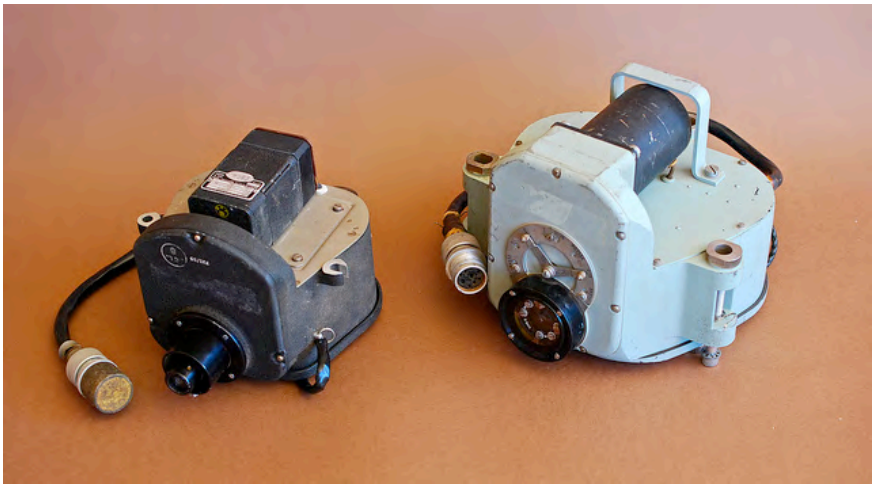
GW Target Aircraft Cameras



Camera		
Camera Type :	GW 1	GW 2
Film Type :	35mm movie film	
Manufacturer :	Dekko	R&J Beck
Year(s) made :	1954–56	1956–58
Dimensions		
Length :[1]	5 ⅜"	8 ¾"
Width :	6 ½"	8 ¾"
Height :	3 ½"–5 ¼"	4"–6 ⅜"
Weight :	3.5kg	6.3 kg
Lens Type		
Type :	ultrawide angle	
Aperture Stops :	f/8 [f/11]	
Focus Settings :	fixed	
Picture Angle :	146°	

In the years following World War II, military planners realised the role and value of using missiles and guided weapons against high-speed aerial targets. The early development of these was fraught with problems, especially in terms of guidance and target approach. British and Australian military planners carried out a major series of tests, the *Anglo-Australian Joint Project*, which ran from 1946 to 1980.[2] Much of the testing of the missiles occurred at RAF Llanbedr in Wales[3] and at Woomera, a large sprawling test complex in South Australia. British aircraft designers focussed on the development of the missiles, while Australian designers focussed on the development of remote-controlled target and telemetry aircraft.[4] In the research area of flight data acquisition, the United Kingdom, through the Royal Aircraft Establishment (RAE), focussed on airborne systems, while Australia concentrated on the ground systems.[5]

The early target aircraft were sourced from surplus fighters and bombers which were converted to allow for pilotless remote-controlled flight. Examples are the Fairey *Firefly* Mk. U.8, a piston-engined fighter of 1943 vintage which was converted as target aircraft from 1954 onwards;[6] the Gloster *Meteor* U.21, a jet-powered fighter (1944, 1955 conversion);[7] and the English Electric *Canberra* U.10, a jet-engined light bomber (1951, 1958 conversion).[8] The *Firefly* were used for weapons trials in the UK, the *Meteor* in both the UK and Australia, and the *Canberra* in Australia only. As early as 1953, however, the Australian Government Aircraft Factories (GAF) began the development of the *Jindivik, a* target drone specifically designed for testing purposes.[9]

At a time before the development of real-time electronic data collection, high-speed cine cameras were required to record the behaviour and relative success (*i.e.* the closeness of approach) of missiles to their intended targets.[10] At the time, the ideal solution, *i.e.* to mount a camera in the nose of the missile, was impossible as the cameras were too bulky and because any space in the rocket nose (where normally the warhead would be installed) was already taken up with telemetry equipment.[11] In addition, the available lenses and lens designs did not have the required coverage. It was not until much later that the necessary camera miniaturisation occurred—and even then the image was limited to a single shot, as in the case of the WRECISS camera.[12]

Thus it was decided to mount the cameras on the target aircraft and to record the missile's approach from that end.[13] By using two sets of cameras, set a specific distance apart, simple triangulation principles could be applied to plot a missile's trajectory (Figure 1).[14]

The U.S.A., which were also experimenting with missile tests at the time, independently arrived at a similar system,[15] the existence of which became to the British designers about two-thirds of the way through their own design process.[16]

Based on British observers' comments, the U.S. system was comprised of a pair of wing pods. Each pod carried, for reasons of redundancy, two sets of four GSAP (Gun Sight Aiming

Point) 16mm cameras that were run at 180fps (by means of doubling the voltage). Each camera was fitted with the standard lens system, to which was added a strong negative meniscus as the supplementary lens (made of plastic) that gave the camera of field of vision of 140º by 160º.[17] The British were quite critical of the image quality that the plastic supplementary lens could achieve and chose not to pursue such an approach.[18] Instead, they preferred to draw on 'fresh' lens designs.

Initially, the British-Australian camera system was meant to be operational by October 1952 to examine tests of *Blue Sky* missiles against B-17 or B-29 drones.[19] This timeline proved impossible to achieve as the units did not become available until 1954—in time for testing the *Blue Streak* programme at Woomera.

Design

The design phase for the target camera commenced in spring 1951.[20] It soon became clear that the camera system necessitated the evaluation and eventual development of *all* three required components: the lens, a camera mechanism suitable for the task, and a wing pod that could house the cameras on the target drones.

Lens Design

The desired coverage of the image was essentially the entire sky around the target aircraft. As conventional cine lenses had too limited an angle of view to effect this, more than one camera had to be used. Modelling was carried out to determine the number of cameras required to fulfil that objective. The results ranged from two cameras, as in the case of lenses with 180º coverage, to the utterly absurd number of 49 cameras if standard cine lenses with 39º coverage were to be used.[21] Not only did a greater number of cameras increase the overall weight of the equipment to be carried, it also increased i) the demands on technical staff responsible for instrumentation maintenance and calibration; ii) the amount of film to be processed; and iii) exponentially increased the complexity of the mathematical computations required for analysis. We need to keep in mind that the latter was a serious consideration in the early days of computing, when much of number crunching such as this was still carried out by highly skilled specialist staff. The preferred option was an array of six cameras with 110º coverage each, or, if the required lenses could be sourced, a system of four cameras with 143º coverage each.[22]

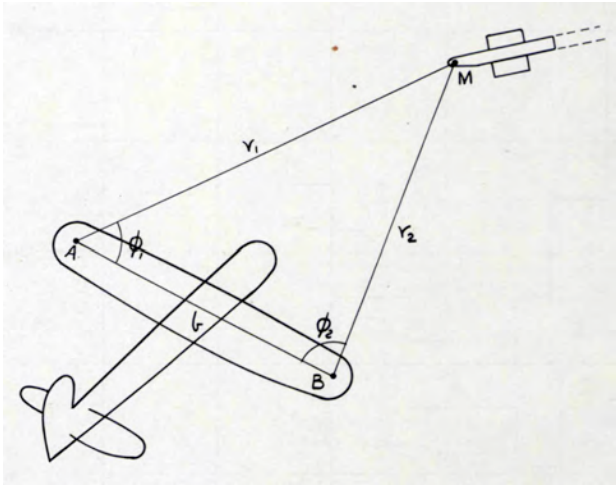


Figure 1. Basic trigonometric approaches were the preferred solution.[23]

The widest angle offered by conventional commercially available lenses at that time was 100º, but these suffered from problematic levels of distortion especially at the periphery. A total of 14 lenses would have been required to cover a sphere when proven, commercially available lenses with a coverage of 90º were considered.[24] Since stereometry was required, that number had to be doubled per aircraft. Clearly, a lens with a wider coverage and a controllable level of distortion was needed. Such designs existed but were commonly far too bulky to be installed in wing pods.[25] Extreme experimental designs by the German lens manufacturer Carl Zeiss (Jena) had just been captured as part of the spoils of World War II.[26] Seriously considered for adaptation,[27] were the Pleon with its 130° angle,[28] as well as the Sphaerogon and its derivatives, such as Zeiss design V1936 nº 18 with a field of 210º at f/6.8.[29] Some sample lenses were ordered by the Royal Aircraft Establishment.

Camera Design

The cine camera also required some consideration. There were no small-sized units on the market that would have allowed for the required speed of 100fps (frames per second).[30] It was assumed that both the Bell & Howell Eymo and the Vinten Model K could be adapted to the needs.[31] The most widely used cine system, the

Howell Type 70, was deemed suitable, but unproven at these speeds.[32] As the images were to be analysed on a frame-by-frame basis, rather than as continual motion, the design of the high-speed camera would not have to be concerned with the accurate registration of the film as it was exposed.[33]

A number of commercial cameras used 16mm or 35mm film. The 35mm solution was favoured because of the larger film area, and thus better resolution. It also allowed the use of a slightly larger focal length (at the same angle of coverage).

Mathematical modelling showed that a film speed of 100 fps was adequate for the need and that an increase to 200fps would not result in dramatically better data quality.[34] A camera speed of 50fps was deemed satisfactory but problems were anticipated in locating the missile in the few useful frames that that speed would produce.

The design specifications also stressed that the cameras had to be of a design that was as simple as possible to ensure reliability; should be easy to maintain; and also cheap to produce so that overall costs could be kept down. After all, ten cameras were to be installed in each target airframe[35] and, eventually with increasing missile accuracy, a high degree of loss and attrition of the target aircraft was anticipated.[36]

By the same token, it was predicted that the target aircraft would suffer losses due to equipment malfunction both in mid-flight and especially during landing. The camera design had to be sturdy enough to protect the film from data loss during such events.[37] Initially it was envisaged to protect the film by 'armour plating…each magazine, or enclosure in a self-sealing light-tight bag of plastic or rubber."[38] Neither did eventuate.

In addition, it was expected that severe vibrations would occur that might affect the performance of the camera. Moreover, there was a need to be able to match the camera mechanism with the small focal distance generated by the lens (see below). Given all three requirements, it was decided to develop a cine camera from scratch.[39]

Designs for the Wing Pods

To record a missile's approach, a camera pod (AMPOR)[40] was developed that carried four cine cameras, each fitted with a lens capable of 143º coverage. A camera pod could therefore cover the entire sky around the aircraft, with the exception of the area obscured by the plane's fuselage.[41] The overlapping coverage required for stereometric analysis was achieved by fitting each target aircraft with two such pods, installed at the tip of its wings (Figure 4).[42]

In addition, to record the effects of wing deflection and thus the motion of the pod in relation to the aircraft, each pod carried (at least initially) a fifth camera, fitted with a conventional lens that (on 35mm film) covered a field of 18º x 24º. Later the registration camera was moved into the fuselage. It took split image (via mirrors) recordings of both pods in a single frame (Figure 15). To aid registration, the pods were painted with an alignment triangle. At least some of the camera pods were fitted with a parachute and homing beacon so that they could be jettisoned and recovered.[43]

Production

To develop the required camera, the Royal Aircraft Establishment approached to two small British companies that were not usually associated with high-end camera designs, but who undoubtedly had the required expertise: the microscope manufacturers R & J Beck and the cine camera maker Dekko. One assumes that the smaller workforce employed by these companies also meant that confidentiality could be monitored more readily.

The Ultra-Wide Lens

R & J Beck, well-known manufacturers of microscopes, was a company with a long history in optical developments. Beck was approached to build sample lenses based on the captured Zeiss lens designs and to adapt them to the Royal Aircraft Establishment's needs. This they did,[44] but they also dusted off a similar design they had built in 1924. In fact, this had formed the basis of the Zeiss lens design concepts: the Robin Hill Sky Lens.[45]

Figure 2. Fairey Firefly U.8 target drone at Manchester (Ringway) Airport 30 March 1955 with the AMPOR Mk 1 wing tip pod .[46]

Figure 3. Fairey Firefly U.9 target drone at Manchester (Ringway) Airport with the AMPOR Mk 1 wing tip pod.[47]

Figure 4. Gloster Meteor *U15 target drone in flight over Wales in 1964, fitted with the thinner version AMPOR wing tip pod (Mk 2)*[48]

Figure 5. English Electric Canberra U10 target drone at RAF Lyneham 8th April 1962[49]

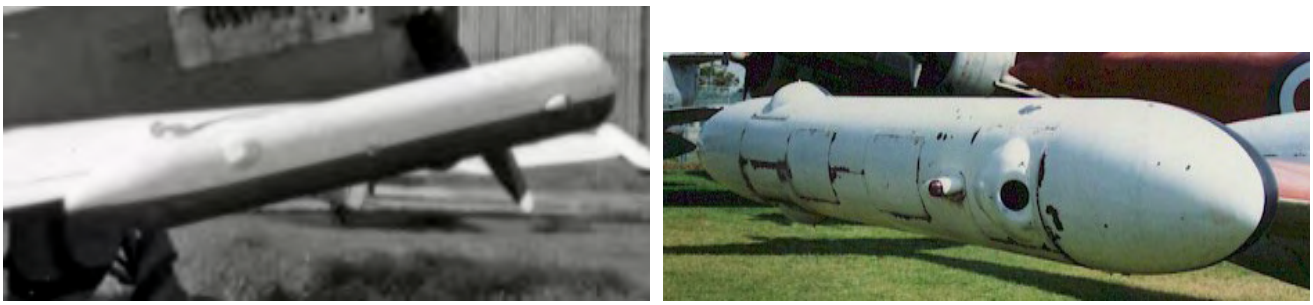


Figure 6. AMPOR wing tip pods, the snub-nosed Mk1 at left, and the round-nosed Mk 2 at right .[50]

Figure 7. AMPOR wing tip pod, round-nosed Mk 2. Note the triangular registration marks on the pod on the left wing[51]

R & J Beck improved on the latter design to create a lens with not only a better performance than the Zeiss lenses, but also one of a much simpler, and hence cheaper, build.[52] Beck developed a modified, smaller dimensioned Robin Hill design (Figure 35) which was accepted by RAE and formally entered production as the G.W. Type 2 lens.

When the production of lenses needed to be increased, it would appear that the Royal Aircraft Establishment again turned to a specialist supplier.[53] While Hilger and Watts Limited (London) were known as manufacturers of scientific and survey instruments,[54] they also designed and built artillery directors and weapon sights for the British military.[55] At the time of writing it is not clear whether Hilger and Watts also provided the lens glass, or whether they only manufactured and assembled the calibrated lens mount, fitting lenses supplied by Beck.

