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Brown, W. C.

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W.C. Brown

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SECRET

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

VISIT TO GOVERNMENT AND INDUSTRIAL LABORATORIES IN ENGLAND

W. C. BROWN

OTTAWA

JANUARY 1952

REPORT ON VISIT TO GOVERNMENT & INDUSTRIAL LABORATORIES IN ENGLAND

10 May to 20 June 1951

1. Purpose This visit to England was made in order to study first-hand the radar and guided weapon development effort, to discuss problems associated with the AA No. 4 Mk 6 and CB radars and to see how best to dovetail our work with that in the U.K.

2. List of Establishments visited

(a) Government Laboratories

T.R.E.	Malvern
R.R.D.E.	Malvern
R.A.E.	Farnborough
A.S.R.E.	Whitley
A.S.R.E.	Portsdown
S.E.R.L.	Baldock
A.G.E.	Teddington

(b) Industrial Establishments

Mullard	London
B.T.H.	Rugby
E.K. Cole	Malmsbury
Elliott Bros.	Boreham Wood
Fairey Aviation Co.	Hayes
English Electric Co.	Luton
E.M.I.	Feltham
G.E.C.	Stanmore
Ferranti	Manchester

3. Organization of Research and Development Work

(a) Guided Weapons

The guided weapon program is directed by Mr. G.H. Gardner of the Ministry of Supply. He and his assistant Dr. R.C. Knight direct the work of 15 experimental establishments in this field.

The use of industrial laboratories in the development of equipment is widespread in England and their facilities and skills are being used to the utmost in the guided weapon field.

Industrial groups are being used

(a) to expand the facilities of government experimental establishments.
(b) to design specialized components
(c) to develop and produce complete guided weapons.

In general the use of government laboratories is limited to the development of new techniques and ideas, assisting industry where their ability or facilities are superior or to provide assemblies such as telemetering equipment and test facilities which are common to many missile programs.

To ensure an integrated program of development it was agreed when the GW program started that the general supervision should be in the hands of one establishment - the Royal Aeronautical Establishment (RAE) at Farnborough was chosen.

All three services have weapons under development and the project leaders in each case are engineers from the service which will be the ultimate user. In this way the needs of the service are kept before the contractors and decisions can be quickly made. These project officers are responsible to the head of the Guided Weapons Dept., RAE - Mr. R.B. Morgan.

In the case of each missile one or more industrial firms were chosen as the development agencies. One of these firms, generally the aerodynamics specialists, was chosen as the prime contractor having overall authority for the development.

(b) Radar

Radar cannot properly be separated from the GW field as most of the radar development is keyed directly or indirectly to the missile development. As in the case of guided weapons the Ministry of Supply directs the program with development shared more equally between government and industrial laboratories. Most of the radar carried in missiles or involved in their guidance is being developed by the industrial contractors. On the other hand the development work on the large ground radars for the centralized control of missiles and on the associated "lamp sets" for beam-riding missiles is being undertaken in government laboratories. Even in the latter cases, however, close co-operation with the industrial firm that will produce the equipment is very evident.

4. General Notes on Guided Weapon Projects

(a) Classification by use

Guided weapons are conveniently classified as
air-to-air missiles (AAM)
surface-to-air missiles(SAM)
surface-to-surface missiles (SSM)
air-to-surface missiles (ASM)

Development in the U.K. is concentrated on the first two types, AAM's and SAM's, for they are fully aware of their vunerable location and consider defensive missiles of the utmost importance.

(b) Classification by method of guidance

The second commonly-used classification is by the method of guidance, namely:

(i) Beam rider -

A beam rider, as the name implies, carries only a receiver with a backward-looking pickup antenna coupled to suitable control surface actuators. The missile rides a radar beam to the target. The radar beam may be optically or electronically controlled.

(ii) Semi-active homing -

In this type of guidance advantage is taken of the large output of the existing radar to use the reflected energy from the target to guide the missile. Conical scanning receiving antennas are commonly used with the error signal resolved to provide steering signals to the control surfaces.

(iii) Fully-active homing -

Here there is no dependence upon the illuminating radar once the missile is launched. The missile contains a complete pulse or cw transmitter and receiver for directing it to the target.

Combinations of these systems are also possible and terminal guidance of the missile by sensitive infra-red detectors is also being considered.

For small air-to-air missiles the beam rider offers some advantages in that the missile equipment is light and relatively simple. In the simplest case optical direction of the beam from the aircraft is possible and is being used in one current project. Semi-active and beam riders restrict aircraft movement somewhat after launching. In the U.K. the emphasis is on beam riders and fully active pulse radar homing for AAM's.

For long range surface-to-air missiles beam riding or semi-active homing is preferred, advantage being taken of the high power, narrow beam radars feasible on the ground or on ships.

(c) Propulsion

At least sixteen missiles or test vehicles are being built in the U.K. Many systems of propulsion are being used to provide a background of experience as broad as possible.

