delay in order to mitigate the smoke problem.

(h) Forestry

Need for Mild Burning

It goes without saying that a mild fire is the aim of controlled burning. Mild burns require closely spaced ignition spots, but this cuts down the aircraft yield of acres/hour. If a 10 x 5 chain grid is needed, then the yield would be about 2,000-4,000 acres per hour with the aircraft flying crosswind on a 10 chain separation; if the aircraft flies into wind on a 5 chain separation, the yield would be 1,000-2,000 acres/hour.

Inspection

The selection of appropriate weather conditions for a given control burn and the methods of lighting employed should be based on the preliminary inspection reports. All inspections must be detailed and accurate enough to ensure an acceptable result.

Edging

The lighting rate for the aircraft will vary between 2,000 and 6,000 acres per hour, depending on strip width. These rates will preclude effective edge control unless the areas have been prepared with a preliminary edging burn. In mixed forest types two burns may be required to produce a clean edge.

Block Size

Block sizes of 8,000-10,000 acres are ideal; with areas larger than this visibility troubles may be encountered because of smoke.

Repeated Burning

Repeated burning will ultimately lead to even fuel concentrations; under these conditions future burning will be easy.

Spreading Rates

A good knowledge of rate of spread is, of course, necessary to determine spot distance, etc.

Experience in Control Burning

It would be inadvisable for any organization inexperienced in large area control burning (1,000-2,000 acres) to go direct into aircraft control burning. A 300 acre burn is a serious enough affair, but a 10,000 acre burn is much more dangerous.

The possibility of large control burns affecting the atmosphere and causing a dangerous air subsidence is a very real one. Under these circumstances a very serious fire could occur and it might become completely beyond control. Officers of any organization in charge of large scale burns should be able to recognize potentially dangerous weather conditions of lapse rate or wind shear. Even though little is known of these factors and their effect on fire control, to ignore present knowledge is inviting disaster.

Stores

The construction of incendiaries is simple but time consuming. Labour for making would possibly be best organized by piece-work at roughly 1¼ cents each; ultimately a filling machine may be built if this proves necessary.

For marking, a supply of hydrogen cylinders, outlet valves and balloons is required by the Divisions involved in the work. Each Division should hold at least six cylinders and several outlet valves before burning commences. On the average one cylinder is used per day for filling balloons, and each marker requires a fully equipped cylinder. Balloons are of the standard type used by the Met. Bureau. These are obtained from the U.K. and a supply of white balloons should be held, since these are the easiest to see. Future balloons should have a thicker skin than the present ones, which are very prone to puncture.

Aircraft fuel, oil and a pump must be available at the airstrip from which the plane operates.

19. Costing

Costs to Date

In the West Australian experiments three different areas were subjected to aerial burning, and the results were somewhat variable, depending upon fuel age, weather and the nature of the areas concerned. To summarize, 53,000 acres were seeded, and 25,000 acres were burnt, i.e. this was the blackened area within the 53,000 acres. With better conditions the 53,000 acres would have been effectively burnt out.

Costs (see Table 1) have been related to the total area of 53,000 acres, taking into account:

(a) Aircraft time, marking time, and bomb costs only, and
(b) As above, but with additional costs for fire suppression crews. Charges for professional officers' time have not been included, nor have any overhead expenses. All crews have been costed at $60 per day per crew; these figures are only estimates and it is hoped that more detailed ones can eventually be supplied by the W.A. Forest Department. Again, the price of the dropping equipment is not included; this costs about $800, but as it will last for several seasons its final contribution to cost can be neglected.

The aircraft was used for 53 hours, of which about 20 hours were spent in ferrying and experimental flying, i.e. some 33 hours were flown while dropping, at an average charge of $42 per hour. Aircraft costs thus amounted to $1,386.

Table 1

Area Acres	Aircraft Cost $	Incendiary cost 5,000 at 6c each $	Crew Cost	Total $	Costs per thousand $	per acre
53,000	1,386	312		1,698	31.80	3c
53,000	1,386	312	34 crew days @ $60 per day 2,040	3,738	70.00	7c

20. Safety

Safety of the men must take precedence over all other matters. Flying low over forest country contains some element of risk and all risks must be prepared for as much as possible. Pilots must be D.C.A. approved and aircraft must be of the highest standard. Twin-engined aircraft are recommended; while the risk of occasionally flying a single-engined aircraft over hostile country is acceptable, it becomes much more serious when the plane is required to fly for several hours each day over country where it would be impossible to carry out a forced landing.