As far as can be ascertained, none of the lenses used in the GW1 and GW2 cameras were ever made in Australia.[56] By 1958 the Beck design was displaced by the Australian-designed Dixon lens with 186º coverage.[57]

The GW 1 Camera

Dekko Cameras Ltd[58] had experience with the production of a range of movie cameras, such as the Dekko Standard (1934),[59] the Dekko 104 DeLuxe (1935),[60] Dekko 110 (1947),[61] and the Dekko 128 (1950).[62] In addition, Dekko produced a range of projectors for 8mm, 9.5mm and 16mm format.[63] During World War II the company had also designed the Dekko type N model 136 (1940) aircraft magazine camera[64] and thus had come to the attention of the Royal Aircraft Establishment.[65]

The required running time of the film strongly influenced the camera design. It was estimated that the missile would be near the target for a period of between 1/10th and a full second. Thus the initial design specifications, which resulted in the GW 1,[66] required a two-second buffer at either end to allow for operator errors in starting the cameras. At the required speed of 100fps, a standard 50ft roll of cine film would provide for a 6 second run time—which was deemed satisfactory.[67] The newly designed ultra-wide lens had a very short back focus, which required a camera to be designed more or less from the ground up. The camera body was designed very sturdily to allow recovery in case the aircraft target crashed.[68] Dekko Camera Ltd developed the camera in close collaboration with RAE and made it available in 1954.[69]

In production, the lens makers R&J Beck provided the complete lens plates, with lenses and graticules in perfect alignment. To maintain the required perfect alignment of lens plate and camera body, the holes for the camera mounting lugs were only machined after the complete unit had been assembled and calibrated.[70]

In the early days of operation, misting of the camera lenses at altitude posed a major problem. To overcome this, the air space between the lens elements was sealed off and, prior to take-off, filled with air cooled to -60ºC temperature.[71] Later, the entire cameras were heated (see description, p. 10).

Over the period of operations, the GW 1 underwent minor design changes and adaptations in the field, among them the improvement of the camera mount to make it more resistant to shock.[72] One of the main problems encountered was that the GW 1 was prone to jamming, leading to a loss of films and thus data.[73] This led to repeated complaints[74] and an assessment of each camera mechanism to ascertain whether this was just a random event or operator's error, or whether there was a systemic issue with the GW 1 design.[75] In the event it was decided that the speed of the GW 1 should be reduced by 10% and that all cameras still in service at the time should be standardised to 90fps.[76]

In addition, of course, operational errors also occurred, such as labelling both ends of a film with 'START",[77] or failing to recharge the batteries of the AMPOR pods, which caused the cameras to run at less than half the expected frame rate.[78]

The GW 2 Camera

Soon after the GW 1 camera entered operational use, R & J Beck developed a successor model.[79] The new GW 2 unit, essentially a scaled-up version of the GW 1 design, was capable of 12 seconds recording time. To facilitate this, the new design included a film magazine that contained

both the feed and take-up spools for 100ft or 25mm film. The extended time allowed to use the AMPOR pod recording mechanism for data collection in trials other than missile approaches, but also permitted to record multiple missile events in the same flight. Improvements in missile observation and telemetry, as well as improved timing commands, meant that the camera could be switched on and off with greater accuracy.[80] As a by-product of the redesign, however, both bulk and weight of the camera unit increased from 3.5 kg to 6.3 kg.

The GW 2 camera had been designed in 1955 and went into production in 1956.[81] As with the GW 1 units, practical experiences showed up minor design flaws and inconsistencies among the GW 2 units[82] that could be rectified with local modifications,[83] some of which became standard retrofits to the units used in Australia.[84]

All five cameras in a single AMPOR pod were controlled by a control unit, which underwent a number of versions (GW1 Control Unit Mk 2, Mk 2A and Mk 3) as well as range of local modifications initiated in Australia, some of which were incorporated into the standard design of the new version.[85]

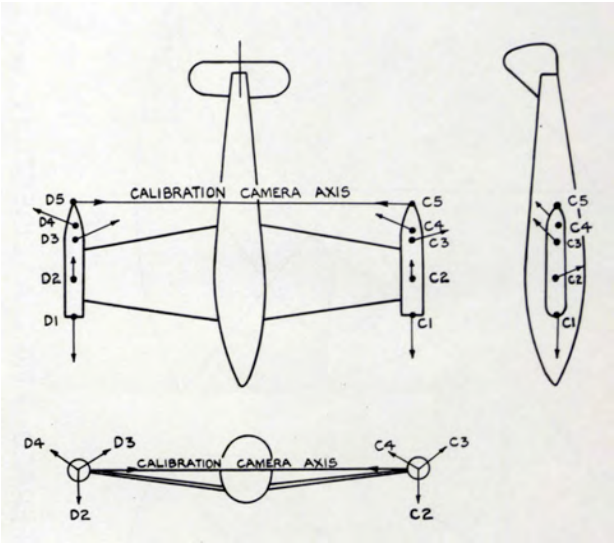


Figure 8. Camera angle arrangement in AMPOR Mk 2 pods mounted on a Fairey Firefly.[86]

Pod Designs

The AMPOR Mk 1 pod, made of aluminium alloy, measured 265cm (8.7') in length and 26.7cm (10 1/2") in diameter.[87] AMPOR Mk 2 pods were also made of aluminium alloy[88] but had the larger diameter of 38cm (15"), with a slightly shorter length of 2.2m (85"), and weighed approximately 43.9 kg.[89] The pods (Mk 1 and Mk 2) had five blisters for the camera lenses (Figure 16), colloquially as 'bugs eyes.'[90] Each camera had a 144º angle of view. To cover the sky surrounding the pod (and thus the aircraft), four cameras, each covering 120º (with some overlap) would radiate from a single point source. While this represented the ideal, it was not feasible because the cameras were too bulky. Thus the same concept was employed, but the single point source stretched along the longitudinal axis of the pod (Figure 8). The camera in the front nacelle looked straight forward along the axis of the pod, while the remaining three units were set at 120º angles from that, looking backwards and down (nº 2), as well as towards (nº 3) and away from the plane (nº 4).

In addition, a fifth unit, fixed at the aft end of the pod, looked straight at the aircraft fuselage to record alignment and wing flex. The camera positions in the port and starboard wing pods were, of course, mirror imaged (Figure 16). It was critical that the cameras were well aligned before the pod was ready for mounting. Extensive, yet rather simple, test facilities were set up to ensure this (Figure 9).[91]

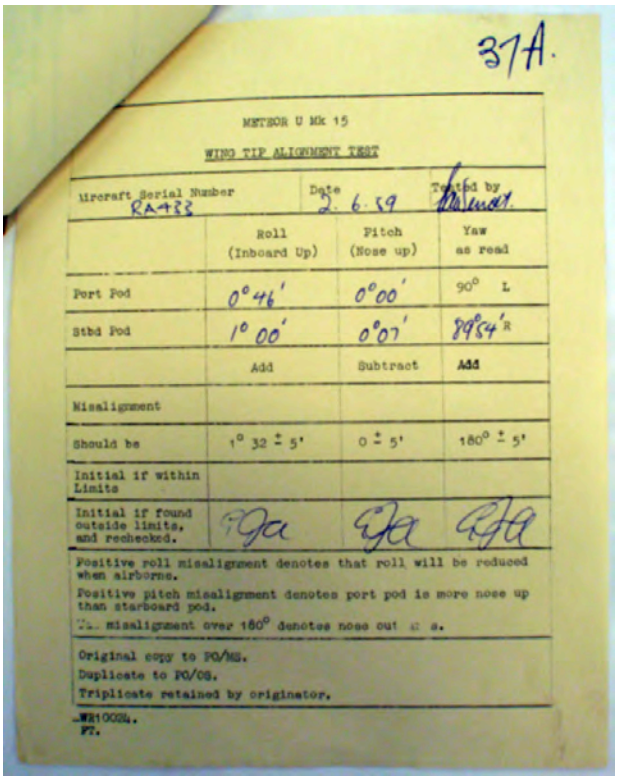
Figure 9. Calibration of AMPOR Mk 2 pods at RAF Llanbedr.[92] *The pod is shown from behind.*

While it proved too difficult to fully synchronise the operation of all five cameras, the required accuracy could be achieved by the inclusion of timing marks at the edge of the film.[93] These transmitted timing commands were common to all air-borne cameras as well as ground-based telemetry equipment[94] and allowed to synchronise the individual frames at the analysis stage.

Overall numbers and costs

Since the total overall numbers of GW 1 and GW 2 cameras produced are not known at the time of writing, some approximations have to be made.

Overall, 74 Fairey Firefly aircraft were converted into target drones between 1954 and 1955,[6] as were approximately 270 Gloster *Meteor* (converted between 1955 and 1965),[7] and 17 British Electric Canberra (converted between 1958 and 1960).[8] The total number of target aircraft, not counting the *Jindivik* drones, would have been about 350. A large number of these would have been fitted with pods carrying GW1 and GW2 cameras. Based on the serial numbers (see p. 20), we can assume that some 3600 ultra-wide lenses were manufactured, which were distributed between GW1 and GW2 units. At four cameras installed in each AMPOR pod and two pods per aircraft, these 3600 UWL cameras of both GW 1 and GW2 type would have been sufficient to serve approximately 450 aircraft.[95]



37A.

METEOR U Mk 15

WING TIP ALIGNMENT TEST

Aircraft Serial Number RA433	Date 2.6.59	Tested by
	Roll (Inboard Up)	Pitch (Nose up)	Yaw as read
Port Pod	0°46'	0°00'	90° L
Stbd Pod	1°00'	0°07'	89°54' R
	Add	Subtract	Add
Misalignment			
Should be	1° 32 ± 5'	0 ± 5'	180° ± 5'
Initial if within Limits			
Initial if found outside limits, and rechecked.			

Positive roll misalignment denotes that roll will be reduced when airborne.

Positive pitch misalignment denotes port pod is more nose up than starboard pod.

... misalignment over 180° denotes nose out ... s.

Original copy to PO/MS.
Duplicate to PO/CS.
Triplicate retained by originator.

WE10034.
PT.

Figure 10. Example of a wing tip alignment test record[96].

We know that the Australian test range had 25 sets of AMPOR Mk 1 pods (fitted with GW1 cameras) available for use, and that at that time none of the AMPOR Mk 2 pods with GW2 had been produced.[97] Additional GW1 cameras sufficient for another 12 pods were in hand at the time,[98] suggesting that a total of 185 GW1 Mark 1A cameras were in hand.

The costs of AMPOR Mk 1 and Mk 2 sets for target aircraft, comprised on 2 pods and 10 cameras each, were 'over £4,000 per aircraft set.'[99]

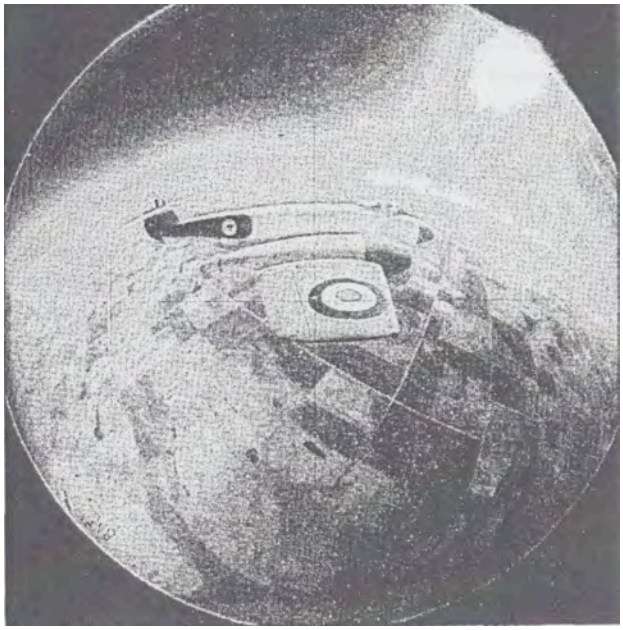


Figure 11. Photograph taken with the WRE lens showing a RAAF Meteor off the port wing of an unidentified target drone.[100]

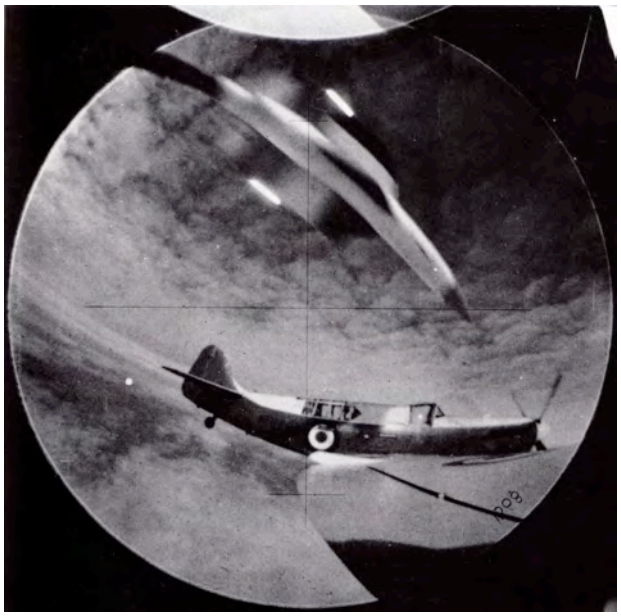


Figure 12. A British Electric Thunderbird Missile passing a Firefly target aircraft over Wales. The image taken was with a GW 2 camera mounted in the starboard wing pod. The original negative measures about 25mm in diameter.[101]

Figure 13. Target Aircraft Camera Dekko GW 1 Mk 1 A fitted with Type 2 Mk 3 lens.

Figure 14. Target Aircraft Camera Dekko GW 1 Mk 1 C fitted with a Type 3 Mk 2 lens.

Operational History

The Target Aircraft Camera GW 1 was deployed by the RAE in 1955 as an automated recording system with a run-time of six seconds. The AMPOR pods with GW1 and GW2 configurations were deployed in both Wales and South Australia in the weapons testing programs of the British Electric *Thunderbird*[102] and Bristol *Bloodhound* missiles.[103]

Intriguingly, the camera system itself was not seen as secret. Some of the GW cameras, as well as complete AMPOR pods, were exhibited at air shows in the United Kingdom,[104] presented at conferences[105] and were described in the popular press[106] as well as academic literature replete with photographs.[107] Academic publications showed examples of the images that could be produced (Figure 11, Figure 12).[108] Some of the latter publications even carried the lens diagram (Figure 35).

