Upper atmospheric research at Woomera: the Australian-built sounding rockets

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Abstract

Sounding rocket programs for upper atmospheric research (UAR) commenced at Woomera in 1957, with the British Skylark project and the Anglo-Australian HARP rockoon program. Shortly afterwards, the Weapons Research Establishment (WRE) inaugurated its own sounding rocket program with the first successful Australian-built sounding rocket, Long Tom, developed from surplus British motors. This research would eventually lead to the development of Australia's first satellite, WRESAT, launched in 1967.

Long Tom became the first more than 10 Australian designed and built sounding rockets that would be employed at Woomera until the demise of the WRE upper atmosphere program in 1976, as the Range was winding down to the cessation of the Anglo-Australian Joint Project. Like Long Tom, most of the early Australian sounding rockets were constructed by the WRE from surplus British motors, but after 1967 the later vehicles had a much higher local content, based on combinations of British motors and/or rocket motors developed in Australia. These new motors were named after constellations of the southern sky, while the rockets themselves bore the names of Australian native birds.

This paper will outline the technical and scientific history of the Australian sounding rocket program, examining its origins and the reasons for its demise. It will look at the sequential development of the various Australian rockets and consider the particular research projects with which they were associated, the relationship with the WRESAT project and the move to Australian production after 1967.

1. Introduction

Prior to the Second World War, little was known of the properties of the Earth's atmosphere above 20km, the limit to which balloons could carry scientific instruments. However, the rapid development of rocketry during and immediately after the war, gave rise to the development of sounding rockets: small vehicles (generally less than 10m long and 30cm in diameter) capable of carrying instrument packages to altitudes of 100km and more, the very fringes of space. By the early 1950s, sounding rockets had become a valuable tool for research into the upper reaches of the atmosphere.

The International Geophysical Year (July 1957-December 1958), initially proposed in 1952, was intended to focus global scientific efforts on the study of the large physical forces which affect the Earth, including the relationship between our atmosphere and the space environment. Along with dozens of other countries, both Australia and the United Kingdom made plans to participate in this program with, among other projects, sounding rockets launched from the Anglo-Australian Woomera Rocket Range in South Australia. It was this initiative that gave impetus to the development of an Australian upper atmospheric research program and, with it, the development of a series of Australian designed and built sounding rockets, composed of various combinations of British and Australian motors. This research provided a wealth of fundamental data on the properties of the mesosphere and contributed to the development of Australia's first satellite, WRESAT, in 1967.

2. HARP: the Anglo-Australian rockoon program

Australia commenced planning its IGY sounding rocket program in 1955, with the Weapons Research Establishment (WRE-the Australian defence scientific and technical research organisation that controlled the Woomera Range and oversaw Australia's space-related activities) initiating the High Altitude Research Project (HARP). [1] The HARP vehicle was to be a rockoon, a combination of balloon and sounding rocket, based on a concept successfully utilised for upper atmospheric research in the US from 1952 [2]. Rockoons used a large research balloon to carry a small rocket high into the atmosphere (in the case of the HARP vehicle, approximately 12km) [3] after which the motor was fired by remote control to carry the payload to a much greater altitude than could be achieved if the rocket launched directly from the ground. Using the balloon to provide a 'free ride' into the thinner air of the upper atmosphere reduced the drag, thus increasing the performance of a small motor. Without its balloon lift, the HARP rocket could only have achieved an altitude of 24km; with atmospheric launch it could attain an altitude of 100km. [4]

The polythene HARP balloon, made in Australia to a Bristol University design, weighed approximately 45kg

empty and, when inflated with hydrogen, expanded to 18m across and 30m high [5]. The HARP sounding rocket was developed, under the guidance of the Propulsion and Aerodynamics Divisions of the WRE, by the Special Projects Division of the Fairey Aviation Co. of Australasia Ltd. The body of the rocket, approximately 5.5m long, with a diameter of 25.4cm, was fibreglass reinforced plastic, with four double-wedge airfoil tail fins. It was powered by a small solid propellant motor, capable of achieving a velocity near Mach 3, with a firing time of 3-4 seconds, which could provide an acceleration of 60g. The rocket weighed 236kg and had a total flight time of 4-5 minutes.[1]

Six British universities provided payloads for the HARP project, using equipment similar to that planned for the first Skylark rockets experiments. [6] The rocket was also equipped to collect and analyse air samples at high altitude, with all data being telemetered to the ground: both rocket and payload were expendable. HARP firings, using dummy payloads, began in early 1957, but the balloon proved difficult to handle in Woomera's random wind gusts, and many launches were unsuccessful. It was eventually concluded that Woomera's uncertain winds made it an unsuitable location for rockoons that had to be launched at specific times to fit within the Range's launch timetable and HARP was abandoned in 1958[7].

3. Long Tom: a cheap 'sighter' rocket

After the demise of HARP, responsibility for upper atmospheric research passed, by default, to the WRE Flight Projects Group, which was tasked with conducting the first Skylark launches in 1957 and also preparing the Range for the introduction of the Black Knight research rocket in 1958.[8] To test the new instrumentation installed to track the Black Knight trials, which would reach altitudes not previously attained at Woomera, the Flight Projects Group, together with the Project Studies group, designed a cheap 'sighter' rocket assembled from surplus British rocket motors. Designated Long Tom[2], the rocket was a two-stage vehicle based on Mayfly motors. The instrumentation head contained radar transponders and a dispenser for radar 'chaff' (thin metallised strips, which could be tracked by ground radar), for testing the Range instrumentation, as well as telemetry equipment. [9] Long Tom could accelerate faster and achieve a higher altitude (approximately 100miles/ 160km) than the Skylark.[3]

Six Long Tom instrumentation calibration flights were made in 1957-58, with the first launch being on October 1, 1957. The first three Long Tom flights were fired from the Skylark launcher, but after a partial boost failure on the third launch, which caused some damage to the launch tower, the British researchers requested the WRE not to use the launcher again.

The Australians therefore designed their own Long Tom launcher, a much lighter and simpler structure than the Skylark launch tower,[4] which took advantage of the rocket's rapid acceleration: the launch rail was only three metres long. Located initially at Woomera's Range 2, this launcher, which was trainable in direction and elevation, would remain in use until the end of the Australian sounding rocket program in the 1970s, being used by several Australian vehicles.

3.1 Long Tom Mk. 1 vehicle description

The Long Tom was based on the Mayfly 9" (22.8cm) solid rocket motor. Three Mayfly motors were clustered to form the first stage, which was stabilised by three fins. The first stage's total impulse was 151,000lb sec (670.8kN/s) with a burn time of 3.6sec.

