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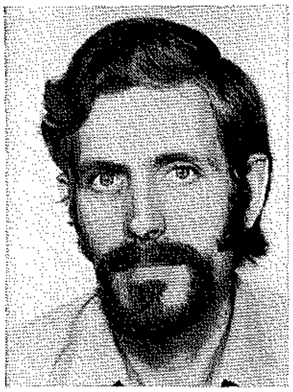
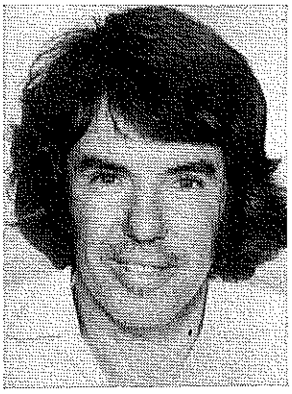
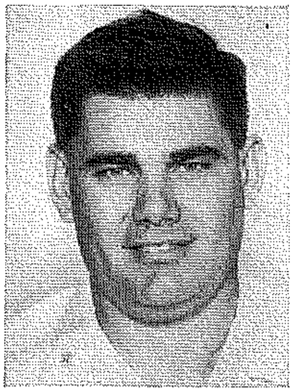
Low Cost Aerial Photography For Agricultural Research

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Introduction

Heterogeneity in vegetation is frequently a major concern in agricultural field studies. In some studies, patterns of variation and corresponding patterns of environmental variables are used in elucidating ecological cause and effect. In other studies, variation is important as it affects the difficulty and expense of measuring and describing vegetation which is being treated as a unit. In both cases a map of the variation is an asset.

A general method for obtaining a map is by sampling on a grid at an appropriate scale. Detection and description of pattern in the data can be efficiently accomplished with the aid of one of the readily available computer programs for numerical analysis. In many instances, patterns are detectable only by this approach, and the main consideration is that of the value of the end product in relation to the cost of collecting and handling the data. However, there are other situations, where the major aerial patterns are easily visible, and it is obvious that a vertical photograph at an appropriate scale would provide a low cost map that could be easily interpreted.

The developments described in this paper were initiated upon the realization that: (1) in the seasonally dry tropical areas of Northern Australia, dramatic variation in native and sown pastures are both common and obvious; (2) air survey firms are not available to perform small jobs at strategic times in scientific studies; and (3) laboratory-owned acquisition systems were not out of the question, i.e. other Australian scientists were actively involved in research on the acquisition and use of large-scale vertical aerial photos in agriculture, some of whose work has now been published (Carneggie *et al.* 1971; Totterdell *et al.* 1972; Torssell 1973). The technology for using photos is largely that which has been employed in forestry for decades, and recent developments are significant with respect to the acquisition of photos. Firstly, the availability of relatively inexpensive electrically-operated 70 mm cameras makes ownership feasible by research groups of a camera system capable of providing high quality, large-scale photographs. Secondly, the availability of high performance aerial color film types in 70 mm format enables greatly enhanced discrimination of vegetation units.

This paper describes an aerial photo acquisition system tailored for agricultural research with due regard for both capability and cost. It is hoped that the information presented will assist in bringing a useful research tool within reach of agronomists and ecologists.

Photography and Navigation System

In addition to the camera, an aerial photo system includes equipment for controlling the camera and directing the aircraft over the subject. Fig. 1 shows the system installed in a Cessna 172.