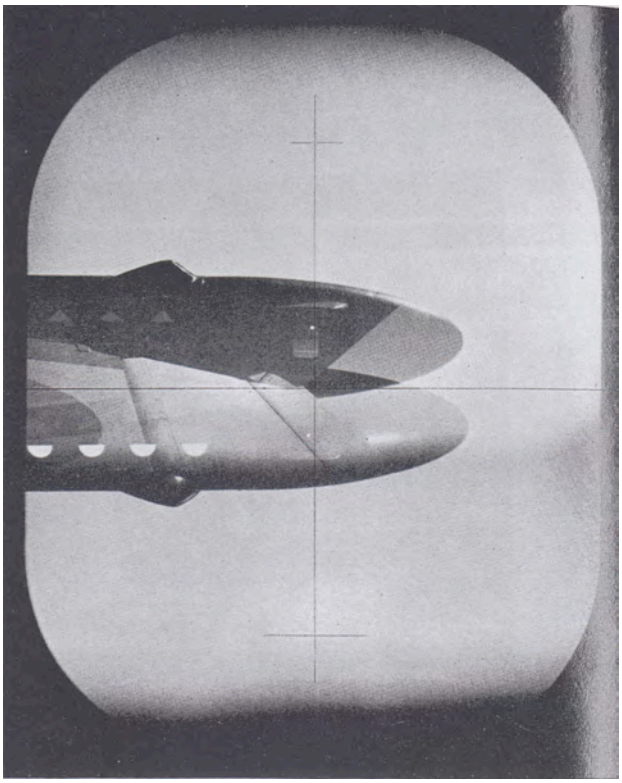


Figure 15. Split field image of the two AMPOR pods mounted on a Meteor target drone.[109]

Figure 16. Comparison of the AMPOR Mk 2 (top) and AMPOR Mk 3 wing-tip pods.[110]*Shown is the starboard pod. Note the blisters for the GW camera lenses in the Mk2 pod, with camera at the right*

The AMPOR Mk 1 pod was mounted on the wingtips of Fairey Firefly[111] (Figure 2) and *Meteor* (Figure 4) target aircraft.[112] The same pod type was initially also intended to be mounted on the *Jindivik* target aircraft being developed by GAF.[113] During the *Jindivik* design phase, however, RAE switched from GW1 to the larger GW2 units, as they were capable of twice the run time.[114]

From about October 1958 onwards all *Meteors* delivered as target aircraft had GW 2 units fitted in their AMPOR pods.[115]

The larger size (2" each way) and especially the increased weight of the new GW2 cameras to be accommodated (6.3kg as opposed to 3.5kg), resulted in the wing-tip pod becoming too large and far too heavy for the *Jindivik*.[116] Even though the new version (AMPOR Mk 2) had a more streamlined nose section, concerns were expressed as to the increased drag as well as the structural stresses the new heavier pods would exert on the airframe.[117]

The early model *Jindivik* suffered from flight flutter,[118] which was exacerbated by the AMPOR Mk. 1 pods as had been shown in wind tunnel simulations,[119] as well as actual flight tests,[120] one of which ended with the *Jindivik* (A92-29) disintegrating in mid-flight and crashing.[121] Despite these negative experiences, some early versions of the *Jindivik* 2A actually carried the AMPOR Mk 2 pods,[122] until a lighter replacement system became available. Their performance as target aircraft, however, was restricted to lower speeds and a more steady flight, which restricted the usefulness of the tests.[123]

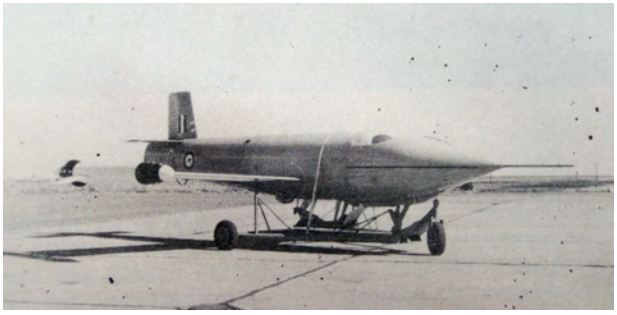


Figure 17. A Jindivik *Mk 2 fitted with AMPOR Mk 2 pods at Woomera in 1958.*[124]

WRETAR

To offset the weight and drag issues encountered, GAF, in collaboration with Australia's Weapon Research Establishment (WRE),[125] developed an entirely new camera. It employed a newly invented lens with 186º coverage,[126] which was a major development for the Australian optics industry.[127] This lens was fitted to a newly designed, oblong 35mm film camera that was also capable of 100fps (WRETAR).[128] Like the GW units before them,[129] WRETAR cameras were capable of 'recognising' a missile within 250ft of the camera (and larger missiles at a greater distance).[130] The WRETAR units were ready for production trials in March 1956.[131]

This new camera system now required only two lenses per wingtip pod as opposed to the previous four.[132] As was noted, this not only resulted in smaller wing pods with a lesser weight to be carried (Figure 16),[133] but it also cut in half the amount of film that had to be processed and analysed.[134]

Figure 18. A Jindivik *Mk 2 fitted with AMPOR Mk 3 pods at Woomera in 1959.*[135]

WRETAR entered service in 1957 and was initially deployed alongside the older *Jindivik* models fitted with the GW2.[136] The WRETAR units were fitted in the new AMPOR Mk 3 wing tip pods of only 5.5 inches diameter,[137] and later in the AMPOR Mk 4 pods which, while larger, were seemingly positioned further towards the fuselage (due to wing tip extensions).[138] Tests showed that the flight flutter, while reduced, still persisted, leading to damage of the pod and aircraft.[139] While all newly built *Jindivik* were fitted with WRETAR units in AMPOR Mk 3 pods,[140] most existing target aircraft retained their GW2 configuration. It would appear that at least some of the Canberra target aircraft were retrofitted with WRETAR units as airframes underwent systems upgrades.[141]

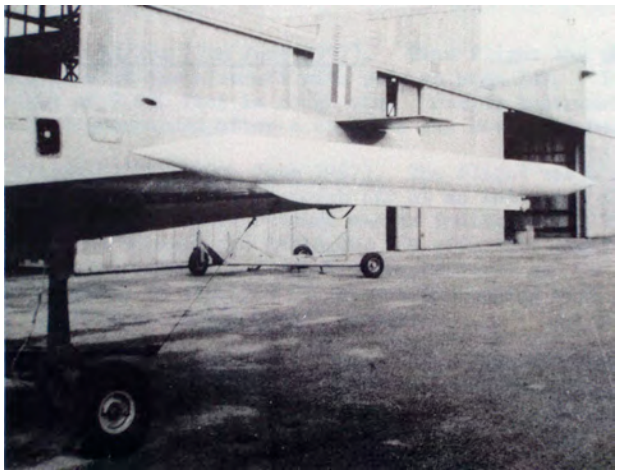


Figure 19. AMPOR Mk 3 pod fitted to a Jindivik *Mk 2 at Woomera in 1960.*[142]

Those target aircraft still fitted with GW 1 and GW2 cameras underwent a natural, gradual attrition due to airframe fatigue, crashes or destruction by missile, eventually removing most GW1 and GW2 units from the operational pool.[143] At one point this caused a major concern as a shortage of GW 2 cameras emerged before the WRETAR Mk 3 pods came off the production line for the *Jindivik*. In a cable, SqdrLdr Fletcher noted that

> "it is requested that you conserve the remaining Mk 2 pods with Mk 2 cameras for specific occasions as called up. In the case of acquisition trials and the early discrimination trials there is no need to carry AMPOR and I suggest this be not fitted on these occasions..."[144]

By 1959 the use of AMPOR Mk2 pods with GW1 and GW2 units ceased and only AMPOR Mk 3 wing tip pods were carried. It appears the last AMPOR Mk2 pods were used up in the Red *Duster Trials* of 1958 and the *Sea Slug* trials of 1959.[145]

It is unclear how many GW1 and GW2 units survive today.

The GW1 and GW2 were part of an analog instrumentation recording program that also saw the development of other specialised cameras, such as the GW 3 Continuous Record Camera to record oscillograph images,[146] and the GW 9 Missile Camera (onboard) to record missiles in flight.[147]

Target Aircraft Camera Dekko GW 1

The *Target Aircraft Camera GW 1* entered production in 1954 as an automated 35mm recording system with a run-time of six seconds at 100fps.[148] The negative pull down of the standard 35mm cine film stock was $^{15}/_{16}$" —*i.e.* five sprocket holes per frame as opposed to the standard four perforations system ($^{11}/_{16}$") employed by commercial 35mm cine cameras. This allowed for nearly circular images of 25mm diameter with only minimal overlap, thereby maximising resolution.[149] While technically the GW1 was a high-speed cine camera, the resulting negatives were not projected as a film but examined as individual frames in order to assess the miss distance of the missile in relation to its target.

Table 1. Data on the Dekko G.W. 1 units available for this study.[150]

Lens		Body		Motor	WRE	Notes
sn	Type	sn	Type	sn	sn	
121	2 Mk 2		Mk 1A			151
	[2 Mk 2]	544/55	Mk 1A		708	152
139	2 Mk 2	602/55	Mk 1C			153
674	2 Mk 2	507/55	Mk 1A	D67747	2325	154
1424	2 Mk 3	1212/57	Mk 1A	D76124	—	155
1501	2 Mk 2	1296/57	Mk1A	D76281	—	156
2037	3 Mk 2	702/55	Mk 1C	D67939	2327	157
2040	3 Mk 2	7xx/55	Mk 1C			158
		717/55	Mk 1C			159
2048	missing	718/55	Mk 1C	D67945		160
2089	3 Mk 2	824/55	Mk 1D	D68112	—	161

A number of GW 1 units have recently (mid-2011) become available on the open market, sold at both on-line and physical auction houses by dealers in Adelaide (South Australia).[162] These units, which appear to have been sourced from a single private estate,[163] seem to have come from military surplus and appear to be units originally used at the Woomera missile range.[164]

Given that several cameras have become available for study, it is now possible to describe these cameras for the wider audience.[165] These cameras were examined either as objects or on photographs. This dataset is augmented by cameras that were depicted in the literature. Table 1 sets out the observed serial numbers of the units and lenses fitted.

Appearance

The body of the camera is shaped like a trapezoid with rounded edges, comprised of a film chamber with removable lid. The underside of the camera carries an electric motor, which is freely accessible for maintenance purposes. The front of the camera housing protrudes downwards and shields the motor from view. The base of the camera shows three protruding lugs for fastening bolts. A front plate, which carries the protruding lens, is bolted onto the front of the housing (Figure 13, Figure 14).

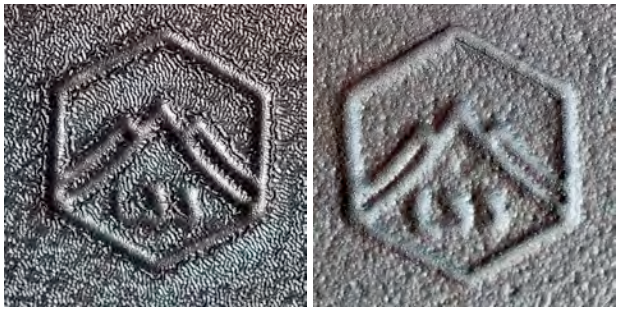


Figure 20. Foundry marks in the lid (left) and front plate (right).

The camera body, painted black, is made of casting aluminium, presumably DTD 424 (as is the case with the GW 2).[166] The underside of the lid, as well as the back of the front plate carry a hexagonal foundry mark, made up of a mountain range with the letters L33 beneath (Figure 20).[167]

The front plate carries a lens mount in its upper third. The mount has a diameter of 1¾" and protrudes for ¼".

The GW 1 unites were fitted with R & J beck manufactured GW2 Mk 2 and GW 3 Mk2 lenses (see p. 21f).

The camera was loaded with 50ft spools of standard 35mm cine film stock. As the film is not contained in light tight magazines, we can assume that the film had a paper leader at both ends which would have allowed an operator to change the film in daylight, without the need to remove the entire camera from its mounts in the AMPOR pod.

Figure 21. Shutter mechanism of the GW 1 Mk 1A

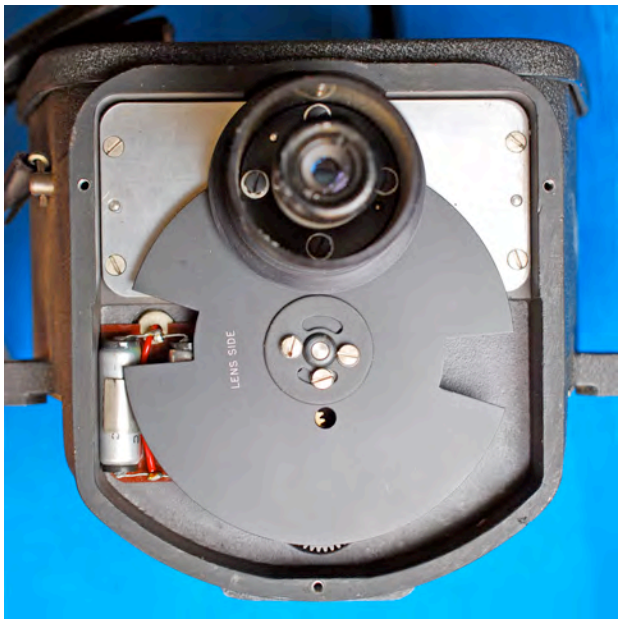


Figure 22. Shutter mechanism in the GW 1 Mk 1C.

Timing lamps in the film path wrote a transmitted time signal in the form of dots and dashes at the edge of the film. The leading edges of the signals were spaced at 1/100th of a second and each signal is either short or long based on a binary code. Every tenth signal was missing and the subsequent batch of nine signals gives (in binary) the time in seconds of the missing signal.[168] As the timing signals were uniform across the testing range, all records could be synchronised at the analysis stage.[169] The cameras used up to two neon lamps, type C.V. 988, to imprint the binary coded data on the film. One lamp was required to record the common time (Figure 23, Figure 26 top), while the inclusion of a second lamp (Figure 26 bottom) allowed the writing of additional data on to the film record.

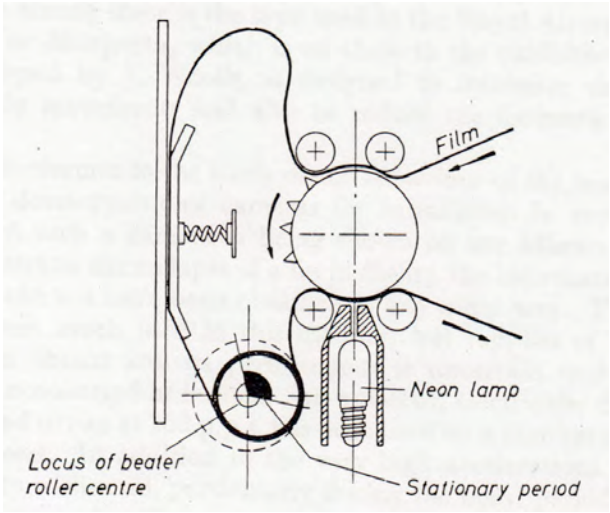


Figure 23. Schematic of film path and timing lamp arrangement.[170]

The power and data cable has a female type multi-pin connector with two power and seven data/controller holes (Figure 24).[171]

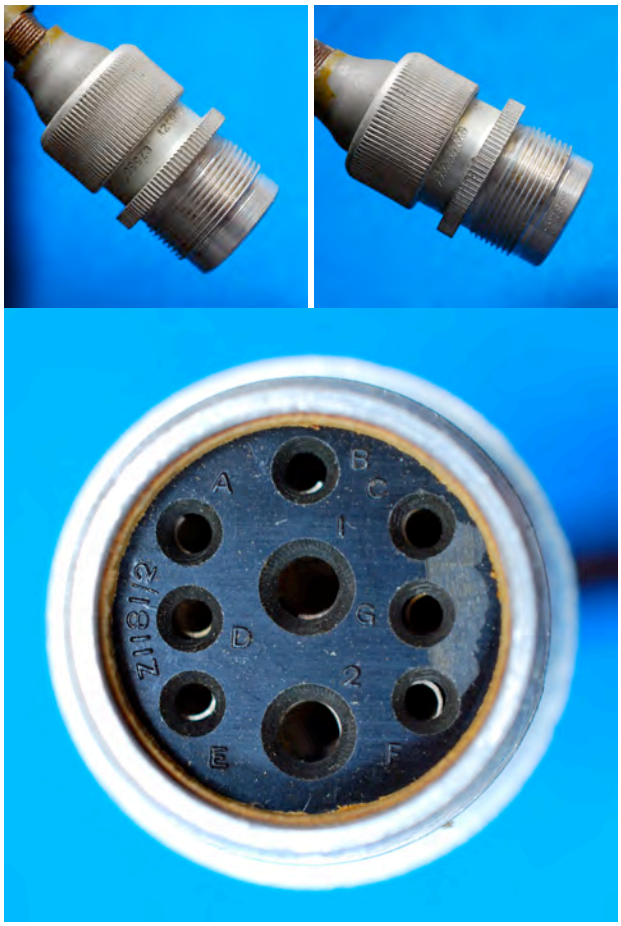


Figure 24. Data and power connector of the GW 1.

