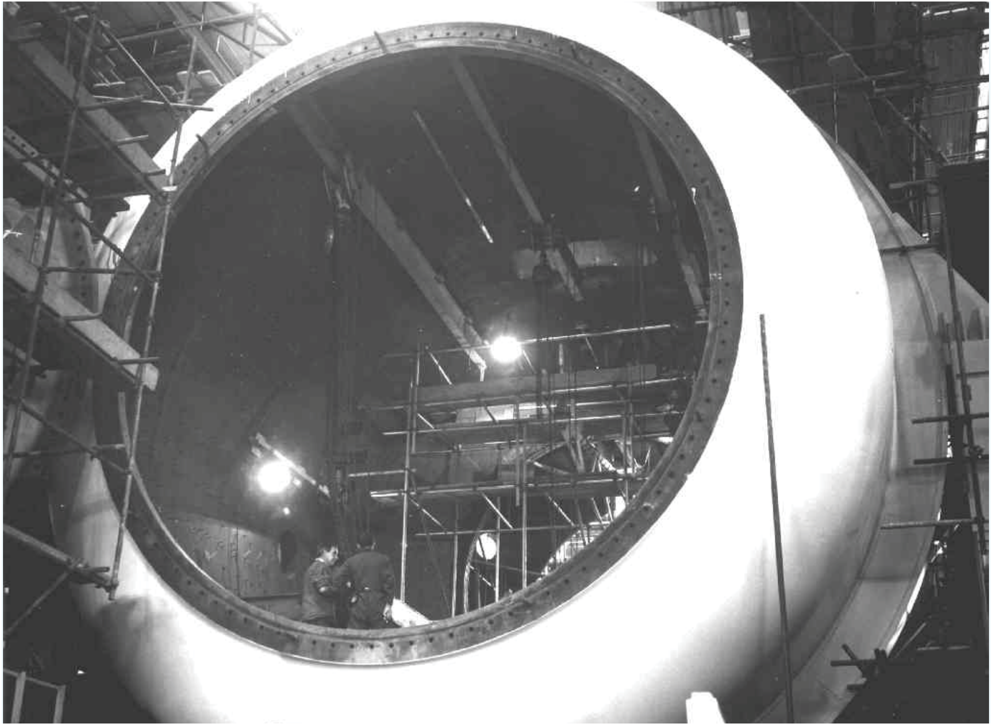

The former National Gas Turbine Establishment
Pyestock

County of Hampshire

Building analysis and recording
Volume 1

August 2005

REGISTERED IFA ORGANISATION

MUSEUM OF LONDON
Archaeology Service

The former National Gas Turbine Establishment Pyestock

County of Hampshire

Building analysis and recording
Volume 1

Site Code: HA-PYE05
National Grid Reference: 483315 154452

Project Manager	Sophie Jackson
Authors	Jon Chandler
	Chris van Schaardenburgh
	Andrew Westman
	Ian McKenzie*
Photography	Maggie Cox
Graphics and design	Kenneth Lymer

* Senior Engineering Consultant
Trusted Experts, QinetiQ

Museum of London Archaeology Service

Mortimer Wheeler House, 46 Eagle Wharf Road, London N1 7ED
tel 020 7410 2200 fax 020 7410 2201
email molas@molas.org.uk
web www.molas.org.uk

Summary (non-technical)

An architectural and historical survey of installations at the National Gas Turbine Establishment (NGTE), Pyestock, Hampshire, was carried out in November 2004 and January–March 2005, in advance of redevelopment of the site. As much use as possible was made of existing, available drawings and photographs. The survey, produced a gazetteer of all the buildings and provided detailed descriptions of the more significant installations, including engine test Cells 1, 2 and 4.

The site, consisting of fairly level, lightly wooded sandy heath, was partly occupied by a golf club in the 1930s. Situated 3km to the west of the Royal Aircraft Establishment (RAE) Farnborough, the land was appropriated by the War Office on the outbreak of World War II and, in 1941–2, RAE expanded on to part of this land in order to test and help develop jet engines. The government set up the NGTE under the Ministry of Supply in 1946 to further this research. NGTE, with headquarters at Pyestock, expanded from the previous area ('Old Site') westwards on to the present site ('New Site'), where test installations and other buildings were constructed from 1949 onwards. The New Site covers 195 acres (79ha) and, at its greatest extent in the 1970s, contained some 200 buildings of different sizes and functions. The largest installations are test cells, comprising very large steel tubes set in massive reinforced concrete foundations, under overhead cranes, enclosed by steel-framed, asbestos-sheeted shelters. Complete jet engines, with air intakes and after-burners, could be fitted inside the cells and there tested under different conditions, including those found, for instance, at high altitude and supersonic speed. Engine components could also be tested separately, at both model scale and full-size, in wind tunnels and on other test rigs.

The first two cells were designed and built in 1952–6, served by a single control room between them, with ancillary structures housing instrumentation, fuel pumps, etc. Air under extreme pressure was provided by a series of compressors. A major compressor facility was built in 1955, in another large building, with reinforced concrete foundations and ground floor, and a steel-framed flat-roofed hall above, clad in asbestos sheeting and glass. Steam, generated in three large boilers in another building, provided heating and power to start the air compressors. Water was used to cool the exhaust gases produced, and was as far as possible cleaned and recycled. Air under pressure was sent through large-diameter overhead pipes, while fuel, steam and water were piped in trenches, for safety. A small power station generated electricity.

Manufacturers were able to test engines in development at NGTE, and the Royal Navy tested marine turbine engines in production. Military requirements during the Cold War (roughly 1947–89), and the development of civil jet aircraft and a supersonic airliner (the Anglo-French 'Concorde'), led to bigger test cells being designed and built for different, bigger and more powerful engines, Cell 3 in 1961, 4 in 1963 and 3 West in 1969. Cell 4 was built specifically to test Concorde's engines, and especially the operation of their air intake as the aircraft manoeuvred. The research activities were rationalised and cut back from about 1980 onwards, facilities gradually being stood down until, in 2000, NGTE was decommissioned. In 2005 research was still being conducted by private firms on some parts of the site into noise reduction (using a large anechoic chamber), oils and lubricants, and military aircraft ejector seats.