The second stage consisted of a single Mayfly motor, stabilised by three cropped-delta fins, which ignited 20 seconds after launch and burned for 3.6 secs. Its total impulse was 50,300lb sec (223.5kN/s). The instrumentation compartment was 9" (22.8cm) in diameter and 3' (91cm) long, capable of carrying a 100lb (45.4kg) payload. It could be fitted with a parachute to allow for experiment recovery, if required. The overall vehicle height was 27' (8.2m) and its overall weight 2,000lb (907.2kg). [10]

3.2 Long Tom becomes a sounding rocket

Although not developed as a sounding rocket, the arrival of Bryan Rofe in the Flight Projects Group[5] in late 1958 led to the Long Tom being deployed in that new role. Rofe, originally trained in meteorology, had become the head of a new meteorological research section in Flight Projects and immediately saw the potential of the Long Tom as a sounding rocket, to

[1] The specifications given here are drawn from data provided in F.I Ordway and R.C Wakeford, 1960, and "IGY Woomera build-up", 1957. It should be noted that there is a discrepancy between the rocket weight quoted in Ordway and Morton (who gives 270kg). I have chosen to use the weight given in Ordway as it is a more contemporary source.

[2] The Long Tom was named, with typical Australian humour, after the notably tall Thomas F. C. Lawrence, at that time Superintending Scientist of the WRE Systems Assessment Division, to which the Flight Projects and Project Studies groups belonged.

[3] There is some evidence that the WRE team set out deliberately to produce a rocket with better performance than Skylark, introduced at Woomera the same year that Long Tom was developed. See P. Morton, 1989, p. 402.

[4] The Skylark launcher at Woomera had been constructed from surplus World War 2 'Bailey Bridge' segments as the material was cheap and readily available.

[5] He had previously been with the WRE Missile Projects Group before transferring to Flight Projects.

complement the research being undertaken with the British Skylark. Rofe recognised that for rocket and missile design and testing, information on the basic upper atmospheric parameters of pressure, temperature, density, windspeed and wind direction was vital [11] and that sounding rockets could provide fundamental data that had both scientific and practical value.

One early Skylark IGY experiment measured the speed and direction of upper atmospheric winds by ejecting and tracking various materials, such as radar 'chaff'. Already carrying a radar chaff dispenser, Long Tom could easily contribute to this research, and, indeed, wind studies using the chaff had already been carried out as part of the Black Knight pre-launch studies [12]. As there was also some spare space available in the Long Tom's instrumentation compartment, the Australian National University was invited to install a micrometeorite detector to expand the range of data collected. [13] A combined Range test/UAR Long Tom was launched in May 1959, with a dedicated aeronomy flight being launched in July 1960.

Despite being already essentially replaced by the HAD and HAT vehicles, to be discussed below, a Long Tom sounding rocket was utilised in May 1962 as part of an experiment to improve the interpretation of satellite weather images. The Long Tom, carrying photographic equipment, was launched to coincide with the passage of a TIROS weather satellite. Cloud images from the Long Tom and TIROS were then compared with images taken from both the ground and a Canberra aircraft.

Although Long Tom was quickly superseded by later Australian sounding rockets, it can claim pride of place as Australia's first successful home grown sounding rocket, which led the way for more than 10 successors over the following decade and more.

3.3 Long Tom Mk. 2

The Long Tom TIROS experiment may also have been a test flight for an improved vehicle, Long Tom Mk. 2, which is known to have been in development by August 1962. [14] According to most launch lists, their was one final Long Tom flight, presumably of a Mk. 2 version in November 1966, in support of solar ultraviolet research, but a 1968 brochure outlining Woomera's sounding rocket facilities lists Long Tom as an operational vehicle and shows a picture of the Mk.2 vehicle as identified by Bryan Rofe. [15]

There is also a discrepancy between the number of Long Tom launches listed in various sources, some quoting 10 launches [16], while others list 16 [17]. Lloyd, in his 1988 monograph [18], lists only 6 Long Tom launches: it is assumed that he refers only to the Long Tom's sounding rocket flights and not its Range testing launches. Since the flights described above account for only 4 UAR flights, that leaves possibly two more (presumably Mk. 2) flights still to be accounted for in Lloyd's 6 and still another 4 potential Mk. 2 flights still to be identified if the total number of Long Tom launches was, in fact, 16. Further research is required to clarify this discrepancy.

The specific characteristics of the Mk. 2 vehicle are difficult to determine, as there is considerable variation in Long Tom data across different sources. While the basic configuration of the uprated rocket did not change, the second stage fins were re-designed to a more rectangular shape and the instrumentation capsule was lengthened to 178cm, giving an overall increase in vehicle height to 8.4m. The payload capacity was increased to approximately 65kg, but with a reduction in apogee to around 85miles (130km).[6]

4. Aeolus: Long Tom's "little brother"

In 1958, the WRE also developed a second small vehicle for use in testing the Woomera Range instrumentation. Like its "big brother" Long Tom, Aeolus (named for the Greco-Roman god of the winds) was assembled from surplus British motors: in this case a cluster of seven LAPStar motors for the first stage, with a single Mayfly as a second stage. With a less powerful boost stage, its apogee was not as high as that of Long Tom, but it was capable of carrying payloads, recoverable if required, between 30 and 140lb (13.6-63.5kg). [19] With the heaviest payloads its apogee was around 47miles (76km), but it could take a 30lb payload to 80 miles (129km). [20]

The name Aeolus suggests that, presumably under Rofe's influence, it was intended from the outset to use the vehicle to investigate upper atmospheric winds in addition to its Range testing role: all its flights, whether for Range development or aeronomy seem to have included a chaff dispenser to measure wind patterns at altitudes from 19 to 48miles (30.6km-77.2km).

Seven Aeolus flights[7] were made between December 1958 and 1961, fired from the Long Tom launcher. Flight number 5, on May 23, 1960 was particularly significant in that it tested a number of photo-theodolites, designed by the WRE to photograph the grenades ejected from Skylark rockets as part of British UAR investigations, a program with which Australia would also soon become involved. [21]

[6] These payload and apogee figures are derived from K.H. Lloyd, 1988, p. 14, however some other sources give the payload weight as between 54 and 82kg, with an apogee between 109 and 121km.

[7] Lloyd lists only 3 Aeolus flights, presumably implying that only 3 were purely UAR flights. However all other sources list a total of 7 Aeolus launches.

Like Long Tom, Aeolus was not best suited to research work and it was soon retired in favour of the first purpose-designed Australian sounding rockets.