All models use the same rotary shutter, comprised of a metal disc of 3 ⅝" diameter, which carries two cut out sections at opposing sides (Figure 21, Figure 22). Each section is ¾" deep and resembles a trapeze, measuring ½" at the centre and ¾" at the rim. This provides an effective aperture of ⅝".

As the GW 1 was a high-speed camera designed to yield images suitable for a frame-by-frame analysis, the design of the mechanism employed must have been an improvement on the Dekko "N" camera mechanism, which exhibited speed variations associated with various degrees of load applied to the system.[172]

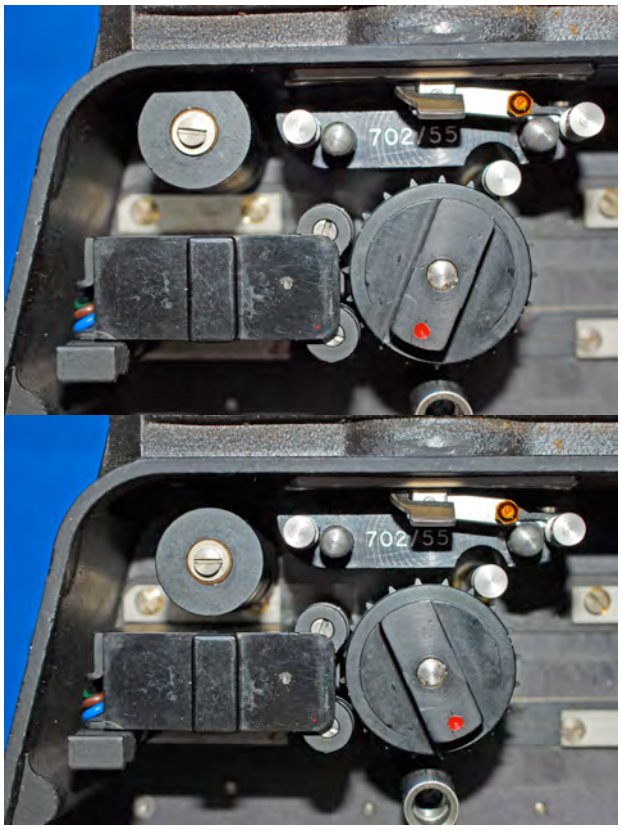


Figure 25. Film advance mechanism of the GW 1 Mk 1C (body #702/55). Note the changing position of the roller at top left. The oblong unit to the bottom left is the timing lamp.

The GW 1 has an in-built heater unit at the base that keeps the camera at an average temperature of 10ºC (50ºF)[173] to ensure that the camera worked well at altitude. While little is known about this, we can surmise that the camera mechanism would have undergone rapid fluctuations in temperature at Woomera. These would have ranged from a high as 60ºC or more in the direct sun, while the aircraft were being prepared for take off on the hard stand or taxiway, to a low of -20ºC at altitude (which would have been buffered by the heater to 10ºC, but with a delay).[174]

Mark I A

The camera body measures 6 ½" in width and 5 ⅜" in length.[175] The camera is 5 ¼" thick at the front and 3 ½" at the back. The underside of the camera allows for the mounting of an electric motor.[176] The front of the camera, which is 1" thick, protrudes by 1 ¾". The camera weighs 3.5 kg (without the take-up spool).[177]

The identification data engraved on the cover for the film magazine-loading bay reads:

CAMERA TARGET AIRCRAFT
TYPE G.W. 1 MK. IA
↑
507/55
DEKKO CAMERAS LTD
28 VOLTS
HEATER

whereby the '28 VOLTS' is engraved on a small black tag (with white letters) that has been screwed on (Figure 13). This suggests that a 12V version of the camera may have been envisaged at one point.[178]

The camera carries corresponding, engraved body serial numbers on the body, the (removable) front plate, the (removable) base that carries the motor and the lid for the film chamber. Based on observed serial numbers, the production period of the Mk 1A camera seems to have been from 1954 to 1957.

The electric motor is mounted on the underside of the camera without any protection. It carries the following identification tag:

TYPE B 12. WINDING SHUNT
H.P. 30 oz. ins. V17. REVER.
R.P.M. 3140 CYC. PH.
RATING 10 secs
No. D67747 | R.B. PULLIN & CO. Ltd
BERNTFORD. MIDDX.
D.C. MOTOR MADE IN ENGLAND
R B Pullin

The back of the described camera carries a dark red, metallic inventory sticker with the text:[179]

WRE
DESIGNATED EQUIPT. SYSTEM
INSTRUMENTATION CAMERA
Nº 2325

Externally, the camera housing also carried a white paint stamp, comprised of the letters "DCL | 8" enclosed in a circle, while internally a similar stamp, reading "DOLA |8 " can be found.[180]

Mark IA variant 1

The Mk 1A unit with a body date of 1955 examined carried a GW Type 2 Mk 2 lens (p. 21).

Camera sn #1212/57 used two neon lamps, type C.V. 988, to imprint data binary code at the edge of the film (see p. 13).[181] The left lamp recorded the common time base,[182] while the second lamp (Figure 26 bottom) allowed the operator to write additional data.

Figure 26. Variations in timing lamp arrangements. Top: GW 1 Mk 1C (sn #702/55) with lens Type 3 Mk 2 lens and one timing lamp.—Bottom: GW 1 Mk 1A (sn #1212/57) with lens Type 2 Mk 3 and two timing lamps.

Mark IA variant 2

A second unit with a body date of 1957 carried a GW Type 2 Mk 2/3 lens. Available for examination was a unit (sn #1212/57) that lacked the lens itself (Figure 27, Figure 28) so that no further details can be supplied.

Mark I B

The existence of a Mark 1B camera can be inferred, but units of this type have not been available for examination at the time of writing.

Figure 27. GW 1 Mk 1A with lens Type 2 Mk 3 (the lens itself is missing).[183]

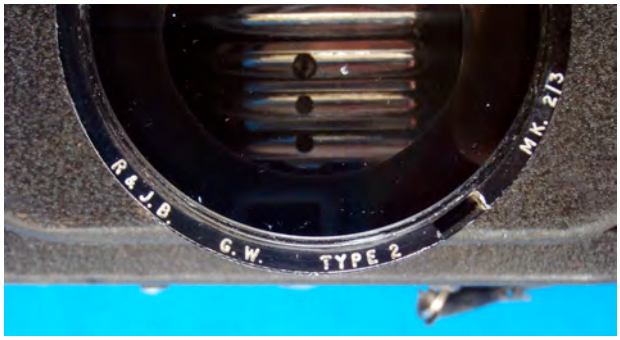


Figure 28. GW 1 Mk 1A with lens Type 2 Mk 3 (the lens itself is missing).[184]

Mark I C

The camera is fundamentally the same as a Mk 1A model, with the same measurements but the following minor variations.[185]

The identification data on the lid to the film chamber read:

CAMERA TARGET AIRCRAFT
CALIBRATING TYPE G.W. 1 MK. IC
↑
702/55
DEKKO CAMERAS LTD
28 VOLTS
HEATER

whereby the '28 VOLTS' is again engraved on a small black, tag with white letters that has been screwed on (Figure 14). The locations where body serial numbers can be found are the same as with model Mk 1A.

The Mk 1C unit examined carried a GW Type 3 Mk 2/3 lens (p. 21). Camera sn #702/55 used a single neon lamp, type C.V. 988, to imprint the common time base in binary code at the edge of the film (see p. 13)(Figure 23, Figure 26 top).[186]

Mark I D

The identification data engraved on the cover for the film magazine-loading bay read the same as those documented for the Mark 1C, with the exception that the text Mk 1C' has been replaced by 'Mk 1D.' The Mk 1D unit examined carried a GW Type 3 lens (p. 21). There appears to be no readily discernible difference between the Mk1C and Mk1D models, either in overall appearance, lenses or mechanics.[187]

Further developments of the GW 1

The GW 1 design appears to have been held in considerable regard by both the British and Australian weapons research establishments, as well as by Fairey Aviation. Despite earlier observations that the camera might have problems with jamming at 100fps, the GW1 proved a design of a small and reliable high-speed camera that could be adapted to other applications. These developments seem to have been carried out by Fairey Aviation Company of Australasia which also developed applications for the WRE-developed Dixon lens,[188] such as the widely used WRETAR as well as the WREROC,[189] WRECISS[190] and WRESTAR.[191] At the time of writing it is not fully clear whether any of the following cameras progressed from the prototype stage to full production.

Monitor Camera

Fairey designed the Fairey Air Services Monitor Camera in 1961 as a high speed ultra-wide angle reconnaissance and survey camera, specifically for tactical reconnaissance photography at medium to low altitudes (less than 1,000 feet),[192] but also, if required, for ground use.[193] The underlying concept was that the image captured by the camera was of sufficiently wide coverage and resolution, that the location (and framing) of higher-resolution standard aerial imagery could be located in the landscape.[194] It appears that the Fairey monitor camera was meant to augment dedicated photo-reconnaissance runs, but, because of its wide coverage, small size and low cost, was also to be installed in standard combat aircraft.

The camera comprised of a Dekko GW 1 unit fitted with a 186º Dixon lens normally used for the WRETAR units.[195] The dimensions given in the Fairey promotional literature (6" x 5.5" x 3 ¼", weight 7 ½ lbs) conform to those of the GW 1.[196] The motor was modified to run at 2fps, giving a total recording time of 8½ minutes on a 50ft roll of standard 35mm film.[197] A 85ft roll of thin-based film could also be used given these slow advance speeds, allowing for 14½ minutes of recording time.[198] At this time, only an image of the camera as shown in a Fairey company publication is available for study (Figure 29). The camera depicted has a riveted plate in the lid, at the location where the second light unit would be located. The function of that component is unclear.

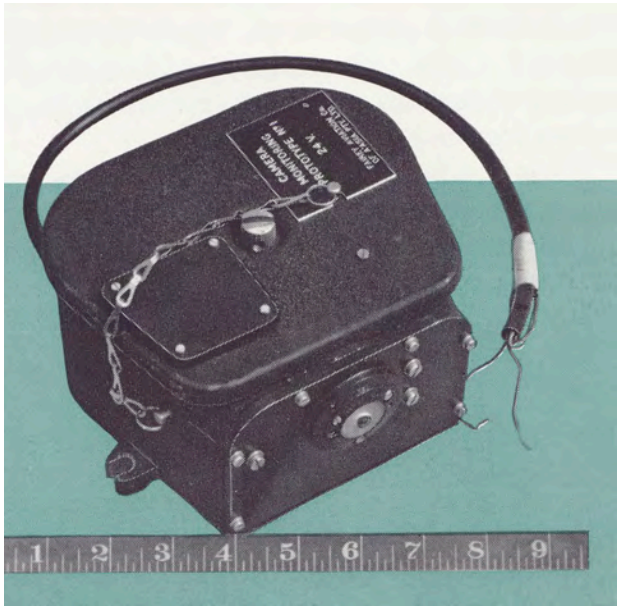


Figure 29. Fairey Air Services Monitor Camera Prototype nº 1.[199]

In order to utilise the camera as a tactical intelligence tool, the time marker system of the GW 1 was modified to allow the pilot to add markers at the film edge on demand, thus making it easier for photo intelligence to quickly identify frames that may show sites or objects of interest.[200]

The camera was designed to be able to withstand a very high G loading, as well as extreme climatic conditions.[201] It speaks to the strength of the underlying design of the Dekko camera mechanism that this could be accommodated.

WREMARC

Two years after the Air Services Monitor Camera, Fairey designed the WREMARC as a 15fps camera to record aircraft instrumentation connected with trials to research the behaviour of falling bombs.[202] The camera was produced in two versions, fitted with different lenses.[203] At this time, only an image of the camera as shown in a Fairey company publication is available for study. The camera depicted has a cylindrical extension in the lid, at the location where the second light unit would be located. The function of that component is unclear.

The Mk 2A unit was fitted with a modified, commercial 250mm telephoto lens, giving a 5° field of vision.[204] To counteract the stresses caused by vibration as well as acceleration, the lens was cased in a support tube (Figure 30).

The Mk 2B unit was fitted with a WRE designed 50mm f/8 lens with a 45° field of vision.[205]

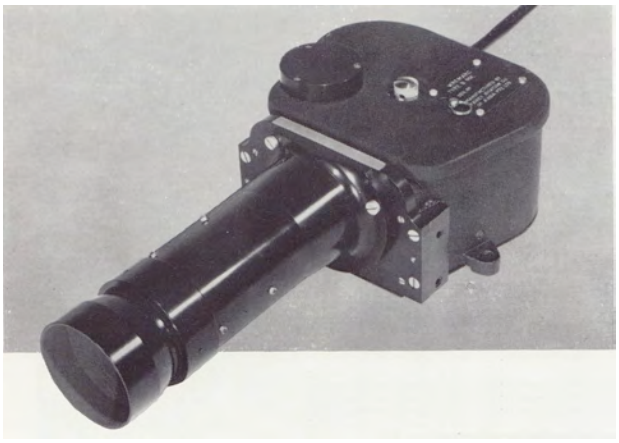


Figure 30. WREMARC Aircraft Instrumentation Camera Mk 2A.[206]

Target Aircraft Camera Beck GW 2

R&J Beck took Dekko's GW 1 design and developed from it a scaled-up version, the *Target Aircraft Camera* GW *2*. This was to serve as an automated 35mm recording system with a run-time of twelve seconds at 100fps.[207] As before, the negative pull down of the standard 35mm cine film stock was $^{15}/_{16}$ inch—*i.e.* five sprocket holes per frame. The camera seems to have become available for deployment in mid or late 1956.[208]

A number of GW 2 units have recently (mid 2011) become available on the open market, sold by dealers in Adelaide (South Australia) and sourced from private estates. These cameras were examined as objects or as photographs. The dataset is augmented by cameras depicted in the literature.

It would appear that the serial numbers of the lenses were carried through to the GW 2 models (Table 2).

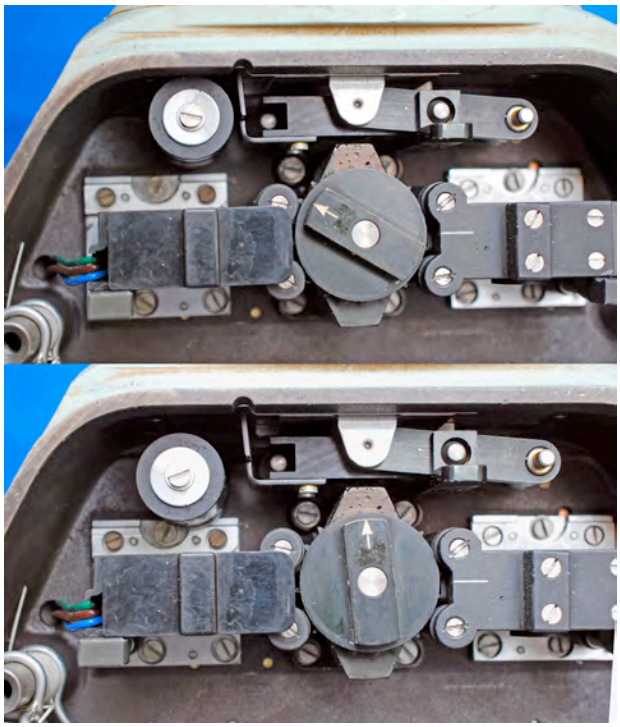


Figure 31. Film advance mechanism of the GW 2. Note the changing position of the roller at top left. The oblong units at the bottom are the timing lamps. Compare with Figure 25.