For small short range missiles, JATO rockets or internal cordite charges are being used. Hydrogen peroxide and kerosene are the fuels in one large SAM, nitric acid and kerosene in another and a ramjet motor in a third.

In the case of test vehicles, liquid oxygen and alcohol, hydrogen peroxide and kerosene, ramjets and solid fuel rockets are in use.

5. Details of Specific Missiles

Air-to-Air Missiles

There are two missiles being developed for air-to-air application; both well illustrate the way in which the work of several firms is being integrated and supplemented by government laboratories.

(i) Blue Sky

"Blue Sky" is the code name of a beam rider for which Fairey Aviation Company is the prime contractor. They are developing the airframe, the guidance and the control equipment. The Plessey Company is assisting in the electronic instrumentation. The warhead is the responsibility of a government laboratory (C.E.A.D.); R.A.E. and E.M.I. are co-operating on the fuse and finally the aircraft radar is being developed by E.K. Cole in co-operation with T.R.E.

"Blue Sky" is intended for use in daylight rear attacks having a cone angle of ±15 degrees. It is a roll stabilized missile, $5\frac{1}{2}$ inches in diameter, 7 ft. long with the two side boosts lengthening this to 9 ft. The weight is 250 lbs. of which 140 lbs. is made up of the two boost rockets. It uses cruciform wings with a set of stabilizing fins separate from the elevators and rudders. The specified launching range is 3500 yards but the overall range of flight is about 8000 yards. The boosts are discarded automatically when the thrust developed reaches zero.

The controlling radar for this missile will eventually have an output of 50 kw on X band with 10 or 12 inch dish and an offset rotating dipole. The beam is optically laid by collimation with gyro stabilized gunsight.

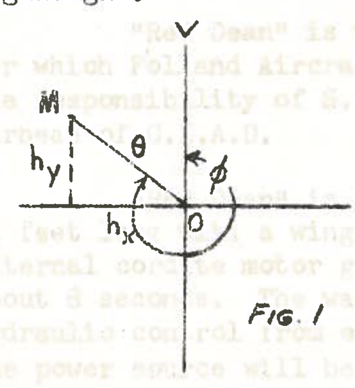


Fig. 1

A conical antenna to accept any polarization is fitted to the rear of the missile. In Fig. 1 let the axis perpendicular to the paper through O be that of the radar dish and assume the missile to be off axis at point M. Then the amplitude of the signal received will be modulated at the dipole spin rate and in the case of this missile the pattern is such that one degree misalignment results in a 10% amplitude modulation.

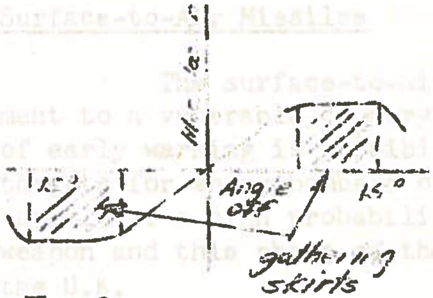


FIG. 2

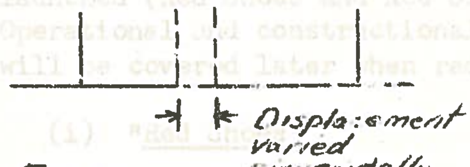


FIG. 3

The angular misalignment signal is multiplied in the missile by a time driven potentiometer to convert the error to displacement from the axis.

In order to resolve this information into displacement of the rudders and elevators the angular position Ø of the missile must be determined with respect to the vertical in Fig. 1. This is accomplished ingeniously by displacing every alternate pulse sinusoidally in time in synchronism with the dipole rotation. In the missile the received signal, multiplied by range, passes together with a reference signal to two phase sensitive rectifiers whose outputs are voltages proportional to h_x and h_y, the displacement error. These outputs are in turn used to control the elevator and rudder settings to bring the missile on course with a minimum of overshoot. The zero of phase reference is against a gyro datum in the missile which is parallel to the main gyro at the start.

The missile is roll stabilized 1/5 sec. after boost separation and is gathered in the radar beam in less than 2½ seconds.

The control surfaces are actuated by compressed air. The electrical power supply consists of a turbo-generator driven by gas produced by the controlled burning of a cordite cartridge.

This missile program is quite far advanced but the missile has not yet been roll stabilized from a ground launch. Production is not likely to commence before 1955.

For details of this missile reference may be made to R.A.E. Report GW-82.

(ii) Red Dean

"Red Dean" is the code name of a fully-active X band homing missile for which Folland Aircraft Company is the principal contractor. Control is the responsibility of S. Smiths, guidance of E.K. Cole, fuze of E.M.I. and warhead of C.E.A.D.

"Red Dean" is a roll-stabilized missile, 13 inches in diameter, 14 feet long with a wing span of 4 feet and a weight of 690 lbs. It has an internal cordite motor giving a boost and coast total time of flight of about 8 seconds. The warhead will probably weigh approximately 100 lbs. Hydraulic control from either a reservoir of oil or an oil pump will be used. The power source will be a turbo-generator cordite driven.