Volume 1: contents

1 Introduction	**6**
1.1 Project background and aims	6
1.2 Site location	6
1.3 Structure of the report	6
2 Sources consulted	**10**
2.1 Introduction	10
2.2 Documentary archive	10
2.3 Drawing archive	11
2.4 Photographic archive	12
2.5 Film and video	14
2.6 Physical objects	14
2.7 Oral sources and consultations	15
2.8 Internet sources consulted	15
3 Method of building analysis and recording	**16**
3.1 Introduction	16
3.2 Drawings in the MoLAS study	16
3.3 Photographs in the MoLAS study	16
3.4 Written records and the report	16
3.5 Deposition of the report and supporting material	17
4 Historical background to gas turbine engine and ramjet research	**18**
4.1 Introduction	18
4.2 Types of gas turbine engines for aircraft propulsion	18
4.3 Early (pre-World War II) jet engine development	20
4.4 Jet engine development during World War II	22
4.5 Jet engine development after World War II	23
4.6 Production testing	25
5 Development of the Pyestock sites	**26**
5.1 Pyestock 'Old Site' (1942–2001)	26
5.2 Pyestock 'New Site' (1954–2002)	27
6 Pyestock at work	**34**
6.1 Test preparation	34
6.2 Data collection	34
6.3 Essential services	35
6.4 Support workshops	44
6.5 Other infrastructure	47
6.6 Safety	47
7 Cells 1 and 2	**50**
7.1 Background and purpose	50
7.2 Description	50
7.3 Alterations and developments	55
7.4 Technical details of working processes	58
7.5 Research undertaken at Cells 1 and 2	60
8 Cell 4	**63**
8.1 Background and purpose	63
8.2 Description	63
8.3 Alterations and developments	71
8.4 Technical details of working processes	74
8.5 Research undertaken at Cell 4	78

9 Other test facilities at Pyestock **81**
9.1 Cell 3 (Bldg 630) 81
9.2 Cell 3 West (Bldg 630) 83
9.3 Admiralty Test House (Bldg 307) 82
9.4 The Glen Test House (Bldg 500) 82
9.5 The engine component test facilities (Bldgs 303, 304, 405, 415, 442, 539, 543, 572 and 590) 82

10 Conclusion **84**

11 Acknowledgements **86**

12 Bibliography **87**

Appendix 1: List of holders for Cells 1, 2 and 4 in the Pyestock drawing archive **89**

Appendix 2: Index of selected archive drawings on a CD accompanying this report **92**

Appendix 3: Index of selected archive prints on a CD accompanying this report **95**

Appendix 4: Index of scanned prints from the MoLAS photographic survey on a CD accompanying this report **98**

Volume 2: Buildings gazetteer (bound separately)

Volume 1: list of figures

[See Appendix 1 for an index of selected archive drawings on the CD accompanying this report.]

Cover Cell 4, looking west into the Plenum Chamber, from the intake side (NGTE 26122)

Fig 1 Site location 7
Fig 2 Site layout at its maximum extent in the 1970s, with buildings identified by number (from Drwg A0/662/1) 8
Fig 3 Survey of the northern part of Pyestock 'New Site' dated Feb 1956 (Drg No. LSG41) 28
Fig 4 Aerial photograph of Pyestock, before the construction of Ively Road, looking southeast 29
Fig 5 Growth of Pyestock's engine testing plant, 1944–1994 (DTEO 1996, fig 1.1) 30
Fig 6 Pyestock's capacity for engine testing (DTEO 1996, table 3.1) 30
Fig 7 Exterior of the Air House (Bldg 621), looking west. Each of the eight vertical exhauster stacks serves one of the sets of air compressors inside the building (CNV00025-F1-24.jpg) 36
Fig 8 Interior of the Air House, looking north-east, showing the southernmost set of air compressors at an upper level inside the building. Service piping and machinery is underneath at ground level. The space in the foreground is a loading bay (MoLAS 015/05/02) 37
Fig 9 Compressors being installed in the Air House (NGTE 19699) 37
Fig 10 Sectional view of a GEC machine in the Air House (DTEO 1996, fig 2.4) 37
Fig 11 Perspective view of a GEC machine in the Air House (DTEO 1996, fig 2.5) 37
Fig 12 Total compressing performance of Air House (DTEO 1996, fig 2.2) 38
Fig 13 Total exhauster performance of Air House and No. 9 and No. 10 machines (after DTEO 1996, fig 2.3) 38
Fig 14 Air distribution at Pyestock (DTEO 1996, fig 2.1)
Fig 15 Flexible support for overhead air pipe near Cells 1 and 2 (MoLAS 021/05/20) 41
Fig 16 Lagged flexible coupling on overhead air pipe near Cells 1 and 2 (MoLAS 021/05/21) 41
Fig 17 Electrical distribution at Pyestock (DTEO 1996, fig 5.2) 42
Fig 18 Fuel distribution at Pyestock (DTEO 1996, fig 5.5) 42
Fig 19 Fuel pipes and other pipes laid in an open conduit forming a 'safety zone', looking west between Cells 3 and 4 (MoLAS 021/05/14) 43
Fig 20 Water tanks north-east of Cells 1 and 2, to store water for cooling; looking south-west. Note water-level gauge on the nearest corner (MoLAS 021/05/10) 43
Fig 21 Water distribution at Pyestock (DTEO 1996, fig 5.6) 45
Fig 22 Water cooling towers under construction south-west of Cells 1 and 2, in the mid 1950s, looking south-west (NGTE 10395) 45
Fig 23 Drainage and effluent system, incorporating recycling of water (DTEO 1996, fig 5.12) 46
Fig 24 Cycle sheds north of the Computer Building, looking east, typical of many on the site (MoLAS 021/05/18) 46
Fig 25 Bus shelter on the east side of The Fairway, looking south-east (MoLAS 021/05/02) 48
Fig 26 Emergency showers outside the Air House, looking west (MoLAS 028/05/09) 48
Fig 27 Warning to wear ear protectors, between Cells 3 and 4, looking west (MoLAS 028/05/24) 49
Fig 28 Standard lavatory and wash-room building east of Cell 4, typical of several on the site, looking south-west (MoLAS 021/05/16) 49
Fig 29 Exterior of Cells 1 and 2 (Bldg 561), looking north-west (CNV00001-F1-01.jpg) 51
Fig 30 Schematic plan of Cells 1 and 2 and ancillary structures (MoD 1974, fig 39) 51
Fig 31 Air pipes in a conduit approaching Cells 1 and 2, looking east. The test cells are at ground level, beyond the edge of the photograph to the left (MoLAS 021/05/15) 52
Fig 32 Schematic longitudinal section through Cell 1 (MoD 1974, fig 40) 52
Fig 33 Schematic longitudinal section through Cell 2 (MoD 1974, fig 41) 53
Fig 34 Engine mounted inside Cell 2, looking north-west (MoLAS 021/05/27) 53
Fig 35 Cells 1 and 2 control room in 2005, looking south (CNV00001-F2-01.jpg) 54

