

AD-A064 126

ATOMIC WEAPONS RESEARCH ESTABLISHMENT ALDERMASTON (EN--ETC F/G 1/3  
ZERO AND SUPERPRESSURE FREE FLIGHT BALLOONING, (U)  
DEC 78 R J BURGESS

UNCLASSIFIED

AWRE-0-61/78

DRIC-BR-66164

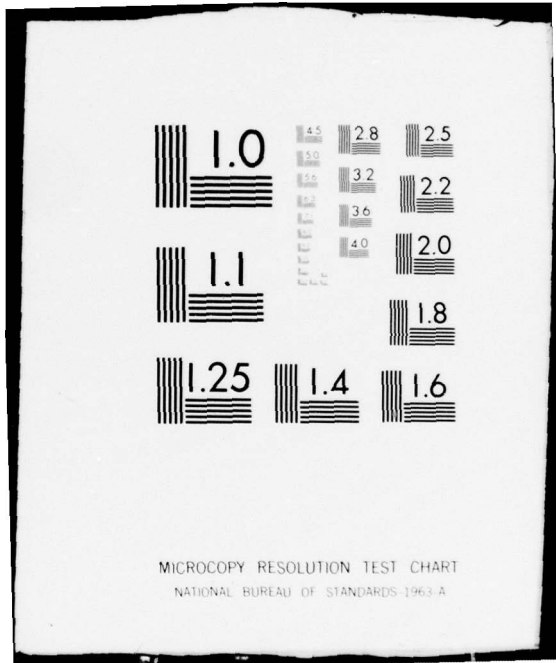
NL

| OF |

AD  
A064126



END  
DATE  
FILMED  
4-79  
DDC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

ADA 064126

DDC FILE COPY

UNLIMITED

LEVEL II

BR66164

AWRE O 61/78

①  
NW



PROCUREMENT EXECUTIVE - MINISTRY OF DEFENCE

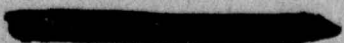
AWRE REPORT No. O 61/78

Zero and Superpressure Free Flight Ballooning

R J Burgess

DDC  
RECEIVED  
FEB 2 1979  
D

Available from H.M. Stationery Office



UNLIMITED

AWRE,  
Aldermaston, Berks.

December 1978

79 01 26 00

© Controller, Her Majesty's Stationery Office, London - 1978



ADMISSION TO	
DTIS	White Section <input checked="" type="checkbox"/>
DDO	Defn Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	AVAIL. and/or SPECIAL
A	

UNLIMITED

**LEVEL II**

(1)

Procurement Executive - Ministry of Defence

AWRE, Aldermaston

AWRE REPORT NO. 061/78

14 AWRE-0-62/78

6 Zero and Superpressure Free Flight Ballooning,

10 R J/Burgess

11 Dec 78

18 DRIC

19 BR-66164

12 26p.

Recommended for issue by

R A Addison, Superintendent

Approved by

J E Potter, Senior Superintendent

DDC  
 RECEIVED  
 FEB 2 1979  
 RECEIVED  
 D

1  
 UNLIMITED

JCB

046 650

79 01 26 067

CONTENTS

	<u>Page</u>
1. INTRODUCTION	4
PART 1: ZERO PRESSURE BALLOON FLYING	5
2. THEORY AND TERMS USED IN BALLOON FLYING	5
3. GAS DATA	5
4. THE ZERO PRESSURE BALLOON	5
5. FLIGHT TRAIN	6
5.1 Ten centimetre radar reflector	6
5.2 Undrawn nylon	6
5.3 Command cutter, clock cutter and small parachute	6
5.4 Main parachute	7
5.5 Payload	7
6. SIZE OF BALLOON	7
7. FREE LIFT	7
8. SIZE OF MAIN PARACHUTE	8
9. FACILITIES	8
10. WEATHER	8
11. LAUNCH PLATFORM	9
12. PREPARATION OF BALLOON AND EQUIPMENT	9
12.1 Balloon	9
12.2 Radar reflector	10
12.3 Undrawn nylon	10
12.4 Command cutter, clock cutter and small parachute	10
12.5 Main parachute	10
12.6 Main payload	11
13. INFLATION	12
14. LAUNCH	12
15. FLIGHT	13
16. CONCLUSION	13

CONTENTS (CONT.)

	<u>Page</u>
PART 2: SUPERPRESSURE BALLOON FLYING	14
17. PURPOSE	14
18. HOW IT WORKS	14
19. MATERIALS	14
20. COST OF BALLOONS	14
21. METEOROLOGICAL CONDITIONS	15
22. FREE LIFT OR SUPERPRESSURE	15
23. BALLAST	15
24. MEASURING GAS	16
25. A FLIGHT CALCULATION	16
26. INFLATION AND LAUNCH	17
27. CONCLUSION	17
FIGURES 1 - 8	18

1.        INTRODUCTION

↙ During the years 1959 to 1975 AWRE maintained a small team which, in cooperation with other agencies and Universities, procured, launched and controlled a large number of free flight balloons of many different types for many different purposes. Most of these flights had a purely scientific objective and were undertaken in support of University Departments, but some had application to the solution of very practical problems, for instance, those associated with the flight environment of the then projected CONCORDE aircraft.

The flights and their objectives were reported as they occurred. The purpose of this report is to place on record the technique for successful balloon flying which was developed over the years.

Two types of free flying balloon were used, each having a different function.

Zero pressure balloons had a capability of carrying 250 kg or less to 5 mb (118000 ft) and remaining at altitude for a maximum of 10 h. The payload was recoverable.

Superpressure balloons had a capability of carrying a much lighter payload (less than 10 kg) to 10 mb (100000 ft) with a possible flight time of many weeks. The payload is not normally recoverable. ↗



## PART 1: ZERO PRESSURE BALLOON FLYING

### 2. THEORY AND TERMS USED IN BALLOON FLYING

A balloon rises because of a differential displacement of air according to Archimedes principle which states that the total upward buoyant force is equal to the difference between the weight of gas and the weight of air displaced. This is defined as the gross lift. Since the balloon, gas and rigging have finite weight, the difference between the gross lift and the weight of the balloon, gas and rigging is defined as the net lift, and since the balloon is used to carry a payload, the difference between the net lift and the payload is defined as the free lift. It is this free lift which causes the balloon and its payload to rise, of course, and the amount of free lift determines the rate of ascent.

### 3. GAS DATA

The densities of air, hydrogen and helium at sea level at standard temperature and pressure are 0.0012929, 0.00008988 and 0.00017847 g cm<sup>-3</sup> respectively, hence the differential densities for hydrogen and helium are 0.0012030 and 0.0011144 g cm<sup>-3</sup> respectively, therefore, hydrogen has 8% more lift than helium for equal volume.