This missile is not expected to be in production before 1957.

Surface-to-Air Missiles

The surface-to-air missile is probably the most important development to a vunerable country, such as the United Kingdom, where a limited range of early warning is possible and there is a heavy concentration of important targets for enemy bombers or missiles. A ground launched weapon of long range capable of a high probability of kill would form a very valuable defensive weapon and this phase of the missile program is being pursued vigorously in the U.K.

There are three such missiles under development, two are ground-launched (Red Shoes and Red Duster), one is launched from a ship (Sea Slug). Operational and constructional details of the surface-based guidance equipment will be covered later when radar developments are considered.

(i) "Red Shoes"

"Red Shoes" is the code name of a semi-active homing missile for which English Electric Co. is the only contractor. The missile is for use with long range AA ground radars and is being designed to climb at a 45 degree angle then to level off at target altitude and home onto the target.

It is 18 inches in diameter, 21 feet long and has cruciform rectangular wings of 57 inches span and four triangular tail control surfaces. It is to be propelled by a hydrogen peroxide-kerosene rocket with four wrap-around boosts which separate when a speed of 2000 feet per second is reached. The kerosene is expelled from a containing bag by steam pressure generated from the hydrogen peroxide. The tail fins are electro-hydraulically operated. The warhead weighs 170 lbs.

The homing head will use a $15\frac{1}{2}$ inch dish with the choice of static split or conical scan yet to be decided. The missile will home all the way to the target and its homing head will require to be locked before launching into the reflected signal from the target flooded by the ground radar. It is probable that the launcher will be traversed automatically from the tracking radar in azimuth and elevation so that the missile head can be locked onto the target when the dish is aligned with the missile axis. The head would then be switched to auto homing and the launcher advanced by a lead angle computed by predictor. In this way a course would be flown requiring the minimum acceration demand. Proportional navigation will be used.

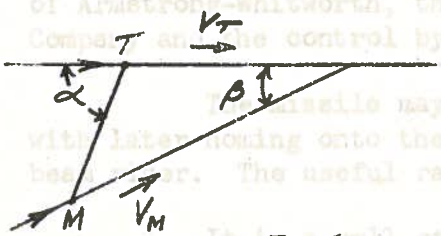


Fig 4

In Fig. 4 if T and M represent the target and missile positions respectively at the same instant, and if

$$k \alpha = \beta$$

then the missile is said to be guided by proportional navigation when k is about 4 or 5.

If k = 0, $\dot{\beta} = 0$ or $\beta =$ constant, resulting in a straight line path.
If k = 1, $\dot{\alpha} = \dot{\beta}$ or $\alpha = \beta +$ constant resulting in a pursuit course for $\alpha = \beta$
If k = ∞, $\dot{\lambda} = 0$ and $\lambda =$ constant.

Thus the sight line does not rotate in space and the missile follows a collision course.

For most missiles a value of 4 or 5 for k is chosen to allow a course intermediate between pursuit and collision, one not demanding very large accelerations.

In "Red Shoes" the most favourable course is selected by programming the k factor with time, k reaching 4.5 at mid-course.

(ii) "Red Duster"

"Red Duster" is the name given to the surface-to-air missile being developed by the Bristol Aeroplane Company, Limited and Ferranti. Bristol, the principal contractor is responsible for the airframe and propulsion. Ferranti is producing the guidance and control.

The missile is ground-launched and is expected to have a useful range of 45000 yards. Later in the program it is hoped that the range can be increased to 120000 yards.

It is a roll stabilized missile, 22 inches in diameter, 20 feet long, weighs about 1500 lbs. and carries a 200 lb. warhead. It differs from other developments in that it uses two moveable monowings of 9 feet span and four stabilizing fins displaced 45 degrees.

Two 14 inch ramjet motors mounted 22 inches off centre, are used for propulsion with a single tandem boost for takeoff.

The control head embodies a 20 inch dish for semi-active homing, the ground radar being the same as that used for "Red Shoes". The use of CW homing is being considered and may be introduced later.

(iii) "Sea Slug"

"Sea Slug" is the name given to a ship-to-air missile being developed for the use of the Royal Navy. The airframe is the responsibility of Armstrong-Whitworth, the guidance is being developed by the General Electric Company and the control by Sperry.

The missile may combine beam riding in its early stage of flight with later homing onto the target but at the moment it is considered as a beam rider. The useful range is 17 miles.

It is a roll stabilized missile 16 inches in diameter, 19½ feet long and weighs 3500 lbs. with a warhead of about 175 lbs. It has cruciform wings and cruciform tail surfaces in the same planes. A nitric acid-kerosene motor is to be used, the fuel being carried in bags from which it is expelled by exhaust gases from a cordite gas generator. The electrical power is supplied by a gas driven turbine-alternator.