4.1 Aeolus vehicle description

The Aeolus first stage consisted of a cluster of seven 5" (12.7cm) LAPStar (Light Alloy Plastic-Star) motors held at the rear by a light metal fairing to which four rectangular fins (similar to those that would be used on the Long Tom Mk. 2) were attached. An aluminium nose casing at the top of the booster tapered to the diameter of the second stage and was crowned with a small cone which fitted into the base of the venturi of the second stage to mate the two together.

The first stage cluster was 16" (40.6cm) in diameter (not including the fins) and 67" long (170.2cm) and weighed 600lb (272.2kg). With a total impulse of 49,140lb sec (218.3kN/s), its burn time was 2.7 sec, which carried the rocket to 0.6 miles (.97km). Here the first stage fell away and the rocket to coasted to an approximate altitude of 3.2 miles (5.1km), where the second stage ignited. [22]

The Aeolus second stage was a single 9" Mayfly motor, the same as that used on the Long Tom, with identical characteristics and fins. Depending upon the weight of the payload, the second stage weight could vary between 520 and 650lb (236-295kg), giving a total vehicle weight between 1120 and 1250lb (508-567kg). After igniting at 3.2 miles (5.1km), this stage carried the rocket to an altitude of 5 miles (8km) before burning out and allowing the vehicle to coast to apogee. The instrumentation compartment was of the same dimensions as the Long Tom and the overall height of the Aeolus was 21.4' (6.52m) [23]

5. Australian UAR revitalised

With Bryan Rofe assuming the leadership of the WRE Project Studies Group in early 1960, and with the utility of sounding rockets demonstrated by Long Tom and Aeolus, a conscious decision was made in 1960 to design sounding rockets appropriate for Australian research programs, using surplus British motors. The research programs planned were intended to complement those already being undertaken by British and Australian researchers using Skylark rockets, to provide a broader data set of both general meteorological and specific Range operation interest.

Due to the limited variety and numbers of surplus engines available, some initial experimentation was undertaken with different configurations of motors, giving rise to several short-lived designs, [24][8] but eventually two vehicle designs were settled on, which were named according to their research function: High Altitude Density (HAD) and High Altitude Temperature (HAT).

6. The HAT Program

The High Altitude Temperature (HAT) vehicle, originally known as High Altitude Test, [25] was the first of the new rockets to become operational. First launched in 1960, it may have been initially used for instrumentation testing, before assuming its permanent research role in measuring the temperature of the upper atmosphere, complementing research being undertaken by the Skylark program and also by its 'sister' HAD. [9]

Early Skylark research aimed to measure the temperature of the atmosphere at high altitude by ejecting a series of aluminised grenades from the rocket at various heights and comparing the arrival times at ground-based receptors of the flash and shockwaves from the grenades. Above 90km, the explosion of these grenades produced glowing clouds that could also be studied spectroscopically to further refine atmospheric temperature determinations: such observations are still one of the few methods available to measure atmospheric temperature at altitudes above 80km. [26]

While Skylark research concentrated on the higher altitudes, HAT, with its maximum altitude around 76km[10], was better suited to studying the temperature at altitudes between 30 and 70km. WRE's Flight Projects Group developed a small dropsonde to take direct measurements of atmospheric temperature and pressure. It was released from the rocket at apogee and fell back through the atmosphere, slowed by a parachute. The parachute itself was also designed to be radar reflecting, to serve as a wind sensor.

The HAT sonde came into operation in early 1963. Suspended from its 15ft (4.6m) parachute by a 10m line, it measured temperature by monitoring the resistance of a calibrated thermistor mounted on a yoke which extended from the sonde. [27] Atmospheric pressure was measured by a WRE-designed gauge, which worked by measuring the electrical resistance of the atmosphere. Although the data was telemetered to the ground, the sonde was also retrieved by airborne recovery, using a helicopter, before impact.[11]

[8] Isolated references can be found in the literature to vehicles like HAM (High Altitude Measurement?) and Koorigal about which little more is now known than their names.

[9] There is some uncertainty about HAT's earliest role. ASRTS indicates that HAT was first launched in 1960, and Rofe mentions it as an active launcher in 1962, however, there is no reference to it conducting scientific research before the introduction of the dropsonde in 1963. While ASRTS lists 64 launches, Lloyd only gives 58, which may imply that there were 6 test flights between 1960 and 63.

[10] Once again specifications vary between sources. ASRTS gives 76km, while FLSRW gives an altitude of 64km and Lloyd 70km.

In late 1963, to further other Australian research already being carried out with Skylark, the pressure instrument on the sonde was replaced by an ozone measuring device, which measured the absorption of ultra-violet radiation as a means of determining ozone levels. [28] The data from this research also fed into work being carried out in the HAD program, to investigate molecular oxygen in the upper atmosphere. In late 1968, a HAT launch was timed to coincide with the overflight of Explorer 37, so that the vertical ozone and molecular oxygen profile obtained by the HAT dropsonde, could be compared with the data from the satellite. [29]

HAT rockets were used for temperature and ozone research until 1969, when the program was transferred to the Kookaburra Mk.1 vehicle: between 1960 and 1970, 64 had been launched (38 of them by the end of 1967) [30]. Although largely superseded by the transfer, a modified version of HAT was still listed as operational at the end of 1971. [31]

6.1 HAT vehicle description

Like its predecessors, HAT was composed of redundant British motors: its first stage comprised of two 7" (17.8cm) Demon solid-fuel motors bound in tandem by a light metal fairing to which four fins were attached. Like Aeolus, an aluminium nose casing at the top of the booster was topped by a small cone fitting into the base of the second stage, providing connection between the two stages. With a total impulse of 45,200lb sec (208kN/s), the first stage burned for 2.3 secs.

The second stage consisted of a single LAPStar motor, stabilised by three small cropped-delta fins. Ignited 21 seconds after launch, the motor burned for 2.7 sec and produced a total impulse of 8,300lb sec (36.9kN/s). Its maximum velocity at second stage burn-out was 2,930mph (4,715kph).The second stage weighed 115lb (52kg) and the total vehicle weight was 573lb (254kg). Overall vehicle length was 210" (5.3m), with the payload compartment 1.02m in length. Initially, HAT could carry a payload of 30lb (13.6kg), but this was later increased to 18kg, through the use of a new upper stage. [32] [12]

6.2 HAT Mk. 2/Cockatiel

Towards the towards the end of HAT's operational life (possibly in 1969), a replacement vehicle named Cockatiel was proposed, using two Australian Dorado motors (essentially Demon casings with locally made propellant) as a first stage and a Lupus 1 Australian motor as a second stage. [33] Although Cockatiel does not seem to have progressed beyond the proposal stage, a modified version of HAT (never, it seems, formally designated Mk. 2) was noted as operational in 1971. It retained the original Demon first stage, but the original LAPStar second stage replaced by the Lupus 1 motor [34], possibly due to the exhaustion of LAPStar stocks. This 53.3kg motor was 25.4cm in length and 12.6cm in diameter. It had a total impulse of 37.8kN/s with a burn time of 4 sec. [35] The number of modified HAT vehicles in the overall launch total has yet to be established.