The advantages of using hydrogen as the lifting gas are the additional 8% extra lift gained, plus the cheapness of manufacture. Its disadvantage is its extreme flammability or, when mixed with air, its explosive nature. The advantage of using helium is that it is inert, but it achieves less lift and has high cost.

It is clearly safer to use helium particularly where a balloon has to be manhandled or if it is thought possible that the balloon will descend still containing gas.

This last possibility is remote with zero pressure balloons because, in normal operation when the payload is cut free, the balloon rises very rapidly, the gas expands at a greater rate than it can escape, pressure builds up and bursts the balloon and all the gas is lost.

### 4. THE ZERO PRESSURE BALLOON

Most zero pressure balloons are naturally shaped or a close derivation from the natural shape. These balloons are designed to assume a natural shape when filled with gas at the floating altitude, and when inflated they look like inverted tear-drops. The balloon simply encloses the gas, therefore it experiences no circumferential stress at altitude (see figure 1). The balloons are made from tapered gores of 0.5 to 1 mil thick polythene heat sealed together. The seams that are formed are sealed with 30 mm wide polythene tape. These tapes converge at the top of the balloon and they are attached at the balloon bottom to an aluminium ring from which the payload is suspended. This system of tapes distributes the load stresses over the whole of the balloon, an arrangement that is particularly necessary for tear-drop balloons whose gores taper down

to a point at which the film alone could support very little weight. As the balloon rises the lifting gas expands until the balloon is completely inflated. At the floating altitude the balloon still has excess buoyancy or free lift and it continues to rise. If the balloon were closed, it would continue to rise until the expanding gas burst it. In order to prevent this happening, zero pressure balloons are left open at the bottom by means of polythene tubing about 1 m in diameter. The excess lifting gas is valved out through this tubing because of the pressure difference which exists between the inside and outside of the balloon. The balloon gradually loses excess buoyancy and settles down at the calculated altitude. Because there is no pressure difference between the inside and the outside of the balloon when it has levelled off, no air flows into it to contaminate the lifting gas except by diffusion. Changes in design to improve the performance of these balloons are constantly made. The balloons that are in current use are slightly indented at the top so that the shape resembles that of a heart rather than an inverted tear-drop. Tetrahedron-shaped balloons were also used with success. Their advantage is cheapness of manufacture, but their size is limited because of the difficulty of inflating and launching them.

5. FLIGHT TRAIN (SEE TYPICAL FLIGHT RECORD, FIGURE 2)

The balloon lifts the "flight train" which comprises the following units, starting with the unit nearest to the balloon and then in descending order.

5.1 Ten centimetre radar reflector

The flying licence requires that the position of the balloon is known at all times. Reflectors are carried so that the balloon can be tracked by service and civilian radar. Also by tracking its descent fixes the payload landing area.

5.2 Undrawn nylon

This is a form of shock absorber and it is described in section 12.3.

5.3 Command cutter, clock cutter and small parachute

The command cutter is a means of cutting the main flying cable by a signal transmitted by the ground station to a command receiver in the main payload and re-directed to the command cutter by cable.

The clock cutter is a secondary means of cutting the main flying cable in the event of a failure of the command cutter. The time set on the clock is generally the maximum time of flight consistent with the payload descending on land so that it can be recovered. This period of time has to be calculated from the meteorological forecast.

The small parachute is capable of supporting a 4 kg load, this being the weight of the two cutters in their boxes. When these cutters return to earth with the main payload, since they are above the main parachute and would lie on top of the parachute canopy, they would distort it. This is prevented by using a small parachute.

#### 5.4 Main parachute

The main parachute is to land the payload at less than  $6 \text{ m s}^{-1}$ . The sizes vary from 8 to 13 m in diameter according to the weight of the payload.

#### 5.5 Payload

The payload comprises the scientific instruments and command receiver. For flights in the UK its weight is restricted to less than 250 kg.

#### 6. SIZE OF BALLOON

The standard size of balloon used is  $42000 \text{ m}^3$  ( $1500000 \text{ ft}^3$ ). Occasionally a  $55600 \text{ m}^3$  ( $2000000 \text{ ft}^3$ ) unit is used. The inflated diameter of a balloon is 50 m (160 ft) and it weighs from 120 to 140 kg (250 to 300 lb). The deflated length of the balloon is around 76 m (250 ft). Such a balloon has a capability of lifting 200 kg to 5 mb (at 117000 ft). The size of balloon required to lift a given payload to a given altitude can be obtained from graphs issued by the various balloon manufacturers. An example is given in figure 1. In order to calculate the size, the following equation can be used:-

$$W = 0.2965 \frac{PV}{T},$$

where  $W$  = gross weight in kilograms,  
 $0.2965^*$  = function of difference between density of air and helium,  
 $P$  = atmospheric pressure in millibars,  
 $T$  = temperature at altitude in degrees Kelvin (ie,  $^{\circ}\text{C} + 273$ ),  
 $V$  = volume of balloon in cubic metres.

#### 7. FREE LIFT

The rate of ascent of the balloon is controlled by the free lift. In practice we calculate the free lift from the equation

$$V = \frac{K\sqrt{A}}{\sqrt[3]{A + B + C}},$$

where  $V$  = rate of rise in feet per minute,  
 $A$  = free lift in kilograms,  
 $B$  = weight of balloon in kilograms,  
 $C$  = weight of payload plus train in kilograms,  
 $K$  = constant depending on the shape of the balloon (1100 for a heart-shaped balloon).

The above equation uses both metric and imperial units and it is a simplified version of a more complex equation for use in the field.

The rate of ascent is very important, too slow a rate and the balloon will slow down and could come to a stop at the tropopause, too

---

\*For hydrogen use 0.3173.

fast a rate and the balloon will overshoot on reaching altitude, spilling a greater volume of gas than that equal to the free lift and from then on the balloon will gradually descend.

The rate of ascent should be between 4 and 4.5 m s<sup>-1</sup> (800 and 900 ft min<sup>-1</sup>).

#### 8. SIZE OF MAIN PARACHUTE

Standard parachutes manufactured by Irvin Great Britain Ltd, Letchworth have been used, which varied in diameter from 8 to 13 m according to the weight of the payload. The parachute is flown in a streamed condition.

For any given payload weight the size of parachute required can be calculated from

$$W = KV^2d^2,$$

where W = weight of payload in pounds,  
V = landing speed in feet per second (normally less than 20 ft s<sup>-1</sup>),  
d = diameter of parachute in feet,  
K = constant = 0.7 × 10<sup>-3</sup>.