Appearance

The body of the camera is shaped like a trapezoid with rounded edges, comprised of a film chamber with removable lid (Figure 32). The underside of the camera carries an electric motor, which is freely accessible for maintenance purposes. The front of the camera housing protrudes downwards and shields the motor from view. The sides and back of the camera show protruding lugs for fastening bolts. Compared to the lugs used in the GW 1 model, these are double lugs both at the base and near the rim of the film chamber. Because they necessitated longer bolts for correct attachment of the camera body to the pod, they have a much smaller tolerance of movement (and hence enhanced accuracy of alignment).

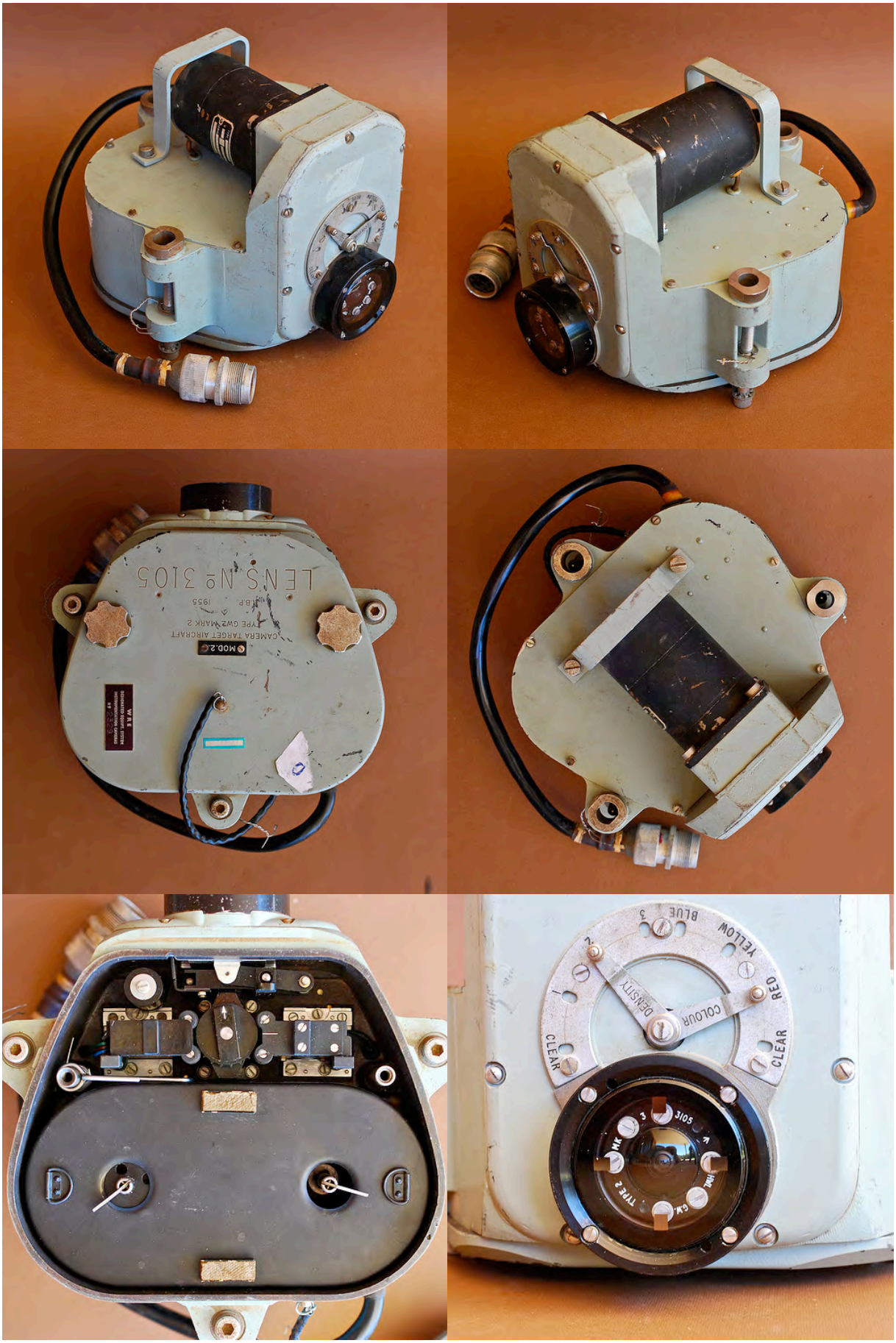


Figure 32. Target Aircraft Camera GW 2 Type 2 Model 2

Figure 33. Target Aircraft Camera GW 2 Type 2A[209]

Table 2. Target Aircraft Camera GW 2 units examined for this study.[210]

Lens			Body		Motor		WRE	
sn	Type	Manuf.	Model	sn	Manufacturer	sn	sn	Notes
553	2 Mk 2							211
2128	3 Mk 3	R&JB	Mk 2 A		Delco, Frigidaire	874	—	212
3105	2 Mk 3	HWL	Mk 2 Mod 2	5686	Croydon Eng Co	562218	2329	213
3218	2 Mk 3	HWL	Mk 2 Mod 2		Delco, Frigidaire	881	—	214
3559	2 Mk?							215
3565	2 Mk 3	HWL	Mk 2 Mod 2		Delco, Frigidaire	?	?	216

Abbreviations: HWL—Hilger & Watts Limited; R & JB—R & J Beck

A front plate, which carries the lens protruding lens as well as a selector for slide-in filters, is bolted onto the front of the housing. All units accessible for inspection were painted light bluish-grey.[217]

The lid to the film chamber is wholly removable. To prevent mixing up the lids of various cameras during reloading of film or maintenance of the pod, the lid to the film chamber is attached to the camera body via a small chain. The power and data cable has the same connectors as the Dekko GW 1.[218]

One of the major mechanical improvements was that the camera included a range of in-built filters that could be selected by means of two levers mounted above the lens (Figure 39). Options available were to select three neutral density filters (clear, 1, 2 and 3) as well as three colour filters (clear, red, yellow and blue).

The camera was loaded with magazines that contained both the feed and take-up spools of 100ft of 35mm film (Figure 32).

Dimensions

The camera body, made of casting aluminium DTD 424, measures 8 ¾" in width the same in length.[219] The camera is 6 ⅜" thick at the front and 4" at the back. The camera weighs 6.3 kg (without the magazine).

The underside of the camera allows for the mounting of an electric motor.[220] The rear of the motor is protected from accidental damage by a removable metal bracket. The front of the camera, which is 1" thick, protrudes by 2". The lens mount, which is screwed onto the front plate with four screws, is a protective cover that 2 ½" in diameter (glass: 2") with a length of 1".

Mark I

The existence of a Mark 1 type camera can be inferred but units of this type have not been available for examination at the time of writing.

Mark 2

The identification data on the lid to the film chamber reads:

MOD. 2.
CAMERA TARGET AIRCRAFT
TYPE GW 2 MARK 2
↑
R.B.P. 1955
LENS Nº 3105

whereby 'MOD. 2.' is engraved on a small black tag with white letters that has been screwed on.[221] The serial number of the body can be found inside the lid for the film compartment (in this case 'Nº 5686'). There does not appear to be a corresponding serial number on the camera body. The lid for body sn#5686 also carried the punched numbers '13X4B5' and 'DTD 424' (surrounded by a circle) as well as what appears to be a small quality assurance stamp 'HJM 8' (also in a circle). The body carried the punched numbers '20P1B7' and again the 'DTD 424' (surrounded by a circle).

Table 2 sets out the observed serial numbers of the units and lenses fitted. The total number of lenses made is unknown at the time of writing. It is possible that the serial number sequence of lenses is sequential and does not distinguish between units used in the GW1 and GW2 cameras.

The back of the described camera (sn #3105) carries an inventory sticker with the text:

WRE
DESIGNATED EQUIPT. SYSTEM
INSTRUMENTATION CAMERA
Nº 2329

The electric motor of the unit fitted with lens nº 3105 carries the following identification tag:

TYPE ADF-24/S89
V 28 DC 16500 RPM
SERIAL 562218
CROYDON ENG CO

In addition, it seems that motors were also sourced from other companies. The electric motor of the unit fitted with lens nº 3105 carries the following identification tag:

Delco
MODEL 2860540
SERIAL 881
VOLTS 24V D.C.
MADE BY FRIGIDAIRE DIV. OF
GENERAL MOTORS LTD. LONDON.

The camera used two neon lamps, type C.V. 988, to imprint data binary code at the edge of the film (see p. 13).[222] The left lamp recorded the common time base,[223] while the second lamp

(Figure 26 bottom) allowed the operator to write additional data.

Mark 2A

The GW2 camera Mark 2A differs from Mk2 only in the nature of the lens used (Figure 33). While the Mk2 has a GW Type 2 ultrawide angle lens fitted, the Mk2A carries a GW Type 3 lens with a narrower field of vision.

The identification data of the GW2 Mk2A camera, as engraved on the lid to the film chamber, read:

MOD. 2.
CAMERA TARGET AIRCRAFT
TYPE GW 2 MARK 2A
↑
R.B.P. 1955
LENS Nº 3218

The examined unit, which is powered by a Delco motor, carries a GW 3 Mk 3 lens (Figure 33).

Lens Options

Two lens options are on record for the GW 1 and GW2 series target aircraft cameras: the GW Type 2 ultra wide-angle lens, and the GW Type 3 lens.

Beck GW Type 2

As discussed earlier, the lens used for the GW and GW2 cameras was a Robin Hill design that had been improved and recomputed by R&J Beck (p 3). A lens diagram, originally published in 1961,[224] shows a broad front element with an extreme convex (full hemispheric) back as well as a cemented back element (Figure 35).

The lens face has six calibrating screws. Two variants are known (Mk 2 and Mk 3) with varying text between the screws and minor design variations. The lens was a fixed focus which was not an issue given the ultra-wide coverage.

Type 2 Mk 2

The lens face reads:

R&JB G.W. TYPE 2 MK 2 674 ↑

whereby the number before the arrow is the lens serial number (Figure 36). The lens was fixed focus with an effective, fixed aperture of f/8.[225] The lens mount, which is screwed onto the front plate, is a protective cover measuring 2 ½" in diameter (glass: 2 ¼") with a length of ½". The lens itself has a diameter of $^{13}/_{16}$".

Type 2 Mk 3

The lens face reads:

HWL G.W. TYPE 2 MK 3 ↑ 3105

whereby the latter number is the lens serial number (Figure 37). The lens was fixed focus with an effective, fixed aperture of f/8.[226]

It would appear that the 'HWL' lens units were . To confuse matters even further, the unit with lens sn #3105 had a lens cover which was engraved (in the inside) with "T.D.2053 ↑ R&J.B." The lens mount, which is screwed onto the front plate with four screws, is a protective cover measuring 2 ½" in diameter (glass: 2") with a length of 1". The lens itself has a diameter of $^{13}/_{16}$". Surrounding the lens are four diodes, places underneath the front covering.

Beck GW Type 3

The GW 1 Mk 1C unit was fitted with a R&J Beck manufactured 12.5 mm diameter GW Type 3 Mk 2 lens, which is marked on the barrel thus:

R & J. B. 2037
G.W. TYPE 3
MK. 2 ↑

The lens mount, which is screwed onto the front plate with four screws, is a protective sleeve that measures 1 $^{5}/_{8}$" in diameter 1 ½" in length. The lens itself has a diameter of $^{7}/_{8}$" (glass: ½") and protrudes from its protective cylinder by ¼."

The lens has a much narrower field of view and appears to be small tele-lens, fitted to the cameras that was used to record the flex of the wing (and thus the position of the AMPOR pod relative the target aircraft's fuselage).

A GW 1 Mk 2A unit was fitted with a R&J Beck manufactured 12.5 mm diameter GW Type 3 Mk 3 lens (Figure 42). At the time of writing,[227] the differences between the Mk2 and Mk3 versions were not obvious. Externally, the lenses appear to be identical.

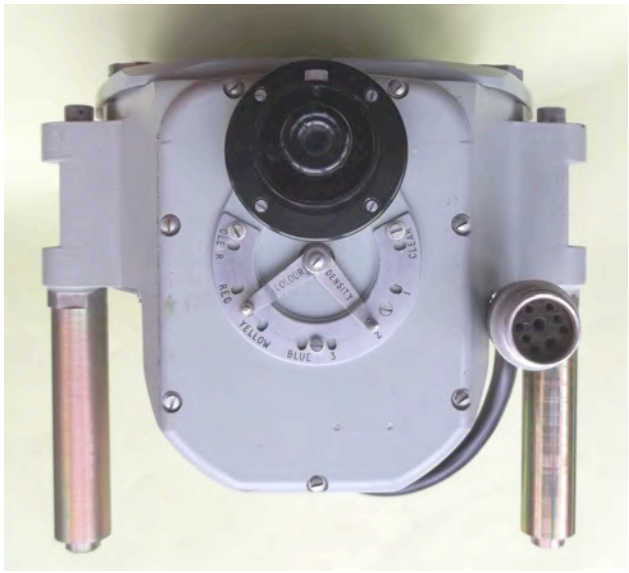


Figure 34. Target Aircraft Camera GW 2 Type 2A seen from the front. Note the mounting pins.[228]

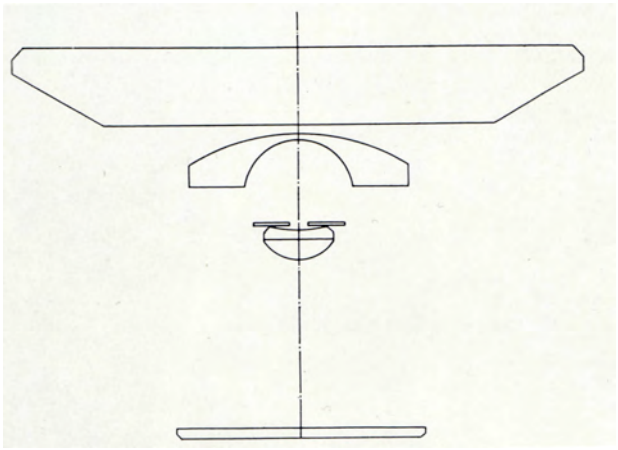


Figure 35. Lens diagram of the modified R&J Beck Robin Hill-design (f18) as used for lens type GW 2.[229]

Figure 36. R&J Beck manufactured lens type GW Type 2 Mk 2.