Initially, HAT vehicles were launched from the Long Tom launcher, which had been moved to Range E, beside the Skylark launcher, by 1962. Later, when, the dedicated HAD launcher was built, HAT rockets were fired from either launcher, depending upon which was available at the time.

7. The HAD Program

Like its 'sister', HAT, the High Altitude Density rocket (HAD) was developed to participate in research on the density of the upper atmosphere already being carried out by Skylark. In addition to providing information on the temperature of the upper atmosphere, the glowing clouds produced by the Skylark grenades could also be tracked and photographed to provide information on atmospheric density at different altitudes. Before the refinement of mass spectrometry techniques, this was the only satisfactory way to obtain data on the density of the upper atmosphere between 80-180km. [36]

The Instrumentation Group of the WRE Aerodynamics Division developed the photometers and camera systems to record the behaviour of these clouds, and in 1962 it was decided to commence a major project, in conjunction with the WRE's Theoretical Supersonics Group (also in the Aerodynamics Division), of glow cloud observation, so that windspeeds and atmospheric density could be deduced from their expansion.

WRE also decided to complement the Skylark work by developing its own rocket and density payload that would concentrate on the lower altitudes between 40 and 90km. This would become the basis for the WRE's longest continuous program of upper atmospheric research, commencing in 1962.

The HAD vehicle was, like HAT, a two stage rocket, based on British Gosling and LAPStar motors. First launched in 1961, it had two test flights before becoming operational in 1962.[13] Between 1961 and 1969, 118 HAD rockets were launched (111 by the end of 1967 [37]), before it was phased out in favour of the Kookaburra and Cockatoo vehicles.

[11] This technique was, however, later abandoned after a retrieval mishap. See P. Morton, 1989, p. 403.

[12] The heavier payload resulted from the switch to the Lupus 1 upper stage.

[13] This assumption of two test flights is based on the difference in total launches listed in *ASRTS* and Lloyd. *ASRTS* gives 118 flights, while Lloyd lists 116

The density measurement payload designed for the HAD was known as the "falling sphere", a two-metre aluminised Mylar balloon, which was launched to its required height and there released to drift down through the atmosphere, while being tracked by radar. The balloon was inflated by isopentane, which provided enough pressure within the sphere to maintain its inflation down to an altitude of 40km. The rate of the balloon's descent allowed density profiles to be calculated, while its sideways drift provided a measure of local windspeed and direction at different altitudes.

Despite early problems with balloon inflation, the "falling sphere" proved itself as an excellent instrument for providing vertical profiles of winds, density, pressure and temperature. Firings were usually made at astronomical twilight, both as an aid to visual tracking (since the sphere appeared as a bright star) and to remove diurnal variations from the data. This proved particularly important from 1966, when a series of monthly launches was instituted that provided what is still considered as one of the best consistent sets of seasonal atmospheric data. [38]

While a single flight could provide a profile of one place at one instant of time, launching a series of rockets at regular intervals could examine how these profiles varied over time. There were several multiple-launch HAD campaigns for this purpose. In 1964, to determine the spatial variation in wind, density and other parameters between Woomera and other parts of Australia, it was decided to conduct a series of firings from Carnarvon, Western Australia, where WRE had downrange radar available to track the spheres. Two campaigns were conducted in which there were simultaneous firings at Carnarvon and Woomera, in order to compare results.[14] A final campaign at Carnarvon saw 10 rockets launched in one 24 hour period, to examine the diurnal effects of atmospheric changes.

In addition to the "falling sphere" experiments, HAD rockets were also used in a collaboration between WRE and the University of Adelaide, to investigate the chemical composition of the upper atmosphere, particularly the profiles of molecular oxygen and ozone. Already working on Skylark projects, from 1962 Adelaide University Prof of Physics, John Carver collaborated with the WRE on the development of UV and X-ray ionisation detectors that could be flown on HAD vehicles to measure different atmospheric constituents.

Because HAD rockets were usually launched at sunset or sunrise, these small detectors were mounted on the sides of the rocket, which was spun at a few revolutions per second, a measurement of atmospheric absorption of certain wavelengths being made each time a detector porthole swept past the Sun. Within a few years Carver's upper atmosphere work with HAD would pave the way for Australia's first satellite, WRESAT, as will be discussed below.

7.1 HAD vehicle description

The HAD first stage was a single 10" (25.4cm) diameter Gosling I solid propellant motor, with four fins mounted directly on the venturi. Its total impulse was 62,500lb sec (27.76kN/s) and the motor's burn time was 2.5 seconds. The 8'4" (2.54m) second stage was a single LAPStar motor, with identical characteristics to that of the HAT second stage.

The HAD vehicle had an overall length of 20' (6m), with an all up weight of 633lb (287kg). It could reach a maximum speed at second stage burn-out of 3,135mph (5,045kph) and attain an altitude of 116-120km. Its payload bay was 89cm in length and the average payload weight was 16kg. [39]

Although, like HAT, HAD initially used the Long Tom launcher, because of the number of launches its program required, it was decided to construct a dedicated HAD launcher by the mid-1960s. This heavy duty structure was designed to cope with a high rate of firings and was located beside the Long Tom launcher on Range E.

8. HAEC: classified upper atmosphere research

In 1964, HAT and HAD were joined by a short-lived companion rocket, referred to as HAEC. Little is known about its research program and there are few references in the literature-even the meaning of its acronymic name is not spelled out in unclassified sources. From what can be ascertained, HAEC appears to have been a classified version of HAT, whose research included meteorological studies below 45km, using a small dropsonde.[15]

The HAEC vehicle used a single Demon motor, like that employed on HAT, for its first stage, but stabilised with three (or possibly four) cropped-delta fins. The Demon, with a burn time of 2.3 secs, delivered a total impulse of 104kN/s. HAEC's second stage was a 3" (7.6cm) 'aircraft rocket motor', stabilised by three rectangular fins, which ignited 18 seconds after launch. With a burn time of 2.8 seconds and a total impulse of 2,500lb sec (11.1kN/s), it propelled the vehicle to its apogee of 150,000' (45.7km). With an all up vehicle

[14] These firings helped to establish that weather patterns occur in the mesosphere, just as they do at lower levels of the atmosphere.