#### 9. FACILITIES

The ideal venue for balloon facilities is the RAE Establishment at the RAF Station, Cardington, Bedford. A large hangar is available for storing all equipment and it is capable of storing an inflated balloon should the need arise. Gas supplies are available from 217 Maintenance Unit on site. Accommodation for the ground station and flight control is readily available and concrete roads give access to the launching sites.

Since the ground station and flight control are mounted in caravans, which leads to mobility, flights can take place anywhere in the UK provided that the area is large enough so that the balloon on ascent would clear the surrounding obstacles and the ground is hard enough to allow the launch platform to be towed across it. This mobility allows flights to be made all the year round.

#### 10. WEATHER

As with all types of balloon flying, the most important controlling factor is the weather. Some of the restrictions that are imposed and controlled by the weather are as follows:-

(a) The type of launch system AWRE normally use can only be carried out in winds of 5 knots or less. Another system known as the anchor line launch could be used to enable a launch to take place in surface winds of up to 8 knots. The conditions when the wind speeds are lowest are generally around dawn.



(b) The flying licence states that no air lane may be entered at an altitude of less than 50000 ft.

(c) At altitudes greater than 70000 ft the wind in the summer always blows from east to west and from west to east during the winter, at varying velocities.

(d) When ready to fly, a weather forecast has to be obtained daily. The anticipated balloon flight path, using the proposed rate of ascent, the duration of the flight and the descent path by parachute, is plotted on a map showing the air lanes. The forecast surface conditions are also considered.

#### 11. LAUNCH PLATFORM (FIGURES 5 AND 6)

As previously mentioned, the standard size of balloon used was  $42000 \text{ m}^3$ , and it had a deflated length of some 76 m and the total area of the  $\frac{3}{4}$  mil (0.00075 in.) polythene film was approximately 1 hectare (or  $2\frac{1}{2}$  acres). Such a bulk of polythene presents a considerable problem in handling and launching without damage. These problems have been overcome by the development by Bristol University of a launch platform which is a combined bed containing the very carefully folded balloon and a weighing machine. The weighing machine enables the lifting gas to be measured by weight. The platform is mounted on pneumatic-tyred wheels so that it can be towed and positioned on the launch site, which could be a grass field.

The appropriate amount of gas at launch will only occupy about 1% of the total volume of the balloon. This means a large amount of uninflated balloon has to be launched before the payload is picked up. This in turn means that the acceleration of the gas bubble and uninflated portion of the balloon would be so great that the bottom of the balloon would be torn out when the payload came to be picked up. A means of slowing the rate of acceleration had to be devised. This was accomplished by fitting a canopy which flies with the balloon over the gas bubble. The canopy is attached by cords to four drums mounted on the launch platform. The length of these cords is 0.8 of the total length of the uninflated portion of the balloon. These cords are wound on to the aforementioned drums. The drums are mounted on two shafts each mounting a flywheel. On launch the inertia of the flywheels restricts the rate of ascent of the balloon so that, at the time of payload pick up, the shock is acceptable to the balloon.

#### 12. PREPARATION OF BALLOON AND EQUIPMENT

Starting with the preparation of the balloon, the flight train equipment is dealt with in descending sequence as shown in the following sections. Knots are used extensively and they should be over-taped with 1 in. wide white linen adhesive tape to prevent any chance of a knot coming undone.

##### 12.1 Balloon

The launch platform is levelled on its jacks and the weighing machine is zeroed.

The balloon is carefully layered or flaked on to the launch platform, making sure that it is the right way round. Some manufacturers pack the balloon with the bottom at the top of the packing case, whereas others pack it the other way round.

The balloon is strapped to the launch platform at a position low enough down the balloon so that the gas bubble can be contained above the strap.

Four equal groups of canopy leaves are tied off after cutting the individual leaves to a length that, when tied together and the balloon filled with gas, the tension is distributed equally among them. The leaves are tied together with a thumb knot and tape. The thumb knots are then tied to the four cords that have been cut to 0.8 of the length of the uninflated portion of the balloon. These canopy cords are wound on to the drums on the launch platform until the canopy leaves are 15 cm from the feed tubes.

#### 12.2 Radar reflector

The reflector is taped to a convenient length of main flying cable, using 1 in. white linen adhesive tape. The flying cable is terminated in a shackle and then it is weighed.

#### 12.3 Undrawn nylon

A feature of undrawn nylon cord is that, when subjected to tension, it stretches more or less in linear fashion to considerably more than (double) its original length. This characteristic is used as a shock absorber between the balloon and the payload, enabling the payload to be picked up gently. The breaking strain of one strand of the undrawn nylon is 90 kg and the working load is 45 kg. The weight of the payload divided by 45 will give the number of strands to be used. Each strand should be 25 m long. These strands are layered into a compartmented polythene dispenser, with each strand terminated in an eye splice at each end, and all strands are attached to one thimble, shackled at each end, and then weighed.

#### 12.4 Command cutter, clock cutter and small parachute

An appropriate length of main flying cable is passed through the two boxes and cutters, both ends being terminated in an eye. One 4.5 V battery in each box is clamped securely and terminals are connected by soldering. The parachute is checked and then the assembly is weighed.

#### 12.5 Main parachute

Having selected the appropriate size, the aluminium shroud line ring is taped into position with white linen adhesive tape. Each individual shroud line is taped to this ring at equidistant spacing to prevent the shroud lines becoming entangled. The main flying cable is reeved through the centre of the parachute when the parachute is lying fully extended. The shackle is attached to the eye at the bottom of the

parachute and secured. The main flying cable is secured to this shackle by a clove hitch and two half hitches, and then it is again taped. The shackle is attached to the top of the parachute; a flying cable is attached to this shackle in a similar manner to the lower shackle. The length of this flying cable from the bottom shackle to the top shackle should be 1 m less than the total length of the extended parachute. A two-core electric cable connecting the command receiver in the payload to the command cutter above the parachute is also reeved through the parachute. This cable is external to the canopy and is taped at intervals down one of the shroud lines. Besides allowing at each end of the parachute sufficient length of two-core cable to reach the command receiver and the command cutter respectively, a further 20% in length of cable than the extended parachute is required to allow for the stretch of the main flying cable. This 20% must be evenly spaced between taping. The assembly is then weighed.

#### 12.6 Main payload

In principle this is the responsibility of the experimenter, but the following must be established if it is safe to fly:-

- (a) Suitability for handling.
- (b) Adequacy of withstanding the launch and landing shocks.
- (c) Safety of the launching crew.
- (d) Security of assembly (even small items falling from high altitudes can be lethal).