No risks should ever be taken with the incendiaries or their method of storage in the aircraft. While incendiaries are safe to handle and to operate, they do increase the fire hazard in the aircraft. Thus to carry an excessive bomb load is to take an unnecessary risk.

Fully trained and safety-conscious crews are essential. The ability to assess risks comes with training which, as well as making a person safety-conscious, enables him to decide whether excessive safety precautions do, in fact, contribute to survival, or merely impair the efficiency of the operation.

It is imperative that all communication systems are adequate for their purpose. Radio failure may sometimes occur, so an alternative, continuously open link between aircraft and ground (119.1 Mcs has been suggested) is necessary for the efficient running of the operation, as well as for the safety of the aircraft and crew.

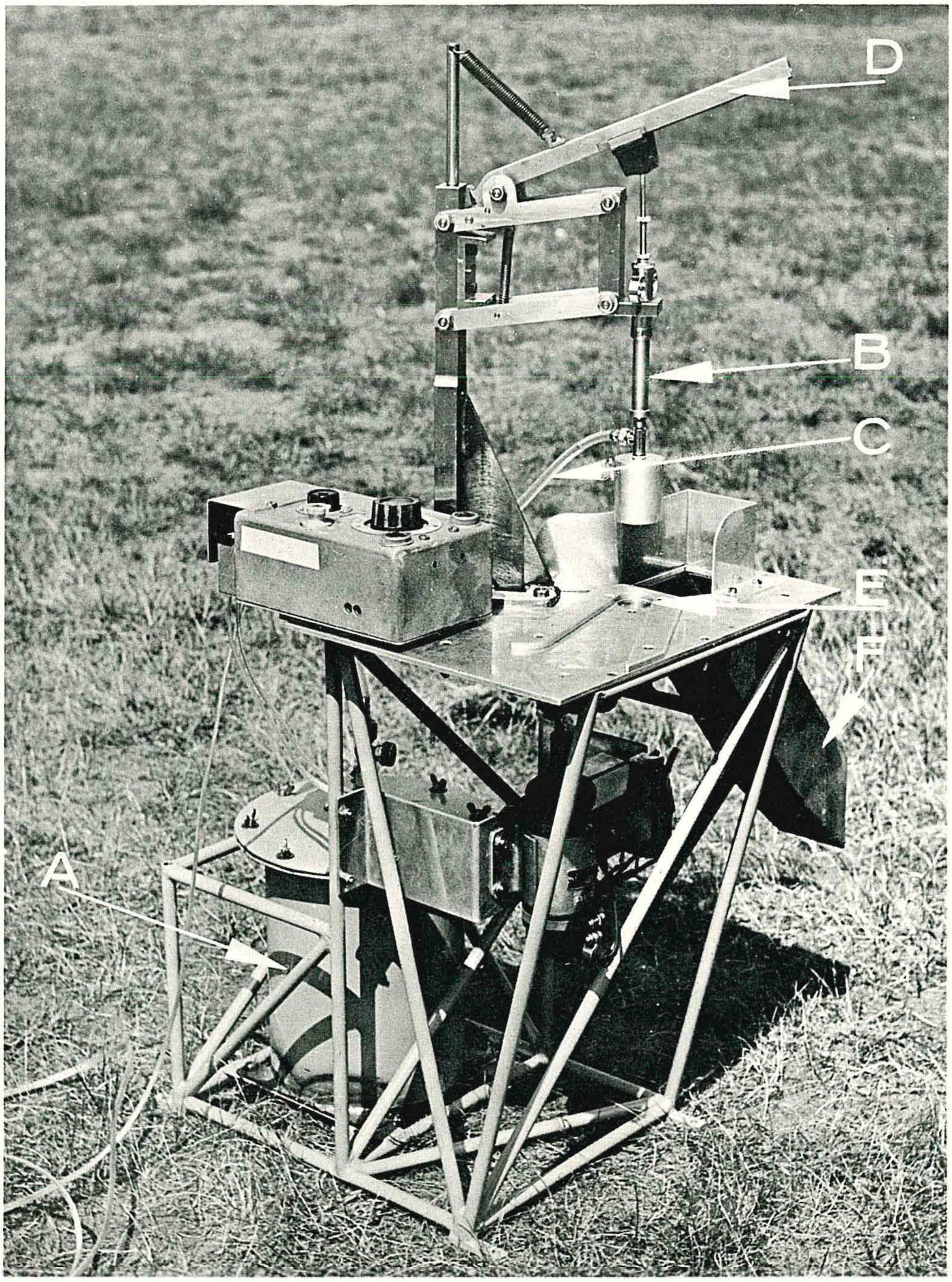

PLATE 1.