Fig 36 Basement under Cells 1 and 2 control room, looking north-west (MoLAS 021/05/29) 54
Fig 37 Gap between Cell 2 (right) and control room (left), looking north, showing the mountings for the test cell separate from the steel frame for the shelter overhead (MoLAS 021/05/33) 56
Fig 38 Exhauster tower at north end of Cells 1 and 2, looking north-east (CNV00016-F1-15.jpg) 56
Fig 39 Cells 1 and 2 under construction, probably early in 1956 (NGTE 14704) 57
Fig 40 Exhaust outlet of engine inside Cell 2, looking south-west (CNV00005-F2-03.jpg) 57
Fig 41 Diagram of air flow in Cell 4 (MoD 1974, fig 72) 64
Fig 42 Schematic longitudinal section through Cell 4 (MoD 1974, fig 74) 64
Fig 43 Exterior of Cell 4 (Bldg 635), at its east end, looking north-west (CNV00014-F5-14.jpg) 64
Fig 44 Exterior of Cell 4, east end, looking north (MoLAS 028/05/12) 65
Fig 45 Air pipes at the west end of Cell 4, looking north-west. The cell's outlet pipes (white) are mainly at a low level, connecting with overhead pipes (blue) to the Air House (CNV00008-F5-08) 65
Fig 46 Air pipes at the west end of Cell 4, looking north-west (MoLAS 028/05/27) 66
Fig 47 A series of air pipes running overhead from the west end of Cell 4 towards the Air House, looking north-west. Large areas of the site are gravelled and possibly sprayed with weed killer, presumably to minimise maintenance (MoLAS 028/05/26) 66
Fig 48 Perspective cut-away drawing of Cell 4, dated 1964, looking north-west (PYE MK9/19/9) 68
Fig 49 Interior of Cell 4, north side, looking west. The lower pipes and ducts shown here had been removed by the time of the survey (CNV00014-F2-08.jpg) 69
Fig 50 Cell 4 plenum chamber, looking south-west. The intake has been disconnected, to the left (CNV00011-F2-07.jpg) 69
Fig 51 Cradle and blowing nozzle inside the plenum chamber of Cell 4, during construction, looking west (NGTE 31947) 70
Fig 52 Pressure door to engine capsule in Cell 4, looking south (MoLAS 028/05/45) 70
Fig 53 Engine capsule in Cell 4, leading to the main exhaust diffuser (to left), and upper spill duct above, looking north. The diffuser can be unbolted and rolled sideways to install and dismantle engines. Note water spray pipes entering the spill duct (MoLAS 028/05/40) 72
Fig 54 Spill ducts and exhaust diffusers leading to cooling stages in Cell 4, looking north-west (MoLAS 028/05/47) 72
Fig 55 Central part of travelling overhead crane inside Cell 4 building, looking east. The sign was added for a film, 'Sahara' (MoLAS 028/05/56) 73
Fig 56 An authentic sign in Cell 4, for Vickers Ltd (MoLAS 028/05/46) 73
Fig 57 Cell 4 plenum chamber under construction, December 1963 (NGTE 25606) 75
Fig 58 Interior of Cell 4 nearly completed, looking south-east towards by-pass ducting (NGTE 33096) 75
Fig 59 Interior of Cell 4 nearly completed, looking south to the plenum chamber (NGTE 29095) 76
Fig 60 Performance limits for Cell 4 (MoD 1974, fig 68) 76
Fig 61 The control room for Cell 4 (NGTE 29710) 80
Fig 62 Cell 3 under construction in January 1958, looking east (NGTE 17348) 83
Fig 63 Marion Pennell and part of the archive of drawings at Pyestock (MoLAS 028/05/05) 85

1 Introduction

1.1 Project background and aims

Astral Developments Ltd has commissioned the Museum of London Archaeology Service (MoLAS) to carry out recording and analysis of the buildings and facilities at the former National Gas Turbine Establishment (NGTE), at Pyestock in Hampshire (hereafter also referred to as the 'site' or 'Pyestock'). The site was one of the foremost gas turbine engine research and altitude engine test facilities in the world. The now decommissioned buildings will be demolished and the site redeveloped. Recording of the buildings has been identified within an appropriate mitigation strategy in line with national and local government policies *Planning Policy Guidance 15: planning and the historic environment* (DoE 1994) and *Planning Policy Guidance 16: archaeology and planning* (DoE 1990). There are no statutorily listed buildings or scheduled monuments located on the site.