It will also have to be decided, in consultation with the experimenter, as to whether the payload can be picked up straight from the ground or whether it will require suspending at the time of launch. The payload is rigged accordingly, ensuring that, on launch, it is correctly suspended in a vertical position. Practical experience indicates that the experimenter's stated payload weight is unlikely to be accurate at the time of flight. It is therefore essential that the weight be verified, as late as possible before launch, by the launch team leader. The experimenter probably has a team of several people working on the payload right up to the time of launch, each one doing a specified job. For example, one particular error at the time of weighing is that the electrical supply is being taken from the mains while the batteries are on charge until the last minute. There is no indication by looking at the payload whether the batteries are in position and there could be more than one set of batteries in use. A set of batteries often weighs about the equivalent of the free lift. Another example of error is that, up to the last minute, parts might have been removed for testing and for adjusting the equipment. The senior experimenter must go through a check list and assure the launch leader that everything is in order for launching. Earlier it has been said that the free lift equation was for use in the field, even during the inflation of the balloon, weights are being altered and the free lift is being continuously corrected.



13. INFLATION

Having obtained the weights of the flight train and payload, the required free lift is calculated. In order to simulate the weights of the flight train and payload, certified 25 kg weights are placed on the launch platform, the number of weights being the multiple of 25 kg to that number below the total weight of flight train and payload. The difference (payload plus train) - (25 × number of weights) is added to the free lift. This weight is set up on the vernier balance arm adjustment of the machine.

The top inflation sleeve of the balloon is connected to the gas supply and inflated until the top of the balloon and the canopy are slightly raised. The top inflation sleeve is disconnected and sealed. The gas supply to the lower inflation sleeve is connected and the balloon is inflated until the balance arm of the weighing machine moves to neutral. The inflation can take place some hours before the launch if it is done in the hangar at Cardington. This gives the gas time to reach ambient temperature, a check to be made to see if the balloon is leaking and final adjustments to be made to the free lift at the last minute. If inflation takes place in the open, the gas may require pre-heating to ambient by passing it through hot water as the balloon should be launched as soon after inflation as possible.

14. LAUNCH

If inflation has taken place in a hangar, the flight train and payload should be prepared ready for launch before the balloon is brought out. If the inflation is to take place in the open, the flight train and payload should be made ready before inflation if possible.

Before the flight train can be laid out, the direction and speed of the wind has to be ascertained. For launch, the payload is placed downwind from the balloon so that when it picks up the payload the balloon should be directly overhead. The speed and direction of the wind is ascertained by inflating 100 g meteorological balloons with gas to give the same rate of rise as the main balloon. Four or five balloons are generally required. These balloons are released one at a time during various stages of preparation to see if the wind speed and direction remain constant. Unfortunately, the lighter the wind, the less stable the direction becomes, altering as much as 60° in 5 min.

Because of the length of balloon plus flight train 20 to 30 s elapse from the time the balloon is released to the time of pick up of the payload. If the wind is 5 knots, the balloon will travel horizontally nearly 80 m which is the maximum possible distance between the balloon on the platform and the payload. If the wind is less, the payload and balloon can be brought closer together.

As the optimum conditions for launch generally exist around dawn, the first and possibly the second meteorological balloon will have to be launched in the dark and tracked by eye for 30 s, by which time the balloon has reached an altitude of 120 to 150 m. Three



people are generally necessary to do this, one to launch the meteorological balloon from a position which is suitably marked for the launch of the main balloon, another downwind to where the package is expected to be picked up and the third to time the flight, shouting out the time so that the second man can hear him. The second man tries to keep track of the balloon, endeavouring to be immediately underneath the meteorological balloon at the termination of the count. This may need more than one meteorological balloon. The position of the second man standing under the meteorological balloon at the termination of the count is the position of the payload at time of pickup. Care should be taken not to lose these positions in the dark.

A sheet of polythene is spread between these two marked positions. On this sheet the flight train is laid out (if laid direct on the ground, the parachute and undrawn nylon picks up moisture which could add up to a significant additional weight).

The payload is positioned and connected to the bottom of the parachute. The electric cable is connected to the command receiver and the command cut down. Having decided the maximum duration of flight, the timer in the clock cutter is set.

Another meteorological balloon is launched and, if necessary, the flight train is moved on its polythene sheet relative to the payload. The main balloon is positioned and shackled to the radar reflector. The final meteorological balloon is launched. The main balloon and the flight train is re-positioned relative to the payload if required and then it is launched.

15.        FLIGHT

During flight the balloon's path is plotted from information given from the radar and the location beacon in the payload. The balloon during ascent would travel towards the East Coast, and after about 90 min (at 75000 ft) it would change direction to the west, overflying the air lanes, to mid to North Wales. By following the plot, a decision has to be made when to cut the payload down, avoiding landing in built-up areas. It takes about 60 min for the payload to descend. When the payload has been located, it has to be recovered. The payload is marked with an address and telephone number and a reward is offered (£5) to the first person to telephone its location to the control room.

16.        CONCLUSION

Because of the multiple air lanes crossing the UK and the limitation of 5 knots maximum wind speeds, opportunities for flying are not as good as say in Australia, but a flying programme has been maintained for a number of years. The development of other launch techniques would increase the maximum wind permissible in which launching can take place.

## PART 2: SUPERPRESSURE BALLOON FLYING

### 17. PURPOSE

AWRE were required to float a balloon at a specified level of air density to determine what trajectory the air took at this specified density. The balloon was to carry a payload which included a sun sensor. This sensor signalled the angle of the sun to a ground station. From this information the balloon's position could be plotted and so the position of that specific parcel of air could be ascertained. The duration of such a flight was to be at least ten days. The density levels were to be between 200 and 400 mb.

### 18. HOW IT WORKS

A superpressure balloon is a non-extensible balloon which is sealed to prevent gas escaping. The balloon is filled with a measured amount of gas which creates sufficient free lift to reach the desired altitude. As the balloon rises the gas expands to a point where it fills the balloon. At this point, since the gas can no longer expand, it converts the free lift to pressure. Since the mass of gas and the volume of air displaced are fixed, the balloon will float at a constant density altitude. Variations in radiation environment will cause changes in the balloon's pressure, but not in its volume. The pressure variation between the balloon at midday and midnight must be less than the superpressure to maintain altitude. Free lift is superpressure so the measurement of free lift is very important, because if it is a little too much, the balloon will burst. The longest flight duration to date is better than 1100 days.