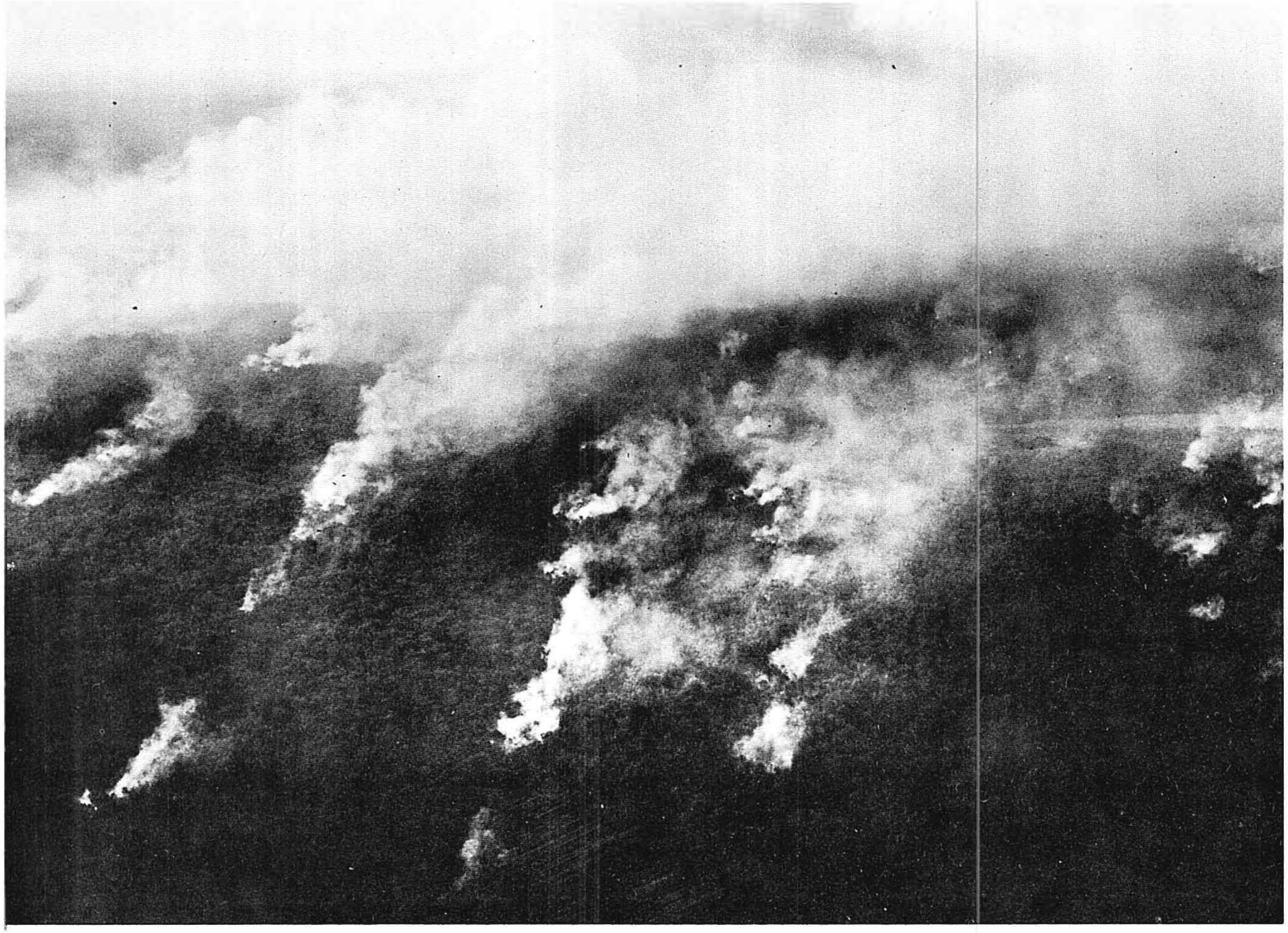

PLATE 2.