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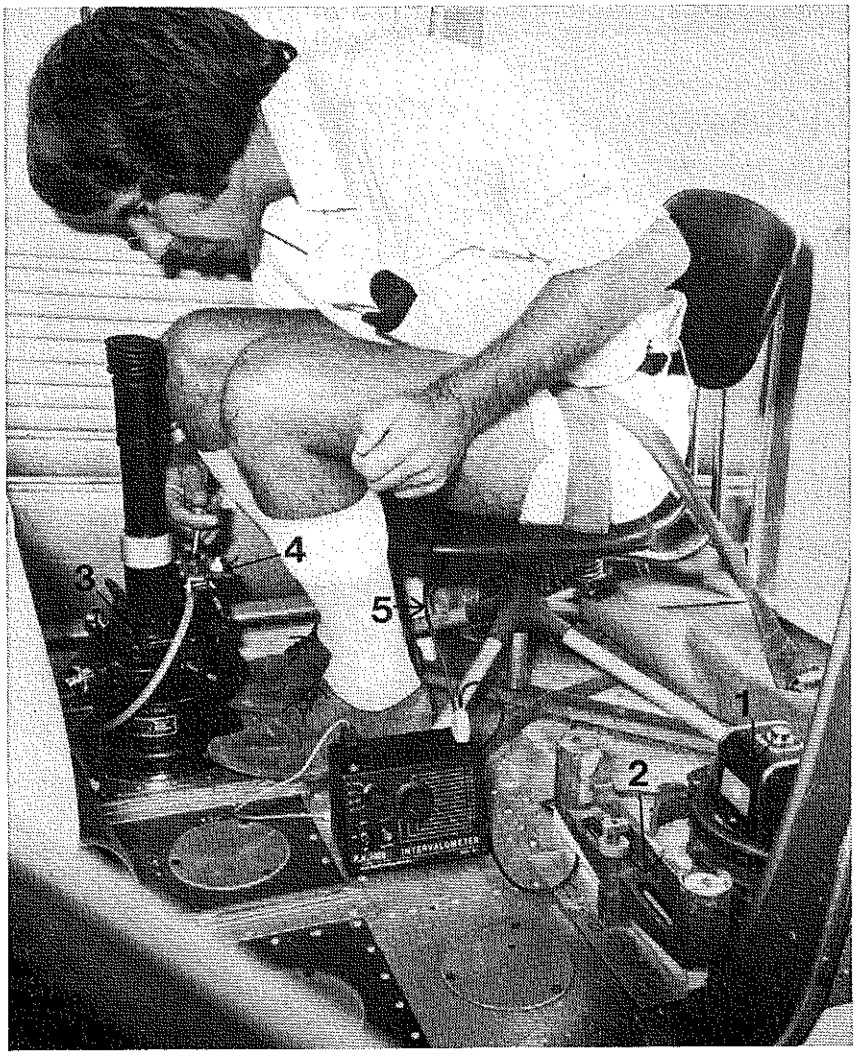


Fig. 1. Photographer–navigator in Cessna 172. The rear bench has been removed. (1) Camera; (2) mount; (3) navigational telescope–camera sight; (4) switches controlling signal lights to pilot; and (5) remote control lead to intervalometer.

Camera

The camera (Figs. 1 and 2) is a Hasselblad 500 EL/70M, electrically operated and powered by self-contained rechargeable batteries. The 70 mm magazines hold 5 m (70 frames) of 70 mm film and can be interchanged at any time without waste of film. Both the 80 mm and 150 mm lenses have proved suitable in this system for a range of scale requirements. (For a given scale, the altitude is proportional to the focal length, e.g. a 1 : 2000 scale is obtained with the 80 mm lens at 150 m and with the 150 mm lens at approximately 300 m.)

Mount

The mount (Figs. 1 and 2) is for use with the Type F-24 camera which is currently being phased out by the Royal Australian Air Force. In the Cessna 172 the mount clips to brackets bolted to the floor. For use with the lighter Hasselblad camera, the sponge rubber cushions in the legs have been replaced with a lower density sponge material. The camera with the focusing hood removed is mounted in an aluminium flange (cut from the body of an F-24 camera) by an L-bracket fixed to the tripod shoe. Rubber shims cemented to the inner surface of the flange opposite the L-bracket ensure that the camera is firmly seated when resting in the mount. The camera is levelled during flight by the two level-adjustments on the mount. When assembled, the camera in the flange can be rotated in the fixed mount to ensure that the film format is tracking parallel with the line of flight despite aeroplane drift, or 'crab'. This is of utmost importance when photos are to be used for composite coverage of a subject, and this is the usual situation with large-scale photography unless the subject is especially small. Drift angle is measured with the navigation telescope.

Intervalometer

The use of an intervalometer (Fig. 1) enables automatic cycling of the camera shutter release, film advance, and cocking at pre-set intervals, thus providing required overlaps of photos. The intervalometer used in this system is a Nikon NC-2 which operates on self-contained batteries. Although it has a range of 0.5 to 20 sec, it is recommended that intervals longer than 5 sec be timed manually (Ulliman *et al.* 1970).

Use of a Hasselblad intervalometer has been reported (Sabins 1973). This requires an external source of 110 volt AC which can be supplied by an inverter using the aircraft's DC power or a self-contained battery and inverter combination.