### 19. MATERIALS

The ideal material for such a balloon would be impermeable to the lifting gas, transparent to the entire spectrum of radiation, experience no volume change due to pressurization and survive manhandling. Unfortunately, such a material does not exist. Reasonable success has been obtained by using a laminated polyester film, polyethylene terephthalate manufactured under a trade name mylar. This film has a modulus of elasticity in excess of 500000 psi at float conditions and therefore the very small variation in volume is acceptable. The material is reasonably transparent to radiation and reasonably impermeable to helium. As a laminate it becomes easier to handle but it is still rather delicate.

### 20. COST OF BALLOONS

To be able to cover any density level between 200 to 400 mb, three sizes of balloons were needed (3.0, 3.2 and 3.7 m). Superpressure balloons were manufactured both in France and America. Those used by AWRE were purchased from Zodiac-Espace of France (after being quoted from both sources). The balloons were made from mylar bi-laminate, each film being 23  $\mu$ m thick. Costs in early 1974 were as follows:-

3.0 m diameter balloon	£576 each
3.2 m diameter balloon	£641 each
3.7 m diameter balloon	£693 each

The cost of packing and transportation, which was considered to be high, is included in the prices shown above.

21. METEOROLOGICAL CONDITIONS

Surface wind conditions at the time of launch should be less than 10 knots. This is to prevent damage to the balloon while handling. A launch can take place in a 20 knot wind provided that the balloon is inflated in some shelter. A ship is an ideal launch platform as it can be sailed to give optimum conditions. Any moisture will adhere to the balloon and be absorbed by the parachute, etc. This weight of moisture could easily become greater than the free lift, which would bring the balloon down. Also moisture will freeze on ascent, thus shortening the lifetime of the balloon. Therefore dry conditions are required at launch and an ascent through cloud should be avoided. Balloons having a float altitude of greater than 300 mb will be above any cloud. Balloons floating below 300 mb are liable to pick up ice from high cumulus cloud and thus be brought down.

22. FREE LIFT OR SUPERPRESSURE

Free lift in the terms of a superpressure balloon is measured as a percentage of the pressure at which the balloon is required to float. A balloon required to float at 300 mb with 10% free lift will have a superpressure of 30 mb. Manufacturers have recommended superpressures of between 10 and 20%. This has been calculated to be high, inasmuch as it is near the actual bursting pressure, and from experience, 8% superpressure was adopted. This 8% gives a slow rate of ascent. To assist the ascent rate of the smaller balloons, a small inflated extensible balloon is attached to the superpressure balloon, the small extensible balloon providing extra free lift and it is so inflated that it will burst at a much lower altitude than the float altitude. Therefore on launch the balloon will fairly quickly clear any obstructions that are in the vicinity, such as a ship's superstructure. An example of the introduction of free lift as a volume of gas is given later.

23. BALLAST

Balloons and the payloads vary in weight. The gross weight when flying a superpressure balloon is critical. In order to correct the variations in balloon and payload weights, and also the variations in altitude requirements, balloons are capable of carrying a greater weight than the payload. Ballast is used to make up the difference between the payload weight and this greater weight. This ballast takes the form of sand and is carried in a polythene bag. The ballast is carried as close to the balloon as possible to minimise oscillation.

24. MEASURING GAS

If an inflation can take place under cover, gas can be measured by weighing. Most inflations, however, take place in the open air and this precludes such a method because of wind on the balloon, etc. This means that gas has to be metered from a reservoir by pressure drop and temperature. This can be calculated as follows:-

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$

where  $P_1$  = pressure drop in reservoir in millibars,  
 $V_1$  = volume of reservoir in cubic metres,  
 $T_1$  = temperature of reservoir in degrees Kelvin,  
 $P_2$  = float level pressure of balloon in millibars,  
 $V_2$  = volume of balloon in cubic metres,  
 $T_2$  = temperature at float level in degrees Kelvin.

25. A FLIGHT CALCULATION

The following are data from an actual flight which was used to illustrate the method used for calculations.

The flight requirement was to float a package at 300 mb.

From the flight requirement the best balloon for that altitude is 3.2 m diameter.

Using the equation  $W = 0.2965(PV/T)$  we get

$$\frac{300 \text{ mb} \times 17.29 \text{ m}^3}{237^\circ\text{K}} \times 0.2965 = 6.489 \text{ kg gross weight.}$$

The balloon and all items in the flight train are now weighed:-

Balloon	2.565 kg
Instrument package	1.926
Parachute	0.237
Cut down device	0.210
Cordage	0.030
	<hr/>
	4.968 kg
	<hr/>
Gross lift	6.489 kg
Balloon plus flight train	4.968
	<hr/>
<u>Ballast required</u>	1.521 kg
	<hr/>

Using the formula

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$



calculate the pressure drop in the reservoir as follows:-

$$\frac{25738 \text{ mb} \times 0.270 \text{ m}^3}{294^\circ\text{K}} = \frac{(300 \text{ mb} \times 1.08) \times 17.29 \text{ m}^3}{237^\circ\text{K}}$$

In order to convert 25738 mb to psi, divide by 68.9476,

$$= 373 \text{ psi at } 21^\circ\text{C}.$$

26. INFLATION AND LAUNCH

The reservoir must be charged at least 4 hours before inflation to allow the gas temperature to equalise with the ambient temperature. The flight train is prepared in order from the balloon downwards:-

Ballast.

Cut down device.

Parachute.

Instrument package with dipole aerial.

The instrument package has to be of sufficient distance below the balloon so that the sun at its zenith does not cause the balloon to overshadow the sun sensor in the instrument package. Also the package must be suspended absolutely vertically and horizontally, or incorrect sun sensor readings will be given.

Having completed the flight train preparation, the balloon is unpacked and laid out on a tarpaulin. The load ring is tied to a suitable anchorage. The balloon is inflated and when the pressure in the reservoir has dropped to the required psi, the gas is turned off. The pressure indicated on the gauge with the gas turned off will rise. Turn the gas on again until the required pressure is attained and then turn it off. The flight train is connected to the balloon load ring, the load ring is disconnected from the ground anchorage, and the assembly is launched.

When launching from a ship, the ship is sailed so that the balloon travels over the side of the ship away from the ship's superstructure.

27. CONCLUSION

In 1968, under the Hamm project, AWRE flew a 66 ft diameter balloon carrying 5 kg to 10 mb from England to Canada. The possibility of flying 100 kg at 5 mb circumnavigating the earth many times is nowadays well within the state of the art.