The mitigation strategy comprises a survey of the facilities of high significance and historic value (Test Cells 1, 2 and 4) at 'Level 3' of the specifications of the Royal Commission on the Historical Monuments of England (RCHME 1996) and a survey of the facilities of moderate or low importance, the remainder of the structures on the site, at 'Level 2'. The primary aim of this report is to provide a survey of the existing buildings, in particular Cells 1, 2 and 4, largely based on existing information, to describe the development of the site since its establishment in the early 1950s and to put the site in the context of gas turbine engine research. This report makes recommendations regarding the future of the extensive archive of photographs, drawings and other documents, currently in various locations, including Pyestock itself.

1.2 Site location

The site covers about 79 hectares, some 3km to the south-west of Farnborough, Hampshire (Fig 1: Ordnance Survey national grid reference to its approximate centre: 483315 154452). The site is relatively level, lying on the gentle eastern slope of a low hill with a high point at 85m OD. The surrounding countryside is woodland and heath.

1.3 Structure of the report

Following this introduction, the report comprises the following sections:

> Sections 2 and 3: methodology and sources. The section outlines the methodology used for the building analysis and recording, along with the sources examined and individuals consulted. It includes a description of the archive information available for Pyestock and the location of its various components.
>
> Section 4: Background to gas turbine engine and ramjet research. This section provides the historical and engineering context of the site by means of a brief account of the development of gas turbine technology including the individuals and organisations involved, such as Sir Frank Whittle, Dr A A Griffith, Hayne Constant, Dr Harold Roxbee Cox (later Lord Kings Norton) and Power Jets and RAE Farnborough, the technical developments from the 1920s and an assessment of the significance of Pyestock in gas turbine engine development.
>
> Section 5: development of the site. This section provides an account of the development of the site, cross-referenced to key archive drawings and photographs and a buildings gazetteer (see below), with an explanation of the function of the key facilities.
>
> Sections 6, 7 and 8: Test Cells 1, 2 and 4. These sections provide a detailed record of the structures and their components based on the results of the MoLAS 'Level 3' survey along with supporting archive

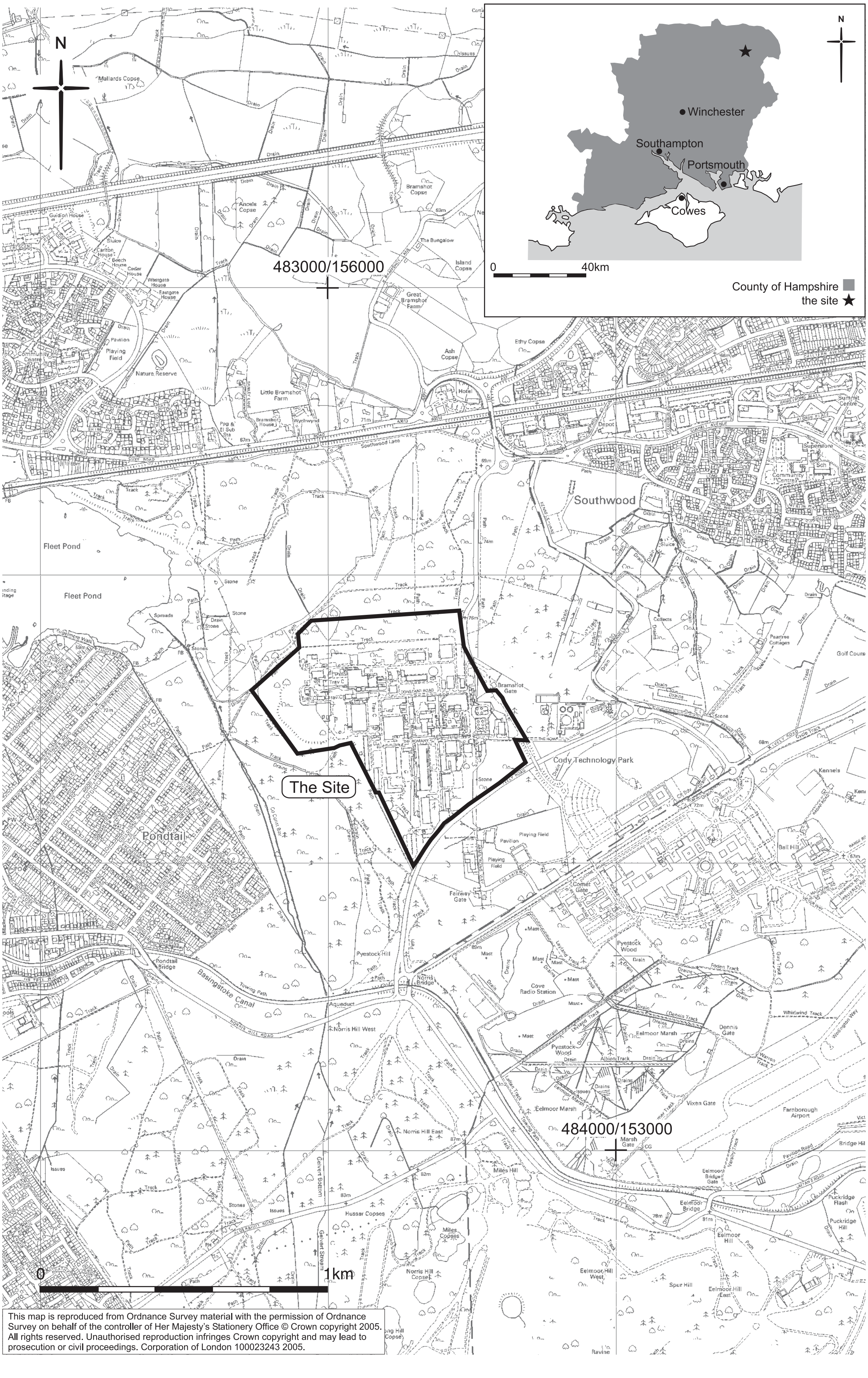

Fig 1 Site location

Fig 2 Site layout at its maximum extent in the 1970s, with buildings identified by number (from Drwg A0/662/1)

information (documentary sources, drawings and photographs), and interviews with former Pyestock staff and members of Farnborough Air Sciences Trust (FAST). The sections include details of how the cells worked, their major modifications and a summary history of the engine tests associated with the cells. They conclude with a description of research work, and working processes and life at Pyestock.