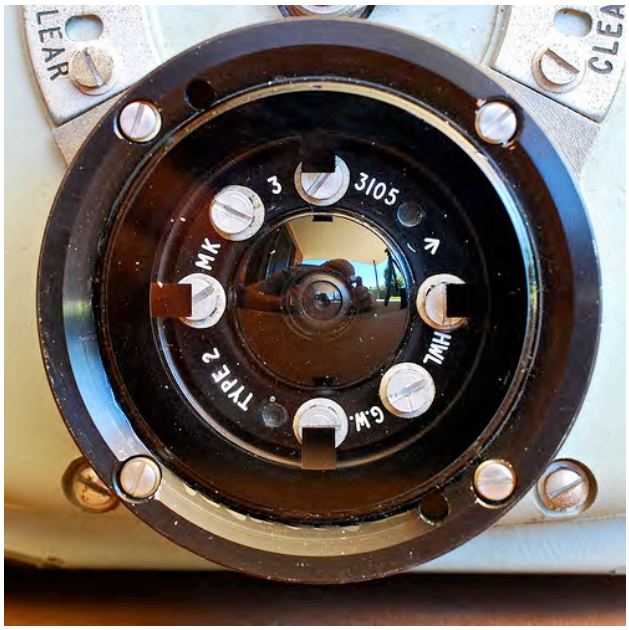


Figure 37. HWL manufactured lens type GW Type 2 Mk 3.

Figure 38. Oblique view of the R&J Beck lens type GW Type 2 Mk 3

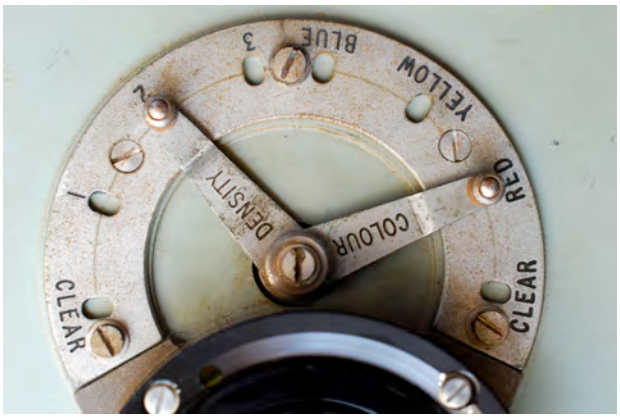
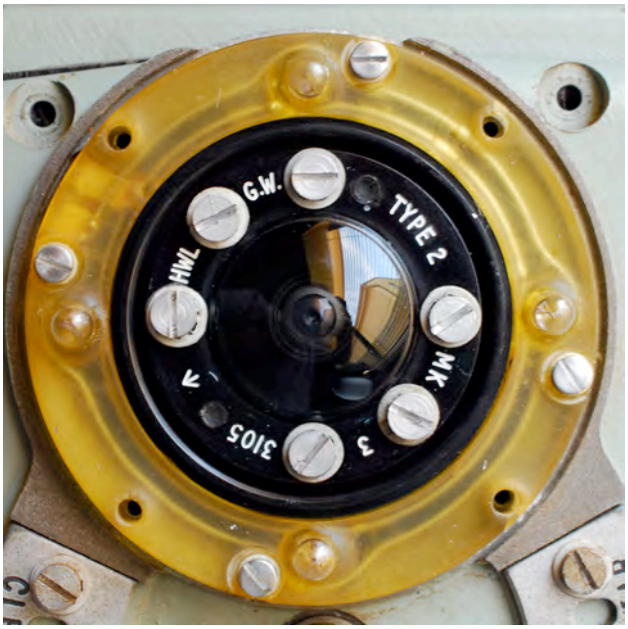


Figure 39. Filter options dial for the R&J Beck lens GW Type 2 Mk 3



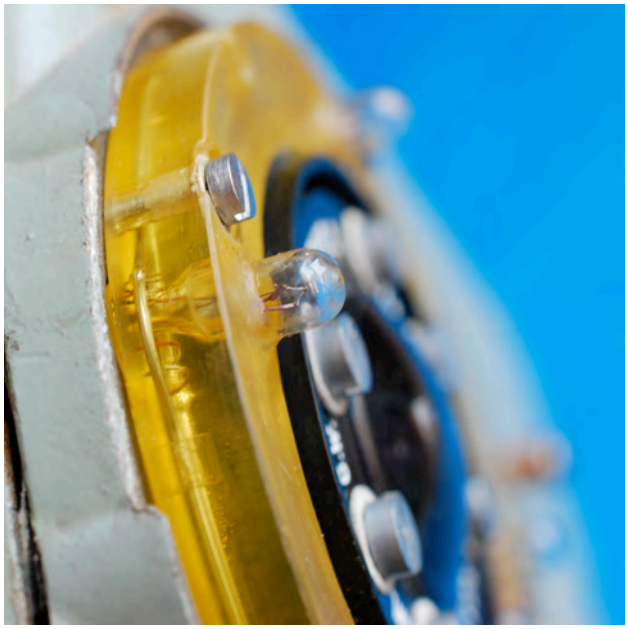


Figure 40. R&J Beck lens type GW Type 2 Mk 3 with lens cover removed. Note the four diodes.

Figure 41. R&J Beck lens type GW Type 3 Mk 2.

Figure 42. R&J Beck lens type GW Type 3 Mk 2.

Figure 43. R&J Beck lens type GW Type 3 Mk 3.[230]

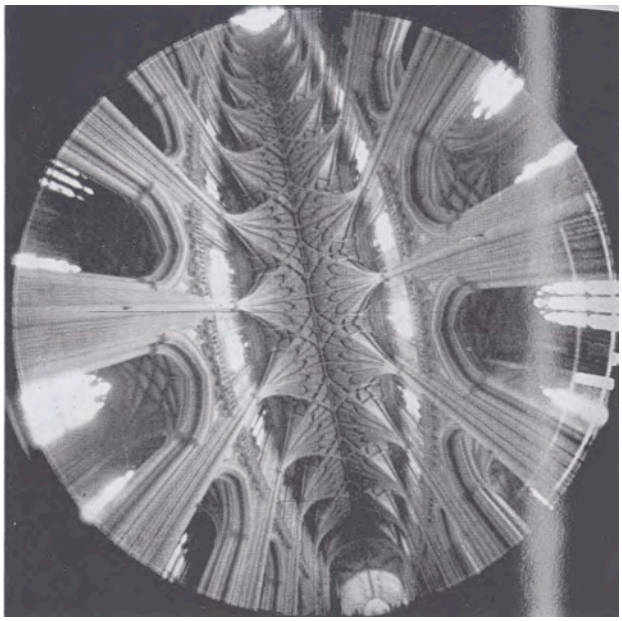


Figure 44. Photograph of the ceiling of Winchester Cathedral showing the distortion of the GW 2 lens.[231]

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Abbreviations and Acronyms

AMPOR—Airborne Missile Proximity Optical Recorder

Fps—frames per second

GAF—(Australian) Government Aircraft Factories

GW —Guided Weapon

HWL—Hilger & Watts Limited (London)

R&JB—R & J Beck (London)

RAE—Royal Aircraft Establishment (UK)

WRE—Weapon Research Establishment (Australia)

WRECISS—WRE Camera Interception Single-Shot

WREROC—WRE Roll Orientation Camera

WRETAR—WRE Target Aircraft Recorder

Endnotes

This report forms part of a broader assessment of specialised cameras and photographic equipment of the World War II and Cold War eras. These studies are comprised of technical assessments (Spennemann, 2015a, 2015b, 2015c, 2015d) and photographic documentation (Spennemann, 2015e, 2015f, 2015g, 2015h, 2015i, 2015j, 2015k, 2015l, 2015m, 2015n, 2015o, 2015p, 2015q, 2015r, 2015s, 2015t, 2015u, 2015v, 2015w, 2015x, 2015y, 2015z).

A preliminary comment on the state of the research regarding target cameras and the available data is in order. This is the first study that compiles the history of these target cameras. In the mid-1980s Peter Morton wrote the history of the Anglo-Australian Joint Project (see endnote 2) and accessed a number of files, mainly relating to the history of events and the overall decision-making. Purely technological aspects were also addressed, but at a more general level. Since then, it seems, some of the records that Peter Morton could access (Morton, 1997) have been re-classified and others moved around.

At this point in time, file material as well as photographic records relating to the use of AMPOR pods in

Australia is being held at a number of Australian Archives facilities, namely Adelaide, Canberra, Melbourne and Sydney, with some parts of the same file and report sequence being held at different locations. The Australian War Memorial (Canberra) also holds some items, as does the library of the Defense Science and Technology Organisation (DSTO) in Melbourne (but the exact extent of their holdings is unclear). Photographic images are held predominantly in Sydney. The vast majority of the material has not been examined, a process that can take up to 90 days. In addition, many are negatives, which are only rarely accessible even if declassified.

Overlaid on this is the perceived level of sensitivity of the file material, which is inconsistent between government departments. One item (Anonymous, n.d.-a), held by the DSTO library and requested as copy or inter-library loan by Charles Sturt University was deemed to be too sensitive and 'can only be released to Department of Defence staff and contractors.' Yet the same item could be freely acquired on microfiche from the U.S.A. and is also openly accessible in the National Archives of Australia (NAA: B5091, ARL Flight Note 28).

The physical cameras themselves were of course at one point also classified equipment until they were sold as surplus.

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1 Length is measured from front of lens to back of film door.

2 For background on the Anglo-Australian Joint Project see Morton (1989).—For general context of UK guided weapons development in the 1950s see Twigge (1993).—For Woomera see also Southall (1962). The activities at Woomera found frequent mention in industry journals (Anonymous, 1951, 1954, 1955, 1957b, 1964b).

3 For a background on the testing programme at RAE Llanbedr see Grumbley (2000); Mills (2000, 2010); B. Smith (2000).

4 Frost and Morton (1988); Keats and J.A. (1958); Morton (1989).

5 Morton (1989, p. 278).

6 In total 74 Fairey Firefly airframes were converted into target drones: 34 Fairey Firefly T.Mk 7 were taken off the production line and converted as Fairey Mk. U8 Firefly; while 40 existing Firefly AS.Mk 5 and Firefly AS.Mk 6 were converted into Fairey Mk. U9 Firefly drones (Taylor, 1974, pp. 341-342).—For the fate of some of them see 'Target Drone Losses' (www.ukserials.com/ losses_drones.htm).—See also Anonymous (1960f, p. 987).—The use of Firefly drones is mentioned, but not discussed in detail in Wilson (1993).

7 The Gloster Meteor drones were needed to simulate the new generation of faster Soviet jet fighters, thus superseding the use of the Fairey Firefly. In the United Kingdom, Flight Refuelling Ltd (Tarrant Rushton) converted approximately 94 Gloster Meteor F4 in 1955 for target drone use as the Gloster Meteor U15. Most of these (approximately 70) were delivered to Woomera. Beginning in 1956 (and lasting until 1970) 108 Gloster Meteor F8 were converted as the Gloster Meteor U16 for use in the UK. In 1962 eight Gloster Meteor were converted into the U21 (one F8, and seven Gloster Meteor U15 conversions) for use in Australia.—In Australia itself, Fairey Aviation converted 15 Gloster Meteor F8 to the Gloster Meteor U21 using kits provided by Flight Refuelling (James, 1987, pp. 300-302).—For the use of Gloster Meteor in the *Anglo-Australian Joint Project* see Morton (1989) and Nuttall-Smith (1961); (Nuttall-Smith & Nunn, 1952).

Not all units were produced according to specifications. Acceptance checks on occasion discovered severe shortcomings: Postagram RAAF SdrLdr Smyth to HQ RAAF Edinburgh dated 3 December 1956 (regarding incorrect wiring and fit out of Gloster Meteor a/c VZ 407); in: Various authors (1956). For the fate of some of these target aircraft see 'Target Drone Losses' (www.ukserials.com/ losses_drones.htm).—See also Anonymous (1960f, p. 987).

A perusal of file material held in the Australian Archives showed that the following units had their AMPOR pods recalibrated (wing-tip alignment tests):

Aircraft	Calibrated	Delivery	Written off
VT175	6-5-58	6-5-48	9-9-58
VT179	11-5-59	27-5-48	25-6-59
VT270	28-4-59	23-9-48	20-7-59
VT286	9-4 & 21-4-59	25-10-48	8-6-59
RA433	2-6-59		
RA438	19-5 & 1-6-59		

Source: Test sheets.—Example: J.H. Gooch, SqrLdr R.Tech.O Fairey aviation, to No 1 Air Trials Unit, Meteor U. Mk 15 VT286 Test Sheet. Dated 9-4-1946. —All cited test sheets on file in: Various authors (1956).

In addition, the following aircraft are on record:

Aircraft	On record	Camera	AMPOR	Source
VT105	Aug 1958	GW2	Mk 2	A
VT230	Aug 1958	GW2	Mk 2	A
VW781	Aug 1958	GW2	Mk 2	A
VZ389	Jun 1958	GW1		B
VZ407	Dec 1956	GW1		C

Sources: A— Gooch, J.H. to Resident Technical Officer, Nº 1 Air Trials Unit, Maintenance Squadron Edinburgh Field, Salisbury SA, dated 1 August 1958. B—Failure of Camera, Target Aircraft, Type GW 1 Mk 1A. HJ. Wood, OS Group WRE to Senior Technical Officer T.A.F. Evetts Field dated 3 June 1958. C—Postagram RAAF SdrLdr Smyth to HQ RAAF Edinburgh dated 3 December 1956 (regarding incorrect wiring and fit out of Gloster Meteor a/c VZ 407).—All contained in: Various authors (1956).

8 A total of 18 English electric Canberra B2 were converted by Short Brothers and Harland (Belfast) into Canberra U.10 target drones (later designated Canberra D10). Seventeen of then were delivered to Australia. All of them crashed or were destroyed by missile hits between July 1959 and May 1965: *Destroyed by missiles*: WD951 (20/7/1959); WD961 (9/6/1959; Bloodhound Trials); WH107 (17/11/1964); WH652 (12/2/1964); WH710 (26/5/1965); WH729 (14/4/1964); WH742 (17/7/1962); WH860 (24/11/1964); WJ623 (12/12/1963); WJ987 (17/10/1959); and WK110 (23/11/1962).—*Destroyed by crash*: WF 929 (15/10/1959); WH705 (28/4/1964); WH733 (30/11/1959); WH885 (1/4/1964); WJ604 (18/2/1964); and WJ621 (17/12/1964)

(Dunn, n.d.) and 'DF Aircraft Serial Numbers RAAF Canberra A84 GAF Canberra Mk.20 & Mk.21, EE Canberra B.2, T.4 & U.10' (Edwards, n.d.).—(Anonymous, 1960f, p. 987).

9 Over 500 airframes were built and the Jindivik is still used by Australia and the United Kingdom for a variety of tasks (Anonymous, 1972; Government Aircraft Factories, [1962?]; Vincent, 1963).

10 The standard aerial cameras that had been widely used for photo-reconnaissance (e.g. Spennemann, 2012), were not suitable for the task.

11 Nuttall-Smith (1961, p. 466).

12 See p. 14 and footnote 190.

13 Nuttall-Smith (1957, 1961); Southall (1962, p. 126).

14 Nuttall-Smith (1957, p. 175); 1961, p. 466). — The underlying mathematics are explained in Evans (1963).—see also Cunliffe (1956).