As in the case of "Blue Sky" the beam riding is accomplished by time modulating alternate pulses from the ground radar with rotation of the transmitter dipole. Consideration is being given to the addition of a 12 inch dish for terminal guidance. One advantage is better target discrimination and also the effect of radome squint can be eliminated by comparing the relative phase of the signals received fore and aft.

G.E.C. are also considering simplifying the missile by placing all computing of courses and acceleration demands on the ship and using a modulated transponder in the missile.

Two ship radars may be used the Type 902 for gathering the missile in the beam and the Type 901 tracking radar for beam guidance to the target. Characteristics of these radars will be left until later in this report.

Air-to-Surface Missiles

The only air-to-surface guided missile being developed in the U.K. to my knowledge is "Blue Boar" a television guided bomb. The airframe, servos and autopilot are being designed by Vickers-Armstrong while the television link is the responsibility of E.M.I. Three sizes are to be made 1000 lb., 5000 lb. and 10000 lb. The 1000 lb. size is to be a practice bomb.

Test Vehicles

For reasons of economy and speed a complete line of test vehicles have been designed to furnish test data on rocket motors, ramjets, launching, control and guidance problems. In most cases the factories are occupied now in turning out these vehicles; none of the final missiles are far enough advanced for production. To indicate the amount of effort being directed to missiles in the U.K., a summary of these vehicles is given below.

RTV-1 - a rocket test vehicle $9\frac{1}{2}$ inches in diameter and 16 feet long, weighing 550 lbs. and propelled by a liquid oxygen and alcohol motor.
The cruciform control fins are actuated differentially for roll stabilization by oil servos, pressure being generated by a cordite charge.
A 620 lb. tandem boost of seven 5 inch rockets is fitted.
A modified SCR 584 radar is used for guidance.
This missile has been successfully roll stabilized.
It is a joint product of RAE, AGE, RRDE and SRDE.

RTV-2 - a large rocket test vehicle, 17 inches in diameter and 25 feet long and weighing 1650 lbs. Propulsion is by a hydrogen peroxide-kerosene motor. It is a product of Folland Aircraft, Limited.

JTV - This is a ramjet test vehicle being produced by RAE and Bristol Aircraft Company for use in the "Red Duster" program. It is 8 inches in diameter, 15 feet long and two 6 inch ramjets provide the thrust during a seven to twenty-five second flight. The fuel is carried in bags and expelled by air pressure.

BTV - A bomb test vehicle which is a half-scale version of Blue Boar and made by Vickers Armstrong.

LTV - A scale model of "Red Shoes" 7½ inches in diameter made by English Electric.

502/STV - A dummy of Sea Slug made by Armstrong Whitworth.

502/MTV - An experimental or preproduction version of Sea Slug.

CTV-1 - A control test vehicle 5 inches in diameter 62 inches long with cruciform wings. This missile has been roll stabilized and is being test fired regularly.

CTV-2 - A non-separating rocket of 5 inch diameter.

CTV-3 - A small scale version of BTV.

CTV-4 - A homing test vehicle, 7½ inches in diameter, 50 inches long carrying at 6 inch fixed dish. This is being made by Ferranti.

CTV-5 - A high altitude vehicle for data on aerodynamics and control. It is 7½ inches in diameter and uses 2 stage boost to reach 70,000 feet.

6. Personal Impressions of G.W. Program

Considering the amount and quality of development work being carried on in other fields, aviation, vehicles, weapons, etc. I found the scope of the G.W. program surprisingly large. A few figures of the man-power involved in the G.W. program may help in appreciating this.

(i) On Red Shoes - English Electric employs 129 - including 52 scientists and engineers.

(ii) On Red Dean - E.K. Cole employs 47 engineers.

(iii) On Blue Sky - Fairey employs a total of 262 not including administration staff.

(iv) On Sea Slug - General Electric Company and Armstrong Whitworth employ over 200 with a target of some 100 more.

(v) On Red Duster - Bristol employ 213 including 88 scientists and engineers.

and Ferranti employ 128 including 62 scientists and engineers.

Personnel figures on the other companies associated with these developments were not obtained but it appears that the number employed on a weapon project may be anywhere from 200 to 400 depending on its size and complexity. This does not include the large staff of the trials establishments who handle the tests made on many types of guided weapons.

Some of the current problems being investigated are:

(i) The heating of solid fuel propellants necessary for proper combustion at high altitudes.

(ii) Methods of monitoring condition of missile either before loading or before launching.

(iii) The effects of surges resulting when missile is switched from remote supply to internal generators.

(iv) The effect of glint on the homing of missiles. Glint is the apparent wandering of the centre of the echoing area over the surface of the airplane as aspect and range change.

(v) The effect of radome squint on the homing of heads equiped with conical scanning.

(vi) Where does a V.T. fuze detonate with respect to the surface of a large aircraft? The wing span of a large bomber is such that if a wing tip explodes the missile little vital damage may result.

(vii) Design of simulators capable of evaluating missile control and guidance performance and probable miss distances when such factors as squint, radar jitter and amplitude modulation due to radar scanning are included.