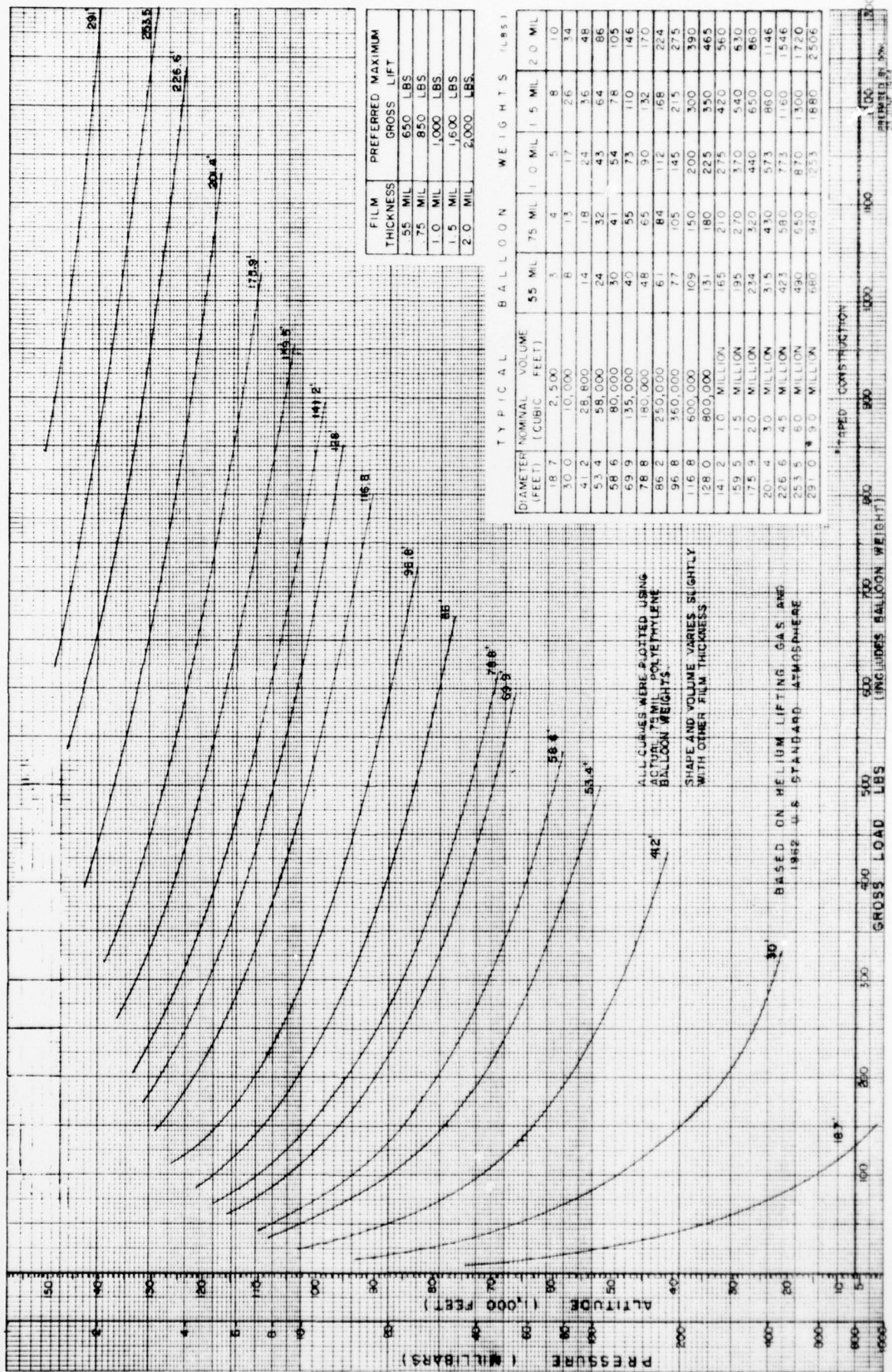


FIGURE 1. LOAD VERSUS ALTITUDE FOR RAVEN TAPELESS POLYETHYLENE BALLOON

PLATFORM ZERO 99

	<u>NOTES</u>	<u>WEIGHT kg</u>
BALLOON	1.5 MILLION ft <sup>3</sup>	139.0
RADAR REFLECTOR		1.5
UNDRAWN NYLON	4 x 25 m	1.5
SMALL PARACHUTE COMMAND CUTTER CLOCKS		1.75
SEARCH & RECOVERY BEACON		2.25
MAIN PARACHUTE	32 ft DIAMETER	9.0
PAYLOAD inc 10kg BALLAST		134.0
	TOTAL	289.0
	FREE LIFT	30.0

LAUNCHED	:	CARDINGTON, BEDS
LAUNCH TIME	:	08.47 hours
RATE OF ASCENT	:	800 ft min <sup>-1</sup>
ALTITUDE REACHED	:	115000 ft
CUTDOWN TIME	:	16.17 hours
LANDING	:	GREAT HOUSE, FARM, LLANLLYWEL, U.S.K
RECOVERY	:	BY BRISTOL UNIVERSITY