15 The U.S. *Sparrow*, *Bumblebee* and *Terrier* trials are referred to in Nuttall-Smith and Nunn (1952, p. 4). The 'Target Aircraft Scoring Camera System" was for the Nike tests, drawing on Fastax 16mm cine cameras mounted in wing tip pods. These cameras were run at 500 fps at 1/400 sec with f/2.7 (Douglas Aircraft Company, [1951]; Nuttall-Smith & Nunn, 1952, p. 21).

Bell & Howell developed a completely new system in 1957 (Anonymous, 1957a).—See also Morgan (1956) and Betty (1957)

16 Nuttall-Smith and Nunn (1952, p. 21).

17 The film used was a 'Special Kodak Color Film', the technical characteristics of which were not known to the observers (Nuttall-Smith & Nunn, 1952, p. 21).

18 Nuttall-Smith and Nunn (1952, p. 21).

19 Nuttall-Smith and Nunn (1952, p. 15).

20 Nuttall-Smith (1961, p. 466); Nuttall-Smith and Nunn (1952).

21 Nuttall-Smith and Nunn (1952, p. 16).

22 Nuttall-Smith and Nunn (1952, p. 23).

23 Nuttall-Smith and Nunn (1952, fig. 4).

24 Nuttall-Smith and Nunn (1952, p. 15).

25 Nuttall-Smith (1961, p. 17).

26 Nuttall-Smith (1961, p. 471) referring to Kaprelian (1947).

27 The Zeiss design (V1936 nº 18) had a field of 210º at f/6.8. Nuttall-Smith (1961, p. 471) calculated that in order to record 143º on 35mm film, the focal length would be 3/8 of an inch (i.e. 9.5mm).

28 Gardner and Washer (1948a, 1948b).

29 Nuttall-Smith (1961, p. 471) calculated that in order to record 143º on 35mm film, the focal length would be 3/8 of an inch (i.e. 9.5mm).

30 Nuttall-Smith and Nunn (1952, p. 18).

31 The cameras differed in weight with a Bell & Howell Eymo weighing about 4.5 kg (10lb) and a Vinten Model K about (5.9kg) 13lb. It was assumed that a stripped down camera could be designed with a weight of only 3.6kg (8lb)(Nuttall-Smith & Nunn, 1952, p. 19).

32 At the time, the most common small camera was the Gun Sight Aiming Camera by Bell & Howell, a 16mm camera designed to record the success of machine guns fired in flight. On the British side, the Williamson G45 fitted the same role. In the initial stages of planning, it had been suggested that an adaptation of either system could trialled (Nuttall-Smith & Nunn, 1952, p. 18). However, although extremely ubiquitous during the WWII, after the war neither the GSAP nor the G45 were in large supply and the thus their performance under missile test conditions was not tested (Nuttall-Smith, 1957).—It is worth noting that the U.S. made use of the GSAP cameras for their own testing (see endnote 15).—For the see GSAP see also Spennemann (2015g).

33 Nuttall-Smith and Nunn (1952, p. 18).—Inaccurate registration would result in image "flicker" on the screen when the images were to be projected as a cine movie.

34 It was also deemed difficult to source a camera mechanism that was both compact and operated reliably at 200fps (Nuttall-Smith & Nunn, 1952, p. 15).

35 Nuttall-Smith (1957, p. 176).

36 For a listing, see (Dunn, n.d.).

37 Nuttall-Smith and Nunn (1952, p. 20).

38 Nuttall-Smith and Nunn (1952, p. 21).

39 Nuttall-Smith (1961, p. 475).

40 AMPOR—Airborne Missile Proximity Optical Recorder (Ramsay & Simmons, 1953).

41 Nuttall-Smith (1957, p. 175).

42 For images of aircraft with wing tip pods, see: Manchester - International (Ringway) photo taken in 30 March 1955 (http://cdn-www.airliners.net/aviation-photos/photos/4/0/0/1708004.jpg)

43 Mackie (1957) see also James (1987, p. 301).

44 It would appear that only very few examples were built.

45 The original Robin Hill Sky/Cloud Lens design as produced by R&J Beck was a 21mm f/8 lens producing 63mm diameter images (Robin Hill, 1924, p. 432; Robin Hill & R & J Beck Ltd, 1924; Stroebel & Zakia, 1993).

46 Image courtesy R.A Scholefield (St. Helens, Lancashire, UK).—See also 467 fig. 2.—First flight as U8 drone on 23 March 1955; lost on 31 October 1957 during a sortie from RAF Llanbedr.

47 Image courtesy R.A Scholefield (St. Helens, Lancashire, UK).

48 Image courtesy of Craig Johnson.

49 Aircraft WH860 on delivery to Weapons Research Establishment at Edinburgh Field, Australia. Destroyed by missile 24 May 1964.—Image courtesy of Robin A Walker.

50 Left image: detail of Figure 2; right image Paul Gloster (Meteor in Detail).

51 Images details of Figure 4.

52 Nuttall-Smith (1961, p. 473).

53 . The GW 2 Mk3 lenses are all marked 'HWL' (see p. 24).

54 . Hilger & Watts Limited (now Hall and Watts Defence Optics Ltd) was formed in 1948 from the incorporation of two long-standing British instrument makers, Adam Hilger Ltd. with E.R. Watts Ltd (Anonymous, 1948; Grace's Guide, 2015a, 2015b, 2015c; Hall and Watts Defence Optics, 2015).—For a range of Hilger & Watts instruments in public collections see (Science Museum Group, 2015).

55 . (Hall and Watts Defence Optics, 2015)

56 In Australia, In 1955-56, the Australian Government Aircraft Factories, in collaboration with Australia's Weapon Research Establishment (WRE), developed a newly designed ultra-wide lens with 186º coverage. (Dixon (1961).—Australian Patent Application filed 24 December 1956.)—These 'Dixon lenses', which were used for the WRETAR, WRECISS and WREROC cameras (see Spennemann, 2015d), were produced by Etherington Optical in Mildura (Edgar, 2000, n.d.), with the bulk of production carried out by Waterworths in Hobart (Proposed improved AMPOR Instrumentation System. R.P. Bonnell,

P.O. Optics and Servomechanisms to Superintendent Techniques, dated 19 March 1956 file nº SA 5270/2 SOA 117. Contained in File: "Incorporation of Modifications AMPOR Cameras Mk 1A.' Australian Archives A705 File 165/2/809).

57 'Wide Angle Lens Systems.' US Patent Filed 23 Dec 1957; Issued 18 Dec 1962. Applicants: Robert P. Bonnell, Jack V. Ramsey and Robert A Dillon, assigned to The Commonwealth of Australia. US Pat. Nº 3068752.

58 Factory location, 1934-1938: Slough, Buckinghamshire; 1938-1950s: Telford Way, East Acton, London, W3, UK.

59 A Bakelite 9.5mm camera ACR 0069 (1.2kg, 59x125x133 mm) with various lens options: Taylor Hobson f/2.5 23mm; Wray London Dekko Anastigmat f/3.5 20 mm; Dekko Anastigmat-National Opt. Co. Leicester; f/2.8 25mm; Dallmeyer Triple Anastigmat f/2.9 25mm; Dallmeyer Anastigmat f/3.5 20mm; Dallmeyer Popular Telephoto f/4 75mm; Cine Lens Ross, London f/1.9 25mm. (Nuttall-Smith, 1961, p. 467 fig.2).

60 A Bakelite 9.5mm camera ACR 0349 (1.45 kg, 59x125x150 mm) fitted with Dallmeyer Speed Anastigmat f/1.5 25mm; SOM Berthiot Paris Cinor B f/1.9 25mm; Taylor-Hobson Anastigmat f/2.5 23mm.

61 A metal 8mm camera ACR 0350 fitted with National Optic Anastigmat f/2.5 12.5mm.

62 A metal 8mm camera (0.9 kg, 63x127x127 mm) with National Optic Anastigmat f/2.5 12.5mm.

63 *Dekko 1* (1937?), 9.5mm projector with crank 60 ft reels 40V. 15W; *Dekko 2* (1937?), 9.5mm projector with motor 60 ft reels 40V. 15W; *Dekko 3* (1939), 9.5mm projector with crank 50V 25W; *Dekko 4* (1939), 9.5mm projector with motor 50V. 25W; *Dekko 5* (1939), 9.5mm projector 400 ft; *Dekko 6* (1939), 9.5mm projector 400 ft; *Dekko 7* (1939), 9.5mm projector 400 ft; *Dekko 8* (1939), 9.5mm projector 400 ft; *Dekko 48* (1939), 9.5mm projector 100/115V. 50 W. 400 ft.; *Dekko 118a (*1947), 8mm projector 500 W; *Dekko 118b* (1947), 8mm projector 500 W; *Dekko 118c (*1947), 8mm projector 500 W; *Dekko 119a (*1947), 9.5mm projector 110V. 500 W.; *Dekko 119b* (1947), 9.5mm projector 110V. 500W; *Dekko 119c (*1947), 9.5mm projector 110V. 750W; *Dekko 126A* (1949), 16mm projector 500W; *Dekko 126B* (1949), 16mm projector 500W; *Dekko 126C* (1949), 16mm projector 500W.—See also (Anonymous, 1935).

64 A 16mm made by 'Telford Products,' London. —The unit was further developed into the Type N Instrumentation camera: Dekko Cameras Ltd (1952).—For assessment of camera capabilities (demonstration of fluctuations in exposure in a frame-by-frame analysis) see (Society of Motion Picture and Television Engineers, 1959p. 156 [exhibited by Benson-Lehner Corp]).

65 It seems that Dekko withdrew from the civilian movie camera market soon afterwards and expanded into the business of electronics and instrumentation ('The Industry' *Flight* 29 July 1957, p. 145). High speed cameras for research and instrumentation purposes continued to be produced Overington (1967), as were adaptations of movie cameras to single shot devices for data recording of experiments (Coleman, 1967).

66 GW—Guided Weapons.

67 Howell (1963).

68 Whether hit by missile or by accident.

69 Nuttall-Smith (1961, p. 475).

70 Nuttall-Smith (1961, p. 475).

71 Nuttall-Smith (1961, p. 475).

72 For the control unit this was resolved by inserting the bolts upside down! Defect report Nº T.A.G. 4/58 Meteor U Mk. 15 Camera Control Unit Shock Mounting. Postgramm J.H. Gooch to Resident Technical Officer RAAF Base Edinburgh Field, Salisbury SA, dated 15 August 1958 in: Nuttall-Smith (1961, p. 481).

73 Cable, Fletcher, Target Aircraft Weapons to SqdLdr Cook, Evetts Field dated 10 Mar 1958 in: Various authors (1956)

74 e.g. a calibration camera of the Meteor U15 AMPOR pod jammed during the *Red Duster* trial PA2/4 on 10 April 1958. Cable, No 1 Air Trials Unit to P.O./M.S. Weapons, dated 11 April 1958.—Similar occurrence with the starboard 1 camera during the *Red Duster* trial PA2/2 on 16 May 1958. Cable, No 1 Air Trials Unit to P.O./M.S. Weapons, dated 29 May 1958.—See also Failure of Camera, Target Aircraft, Type GW 1 Mk 1A. HJ. Wood, OS Group WRE to Senior Technical Officer T.A.F. Evetts Field dated 3 June 1958.—All in: Various authors (1956).

75 in: Various authors (1956).

76 Cable, Fletcher to SqrLdr Cook, Evetts Field "AMPOR camera pod, standardize on 90 frames / sec" dated 25 Aug 1958. A handwritten annotation on the cable notes" All Mk IA cameras fitted to both Meteor and Jindivik a/c are being altered to 90 frames per second as required and man-power permits." Signed Roth 29 August 1958 in: Various authors (1956).

77 Cable, Fletcher to SqrLdr Cook, Evetts Field, regarding Trial MU/16 on 21 February 1958. Dated 25 February 1958 in: Various authors (1956).

78 The units of aircraft VT105 (test PA 10/13 nº 157, fired 19 March 1959) ran at the following rates: S1/45fps; S2/33fps, P1/36fps, P2/27fps. Cable Paech, PO/MS to J.Wood, dated 7 April 1959. Handwritten annotation blames the flat batteries (and unit P3 had a film jam…). in: Various authors (1956).

79 Various authors (1956).

80 Nuttall-Smith (1961, p. 476).—See also Davies (1956).

81 A paper discussing the production and introduction of the new WRETAR cameras noted that the GW2 units had not come off the British production lines as of 19 March 1956: Proposed improved AMPOR Instrumentation System. R.P. Bonnell, P.O. Optics and Servomechanisms to Superintendent Techniques, dated 19 March 1956 file nº SA 5270/2 SOA 117. Contained in File: "Incorporation of Modifications AMPOR Cameras Mk 1A.' Australian Archives A705 File 165/2/809.

82 The design of the take-up clutch resulted in inconsistent tension: Minute G.M. Taylor, Resident Engineer WRE to Resident Technical Officer, Nº 1 Air Trials Unit, Maintenance Squadron Edinburgh Field, Salisbury SA, dated 31 July 1958 in: Various authors (1956)

83 "Mods. to take-up spindle assy. Cameras GW2 and G.W. 2A Mod. AA14" [Technical drawing] D118-37. Dated 3 Aug 1958 in: Various authors (1956).

84 e.g the directive to modify the AMPOR pods of three aircraft VT105, VT230 and VW781 (all Gloster Meteor): Gooch, J.H. to Resident Technical Officer, Nº 1 Air Trials Unit, Maintenance Squadron Edinburgh Field, Salisbury SA, dated 1 August 1958 in: Various authors (1956).

85 Modification—Camera Control Units Mks. 2, 2A and 3. Meteor & Jindivik. Memo F.R. Green, Chief Engineer, Fairey Aviation Company of Australasia, to P.O./T.A. Mr Leslie, via The Controller, W.R.E., Salisbury SA. Dated 28 May 1958 in: Various authors (1956).

86 Various authors (1956).

87 Cunliffe (1956, fig. 1).

88 Dietz (1960).

89 Kepert (1993b).

90 Emslie and Traill-Nash (1956, p. 15).

91 In addition to the fixed concrete facilities shown Figure 9, the equipment comprised of: Micro-alignment telescope (part nº 112/365); two mounting spheres (112/365), clamp key (116/27) stride level (TB/40) and three jigs (1004/11E; 1004/862E, 1004/863E). All was contained in a box measuring 6' x 6' x 6" (Minute J. Wood to SqdrLdr Smythe, Evetts Field, dated 19 March 1957 in: Bennett (1960, p. 3).

92 Various authors (1956).

93 Cunliffe (1956, p. 4).

94 Nuttall-Smith (1957, p. 177).

95 Note that the early AMPOR pods carried fifth camera to record the flex of the wing (and thus the position of the AMPOR pod relative the target aircraft's fuselage). This was later achieved by a mounting into the fuselage a camera fitted a split mirror lens. These fifth cameras carried in the AMPOR pods are not included in these calculations as they used standard lenses.

96 Contained in: Cunliffe (1956, p. 6).

97 Proposed improved AMPOR Instrumentation System. R.P. Bonnell, P.O. Optics and Servomechanisms to Superintendent Techniques, dated 19 March 1956 file nº SA 5270/2 SOA 117. Contained in File: "Incorporation of Modifications AMPOR Cameras Mk 1A.' Australian Archives A705 File 165/2/809.