Section 9: work undertaken at other test cells and engine component test facilities. A description of the testing that was carried out at the other test cells on the site (Cells 3 and 3 West, the Admiralty Test House, the Glen Test House and the engine component test facilities and laboratories).

Section 10: conclusions and recommendations.

Volume 2, which is bound separately, contains a gazetteer of the main structures on the site including a description of the structure and its function, illustrated with a photograph and archive drawing, where available. Each entry has the official Pyestock building number, which is cross-referenced to the site plan (Fig 2) and referred to in the report text.

The report is fully illustrated and is accompanied by a CD containing selected scanned archive drawings, selected archive photographs and photographs taken by MoLAS as part of the present study.

2 Sources consulted

2.1 Introduction

There is an extensive archive of information, documenting the buildings, machinery and processes at the site. This archive is arguably of as much significance as the physical remains of machines and buildings, particularly since the cells and associated equipment have been partly stripped or obscured.

The following section provides a summary of the research undertaken for the present study in order to attempt to locate the documentary, photographic and drawn archive. Some of this primary source material was drawn upon in order to provide background material for the present report. Preservation of all or some of the archive forms is one of the recommendations made by this report (see Section 10, below).

2.2 Documentary archive

2.2.1 Documentary material consulted for present report

Although there are no definitive histories of former NGTE Pyestock, QinetiQ (unless indicated otherwise) provided MoLAS with a number of unpublished brochures, reports and mementos, which provided considerable background material for the work carried out on the site. These comprise:

> Official brochures dated 1974 (MoD 1974), 1996 (DTEO 1996) and an undated brochure (MoD nd).
>
> An unpublished booklet of photographs, undated but probably 2002, entitled *Engine Test Department, a memento: Pyestock 1947–2002*.
>
> An unpublished personal memoir by Peter F Ashwood, provided by the author, entitled *Pyestock, Farnborough, Hants: where aero-engine research flourished* (cited hereafter as Ashwood 2003).
>
> An unpublished article by the Ministry of Supply, entitled *National Gas Turbine Establishment, Pyestock, Hants: visit of the press September 1955. Notes on buildings*.
>
> An unpublished lecture by H Roxbee Cox entitled 'Ministry of Supply, May 1947, National Gas Turbine Establishment, Pyestock, Hants.'
>
> Unpublished reports by the Ministry of Supply in 1955 (MoS 1955), and the Ministry of Aviation in 1960 (MoA 1960). These were kindly provided by FAST.
>
> An article by Ian McKenzie in a FAST 2002 newsletter, entitled '60 years of gas turbine research at Pyestock.' At the time of the present study Ian McKenzie was writing a book about Pyestock.

2.2.2 Manuals and handbooks

The Pyestock drawing archive room (discussed in more detail below) contains some 30 technical handbooks related to the operation and maintenance of the test facilities. This is not a comprehensive collection. In addition, it was noted on a site visit that a number of such handbooks are still inside the test cell control rooms, although these are generally in a poorer condition due to the damp environment. Approximately 30 manuals of Cell 4, which were absent from the drawing archive room, were found in Cell 4, and other manuals were found in the basement under the control room of Cells 1 and 2. On the suggestion of MoLAS staff, these were taken to the archive room to dry out. FAST apparently hold no such handbooks.

Although information in the manuals and handbooks was considered too technical in nature for the present study, diagrams and drawings were selected for illustrative purposes.

2.2.3 Documentary material not consulted

Documentary material consisted of reports, project files and personnel files. The vast majority of project files were apparently destroyed (Geoff Kerrison, QinetiQ, pers. comm.). Those that survive have not remained on site and have ended up in a number of different places:

> The Defence Science and Technology Laboratory (the non-privatised section of what was DERA), is believed to have acquired a selection of reports along with material from the Pyestock library.
>
> The National Archives at Kew acquired MoD archives and defence records. The vast majority of this material comprises records created or inherited (typically after 30 years) by the Department of Scientific and Industrial Research and related bodies, the Ministry of Aviation and its successors, and the Air Registration Board and related bodies (Joe Kelly, National Archives, pers. comm.).
>
> QinetiQ has acquired a number of reports along with material from the Pyestock library. Some of this material is understood to be located at the Farnborough site and at the QinetiQ Information Warehouse at Boscombe Down. Some material may be held at other QinetiQ sites (Geoff Kerrison, QinetiQ, pers. comm.).
>
> FAST acquired a number of project files and related files along with material from the Pyestock library. These are held within the museum and are in the process of being indexed. Some of the library material may have been subsequently passed on to Farnborough Library.
>
> Ministry of Defence (MoD) Archives holds records of personnel who worked at Pyestock.
>
> In 1994, staff from the National Museum of Science and Industry (NMSI) in London took on the RAE Museum collection from the RAE Farnborough (DRA at that time), prior to the site closing in 1995–6. This comprised *c* 1500 objects, including files and reports. Other NGTE archive material has been transferred to other organisations in the years when Pyestock was active, for example the College of Aeronautics at Cranfield and the NMSI (Geoff Kerrison, QinetiQ, and Andrew Nahum, NMSI, pers. comm.).

2.3 Drawing archive

At the time of writing the Pyestock drawing archive was held entirely in the otherwise decommissioned Main Workshop (**Bldg 407**; Fig 2). Marion Pennell, who formerly worked in the Pyestock drawing office, has managed the collection for the last six years. Marion was very helpful in providing an indication of the size of the archive and how it was indexed, and kindly scanned drawings that MoLAS selected for the present study (see Section 3, below). These drawings comprise site surveys, plans of foundations, services and floor layouts, and building elevations and sections, in addition to drawings of the equipment contained in the buildings and test cells.