A cassette tape recorder and a set of tapes, each with recorded signals at a required interval, can be substituted for an intervalometer for economy. The sacrifice made, in addition to loss of automation, is a 'blank spot' between the minimum interval of 1 sec (the camera operating on automatic mode) and the minimum interval which can be accurately repeated manually on cue from the recording, i.e. *c* 2 sec. The consequent limited capability to obtain photo scales between 1 : 2000 and 1 : 4000 can be tolerated in many applications.

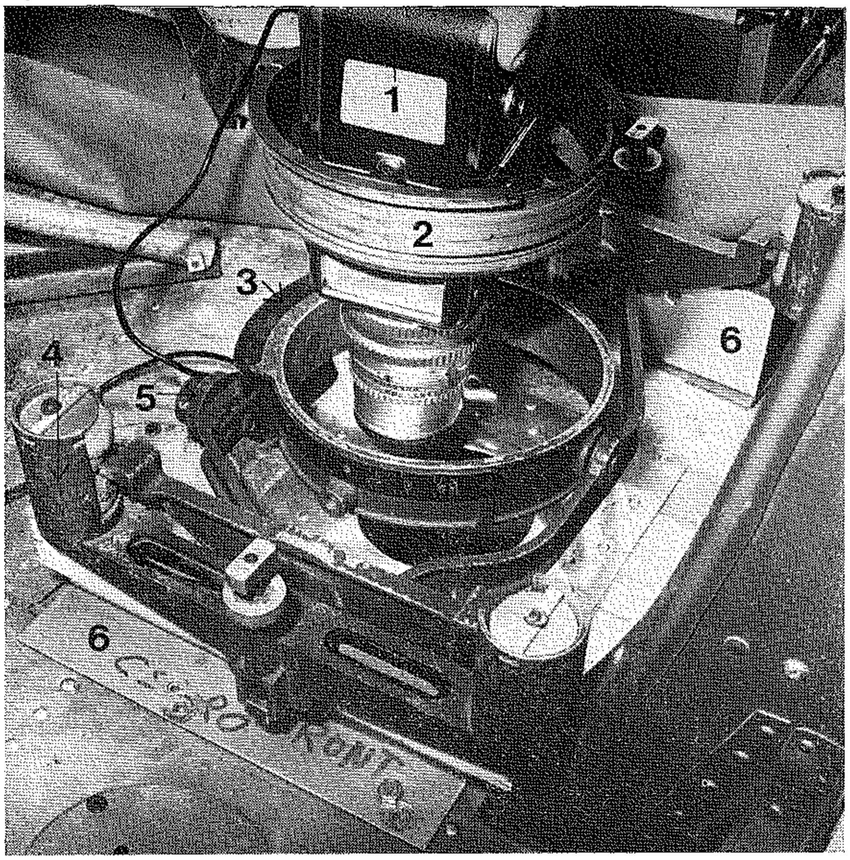
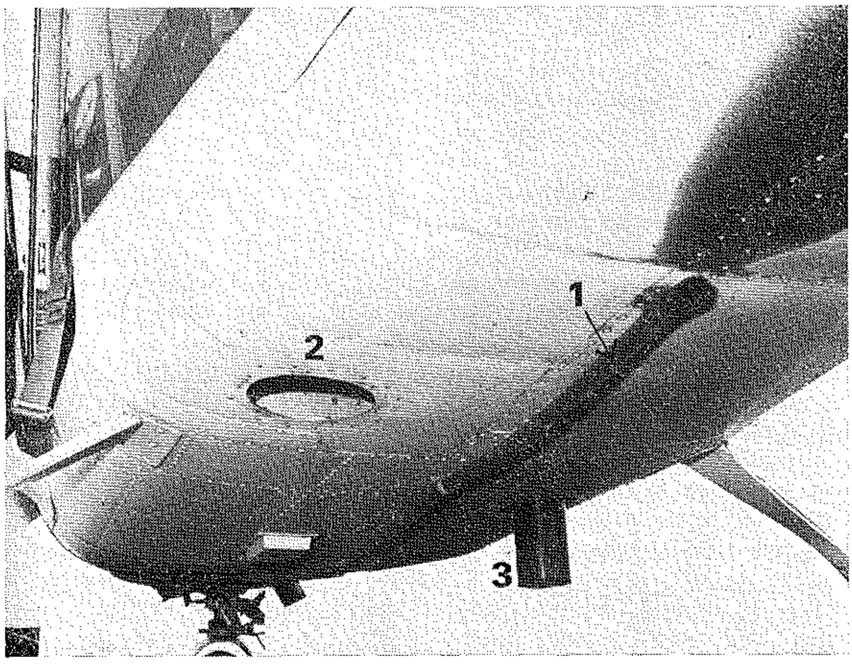