98 *ibid.*

99 *ibid.*

100 Steel (1964).

101 Source: Steel (1964, p. 840 Fig 1).

102 Anonymous (1966).

103 Anonymous (1962).

104 Various authors (1956).

105 Michaelis (1957, p. 412).

106 e.g. Anonymous (1956a, 1956b).

107 Nuttall-Smith (1957).

108 Additional images in Nuttall-Smith (1961) and Nuttall-Smith (1961).

109 Nuttall-Smith (1961, p.469 Figure 4).

110 Nuttall-Smith (1961, p.478 Figure 14).

111 Morton (1989, p. 279).

112 Cunliffe (1956, p. 6).

113 Conway (1959a).

114 Anonymous (1961b).

115 Cable, Fletcher, Target Aircraft Weapons to SqdrLdr Cook, Evetts Field, dated 24 October 1958 in: Morton (1989, p. 278).—See also directive to modify the AMPOR pods of three aircraft VT105, VT230 and VW781 (all Gloster Meteor): Gooch, J.H. to Resident Technical Officer, N° 1 Air Trials Unit, Maintenance Squadron Edinburgh Field, Salisbury SA, dated 1 August 1958 in: Various authors (1956).

116 Various authors (1956).

117 Jindivik Mk 2 with Mk 1 and Mk 2 AMPOR pods: Anonymous (n.d.-a)

118 Anonymous (n.d.-b); Keeler (1959).

119 Keeler, Dietz, and O'Keefe (1959); Kepert (1993a, p. 45ff); Keeler, Licciardo, and Dietz (1959)—also (Emslie & Traill-Nash, 1956).The AMPOR pods also increased drag on the airframes (Keeler, 1959).

120 Keeler (1959).

121 The dates for the crash are confusing. Keeler, Dietz, et al. (1959) states that A92-29 crashed on 10 February 1956, while Crisp (1956, p. 8) claims it crashed on 10 February 1952.

122 Kepert (1993a, p. 45).

123 Anonymous (1960f, p. 987).

124 Keeler, Dietz, et al. (1959), Keeler, Licciardo, et al. (1959).

125 For background on the Weapons Research Establishment see Keeler, Dietz, et al. (1959).—In addition to other instrumentation and analysis tools, the WRE continued to develop camera designs Dougherty (2006).

126 Bonnell (1969).—'Wide Angle Lens Systems.' US Patent filed 23 Dec 1957; issued 18 Dec 1962. Applicants: Robert P. Bonnell, Jack V. Ramsey and Francis Alfred Thomas Dixon, assigned to The Commonwealth of Australia. US Pat. Nº 3068752.—A British Patent Application for the lens was apparently filed 24 December 1956 but details cannot be accessed via the IP Australia database.—This lens was not only used in the WRETAR units (see endnote 128), buts also in cameras carried onboard the missiles themselves, such as WREROC (see endnote 189) and WRECISS (see endnote 190).

127 Dixon (1961).

128 WRETAR—Weapons Research Establishment Target Aircraft Recorder.—See Steel (1964).

129 Dixon (1961).

130 Cunliffe (1956, p. 6)—WRETAR were designed with various specifications, running from 100 to 160 frames/second: (Evans, 1963).—For WRETAR see also: Royal Aircraft Establishment (1968) Air Targets at the R.A.E. Aberporth Range. *Air Targets Issue* 3, November 1968. AVIA 6/23916. Royal Aircraft Establishment (Ranges Division).—(Wood, 1962).

131 At an estimated cost of £2,500 for four cameras in two AMPOR Mk 3 pods: Proposed improved AMPOR Instrumentation System. R.P. Bonnell, P.O. Optics and Servomechanisms to Superintendent Techniques, dated 19 March 1956 file nº SA 5270/2 SOA 117. Contained in File: "Incorporation of Modifications AMPOR Cameras Mk 1A.' Australian Archives A705 File 165/2/809.

132 A fifth camera that was originally carried to record wing flex was replaced by a mirror unit mounted in the fuselage: Vincent, Jindivik, *op. cit.*

133 It reduced the weight of each pod by 70 lb and provided a much narrower diameter (6" as opposed to 12½"): A.M.P.O.R. for Target Aircraft. Memorandum N.W.Hodgson, Manager GAF, Fishermen's Bend, to Controller WRE, Salisbury. Dated 3 November 1955. Contained in File: "Incorporation of Modifications AMPOR Cameras Mk 1A.' Australian Archives A705 File 165/2/809.

134 A. T. Smith (1973).

135 Conway (1959b).

136 In the UK WRETAR was known as WRE Mk. 1 Dietz (1960).

137 Some flutter remained: (Evans, 1963).

138 Bennett (1960); Dietz (1960).—Eventually Mk5, Mk9 (stainless steel) and Mk 12 (12ft long aluminium alloy) pods were developed (Anonymous, 1961a, 1964a).

139 Kepert (1993b).

140 Dietz (1960).

141 Dietz (1960).

142 Dietz (1960).

143 E.g.: after trial K/A/345 the starboard pod remained and the cameras could be salvaged for future use: Cable, Fletcher, Tar-

get Aircraft Weapons to SqdLdr Cook, Evetts Field dated 10 March 1958 in: Conway (1959b).

144 Cable, Fletcher, Target Aircraft Weapons to SqdrLdr Cook, Evetts Field, dated 24 October 1958 in: Various authors (1956).

145 "The results of AMPOR from SeaSlug W/M Firings PG 71, 72, 73 T.I E122 have proved to be excellent." Cable SSPO to PO/R dated 4 May 1959, serial MP5423/6/3. in: Various authors (1956).

146 The camera was jointly developed by the *Royal Aircraft Establishment* and Cinetra Ltd. It took 200ft rolls of daylight loadable 35mm cine film. The design had a geared advance that allowed for recording speeds of 1 inch/sec to 128 inches/second. The camera came with three interchangeable lenses (1 ¼", 2" and 3") all with f/1.9. A time marker unit was also fitted.—For details and specifications of the camera, see: Various authors (1956).

147 The 16mm camera, running at 100 frames/sec, was designed and built by Specto Ltd, (Vale Road, Windsor, UK). It came with four Specto Ltd. lenses (1/2" f/4; ¾, f/4.5; 1 ½", f/1.9 and 3', f4). In addition, it could accept lenses designed for the G.S.A.P. cameras. The camera used a circular disc shutter with two sectors cut out of the rim. At 100 frames/sec the shutter speed was 1/210th. The 50ft of daylight loadable 16mm film allowed for 20 seconds of running time.--For details and specifications of the camera, see (Brooks, 1958).

148 Husbands (1960).

149 Nuttall-Smith (1961, p. 475).

150 Examined as objects or via photographs.

151 With a GW 2 Type 2 lens fitted. Nuttall-Smith (1957, p. 176).

152 The camera carried the Salisbury ID 708 and was carried in the starboard I position (hence most likely fitted with a Type 2 Mk 2 lens) in an AMPOR pod fitted to a Gloster Meteor U15 sn#VZ389 : Failure of Camera, Target Aircraft, Type GW 1 Mk 1A. HJ. Wood, OS Group WRE to Senior Technical Officer T.A.F. Evetts Field dated 3 June 1958.—Cable No 1 Air Trials Unit to P.O./M.S. Weapons, dated 29 May 1958 in: (Nuttall-Smith, 1961, fig. 12).

153 Scammell Auctions (Adelaide) Auction 722 Lot 76 (22 Oct 2011): .—Scammell Auctions (Adelaide) Auction 501 lot 696 (31 October 2011).—*ex* Adelaide Auctioneers September 2011; data based on images *via* George Philippou (Adelaide).

154 Photographica Collection Dirk HR Spennemann, *ex* George Philippou (Adelaide); *ex* Adelaide Auctioneers September 2011.

155 Pers. comm. Dave Perrot (Gippsland). Incomplete camera, lens and shutter assembly missing.

156 Pers. comm Colin Hall (Birmingham, UK).

157 Photographica Collection Dirk HR Spennemann, *ex* ebay/ George Philippou (Adelaide); *ex* Adelaide Auctioneers September 2011.

158 *ex* Adelaide Auctioneers September 2011; data based on images *via* George Philippou (Adelaide). The resolution is insufficient to work out the full serial number.

159 Mounted in Meteor U15 aircraft # VT118 (Cable Robert Kee , Nº 1 AIRTU to P.O./TA (Fletcher) 11 June 1954 (Various authors, 1956).

160 eBay 230689668796 (November 2010).—The camera was lacking its front, plate, lens and shutter assembly. Some serial number details could be inferred from the name tags.

161 Photographica Collection Peter Naylor (Perth).

162 One unit, sn #2089, was acquired on eBay from a dealer based in Ipswich, who in turn it had acquired it at a local auction of a deceased estate (pers. comm. Pete Naylor, Perth).

163 A number of cameras were apparently acquired as a job lot in early September 2011 (at Adelaide Auctioneers, Kent Town, SA). They were then dispersed *via* Scammell Auctions (Adelaide) as well as *via* eBay (pers. comm. George Phillippou, Adelaide).

164 Some of the cameras carry inventory tags of the defunct WRE (now DSTO). On record are WRE serials 2325 (GW1 Mk1A), 2327 (GW1 Mk1C) and 2529 (GW2). The close sequence of numbers, irrespective of type, suggests that the cameras originated from a former type collection.

165 The Australian Archives contain a number of records related to the GW 1, mainly dating to 1958. These files have not yet been examined and are, at the time of writing, inaccessible to the public.

166 DTD 424 is a corrosion resistant casting aluminium (British Specification; British Aluminium Co.), used for high stress mechanics, such as gear boxes and crank cases, as well as for cylinder heads and oil pans Various authors (1956).

167 At the time of writing (July 2015), the foundry has not been identified—despite wide-ranging enquiries in the United Kingdom.

168 This is the TIM-10 timing code, which is still used today.

169 Nuttall-Smith (1961, p. 476).

170 Nuttall-Smith (1957, p. 177 fig. 2).

171 The numbers on the connector associated with camera body nº 702/55 are as follows: "5x/6321 CZ56078 PSV" with the number "C227307" struck out by eight 'X'. The number "Z27894" appears at the tip. The plastic face reads "Z1181/2" with part of the a number scratched out.—The connector associated with camera body nº 1212/57 has the same codes, except for the strike-out. —The connector associated with camera body nº 507/55 has the same codes, except for the 'PSV'.

172 Woldman and Frick (2000, p. 88).

173 (Anonymous, 1956b).

174 It is possible that the camera temperature never dropped below 10ºC is the flight plan saw a gradual ascent.

175 The measurements are given in inches as that was the standard of measurement at the time the camera was produced—and all ascertained dimensions indeed conform to this.

176 The motor has a square cross section and measures 2" x 2" x 3 ½".

177 For a photographic documentation of the camera see Spennemann (2015v).

178 The reasoning is that otherwise the voltage would have been engraved on the lid as part of standard labelling procedure.

179 In addition to WRE inventory numbers found on other GW units (see Table 1 and Table 2), similar stickers were noted on two Vinten HS300 high-speed cine cameras offered at an online auction in Melbourne: sn #1210 (eBay 220899860663 November 2011) and sn #1410 (eBay 290632699881 November 2010).

180 Body nº 121/57 (lens sn#1424) has the stamp D.O.L.A. |10" on the back of the casing and the stamp "D.O.L.A. | 6" on the light unit inside.

181 Nuttall-Smith (1961, p. 476).

182 Nuttall-Smith (1957, p. 177 fig. 2).

183 The sole GW 1 Mk 1A with lens Type 2 Mk 3 unit available for examination is unfortunately lacking the entire lens and shutter unit.

184 The sole GW 1 Mk 1A with lens Type 2 Mk 3 unit available for examination is unfortunately lacking the entire lens and shutter unit.

185 For a photographic documentation of the camera see Spennemann (2015v).

186 Nuttall-Smith (1961, p. 476).

187 Based on images provided by Peter Naylor, Perth.

188 Anonymous (1959).

189 For details on the *WREROC* (Weapons Research Establishment Roll Orientation Camera) see Spennemann (2015d, 2015z).

190 *WRECISS* (Weapons Research Establishment Camera Interception Single-Shot).

191 (Anonymous, 1960a, 1960b, 1960c, 1960d, 1960e; Beharrell & Collier, 1966; Dixon, 1961).

192 It was acknowledged the resolution of detail at ultra-low altitudes would be difficult at the extreme edges of the image as these areas would demonstrate too much distortion Spencer (1969).

193 Anonymous (1961c).

194 Anonymous (1963, p. 42).

195 Anonymous (1963, p. 42).

196 Anonymous (1961c).

197 Common film stock used was Ilford R101 or similar panchromatic emulsions Anonymous (1961c).

198 Anonymous (1963, p. 42).

199 The data tag reads " CAMERA | MONITORING | PROTOTYPE Nº 1 | 24 V | FAIREY AVIATION CO | A'ASIA PTY LTD".—Image after Anonymous (1961c).

200 Anonymous (1963, p. 42).

201 Anonymous (1961c).

202 Anonymous (1963, p. 42).

203 Again it is unclear how many units were actually manufactured.

204 Anonymous (1963, p. 41f).—In the absence of actual examples that can be examined, it is unclear which commercial tele lens found use in the WREMARC.

205 Anonymous (1963, p. 42).

206 Anonymous (1963, p. 42).

207 Anonymous (1963, p. 41).

208 See Endnote 81.

209 Images courtesy Colin Hall (Birmingham, UK).

210 Examined as objects or via photographs.

211 Morton (1989, p. 278).

212 Pers. comm. Colin Hall (Birmingham, UK).

213 Photographica Collection Dirk HR Spennemann.

214 Pers. comm. Colin Hall (Birmingham, UK).

215 Scammell Auctions (Adelaide) Auction 722 Lot 76 (22 Oct 2011).

216 eBay 350503754089 (November 2010), *ex* Scammell Auctions (Adelaide) Auction 501 lot 753 (31 October 2011); ex Adelaide Auctioneers (September 2011).—Information also pers. comm. Wayne Urmston (Geelong).

217 For a photographic documentation of the camera see Spennemann (2015x).

218 The numbers on the connector of unit lens sn#3105 are: "5x/6353 CZ56074 PS87" with the number "Z49803" at the tip. The plastic face reads "Z1181/2"' and "5x/122".—The plastic face of unit lens sn#2128 carries the same numbers.

219 The measurements are given in inches as that was the standard of measurement at the time the camera was produced—and all ascertained dimensions indeed conform to this.

220 The motor has a round section and measures 3" in diameter and x 3 ¼ " in length.

221 An examination showed that the tag does not cover up any previous engraving.

222 Nuttall-Smith (1961, p. 476).

223 Nuttall-Smith (1957, p. 177 fig. 2).

224 Nuttall-Smith (1961, fig. 12).

225 Nuttall-Smith (1961, p. 473, fig. 9).

226 Nuttall-Smith (1961, p.474 Figure 11).

227 In July 2015,

228 Images courtesy Colin Hall (Birmingham, UK).

229 Source: Nuttall-Smith (1961, p. 473, fig. 9).

230 Images courtesy Colin Hall (Birmingham, UK).

231 Nuttall-Smith (1961).

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