FIGURE 2. TYPICAL FLIGHT RECORD

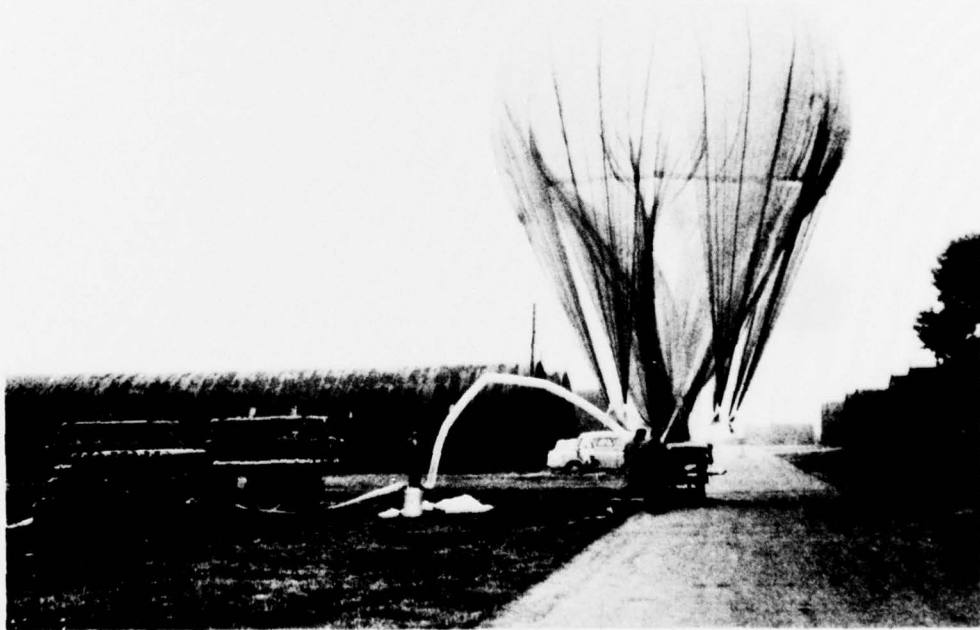


FIGURE 3. INFLATING IN OPEN AIR



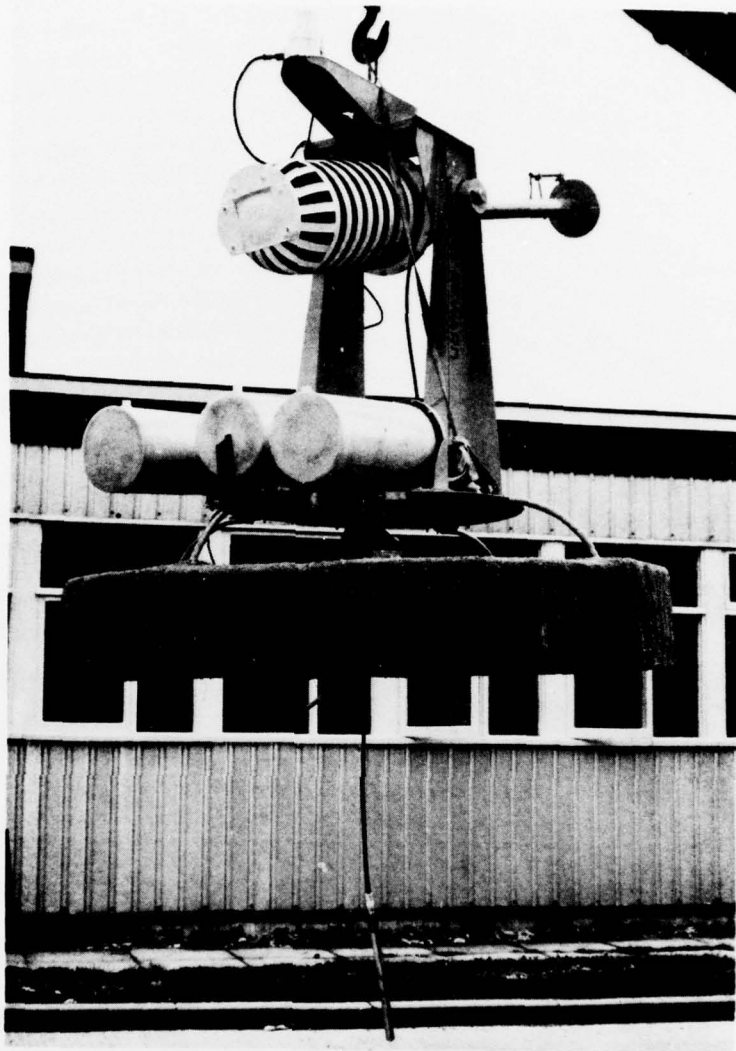


FIGURE 4. PAYLOAD

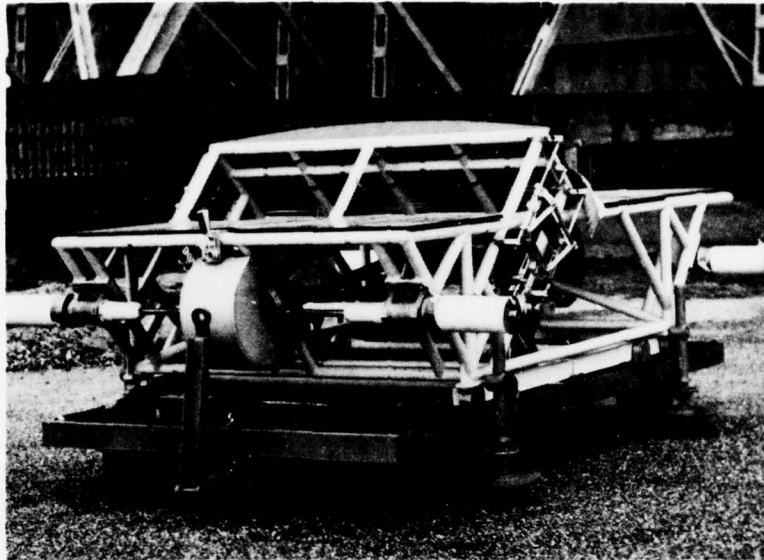


FIGURE 5. SMALL LAUNCH PLATFORM



FIGURE 6. LARGE LAUNCH PLATFORM

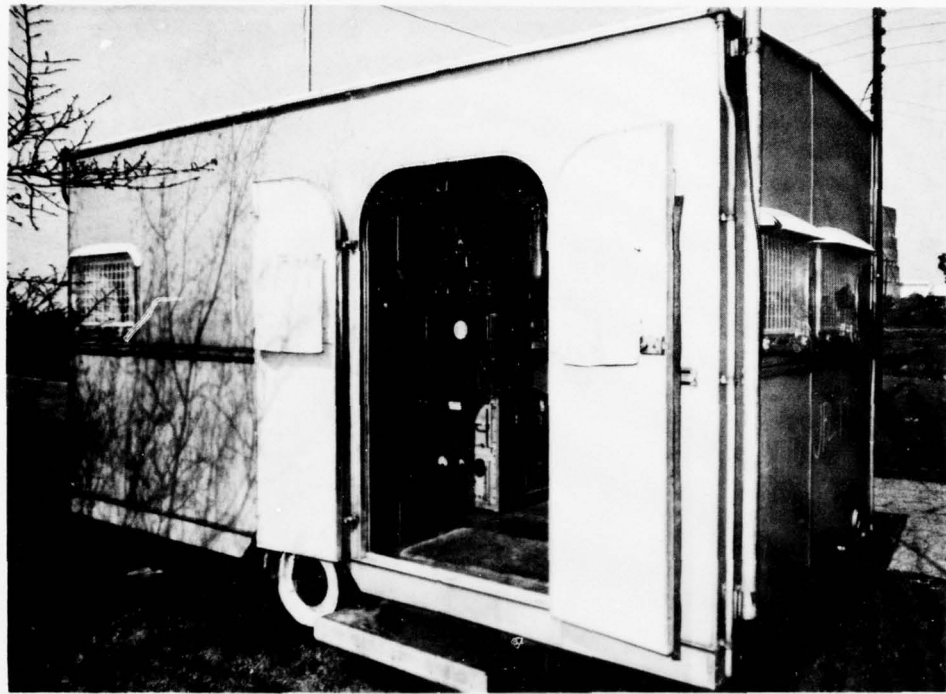


FIGURE 7. GROUND STATION



FIGURE 8. CONTROL ROOM

## DOCUMENT CONTROL SHEET

Overall security classification of sheet ..... Unclassified .....