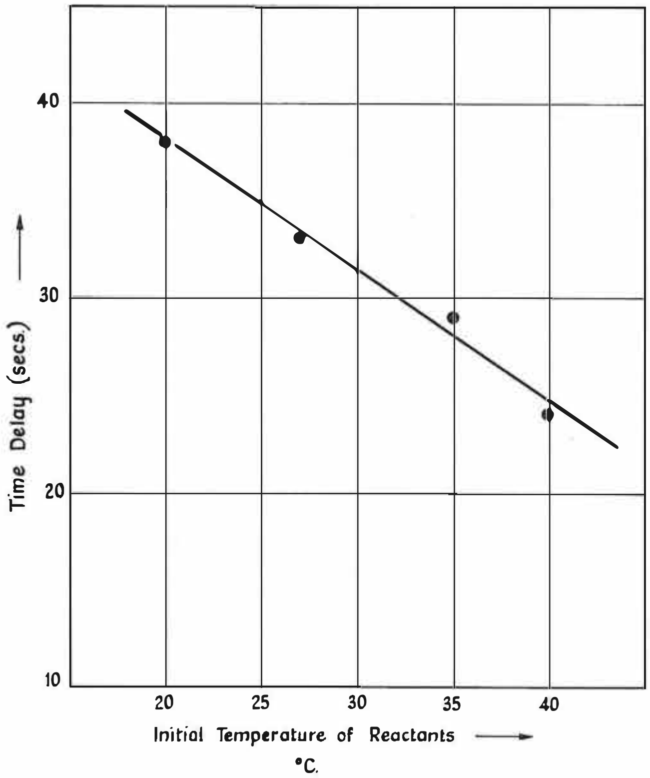

FIG. 1. VARIATION OF TIME DELAY IN CHANGES IN TEMPERATURE FOR ONE SAMPLE OF POTASSIUM PERMANGANATE.