The archive comprises *c* 40,000 paper copy drawings (Marion Pennell pers. comm.) in a single room, *c* 20m long by 5m wide. The room is heated when in use, and conditions are not archivally stable.

The drawings are grouped in cupboards according to the building they relate to, and are hung on wooden holders according to subject (i.e. site plans, air supply, etc). There are *c* 900 holders. The first and last sets of holders (numbered 1–47 and 736–900) were destroyed when, several years ago, the archive was moved to its present location, as there was not enough space for them (Marion Pennell pers. comm.), but they still exist on microfilm (see below). These drawings were to do with tests by private firms such as Rolls-Royce. It was standard drawing office practice to destroy outdated site plans (Marion

Pennell pers. comm.). The majority of the NGTE Old Site drawings have been destroyed, although some are held by FAST (Geoff Timmins, former Senior Engineer at Pyestock, pers. comm.).

Few of the paper drawings are originals, most being copies. Many drawings have deteriorated over the years through general wear and tear, but they are generally in good condition and can be scanned and reproduced with reasonable legibility.

Approximately 90% of the original drawing archive exists on microfilm, although the microfilms and their indexes are currently stored in the same building as the paper archive. Selected drawings were copied on to microfilm 10–15 years ago, although unfortunately there was no quality control and the quality of reproduction varies considerably; in many cases the microfilm copy is better than the surviving paper copy as the latter has been subject to subsequent wear and tear. In a number of cases, the microfilming was so bad that the film is almost blank and of no use (Marion Pennell pers. comm.)

Within six months of the announcement in 2000 of the closure of the Pyestock site, most of the drawings related specifically to test projects and test equipment, both paper and microfilm, were destroyed. This was probably because they were thought to be of no further use. In 2004, commercially sensitive material was destroyed as it was considered of no technical value to QinetiQ and not appropriate for public release. All drawings considered to be of technical value to QinetiQ have been scanned and are held electronically by QinetiQ.

Project drawings, mostly on microfilm but some on paper, of historical importance and not of a commercially sensitive nature were selected by members of FAST who formerly worked at Pyestock, and passed on to FAST between 2000 and 2004.

Drawings were selected from the archive for scanning in order to illustrate the present report. These are either reproduced here as a figure or may be found on the accompanying CD. As mentioned above, the survey focused on Cells 1, 2 and 4. For these structures, plan, section and elevation drawings were selected, in addition to drawings showing machinery and layout. For other main buildings at Pyestock, drawings showing the general layout were selected, and where relevant, a machinery layout drawing was also selected for illustrative purposes. Drawings of the layout of the systems and support facilities were also chosen to show the relationship between the different buildings and the site-support facilities. Drawings have usually been scanned from microfilm as often their quality is better than that of the paper copy.

2.4 Photographic archive

In 1994, staff from the NMSI took on the RAE Museum collection from the RAE Farnborough (DRA at that time). The site closed in 1995–6. This comprised *c* 1500 objects, including photographs.

In June 2000, Hillary Roberts, Head of Collections, Photograph Archive at the Imperial War Museum (IWM), assisted by Dick Snell, Custodian of the DERA photographic collection at Farnborough, carried out a survey of the photographic collection according to the terms of the Public Records Act and by agreement with The National Archives, Kew.

As a result of a number of organisational changes in the 1990s (described in Section 5, below), collections from related establishments that were closed down or merged were sent to Pyestock for safekeeping; for instance, Building 415 at Pyestock became DERA's southern area repository for documents and photographs (Geoff Timmins and John Binge, FAST, pers. comm.). Consequently, at the time of the survey, the collections at Pyestock included photographs from other establishments, including Cardington, NGTE, RAE (DERA) Farnborough, RAE (DERA) Bedford, etc.

MoLAS contacted Hillary Roberts and obtained details of the survey. The photographic collection at Pyestock originally comprised the following (list provided by FAST):

> Power Jets (PJ series) Collection, comprising *c* 7,000 negatives of tests taken between 1940 and 1953;

NGTE Pyestock P Series Collection, comprising *c* 3,300 negatives;

NGTE Pyestock PB Series Collection, comprising 5,974 negatives of tests taken between 1964 and January 1975;

NGTE Pyestock PA Series Collection, comprising 5,572 negatives of tests taken between August 1961 and December 1974;

NGTE Pyestock PY Series Collection, comprising *c* 160,000 negatives of tests taken between January 1975 and April 1996;

NGTE Pyestock Print Collection of NGTE and possibly Power Jets tests from the 1940s onwards. These are in contained within over 19 photograph albums and over six boxes of prints;

RAE/ DRA/ DERA J Series Collection of tests conducted under DRA/ DERA Farnborough after April 1996 and comprising *c* 50,000 negatives.

Following this survey, a review of the significance of the photographic collection was made during 2001 and 2002 by a team of experts from QinetiQ and the IWM, with former staff at Pyestock, under the supervision of the National Archives. The work entailed examining the different photographic indexes and reviewing the nature, historical significance and quality of the photographs. The photographs were grouped according to three levels of importance:

A – very important
B – important
C – less important

All photographs in group A went to the Photographic Department of the IWM. Group B was divided between the IWM and FAST Photographic Collection at Farnborough. Group C went entirely to FAST. Roughly 40% of the photographic collection went to IWM, the remaining 60% went to FAST (Hillary Roberts, IWM, and Joe Kelly, National Archives, pers. comm.).

The NGTE negative collections held by the IWM and FAST largely comprise project negatives of a technical nature covering the different aspects of the engineering and research projects that took place. The collections also include a comprehensive record of buildings, test facilities and aerial surveys taken at intervals. There is some coverage of departmental or smaller groups of people but very few examples of individuals. Almost no record exists of social events.