Fig. 2. Hasselblad 500 camera being lowered into F-24 mount. (1) Interchangeable 70 mm magazine; (2) mounting flange affixed to camera tripod shoe; (3) protractor scale used in off-setting camera for aircraft drift; (4) cushioned leg; (5) levelling knob (a second is out of view); and (6) channel bolted to floor.

Fig. 3. Underside of aircraft showing (1) breather tube extension; (2) opening for camera; and (3) telescope with mirror withdrawn and end cover in place.



Navigation Telescope

The navigation telescope (Fig. 1) is a World War II Williamson model. It is equipped with an adjustable mirror that enables forward viewing up to 90° from the vertical. Drift is measured by rotating the body in the mount until an object is tracking parallel to the fore and aft lines on the graticule. The degree of drift is read from the angular scale on the outside of the telescope body, and the camera angle is adjusted correspondingly. The telescope also serves as a sight to aim the camera, since the film format is outlined on the graticule.

Navigation Signal Lights

The navigation signal lights provide visual communication between the navigator-photographer and the pilot. This avoids any audio competition with the pilot's radio communication in DCA-controlled airspace. An assembly comprising three lamps of different colors shaded by a dark hood is mounted on the instrument panel. The end lights are direction signals, controlled by a single pole-double throw switch on the column of the navigation telescope. The rate of flashing of a light is proportional to the required degree of course correction in that direction. The central light is turned on during camera operation by a second switch on the telescope column.

Aircraft Modifications

The modifications required for a Cessna 172 are few and simple. The positions of the holes required for the camera and telescope can be seen in Figs. 1 and 3. Other positions were investigated, but those chosen involved the least complication with structural members, wiring, etc. In the case of the camera, the hole in the floor is an unmodified 10 cm inspection hole. A 15 cm hole was cut in the skin and the margins reinforced with a ring of 'Alclad'. In the case of the telescope, the existing inspection hole was enlarged to 15 cm and a 10 cm hole was cut in the skin, the margins of both holes being reinforced. The only other modification required is an extension of the crank case breather tube along the belly beyond the camera to prevent oil fumes condensing on the telescope and camera lenses (Fig. 3). This is simply a flexible plastic tube with support clips at intervals.

System Capabilities and Limitations

Photography

For the agronomist or ecologist considering the purchase of equipment for an aerial photography system, the primary decision concerns the choice of a camera. The few groups who have pioneered the use of large-scale 70 mm photos for describing vegetation have done so with Hulcher (Aldrich *et al.* 1959), Mauer (Carneggie and Reppert 1969), and in Australia, Vinten (Carneggie *et al.* 1971, Totterdell *et al.* 1972) cameras. Although not designed for vertical aerial use, the Hasselblad 500EL is the cheapest electrically operated 70 mm camera on the market, and an evaluation of its limitations for agricultural applications in relation to the higher priced alternatives must be made.

The primary limitations of the Hasselblad are (1) limited maximum scale that can be achieved due to relatively slow shutter and cycling speeds (Totterdell *et al.* 1972), and (2) film magazine capacity of 5 m. Although the latter is a serious limitation for certain applications where long transects are required, this is not usually the case in agricultural research. As regards the former, a maximum cycling speed of about 1 sec limits maximum scale to 1 : 2000 with 60% overlap (required for stereo viewing), whereas a minimum shutter speed of 1/500 sec limits scale to about 1 : 1000 (with no overlap). In comparison, the Vinten camera used by Carneggie *et al.* 1971, at 6 frames/sec and 1/1000 sec shutter speed, achieved a scale of 1 : 600 with 60% overlap.

Fig. 4. Paddock (5 hectares) for a grazing experiment at CSIRO's "Lansdown" Research Station showing the mosaic of variation in vegetation at a scale of 1 : 2000. Dark tones depict perennial bunch grass; medium tones are annuals (mainly Townsville stylo); and light tones are bare soil. The photograph was taken in August 1970 using an 80 mm lens, from an altitude of 1300 ft (film scale = 1 : 5000). Arrow indicates 10 by 10 m exclosure also shown in Fig. 5 at larger scale.