(viii) Handling of dangerous fuels by the services.

(ix) Storage, handling and loading and arming of missiles on ships.

Mr. Sargeaunt, the Deputy Scientific Adviser to the War Office, stressed some important roles for guided weapons which merit consideration:

(a) Anti-tank missiles.

He foresees a missile about 6 inches in diameter with a 40 or 50 lb. warhead and a range of about 3,000 yards. The guidance could be either optical, command control or infra red homing.

(b) Semi-active Anti-aircraft missile combined with infra red terminal guidance.

7. General Notes of Radar Projects

While a large amount of effort is being put into the improvement of airborne offensive radar equipment, AI and H_2S type equipments, I believe it correct to state that by far the largest effort is being concentrated on long range radars, complex GCl equipments with automatic data storage and transmission and tracking radars. These developments are designed to meet the demand for aircraft interception, plotting, sector control, missile training, control and guidance as integrated systems.

The notes to follow will cover primarily these radars for ground or ship mounting. Generally speaking all long range early warning is the responsibility of the R.A.F. including preliminary identification and the operation of the ground observer corps. The Army is in charge of all radar from the A/A operation room to the missile and gun sites.

While the services have made some attempt to standardize at least on features of their GCl radars there are different requirements in each case and the result is three different equipments, the Navy and the R.A.F. units are basically the same, however. The Army equipment is called Orange Yeoman and the Navy set the 984. Details will be given later.

8. Details of Specific Radars.

(a) High Power Early Warning Developments

The only new early warning equipment seen was the S/band experimental set at TRE designed for a maximum power of 2 megawatts and a maximum range of 200 nautical miles. The pulse length is 2μsec., the p.r.f. being 250.

The antenna has an aperture of 50 feet by 25 feet, permitting a resolution of $\frac{1}{2}$ degree and a plot rate of 4 per minute. No rotating r.f. couplings are involved as the transmitter is rotated with the antenna assembly.

Ranges of 160 to 180 nautical miles were reported on a Meteor fighter whose echoing area is slightly more than 5 square meters.

This radar, and all others above 600 kw., uses the BM 735 magnetron. This tube has not given satisfactory performance in most cases but every possible effort is being made to correct the troubles and get it into full scale production.

A second early warning equipment on 25 cms. has been started at Marconi.

Another S band set with MTI (ACRMKV1) and a power output of 500 KW is coming along nicely at Cossors it was reported.

(b) Naval Radar

(i) Gun Control

Radar 992 is a target designation set on S band with a power output of 2 megawatts and elevation cover to 40 degrees. Pulse length 1 sec, p.r.f. 1500.

The antenna is a cheese 12 feet wide and 9 inches high mounted on a stabilized platform. The specified bearing accuracy is $\pm\frac{3}{4}$ degree, the range accuracy $\pm$200 yards.

The displays include four 360 degree 'B' type and a master PPI. Height data is supplied by a second fire control radar.

The output data is routed by the Gun Direction Officer to the weapon having optimum cover for the target. No IFF is fitted as yet; the target date for completion of the development model by A.S.R.E. is September 1951.

Radar 932 is a re-engineered 931 on K-band for low angle surface gunnery. Six are to be produced by Sperry.

Radar 905, being developed by Elliotts, is unique in that it uses static split for reception. A single transmitter dish is used surrounded by a 4 section multiple lens for reception.. Phase comparison of the separately received signals is used to provide error signals in azimuth and elevation. The transmitter is 250 kw, X band with $\frac{1}{4}$ μsec. pulse and a p.r.f. of 1000. Analysis of tests will be completed by June 1952.

(ii) Missile Control

A radar with a broad beam known as type 902 is used to gather the missile after which it is passed to a type 901 guided weapon control radar.

The 901 radar uses a conical scan with two diametrically opposed horns rotating together. One horn is used for transmission and reception, the second is for reception only. The receiver output from the T-R horn is divided by that from the other horn to remove scan modulation leaving only modulation due to misalignment. The division is accomplished by subtracting the outputs of logarithmic receivers.

The output power is 250 KW, pulse length 1/3 μsec. and the p.r.f. 2,000 pps.

An interesting feature is the use of a small deflection plate to direct the energy into the 6 ft. dish. This is provided to speed up the autofollow response. The deflection plate has a separate servo loop and it can be jittered very quickly. The main dish is traversed more slowly by a second servo loop, the position of the reflector plate being automatically changed to compensate for this.

The beam deflector plate serves a second purpose in the acquisition role for it can be oscillated at 7 cycles per second in either plane to produce an elevation versus bearing display within the range gate. It can be stopped in 1 second for the auto follow role. The volume scanned during acquisition is 4½ degrees in bearing 14 degrees in elevation and 500 yards in length. The elevation search rate is 0.8 degress per second sinusoidally at 1/3 cycle per second. The search time at best is 1.5 seconds.

Several models of the 901 are being built, the final model for shipboard use, the 901 Y/3 will be ready at the beginning of 1955.