[15] This information is derived from the abstract of a restricted document *HAEC: a Medium Altitude Sounding Rocket for Meteorological Research* held in the library of the Defence Science and Technology Organisation (successor of the WRE) at Salisbury, South Australia

weight of 310lb (140.6kg), the HAEC payload was only 6lb (2.7kg). [40]

Six HAEC vehicles were launched between 1964 and 1966, but little else is known about the project at this time.

9. From sounding rocket to satellite: WRESAT

In late 1966, Australian upper atmosphere research took the step from sounding rocket to satellite as the result of a fortuitous combination of circumstances. In 1966, the US, Britain and Australia were involved in a tripartite project to investigate the physics of high velocity warhead re-entry into the Earth's atmosphere. Project Sparta used Redstone boosters, with two small solid upper stages, to launch the re-entry test heads for this program. 10 Redstone rockets were brought to Woomera, but by the latter part of 1966, it was obvious that only 9 would be needed to complete the research project.

Two senior WRE officers, Superintendent of Trials, Jeff Heinrich and the Superintendent of the Systems Assessment Division, Peter Twiss, realised that this spare vehicle could make an ideal satellite launcher. Together with Bryan Rofe, head of the Flight Projects Group, which oversaw the Woomera sounding rocket programs, they became excited by the possibility of extending the WRE's upper atmosphere research into orbit with the development of an Australian satellite. [41]

An informal approach to the American representatives by Twiss and Heinrich received a positive response: instead of being shipped back to the US, the vehicle would be formally offered to Australia. In addition, the US Sparta team offered to prepare and fire the Redstone for the Australians. Whilst this was an advantageous bonus for the WRE, it also placed the project on a very tight schedule, because it meant that the satellite would have to be ready for launch by the end of 1967, when the Sparta project would be complete and the Americans returning home.

Thus, in the incredibly short span of only 11 months, Australia's first satellite, WRESAT (WRE Satellite[16]) was designed, constructed, tested and finally launched on November 29, 1967. [42]

With the WRE's existing expertise in upper atmosphere research, and given the short development period, it was decided that WRESAT's scientific payload should consist of instruments very similar to those already employed on the sounding rocket programs, both for ease and speed of development and also to extend the research already undertaken with HAD and HAT, by providing comparison data from orbit.

The University of Adelaide team under John Carver, together with Rofe's team at WRE, developed a suite of instruments to detect and record solar radiation at three of the wavelengths that most directly influence the temperature and composition of the upper atmosphere. There were two sets of three ion counters to measure ultra-violet radiation, X-ray counters and a photocell, filtered to allow the passage only of a light wavelength strongly absorbed by ozone. These detectors were also used for measurements of the temperature of the solar atmosphere.

Another experiment, exploiting the sunrise and sunset observed in each 90 minute polar orbit, used ion chambers that detected the absorption of the Sun's rays at these times to measure molecular oxygen density. A geocoronal experiment, using a small Lyman alpha detecting telescope, was also included, following on from research conducted in 1966 with the Long Tom Mk. 2. [43]

Three days after WRESAT's launch, a Skylark rocket fitted with identical instruments was launched from Woomera. Attaining an apogee of 100km, against WRESAT's perigee of 169km, the two craft provided complementary data that also provided a check on WRESAT's instruments, demonstrating that they were functioning correctly. [44] Their joint measurements showed that a "ledge" in the zone profile at 110-120km is a common feature of the lower thermosphere, which confirmed the findings of other sounding rocket research. [45]

Because of the short development time, the WRE was not able to design a solar array for WRESAT, and the satellite was only battery-powered, giving it a very limited operational lifespan of only 5 days.[17] During this period it gathered a large amount of data on upper atmospheric conditions at all latitudes, from pole to pole. However, because of the short duration of the mission, this data could do little more than provide a check on the data already gathered by HAD, HAT and other sounding rockets and could not contribute to the long term studies of fluctuations in the levels of ozone and molecular oxygen over time.

10. The move to Australian production

Between late 1966 and the end of 1967, the effort needed to develop WRESAT within its very tight schedule was so intense that, except for the monthly HAD launches, all other UAR activity at Woomera

[16] The WRESAT satellite was officially designated WRESAT-1, because the development team hoped that it would be the first of a series of small scientific satellites. However, due to lack of support from the Australian Government, there were no follow-on satellites

[17] WRESAT continued to transmit telemetry data for a further 5-6 days, before finally falling silent. It eventually re-entered the atmosphere on January 10, 1968

virtually ceased during this period. This hiatus enabled the Flight Projects Division to re-assess its sounding rocket programs and consider their future development once regular firing resumed in 1968.

Although the first Australian sounding rockets were made up from surplus British motors, even in the early 60s it was recognised that their supply was limited and, as early as 1964, attempts were made to design and manufacture motors in Australia that would replace the British ones. Although the early tests of the first Australian motor, Vela, were not particularly successful (as will be discussed further below), it paved the way for local production of rocket motors to begin in earnest once the WRESAT project had been completed, forming the basis of an entire new family of Australian sounding rockets. Although some British motors continued to be used, there were ongoing efforts to replace them with Australian-made equivalents into the last days of the WRE sounding rocket program.

In developing their new Australian motors, the Flight Projects Group worked with the WRE's Rocket Propulsion Group to design simple, functional vehicles tailored towards the requirements of particular research programs. The WRE Chemistry and Physics Division developed cast composite solid propellants for these new motors, which were constructed and filled by the explosives factory operated by the Department of Supply at Maribyrnong in Victoria. [46][18].

These new motors were named after the constellations of the southern sky: Vela, Lupus, Musca and, later, Dorado and Indus. Musca was an entirely WRE-developed motor, while Vela was a modified Scarab casing filled with Australian-produced propellant. The Lupus was, similarly, a LAPStar casing filled with Australian propellant. The Dorado motor was a Demon replacement, using a Demon case filled with an Australian-made charge, while the Indus was intended as a Gosling motor replacement. However, the Australian UAR program was cancelled before it actually saw service. [47]

These motors were combined in various ways to produce sounding rockets that were, with one exception (Aero High), named after Australian native birds: Kookaburra, Cockatoo, Lorikeet and Corella. Different propellants were used in different versions of the motors, creating different Marks of some rockets, with varying performance.

11. Aero High: Australian production test-bed

The first, and the largest, vehicle to use an Australian-made motor was Aero High, first launched in 1964 to participate, like HAD and HAT, in another WRE program designed to complement research being undertaken with Skylark.