Sieve analysis	> 25	61%
	25-52	25%
	52-110	11%
	100-150	1%
	< 150	1%

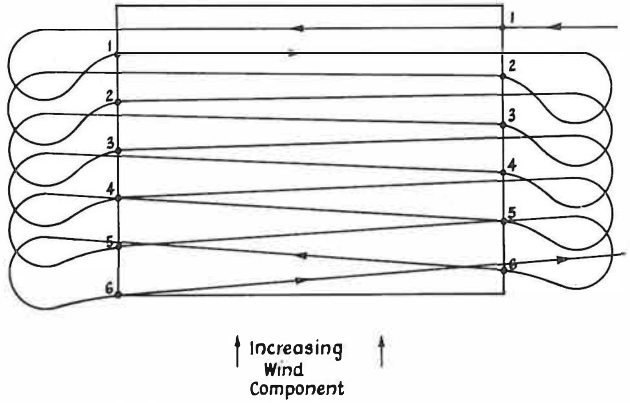

FIG. 2 FORE & AFT PATTERN

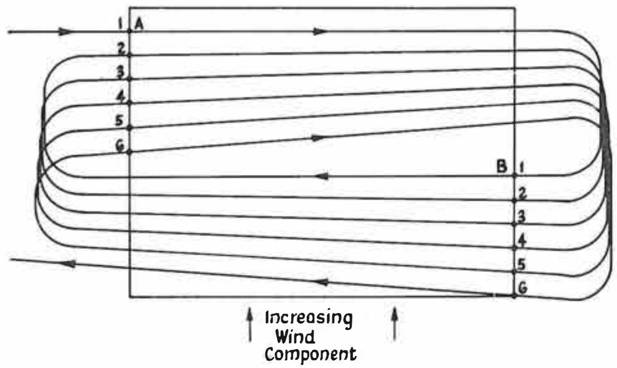

FIG. 3. RACECOURSE PATTERN

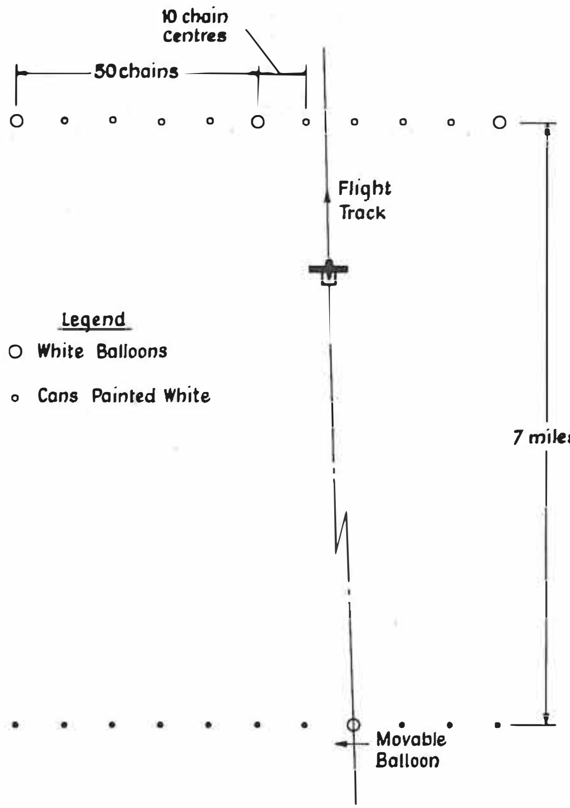

FIG. 4. TRAINING RANGE.

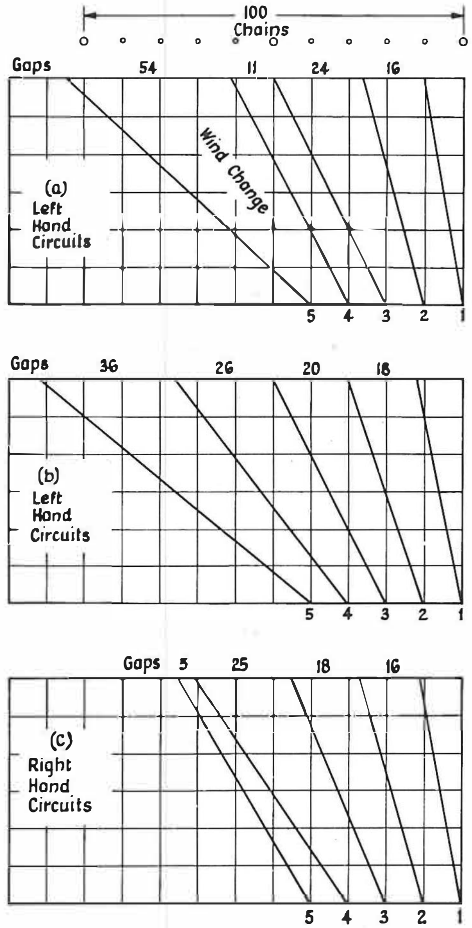

FIG. 5. MEAN TRACKS, 2/12/65
(Crosswind)

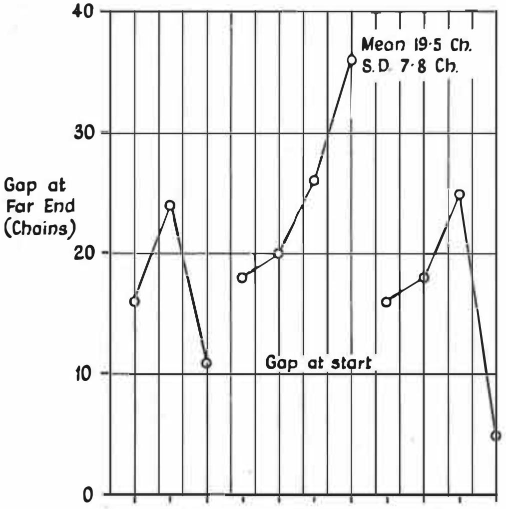

FIG. 6. DISTRIBUTION OF GAPS AT FAR END OF TRAINING RANGE. 2/12/65
(Crosswind)

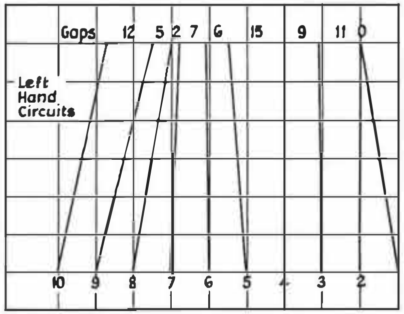

FIG. 7 MEAN TRACKS
(1 degree/run correction)