The FAST collection comprises negatives, partly indexed, and prints, not indexed. At the time of writing, the prints have been transferred from a temporary room set aside by FAST for such material in a stores building (**Bldg 405**) at Pyestock to the FAST museum. The negative collection at FAST is made up from different collections, each with its own method of filing. Some are listed by projects; others are listed as a more general collection. Although registers of most collections are available, what is listed in the registers is not necessarily still in the collection. Even though the collections are large in size, it does not necessarily mean they cover the whole of NGTE's history. The NGTE collection has been eroded over the years as photographs considered no longer to be of use were disposed of due to lack of space (Geoff Timmins and John Binge, FAST, pers. comm.).

The NGTE prints held by FAST comprise several hundred prints covering both NGTE and its predecessors. MoLAS examined these and found that the majority show the 'Old Site' and 'New Site' under construction.

Peter Cooper of FAST has recently taken a number of photographs of the site since it was decommissioned. These photographs were made available to MoLAS, and some of them have been used to illustrate this report (and their captions identify them as being from this source).

Photographs for the present report have been taken from the MoLAS survey, from brochures, from Peter Cooper's survey, and also from the FAST print collection (with the kind assistance of Geoff Timmins). MoLAS examined a large number of negatives of the NGTE photograph collection at FAST, but no attempt was made to reproduce these, as there are no readily available facilities to do so at the museum.

2.5 Film and video

2.5.1 Cine-film archive

Most of the cine-film (in 8mm, 16mm and 35mm formats) related to Pyestock was acquired by the IWM as part of the RAE Farnborough film archive (Hillary Roberts pers. comm.).

Duplicate cine-film material from the RAE Farnborough was passed on to the FAST collection. Whether any Pyestock footage was included in this is doubtful since most of the cine-film taken at Pyestock, all of which was shot by NGTE photographers prior to NGTE merging with RAE in 1983, was unedited and destroyed many years ago. Since then, very little, if any, cine-film was shot at Pyestock. However, approximately nine years ago, when a common photographic archive was established, any existing Pyestock footage may have been included, with the possibility that should there have been duplicate material it would have passed to FAST (John Binge, FAST, pers. comm.).

Additionally Ministry of Technology material was donated to the IWM in the 1960s, containing some RAE Farnborough and NGTE Pyestock material (K Gladstone, IMW, pers. comm.).

2.5.2 Recent video footage

QinetiQ hold recent hand-held video camera footage of Pyestock that was taken by Dave Burnie following the decommissioning of the site. MoLAS obtained and examined the footage as part of the present assessment. A copy of the video is included in the project archive.

2.5.3 Film and television

Cells 3 and 4 were used in 2004 as film sets in the Hollywood film 'Sahara' (released March 2005). In preparation for filming, partial and fairly minor alterations included repainting, and the installation of minor structures and a false roof to Cell 3 were carried out. This was not the first occasion that Pyestock had been used for filming; Thames Television filmed several episodes of 'The Bill' during 2004 and several episodes of 'Red Dwarf' were filmed in Cell 4 during the mid 1990s. As long ago as 1968 location shots for a minor 'B' film 'Some Girls Do' were filmed in and around the test facilities.

2.6 Physical objects

Most portable objects, such as test equipment and controls, have been removed from the Pyestock site.

FAST hold a number of objects related to early jet engine research and also a representative selection of objects removed from Pyestock since the site was closed. Early jet engine components include the Power Jets (Whittle) W2/700 exhibition engine and the RAE/ Metropolitan-Vickers F2/4 Beryl engine compressor. Other objects include test compressors, accurate scale models of Cells 1 and Cell 3 West (for display purposes), nameplates of buildings and roads, the official NGTE crest, and a scale model rig of part of Cell 3 West, which was used to develop the cell exhaust diffuser geometry before the testing of each new engine type.

During the course of the present study, equipment and installations from the site were in the process of being salvaged for reuse at other test facilities. The Combustion Test Facility from the Battle Test House (**Bldg 543**) had been dismantled for re-erection at a new test site. The air fan and part of the ducting from the dry air supply to Cell 3 West had been moved for reuse at the Noise Test Facility (**Bldg 590**).

2.7 Oral sources and consultations

MoLAS staff were taken on very informative tours of the site by two former Senior Engineers at Pyestock, Ian McKenzie and Geoff Timmins, on the 3 November 2004, and again by Geoff Timmins on the 24 January 2005. These tours included detailed commentaries on the buildings, in particular the major test facilities including Cells 1, 2, and 4, and the Plant House and the Air House.

In addition, the following individuals were consulted in the course of the study:

> Ian McKenzie – information on technical and historical issues and co-author of this report.
>
> Marion Pennell, Head of Drawing Office, Astral Developments Ltd, for information on the drawing archive.
>
> Ken Walles, retired scientist NGTE Pyestock and Maurice Shakespeare of FAST, for information on archive material at FAST.
>
> John Bindge of FAST, for information on the NGTE photographic collection at FAST.
>
> Mrs Hillary Roberts, Head of Collections Management, Photograph Archive, Imperial War Museum, for information on NGTE photographic material at the IWM and the material selection process.
>
> Mr. Joe Kelly, Client Manager to the Ministry of Defence, National Archives, for information on NGTE photographic material at the IWM and the material selection process.
>
> Andrew Nahum, Senior Curator (Aviation), the National Museum of Science and Industry, London, for information on NGTE material held at that museum.
>
> Mrs Pam Turner, QinetiQ Library, Farnborough, for information on NGTE material held by QinetiQ.
>
> Dr Geoff Kerrison, manager, Information Strategy, for information on the NGTE material selection process.

2.8 Internet sources consulted

The Internet unfortunately holds little information on Pyestock itself. A number of websites with general information on jet engine research and its historical development in an international context were consulted as part of the present study. Section 12 provides a list of the websites consulted.

3 Method of building analysis and recording

3.1 Introduction

The method used for building analysis and recording follows RCHME standards (RCHME 1996). An RCHME 'Level 3' survey, comprising a full analytical record accompanied by a detailed drawn and photographic record, was applied to Test Cells 1, 2 and 4. These testing facilities had been identified in recent environmental assessments (MoLAS 2005; Harris 2003) as being of high significance and historic value. An RCHME 'Level 2' survey, comprising a summary written description with illustrations where appropriate, was carried out on the remainder of the structures on the site. The aforementioned assessments had identified these structures as being of moderate or low importance.