The occurrence of chemiluminescent reactions between the constituents of the atmosphere and the various chemicals released during different early Skylark experiments, such as those creating the glowing clouds in the grenade experiments, attracted the interest of chemical researchers: they began to use Skylarks to emit trimethyl aluminium (TMA) and other chemicals into the atmosphere to study the reactions. WRE's Chemistry and Physics Division realised that this provided a powerful tool to study gas phase chemical reactions in a "wall-free" environment.

To meet their research interests a new sounding rocket, Aero High,[19] was developed, for the dual purpose of studying chemiluminescent reactions and measuring various parameters of the upper atmosphere between 65 and 200km. Aero High was designed to release grenades doped with chemicals of interest (principally TMA and nitrogen dioxide), so that an estimate of the atomic oxygen profile could be determined. [48]

Aero High seems to have been intended as a test-bed for an Australian designed motor, as part of the long-term plan to replace the British motors with locally made product. While its first stage was a British Gosling IV, its second stage was a new, Australian-developed motor called Vela[20]. Developed by WRE's Propulsion Division, Vela was a modified Scarab motor casing, filled with an Australian-developed charge. [21]

The first two test flights of Aero High in 1964 were only partially successful[22], and the vehicle was then shelved until 1968 (presumably while more development was carried out on the Vela motor). With the resumption of Australian UAR work after WRESAT, Aero High was again put into service for "chemical seeding" experiments: this time 12[23]

[18] The Department of Supply was the Australian Government department under which the WRE was also located.

[19] Presumably named in analogy with "Aero Mach" (Jabiru Mk.2), the Australian hypersonic research rocket that was also first launched in 1964. The development of the two vehicles seems to have been undertaken simultaneously.

[20] Named after the southern sky constellation of "the Sails", part of the older constellation of Argo. It is unclear why an Australian constellation designation was chosen.

[21] There is little information available on the actual origins of the Vela and no clear indication of how it was 'modified' from the original Scarab motor

[22] P. Morton, 1989, p. 404, indicates that the tests were unsuccessful, but does not detail how they were unsatisfactory. It is assumed that the Vela motor failed in some way, possibly through sub-standard performance, which may have been due to problems with the Australian-produced propellant

[23] Lloyd gives 19 Aero High flights, but all other sources quote 12 (from 1968) or 14 (including the 1964 flights). Lloyd's figure may include some additional test flights

launches were carried out between 1968-1972, now dispensing TMA, lithium vapour, and nitrogen tetroxide, to produce glowing trails that could be observed for several hours. [49] Similar research was also carried out using Kookaburra and Cockatoo rockets, and in 1970-71 campaigns combining Aero High firings in conjunction with these other vehicles were undertaken. Up to 6 rockets would be launched at intervals over a period of about 10 hours (mostly in darkness), to obtain a coherent set of readings at altitudes ranging from 25-200km. [50]

Towards the end of the WRE upper atmosphere program, a new vehicle, Corella, was introduced to continue the Aero High chemiluminescent studies program.

11.1 Aero High vehicle description

As already noted, the Aero High first stage was a British Gosling IV 10" (25.4cm) motor. Stabilised by three cropped-delta fins, this motor produced a total impulse of 100,000lb sec (444.2kN/s) with a burn time of 4.5 seconds. The second stage was the Australian Vela motor, which, when operating successfully from 1968, had a total impulse of 30,000lb sec (133.3kN/s) and a burn time of 5 seconds, after ignition at 14 seconds after launch. 10'3" (3.13m) long and 8.3" (21.1cm) in diameter, the Vela weighed 600lb (118kg), of which 58.98kg was the charge mass.

Aero High had an overall length of 269" (6.83m) and an all up weight of 930lb (421.8kg). The payload compartment 175cm in length and the maximum payload weight 120lb (54kg) [51]. Aero High could reach an altitude of 650,000' (200km) and was fired from its own its own dedicated launcher at Range E.

12. Kookaburra: the first "all Australian" rocket

Despite its early difficulties with the Vela motor, WRE's Propulsion Division pressed on with Australian motor development and in 1968 introduced the first "all Australian" sounding rocket, Kookaburra, combining its new Lupus and Musca motors.

A small rocket, at 3.5m less than half the length of its "grandfather" Long Tom, Kookaburra was intended to supersede the HAT vehicle, although the two were actually in operation together until 1969 and possibly 1971.[24] It remained in use until 1975 with a total of 115 launches over three Marks.

between 1964-68 not otherwise recorded, but his figures have repeatedly shown discrepancies with other sources and may be incorrect.

[24] As noted previously, HAT was apparently still operational, in a modified version, in 1971, though much less frequently used after the introduction of Kookaburra.

In 1969, the HAT dropsonde program was transferred to the Kookaburra, which continued to be used for this work until the UAR program was shut down in 1975. Kookaburra also took on, in conjunction with Cockatoo, some of the former HAD program, assisting to launch "falling spheres" as part of the monthly data gathering firings. In March 1970, a major Anglo-Australian-Indian experiment was carried out across the Indian ocean, with Kookaburra rockets being launched simultaneously from Woomera, Gan (Maldives) and Tumba (India), as a comparative assessment of atmospheric temperature and ozone levels. [52]

As part of an increased emphasis on ionospheric research introduced into WRE from 1970, Kookaburra vehicles were also used to launch a differential absorption experiment designed by the University of Adelaide, which used a rocket-borne receiver to measure the strength of 2MHz radio waves transmitted from the ground, in order to determine electron density profiles.

12.1 Kookaburra Mk. 1 vehicle description

The Kookaburra Mk.1 vehicle consisted of a Lupus 1 first stage, with a Musca second stage. The Lupus motor was created from a British LAPStar casing, filled with a locally manufactured charge, while the Musca was an entirely Australian designed and built motor, developed by WRE and constructed at Maribyrnong. [53] Needle-like in appearance, the Kookaburra was 138" (3.5m) and weighed only 52kg. It could reach an altitude of 75km with a payload of 10lb (4.5kg). The payload compartment was 52cm in length.

The Lupus first stage was 5" (12.7cm) in diameter and 17.3cm in length, stabilised by 4 square fins of 15cm by 15cm attached directly to the venturi. It weighed 33.6kg, of which 18.24kg was charge mass. With an average thrust of 9.46kN, it produced a total impulse of 37.8kN/s and had a burn time of 4 seconds.

The Musca upper stage, with four rectangular fins 11.5cm by 15cm, was 17.7cm long, with a diameter of 8.9cm and a mass of 19.2kg, of which 8.33kg was propellant. Igniting at 20 seconds after launch, it burned for 3.6 seconds and produced a total impulse of 19.1kN/s. [54]

Kookaburra could be launched from either the Long Tom or HAD launcher, depending upon availability. 84 Kookaburra Mk.1 flights were made.