To those pioneering research on the technique, a camera capable of the widest range of scales is required and finance is unlikely to be a serious limitation. However, a majority of agricultural scientists, who would welcome photos as an additional tool, just cannot afford the higher priced cameras. The crucial question is, therefore, 'how essential is the larger scale achieved by the more expensive cameras?'

For some applications the larger scale is reported to be essential. Detection of beetle damage in pine trees was successful at 1 : 600 but not at 1 : 1000 (Aldrich *et al.* 1959). In an arid rangeland vegetation with low ground cover, scales of 1/600-1/800 were required to detect and interpret relatively small plants, but plant communities containing predominantly larger plants could be studied effectively at smaller photographic scales (1/1000-1/2000). The latter scales were also superior for evaluating ground surface variation (Carneggie *et al.* 1971).

In 2 years of experience with the Hasselblad system, photographing tropical pasture vegetation in North Queensland, we have found that the attainable scale (1 : 1500) has been adequate to map the useful patterns of variation in vegetation under study. In most instances, a smaller scale has proved more suitable. In contrast to the arid rangeland situation, the primary units to be resolved are usually not small isolated plants, but 'patches' in a mosaic of more or less continuous herbaceous vegetation (Figs. 4 and 5). Recent observations of vegetation and discussions with workers in other subhumid tropical and subtropical areas of Australia indicate that this system would provide equally adequate results in describing the most important patterns of variation in vegetation in these areas.

Navigation

In the papers published to date on large-scale aerial photography, discussion of capabilities and limitations deals almost exclusively with ground resolution, i.e. the ability to distinguish between objects of interest on the photograph. This is mainly a function of shutter speed, cycling speed (assuming stereo overlap is required) and film characteristics. Navigation receives little or no mention. Yet, for agricultural research applications, navigation is equally important to ground resolution, and even more difficult to control.

In contrast to many survey or inventory applications, in agricultural research the subject is usually a discrete area, such as a paddock or plot. A photo of the area *adjacent* to the study area is unacceptable, no matter how excellent the ground resolution. Accurate navigation minimizes the need for reflights after the developed film is examined. Not only are time and money lost in reflights, but important attributes of the subject may have changed in the time lapse between flights. (Such is the risk when transient color differences are being used to discriminate among species.)

The forward-looking telescope has provided a good navigational capability in this system. Although the telescope adds significantly to the total cost, we consider its contribution in measuring drift, and as a camera sight, to be indispensable for consistent success. At altitudes greater than 1000 ft (300 m) navigation is relatively simple. The navigator-photographer can sight on the upcoming target, the pilot can respond to course correction instructions, and then use his aiming sight to hold course. At lower altitudes, use of the telescope becomes more difficult due to the 'speed' of objects on the ground, but with experience, an operator can work effectively down to 500 ft (150 m).

Although larger scale is possible with the more expensive cameras with faster shutters and cycling, unless this is attempted by the use of longer lenses and not, as is often the case, by flying at lower altitudes, much of the potential advantage may be lost due to limitations in navigation.