(c) Army Radar

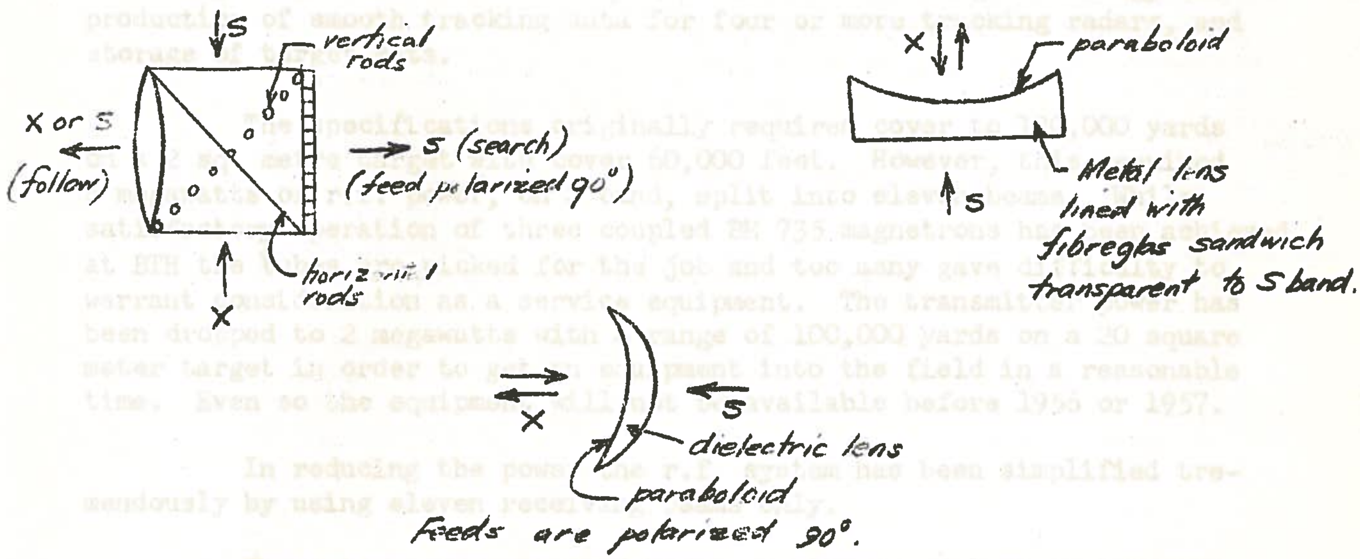
Apart from the Orange Yeoman GCI equipment which will be described separately later the Army have under development the following radar equipments.

(i) "Yellow River" and "Violet Ray"

These two radars are to be used together to control ground-to-air missiles Red Shoes and Red Duster.

The Yellow River set, otherwise known as the AA No. 3 Mk 9, is an accurate, S-band, autofollow fire control set which will give greater ranges on smaller targets as compared with the present AA No. 3 Mk 7.

Yellow River will direct the Violet Ray lamp set onto the target. The latter set is intended to flood the target so that the missiles will home accurately onto it. Violet ray will have a narrow X band beam for guidance and a broader S band beam for missile gathering. About 1 megawatt on 8 cms. will be used with an antenna of 8 feet aperture. Several ingenious antennas have been suggested all of which use the wide difference in wavelength to permit placing the X and S band feeds on opposit sides of the lens.



(ii) <u>Light A/A Skysweeper Radar</u>

This X band radar as projected would scan a volume defined by 360 degrees in bearing, 40 degrees in elevation every second with a range of 12,000 yards on a 15 sq. meter target. Provision to close the scan to 15 degrees in aximuth for tracking is required.

A trial model used a Foster scanner with a 50 kw, 4,000 p.p.s. transmitter, but the range was not adequate and the clutter was bad so an interim equipment giving range only is being proceeded with.

(iii) <u>C W Beacon in Aircraft</u>

A small beacon equipment having apower output of about 1 watt on 6 cms. has been designed at RRDE. This can be tracked by radar AA No. 3 Mk 7 easily to 200 miles. A computer accurate to 1 minute of arc has been designed to calculate automatically the aircraft's location from data from two D.F. sets.

(iv) <u>GCl Type Radars</u>

<u>Orange Yeoman</u>

The Orange Yeoman is an RRDE developed target designation equipment. Target data is fed by the R.A.F. early warning and GCI equipments to the Orange Yeoman with instructions for A/A or guided weapon engagement. The target data is assessed at AAOR and passed to one or more tracking radars best positioned to deal with that target. They in turn put on the appropriate lamp set on AA battery and the engagement begins.

Because of its central location and the amount of filtering, identification etc. which has to be done at AAOR the Orange Yeoman has to be a long range radar with extensive facilities for height finding, the production of smooth tracking data for four or more tracking radars, and storage of target data.