12.2 Kookaburra Mk. 2 description

The Mk. 2 version of the Kookaburra was introduced in late 1972, with the development of the Lupus 2 motor. In 1971, the Rocket Propulsion Group,

requested to improve the performance of the Australian motors, set out to improve the Lupus by developing new, higher-energy, hydrocarbon propellants. The new propellant, coupled with a change in the shape of the venturi, produced a 21.5% increase in total impulse for the Lupus 2. [55]

Kookaburra Mk. 2 was therefore composed of a Lupus 2 first stage and Musca second stage. The Lupus 2 had a mass of 35.7kg (of which 19.87kg was propellant), but otherwise retained the same physical characteristics as its predecessor. Its total impulse was increased to 46kN/s and its average thrust to 11.49kN. The increased performance allowed it to carry its 4.5kg payload to 128km. There were 27 firings of this vehicle. [56]

12. 3Kookaburra Mk. 3

Further improvements in the performance of the Lupus motor were desired, and the WRE undertook additional propellant and design research to produce a lengthened Lupus 3 motor, with further increased performance, in 1974. The Lupus 3 motor became the basis of the Kookaburra Mk. 3 sounding rocket, which was used to replace the Cockatoo 1 vehicle, due to the diminishing stocks of its Gosling motors.

Kookaburra Mk. 3 still retained the Musca motor for its upper stage, but its Lupus 3 first stage was increased in length to 196cm, which, with a slightly increased payload compartment length of 57cm, increased the overall vehicle length by 37cm.With a weight of 41kg (and a charge weight of 25.4kg), the Lupus 3 had a total impulse of 60.9kN/s and could drive the Kookaburra to an altitude of 140km for the same 4.5kg payload. [57]

Due to the termination of the WRE sounding rocket programs by 1976, only 4 Kookaburra Mk. 3 were fired before the end of the program.

13. Cockatoo: HAD's successor

Just as Kookaburra was designed to replace the HAT rocket, so Cockatoo was designed to supersede HAD, with the resumption of upper atmosphere research post-WRESAT. A much larger vehicle than Kookaburra, Cockatoo used a combination of British and Australian motors, with a Gosling I first stage and a Lupus 1 second stage.

In taking over from HAD, Cockatoo became the prime launch vehicle for "falling sphere" experiments, and two-thirds of its more than 60 launches over the period 1968-73 were dedicated to this program. It was also continued the earlier HAD experiments with UV and X-ray detectors, to measure the atomic and molecular oxygen and nitrogen content of the upper atmosphere, as well as dispensing silver strips at 50km altitude to assist in measuring atomic oxygen.

More versatile than its predecessor, Cockatoo was used to carry a variety of atmospheric compositional experiments. In conjunction with Aero High's chemical seeding experiments, it was used to release lithium trails to measure upper atmospheric winds and turbulence at about 80km in altitude (this research also complemented work being undertaken by British teams with Skylark rockets). Following on from the WRESAT experiments using a Lyman alpha detector, Cockatoo carried similar instruments to detect both atomic and geocoronal hydrogen. Another atmospheric composition experiment saw an upwards pointing telescope, sensitive to near-infrared radiation in the emission bands of the OH radical, used to investigate chemical reactions occurring between 80-122km. [58]

13.1Cockatoo Mk. 1 vehicle description

Like its predecessor HAD, Cockatoo used a British Gosling I motor as its first stage, with an Australian Lupus 1 as its second stage. The Gosling stage was identical in design and characteristics with the HAD first stage, the only exception being that the Cockatoo vehicle was stabilised by four rectangular 30cm by 45cm fins, different from the earlier HAD design, mounted on the venturi.

The Lupus 1 motor, which ignited 20 seconds after launch, had the same physical and performance characteristics as a second stage, as it had as a first stage vehicle for the Kookaburra. With a 89cm payload compartment and a maximum payload of 18.1kg, the Cockatoo Mk. 1 could reach an apogee of 130km. The overall vehicle length was 6.24m and its all up weight, 302kg. [59] 49 Cockatoo Mk.1 vehicles were fired using the original HAD launch rail.

13.2 Cockatoo Mk. 2, 3 and 4 vehicle description

Like Kookaburra Mk. 2, Cockatoo Mk. 2 came about as a result of the redevelopment of the Lupus motor, to produce the uprated Lupus 2. Thus the Cockatoo Mk. 2, introduced in late 1972, consisted of a Gosling I first stage, still unchanged from the Cockatoo Mk. 1 and a Lupus 2 second stage, with the same physical and performance characteristics as on the Kookaburra Mk. 2. The improved performance allowed for an increase in payload compartment size, to 102cm, as well as an increase in payload weight, to 21kg. The new vehicle could also reach the higher altitude of 145kg [60]. Four Cockatoo Mk. 2 vehicles were launched before a critical shortage of Gosling I motors, led to the use of "ballasted" Gosling IV motors to replace the Gosling I, this creating the Cockatoo Mk. 3 and 4 vehicles, before the Cockatoo was finally phased out in favour of the Kookaburra Mk. 3.

Gosling IV motors (the same as that used on Aero High), carrying about 100kg of ballast, [61] were used as the first stage on the Cockatoo Mk. 3 and 4 vehicles, the only difference between the two being in the upper stages: the Mk. 3 vehicle used Lupus 2, while the Mk. 4 used Lupus 1. The performance characteristics of the ballasted Gosling IV are not available, but those of the upper stages were identical with their characteristics on the Kookaburra and earlier Cockatoo Marks.

Cockatoo Mk. 3, of which 9 were fired, was essentially the same as the Cockatoo Mk. 2 in regard to payload capacity, weight and apogee. Cockatoo Mk. 4, of which 16 were launched, had a smaller payload compartment of 35cm and a payload weight of 16kg. It could only attain the slightly lower altitude of 135km. [62] With the introduction of Kookaburra Mk. 3 in 1974, as has been noted above, the Cockatoo sounding rocket was retired.

14. Upper atmosphere research re-organised

A re-organisation of the WRE in 1969, led to the amalgamation of the two main groups conducting upper atmosphere research, Flight Projects (working with the Australian rockets) and Upper Atmosphere Physics (working primarily with Skylark projects), into a single group. This new section, Upper Atmosphere Research, was located within the renamed Aerospace Division. Bryan Rofe became the Principal Officer of this new group, until his promotion out of WRE in 1970, when he was replaced by Phil Pearson, who had been heavily involved in the development of the Australian motors. Pearson remained in charge of the group until it was disbanded in 1976.