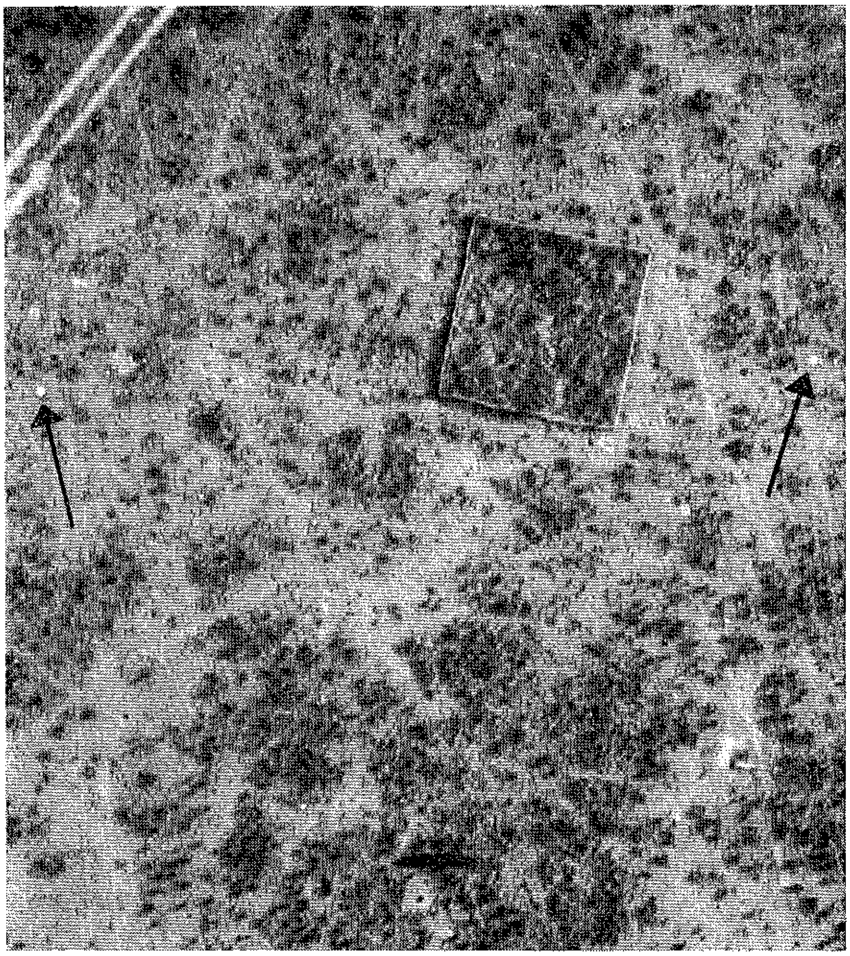


Fig. 5. A portion of the paddock shown in Fig. 4 at a scale of 1 : 400. The photograph was taken in September 1971 using a 150 mm lens from an altitude of 700 ft (film scale = 1 : 1500). Minimum practical ground speed (90 knots) and maximum camera cycling speed (~ 1 frame/sec) resulted in end lap of *c.* 40%. Interpretation of tonal differences is as in Fig. 4. Arrows indicate permanent reference markers (35 cm diam. galvanized iron 'stump cap' mounted on star picket) on a 40 m grid.

Costs

Although the camera accounts for most of the total cost, it need not be committed entirely to aerial use, but may serve as a general purpose scientific camera. Although the use of the 150 mm lens for aerial work is superior for work at maximum scale, if dual purpose use of the camera with minimum capital cost is required, then the 80 mm lens is recommended.

The greatest opportunity for reducing cost is by local fabrication of the intervalometer, or use of a tape recorder for cueing manual operation. A circuit diagram for an intervalometer has been published by Totterdell *et al.* (1972).

The cost of providing suitable modifications to the aircraft to equip it with the camera and telescope in Townsville, Queensland, was approximately $60 in 1972.

A general comparison of the costs of employing a commercial aerial surveyor against our system is difficult mainly because of the immense but intangible value of having pictures taken at the optimum time with regard to phenology of species, weather, etc. However, a specific example will illustrate the savings possible. In 1970 tenders were called for aerial photography of a 3000 ha research area in north Queensland at a scale of 1 : 6000. The average of the three quotations received for supply of color negatives was $2370. This job was done in 1972 with the 70 mm system at a cost of $160, including commercial developing of the color negatives. (This does not include the time of our own photographer-navigator — 9 hours including pre- and post-flight work. As is the case in most research establishments, this is a fixed cost.) The savings on this single job offset the initial cost of the camera.

Operational Procedures

A memorandum describing detailed procedures for constructing and using this system is available from the authors upon request.

Air Navigation Regulations in Australia

Modification of Aircraft

(Regulation 32)
Prior approval from the office of the Director-General of the Department of Civil Aviation is required before an aircraft may be modified. After modifications have been completed, 'an aircraft maintenance engineer licensed for the purpose or an approved inspector must certify that the aircraft is airworthy'. In order for this certification to be granted, the design, materials, components and workmanship must comply with the drawings, specifications and instructions the Department of Civil Aviation has approved.

Aerial Photography

Vertical aerial photographs may be taken only by the holder of an aerial work licence endorsed for aerial survey or aerial photography (Regulation 118). (Many air charter firms qualify for this activity.) The pilot for aerial work operations must hold a Commercial Licence (Regulation 51, 191).

We have experienced no problems in getting modifications made and approved when the matter was placed in the hands of a reputable engineering firm. Photographic operations were carried out in conjunction with the same firm.*

*Rex Aviation, Townsville.

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