The specifications originally required cover to 120,000 yards on a 2 sq. metre target with cover 60,000 feet. However, this required 6 megawatts of r.f. power, on S band, split into eleven beams. While satisfactory operation of three coupled BM 735 magnetrons has been achieved at BTH the tubes are picked for the job and too many gave difficulty to warrant consideration as a service equipment. The transmitter power has been dropped to 2 megawatts with a range of 100,000 yards on a 20 square meter target in order to get an equipment into the field in a reasonable time. Even so the equipment will not be available before 1956 or 1957.

In reducing the power the r.f. system has been simplified tremendously by using eleven receiving beams only.

The antenna uses stacked horns, a mirror and lens to keep the turning radius of the assembly within 18 feet.

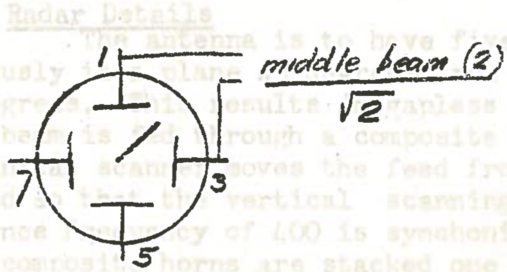
Accuracy of plot	± 500 yds. in plan ±1500 ft. in ht.
Data rate	3 sec. to APF

Unusual Features

Receiver gain stabilized and equalized in fly back time of the sweep by a delayed pulse oscillator and AGC loop.

Height Tube

The receiver signals are passed to the deflection plates of a CRT. The t race is deflected at an angle corresponding to the elevation angle of the target.



By adding $\frac{1}{\sqrt{2}}$ of intermediate beam signal to adjacent pairs the effect of a eight plate tube is obtained.

By putting collector plates on inside of the CRT screen the height data can be resolved into four height layers and targets can then be selected for display in any one zone.

Displays

In the Orange Yeoman equipment provision is made for six trackers to handle 36 targets. There are three target allocators to assign targets to these trackers. When a new target appears on the allocator's display, he hooks the target by means of the joy stick control which moves a ring marker to surround the target. When the button on the joy stick is pressed, a similar ring marker appears on the tube before the selected tracker. The tracker hooks the target with his ring marker and by pressing the buttom on the joy stick control passes the present position data on that target to the store. He then proceeds to place his marker in turn on the other targets for which he is responsible and so passes up-to-date data to the target store.

The store is scanned several times per second to give a composite display of marker data for the use of the officer in charge. Only synthetic signals from the data store are displayed on his tube together with target designation number, height, size of raid, etc. indicated by numerals on the display. The identification of the target is indicated by shading. For instance, the two figure target designation number may be shown half white and half black, or the reverse, or all white on black or all black on white as a means of indicating the target identification.

A feature unique to Orange Yeoman is the track-while-scan units provided for auto-following target movement. These are 12 in number and they may be individually locked to targets for which smooth data rates have to be provided for the accurate tracking radars.

An important feature of the Orange Yeoman is the automatic binary-coded data transmission link that is provided between it and the tracking radars. The link may use either wire or radio. The encoding units for this system have been built into conventional magslip housings so that they may be installed as replacements for existing magslips where automatic transmission is desired.

984 Radar with Comprehensive Display System

This set has been designed by A.S.R.E. in conjunction with Elliott Brothers to provide a comprehensive aircraft control system for aircraft carrier installation. In its display and store features it is somewhat similar to the Orange Yeoman.

(i) Radar Details

The antenna is to have five one-degree beams which are swept simultaneously in a plane 45 degrees from the vertical through a vertical angle of $4\frac{1}{2}$ degrees. This results in gapless vertical cover from 0 to 24 degrees. Each beam is fed through a composite horn made up of 20 individual horns. A mechanical scanner moves the feed from one horn to the next in 1/400 of a second so that the vertical scanning rate is 20 per second. The pulse recurrence frequency of 400 is synchonized with the scanner rotation. Five such composite horns are stacked one above the other and tapered in power. Beam forming is by a 14 foot S-band lens having a 14 foot focal length. Two such antenna systems are placed back to back on the rotating platform at 5 r.p.m. so that a 6 second data rate is achieved by interlacing the outputs of the two antenna systems.

The radar is being designed to utilize 3 BM735 or equivalent magnetrons giving a total power of 6 megawatts. The 6 megawatts is to be divided between the beams from lower to upper as follows, 2 megawatts, $1\frac{3}{4}$ megawatts, $1\frac{1}{4}$ megawatts, $\frac{3}{4}$ megawatt and $\frac{1}{4}$ megawatt.

The required range of the equipment is 120 nautical miles on a Mosquito aircraft with the beams moving and 160 nautical miles with the beams fixed.

(ii) Display Features

All the features of this equipment have not been fully decided but at the moment, ten display tubes are envisaged per equipment. Seven of these feed data to the automatic store, a detector tracker feeding early warning data, two analyser displays and 3 trackers, (2 with 9" P.P.I., the 3rd with a 12" P.P.I.) and a detector display. Taking data from the store for synthetic displays are a master tactical display on a 15" tube, a 9" tactical display and a skitron display.