In 1970, after a decade of research essentially unsupervised by higher ministerial scrutiny, an Interdepartmental Committee investigating activities at Woomera in the light of the future winding down of the Anglo-Australian Joint Project, under which the Range had been established, [63] reviewed the upper atmospheric research at Woomera. It determined that UAR should continue, but directed that it should be slanted more towards ionospheric observations, with possible defence relevance. This injunction not only changed the course of future upper atmosphere research at Woomera, it also sowed the seeds of the program's demise. Following the Committee's report, there was a strongly held view that research which did not contribute directly to Australia's defence capabilities, should not be supported by Defence funds, and the Upper Atmosphere Research Group had to regularly fight for its funding, and its very existence, henceforth. [64] A proposal to transfer the Group to the Department of Science came to nothing and, by 1975, UAR at Woomera had become a casualty of the wind-up of the Joint Project. Sounding rocket activity without obvious defence applications could not be justified in a tougher economic climate [65] and the launch programs ceased in 1975, with the Upper Atmosphere Research Group being formally disbanded in 1976.

However, before the UAR program was terminated, the Committee's recommendation to focus UAR work on ionospheric research gave rise to two new experiments that were originally flown on Cockatoo rockets, before being transferred to the new Lorikeet vehicle. These were: the swept frequency plasma probe, which measured electron density by observing resonances in the ionospheric impedance; and a nose-tip Langmuir probe, designed to collect electrons in order to provide small-scale details in the electron density profile. These experiments were flown together and often included on flights in the chemical release program.

15. Lorikeet: the Cockatiel design revived

Although the Cockatiel vehicle originally proposed as a replacement for HAT did not proceed to development, its concept was resurrected in 1973 for a new HAT replacement, superseding the early Kookaburra Marks, known as Lorikeet. Lorikeet was the first rocket to use the Australian Dorado motor, although unlike the Cockatiel, it had only a single Dorado as its first stage, with a Lupus motor as an upper stage.

The Lorikeet took over the HAT/Kookaburra dropsonde program and also assumed the UV and X-ray detectors, swept frequency probe and Langmuir probe from Cockatoo as it was phased out. A small mass spectrometer designed by the University of Adelaide to measure neutral and positive ion species in the 10-40amu range was also flown on Lorikeet, to provide an independent source of information for comparison with the absorption photometry experiments that had been going on for many years.

15.1 Lorikeet Mk. 1 and 2 vehicle description

Developed, along with the Corella rocket, under the leadership of Phil Pearson, the Lorikeet Mk. 1 utilised a Dorado motor to replace the older HAT Demon. As noted earlier, the Dorado was a Demon casing with Australian propellant. Both versions of the Lorikeet used the Dorado first stage: the Mk. 1 vehicle had a Lupus 1 second stage, while the Mk. 2 rocket had Lupus 3 as its upper stage. Introduced in late 1973, only two Lorikeet Mk. 1 were launched, probably as test flights, before the Mk. 2 was introduced in 1974, with the availability of the Lupus 3. There is some discrepancy with the number of Lorikeet flights: Morton mentions only four altogether before project cancellation, while Lloyd lists six Mk. 2 flights in addition to the Mk. 1 tests. [66]

The Dorado motor was 17.3cm in diameter and 310cm in length, with a mass of 139.3kg (and a charge mass of 73.64kg). It was stabilised by 4 rectangular fins, 35cm

by 45cm. With a burn time of 4.12 secs, it had a total impulse of 173.1kN/s and an average thrust of 42kN.

The Lupus 1 and 3 upper stages had the same physical and performance characteristics as those used on the Kookaburra vehicles. In both Lorikeet Marks the payload compartment was 102cm, with a payload weight of 21kg. The Lorikeet Mk. 1 had an apogee of 75km, while the Mk.2 version could achieve an altitude of 140km. [67]

16. Corella: the last Australian sounding rocket

In 1974, with the termination of sounding rocket launches only a year away (though not yet anticipated), a replacement vehicle for Aero High was introduced, known as Corella. Aero High's experimental work with glow clouds from aluminised grenades, and the lithium trail research undertaken with both Aero High and Cockatoo, were transferred to Corella, but the vehicle made only two flights before its program was shut down.

When initially designed in 1970, Corella was intended to use an Australian Indus [68] motor as its first stage, the Indus being then planned as a replacement for, initially, the British Gosling I motor (originally used on HAD and Cockatoo) and then the Gosling IV motor, used with Aero High. [69] The Indus was still under development when the Corella was brought into service, and so a Gosling IV was utilised as the first stage, as an interim measure until the Indus became available. [70] However, as noted, there were only two Corella flights and Indus never came into service. The Corella's upper stage was a Dorado motor.

The Gosling IV characteristics for the Corella's first stage were the same as for the Aero High first stage, although four rectangular fins seem to have replaced the Aero High's three. The Dorado's characteristics seem to have been the same as for its first stage use on Lorikeet. The Corella had a payload compartment of 147cm in length and could carry 45kg to a height of 200km. Its overall height was approximately 8m and its all up weight approximately 445kg. [71]

17. Conclusion

As already discussed above, the Australian sounding rocket program was terminated in 1975-76, due to the winding down of the Anglo-Australian Joint Project and a change in attitude on the part of the Australian Government towards spending on defence research. During the period 1960-1976, the upper atmosphere research conducted at Woomera contributed significantly to knowledge of the upper atmosphere and remains, in some areas, some of the best long term data sets for the southern hemisphere. It is unfortunate that the research was terminated just at the point where it was reaching maturity and starting to yield long term results, not only scientifically, but in the level of technical expertise in all aspects of sounding rocket construction that had been developed within the different branches of the WRE and Department of Supply.

In addition to developing the technical skills of the WRE divisions involved in the UAR program, some of the most significant research results were: the "falling sphere" experiments provided more than a decade of monthly data which provided the basis for reference atmospheres and gave detailed information on seasonal changes; the ozone sonde results helped to provide the first evidence of the importance of water vapour on the ozone density profile and helped in understanding the effects of human-made pollution on the Earth's weather systems; the chemiluminescence experiments provided valuable evidence on chemical reactions in the upper atmosphere, and on the behaviour of atmospheric tides and winds; the ionospheric research contributed greatly to knowledge of layering in the ionosphere, while the various experiments to determine atmospheric composition helped to provide a unique determination of the atomic hydrogen density profile in the atmosphere.

The Australian sounding rocket program, conducted on the back of other missile research at Woomera was an outstanding achievement for its day, if much overlooked and forgotten by later generations.

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