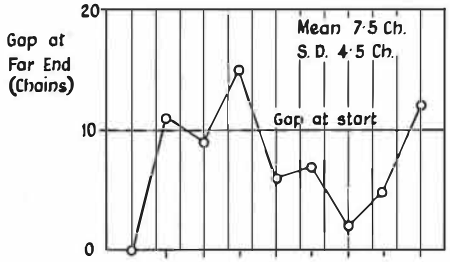

FIG. 8. DISTRIBUTION OF GAPS AT FAR END
3/12/65
(Along Wind)

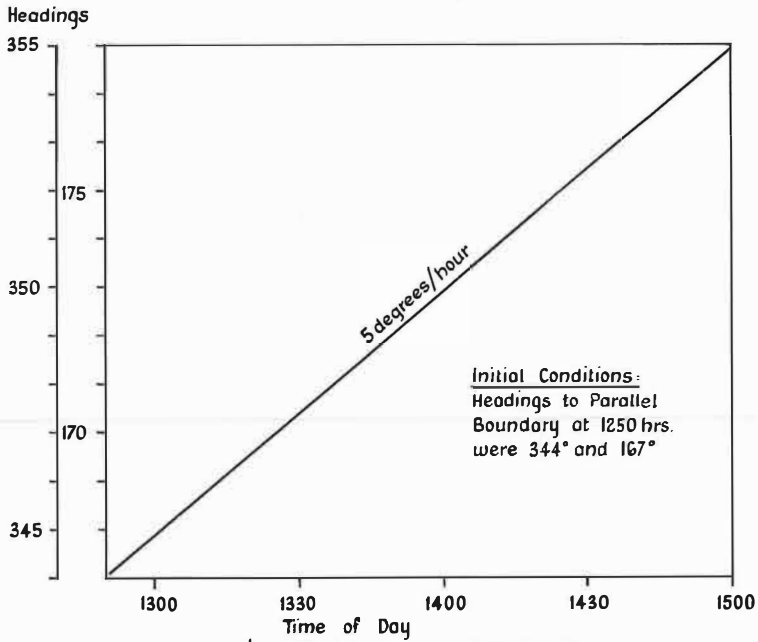

FIG. 9. PILOT'S PRECESSION CORRECTION GRAPH

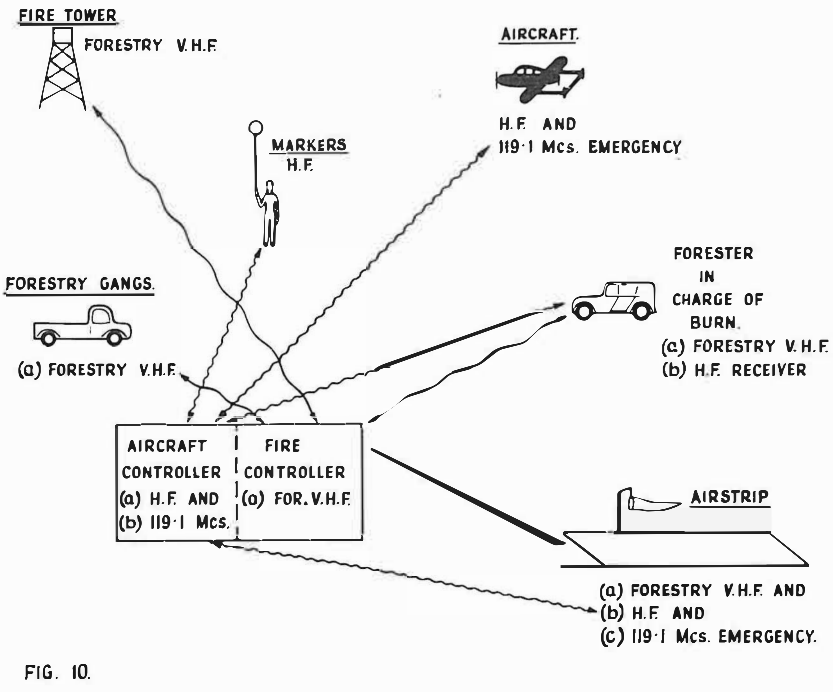

FIG. 10.