Height data from the 984 radar is displayed before the analyser on 5 height tubes of 1" diameter. From these tubes, displaying the individual beam signals, the analyser can estimate height to 1,000 feet and feed that data to the store. The data from the store including track number, assigned identity and assigned height are repeated back on the cathode ray tube numerically by means of scanned monoscopes. A target identity is shown by one of ten symbols whose shading from light to dark shows in three stages whether the raid is by a single aircraft, a few, or many aircraft. A line beside the symbol shows by three vertical lengths whether the targets are low medium or high in altitude.

On the master tactical display tube are shown synthetic signals from the stored marker data, the store being swept 11 times per second. At this display console the operator may select for display signals originating at any one of the trackers units individually or may combine all targets stored in one master display. Identification of the target is made possible by using a joy stick to place a ring marker around the suspected target. This operation displays on a small CRT the target track number, identity and height of the ringed marker. Alternatively if it is required to determine which target corresponds to a given track number, the track number may be punched on a decimal keyboard and the printed number from a monoscope will appear beside the corresponding marker signal.

The operator, by setting appropriate switches can separate and display selectively targets in given height layers, targets of any desired track number or targets of one desired identity.

The display also has a pointer marker which can be used to draw the attention of any one of the trackers to a particular target or target grouping that the supervisor may require to be studied and reported upon. This marker when moved by the supervisor's joy stick can be made to appear on the tracker's display and so circle and identify a given target or group. The supervisor is in telephone communication with the trackers so that any desired action can be taken at his request.

From the supervisor's console it is also possible to erase data from the store on stale targets at will. No loss of radar or display efficiency results from the addition of the markers to the scopes as a time interlace system is used to display them in the fly-back time of the sweep. The pulse recurrence frequency is 500 and since it is desired to have a flickerless display on the trackers scope, a marker repetition frequency of 33 cycles per second is used which obviously limits the number of such markers and features that can be displayed. At the moment eight markers are displayed per trackers scope together with the circular hook marker and the pointer marker repeated from the supervisor's console.

While an operating system of this type has been displayed during October 1951, some features are still undergoing change and development. At the moment the tracker has to decide which track he will bring up to date in turn. The designers are considering the addition of sequential tracking which would automatically position the ring marker at the last plot of the following target. Thus only a differential adjustment would be necessary to take care of target movement.

While not a integral part of the comprehensive display system, a digital transmission system is being designed for use with this equipment.

Automatic Data Utilization System (T.R.E. Development)

The automatic data utilization system being developed at T.R.E. is based essentially on the comprehensive display system with extensive modifications to make it suitable in the air defence system of Great Britain. Features of this equipment include:-

1. The store retains two previous positions of each target and repeats them on the trackers CRT to aid in the separation of targets by giving a visual indication of the track.

2. The circular hook marker is automatically positioned to the last position of the new target on the tracker's tube to prevent error. Thus only a differential movement of the marker control is necessary to bring any track up to date in the store. The joy stick push button in this model does not insert data in the store but changes the movement control from course to fine for fine setting on the target. A separate push button on the console inserts the data in the store.

3. A two-letter track data identity code is used, together with symbols for approximate strength and approximate height of the rate. By displaying lines to the rear of the target symbols the edges of the mass range can be designated.

4. If the tracker fails to bring the store data up to dat three times, indicating a stale track, the track data is automatically removed from the store.

5. A high-speed photographic system developed by Kelvin-Hughes is used to photograph the display of the final synthetic picture in 15 seconds.

6. The system allows for 8 tracks per tracker with one height tube and operator each tracker. The system is supposed to handle a maximum of one hundred targets.

7. Data is passed to the command centre by encoded transmission.

8. Automatic tote boards to show the status of all targets and friendly aircraft are provided on which new tracks are indicated by arrows. The data displayed on these boards includes a reference track number, identity, estimate of strength, height of targets and remarks.

8. <u>Infra-red</u>

Development of guided missiles has awakened new interest in uses of infra-red in the U.K. It is being actively considered and development is proceeding on infra-red homing heads for use against aircraft and later against tanks and vehicles. It is also being considered for use in missile Active research and development is underway on ground weapons using image converter tubes. Lead sulphide, lead selenide and lead telluride cells of high sensitivity are being developed and made at T.R.E. The service use the highly sensitive telluride cell has been limited by the necessity for cooling to extremely low temperatures.

In general I found the amount and standard of the development work in the U.K. to be very impressive. There is no shortage of original ideas or of competent personnel to discuss them.

While this report presents a reasonably comprehensive review of the material covered during my visit, a great deal of numerical data and detail has been omitted. I will be glad to supply this additional data on any of these projects to any reader who needs it.

I would like to place on record here my appreciation of the assistance provided by the scientists and engineers of the many laboratories visited. Their kindness and co-operation made the visit a most pleasant and stimulating one.

W.C. Brown