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R), (C) or (S)).

1. DRIC Reference (if known) -	2. Originator's Reference AWRE Report No. 061/78	3. Agency Reference -	4. Report Security Classification UNLIMITED
5. Originator's Code (if known) -	6. Originator (Corporate Author) Name and Location Atomic Weapons Research Establishment, Aldermaston, Berkshire		
5a. Sponsoring Agency's Code (if known) -	6a. Sponsoring Agency (Contract Authority) Name and Location -		
7. Title Zero and Superpressure Free Flight Ballooning			
7a. Title in Foreign Language (in the case of Translation) -			
7b. Presented at (for Conference Papers). Title, Place and Date of Conference -			
8. Author 1. Surname, Initials Burgess R J	9a. Author 2 -	9b. Authors 3, 4 .... -	10. Date pp ref December 1978 24 -
11. Contract Number -	12. Period -	13. Project -	14. Other References -
15. Distribution Statement No restriction			
16. Descriptors (or Keywords) (TEST) Balloons			
<p><b>Abstract</b> The flights and their objectives were reported as they occurred. The purpose of this report is to place on record the technique for successful balloon flying which was developed over the years.</p> <p>Two types of free flying balloon were used, each having a different function.</p> <p>Zero pressure balloons had a capability of carrying 250 kg or less to 5 mb (118000 ft) and remaining at altitude for a maximum of 10 h. The payload was recoverable.</p> <p>Superpressure balloons had a capability of carrying a much lighter payload (less than 10 kg) to 10 mb (100000 ft) with a possible flight time of many weeks. The payload is not normally recoverable.</p>			



Some Metric and SI Unit Conversion Factors

(Based on DEF STAN 00-11/2 "Metric Units for Use by the Ministry of Defence",  
DS Met 5501 "AWRE Metric Guide" and other British Standards)

Quantity	Unit	Symbol	Conversion
<u>Basic Units</u>			
Length	metre	m	1 m = 3.2808 ft 1 ft = 0.3048 m
Mass	kilogram	kg	1 kg = 2.2046 lb 1 lb = 0.45359237 kg 1 ton = 1016.05 kg
<u>Derived Units</u>			
Force	newton	$N = \text{kg m/s}^2$	1 N = 0.2248 lbf 1 lbf = 4.44822 N
Work, Energy, Quantity of Heat	joule	$J = \text{N m}$	1 J = 0.737562 ft lbf 1 J = $9.47817 \times 10^{-4}$ Btu 1 J = $2.38846 \times 10^{-4}$ kcal 1 ft lbf = 1.35582 J 1 Btu = 1055.06 J 1 kcal = 4186.8 J
Power	watt	$W = \text{J/s}$	1 W = 0.238846 cal/s 1 cal/s = 4.1868 W
Electric Charge	coulomb	$C = \text{A s}$	-
Electric Potential	volt	$V = \text{W/A} = \text{J/C}$	-
Electrical Capacitance	farad	$F = \text{A s/V} = \text{C/V}$	-
Electric Resistance	ohm	$\Omega = \text{V/A}$	-
Conductance	siemen	$S = 1 \Omega^{-1}$	-
Magnetic Flux	weber	$\text{Wb} = \text{V s}$	-
Magnetic Flux Density	tesla	$T = \text{Wb/m}^2$	-
Inductance	henry	$H = \text{V s/A} = \text{Wb/A}$	-
<u>Complex Derived Units</u>			
Angular Velocity	radian per second	rad/s	1 rad/s = 0.159155 rev/s 1 rev/s = 6.28319 rad/s
Acceleration	metre per square second	$\text{m/s}^2$	1 $\text{m/s}^2 = 3.28084 \text{ ft/s}^2$ 1 $\text{ft/s}^2 = 0.3048 \text{ m/s}^2$
Angular Acceleration	radian per square second	$\text{rad/s}^2$	-
Pressure	newton per square metre	$\text{N/m}^2 = \text{Pa}$	1 $\text{N/m}^2 = 145.038 \times 10^{-6} \text{ lbf/in}^2$ 1 $\text{lbf/in}^2 = 6.89476 \times 10^3 \text{ N/m}^2$
	bar	$\text{bar} = 10^5 \text{ N/m}^2$	-
Torque	newton metre	$\text{N m}$	1 in. Hg = 3386.39 $\text{N/m}^2$ 1 $\text{N m} = 0.737562 \text{ lbf ft}$ 1 $\text{lbf ft} = 1.35582 \text{ N m}$
Surface Tension	newton per metre	$\text{N/m}$	1 $\text{N/m} = 0.0685 \text{ lbf/ft}$ 1 $\text{lbf/ft} = 14.5939 \text{ N/m}$
Dynamic Viscosity	newton second per square metre	$\text{N s/m}^2$	1 $\text{N s/m}^2 = 0.0208854 \text{ lbf s/ft}^2$ 1 $\text{lbf s/ft}^2 = 47.8803 \text{ N s/m}^2$
Kinematic Viscosity	square metre per second	$\text{m}^2/\text{s}$	1 $\text{m}^2/\text{s} = 10.7639 \text{ ft}^2/\text{s}$ 1 $\text{ft}^2/\text{s} = 0.0929 \text{ m}^2/\text{s}$
Thermal Conductivity	watt per metre kelvin	$\text{W/m K}$	-
<u>Odd Units*</u>			
Radioactivity	becquerel	Bq	1 Bq = $2.7027 \times 10^{-11} \text{ Ci}$ 1 Ci = $3.700 \times 10^{10} \text{ Bq}$
Absorbed Dose	gray	Gy	1 Gy = 100 rad 1 rad = 0.01 Gy
Dose Equivalent	sievert	Sv	1 Sv = 100 rem 1 rem = 0.01 Sv
Exposure	coulomb per kilogram	C/kg	1 C/kg = 3876 R 1 R = $2.58 \times 10^{-4} \text{ C/kg}$
Rate of Leak (Vacuum Systems)	millibar litre per second	mb l/s	1 mb = 0.750062 torr 1 torr = 1.33322 mb

\*These terms are recognised terms within the metric system.

Available from  
**HER MAJESTY'S STATIONERY OFFICE**  
49 High Holborn, London W.C.1  
13a Castle Street, Edinburgh 2  
41 The Hayes, Cardiff CF1 1JW  
Brazenose Street, Manchester 2  
Southey House, Wine Street, Bristol BS1 2BQ  
258-259 Broad St., Birmingham 1  
80 Chichester Street, Belfast BT1 4JY  
or through any bookseller.

*Printed in England*

ISBN 0 85518127 3