The method of recording made as much use as feasible of the available drawing archive and high quality photographs of the facilities in use. A new photographic record has been made of the site in its present condition, consisting of details of Test Cells 1, 2 and 4, general views of the remainder of the site, together with a description of the buildings, machinery and processes.

The work has been carried out in accordance with applicable professional guidance for such work, especially RCHME's *Recording historic buildings: a descriptive specification*, (3rd edition 1996), and the IFA's *Standard and guidance for archaeological investigation of standing buildings or structures* (1999).

3.2 Drawings in the MoLAS study

There is an extensive archive of engineering drawings preserved at Pyestock, and consequently no attempt was made to provide a new measured survey of Cells 1, 2 and 4 as part of the present study. An extensive search was made of the archive, which revealed plans, sections and elevations of Test Cells 1, 2 and 4, together with detailed design drawings of the components of the cells themselves. A selection of the most useful and relevant drawings was scanned, saved on CD and, where appropriate, reproduced as in the present report. In addition, Geoff Timmins and Ian McKenzie identified a number of relevant drawings for scanning.

3.3 Photographs in the MoLAS study

A MoLAS Senior Photographer took photographs of Test Cells 1, 2 and 4 and the site generally. These included medium format, 35mm and digital photographs of relevant parts of the facilities, producing digital images and colour negatives and transparencies. The images include the setting of areas of interest as well as details. For each photographic image the subject matter, direction of view and circumstances were noted, permitting efficient indexing of images and appropriate reference to them in other records, the gazetteer and in the report. A metric scale rod was included in these images where appropriate.

The approach taken for the MoLAS photographic survey, in light of the existing photographic archive and more recent footage, was to focus on the context of the test cells in relation to surrounding structures, achieved through a variety of general shots. Photographs were also taken of things that are usually normally ignored in past photography, but which tell the reader about the working environment, for example, signage indicating the required wearing of ear protectors and examples of the once-numerous bicycle sheds that illustrate the size of the site and how people got about.

3.4 Written records and the report

An experienced MoLAS Building Analyst visited the site and provided a detailed written description, with sketch drawings, of the structure and existing condition of Cells 1, 2 and 4. This was informed by the archival drawings, photographs and documentary sources collated as part of the present study. A brief written description was also provided of all of the main structures for inclusion in a gazetteer of the main structures and buildings (Volume 2 of this report). MoLAS worked with FAST to ensure that the most significant parts of the test cells and associated plant have been described and explained appropriately. The MoLAS records consist of stable paper copies and digital records. As the machinery and processes used at Pyestock were highly technical and specialised, former Pyestock staff and members of FAST have reviewed the descriptive text. Ian McKenzie has edited the report, contributed portions or the text and has portions of the text.

3.5 Deposition of the report and supporting material

The nature of the project means that it lies outside the remit of Hampshire Museums Service (Kay Ainsworth pers. comm.). Aldershot Military Museum in Hampshire (Queens Avenue, Aldershot GU11 2LG) has fulfilled a curatorial role and assigned an accession number to the project archive: R2005.5. The final report and supporting material will be deposited at this museum.

Copies of the report will be deposited in publicly accessible repositories, notably the National Monuments Record (NMR), in Swindon, English Heritage in London, Hampshire County Council Environment (Archaeology) Department, and FAST at Farnborough.

In addition, an article will be written for a non-technical audience, which can be published in an appropriate local historical or archaeological journal.

4 Historical background to gas turbine engine and ramjet research

4.1 Introduction

This section provides a brief explanation for the lay reader on how gas turbine engines work and of the different types of engine. This is followed by an historical background to gas turbine engine and ramjet research in the United Kingdom and abroad, from its origins to present day, which is intended to provide a broader context for the work undertaken at Pyestock.

Prior to the jet engine, aircraft propulsion involved the use of propellers powered by piston engines. For high performance military aircraft, this technology had reached a peak by the end of World War II, with high-powered liquid- or air-cooled piston engines driving variable-pitch propellers. Altering the pitch of a propeller blade, its angle relative to the airflow, maximises the propeller's efficiency over a wide range of aircraft speeds from take-off and landing to cruising. Aircraft propulsion is an application of Newton's third law of motion: action and reaction are equal and opposite. Essentially, this basic principle applies to both propeller and jet propulsion. They differ only in that the propeller applies a small acceleration to a large mass of air whereas, with jet propulsion, a large acceleration is given to a much smaller mass of air for the same equivalent power or thrust. At high altitudes, where the air is less dense, the potential exists for aircraft to fly faster for a given power due to the reduced drag. For propulsion, it is necessary for the velocity of the propulsive jet (be it from a propeller or a jet) to be greater than the aircraft velocity. Thus, the high aircraft speeds desired for flight at high altitude are beyond the scope of a propeller due to its low propulsive velocity.

The gas turbine engine is generally associated with aircraft propulsion, but it can equally be used to generate power on the ground or at sea. The working of the engine is fairly simple. The thermodynamic cycle is very similar to that of the four-stroke compression-ignition diesel engine but, instead of the intermittent cycle of induction, compression, ignition and exhaust associated with the diesel engine as a piston moves back and forth in a cylinder, the gas turbine cycle is continuous. Air is entrained into a gas turbine through an intake by a compressor, which raises its pressure and temperature. From the compressor, the air passes into a combustion chamber where fuel is injected. The combustion process causes the mixture to rise further in temperature. The high-pressure high-temperature gas is then expanded through a turbine, connected to the compressor by shafting; the work extracted from the gas by the turbine drives the compressor. The gas, now cooler and at lower pressure, passes along a jet pipe to be exhausted to the atmosphere through a propelling nozzle.

In comparison with piston engines, gas turbines have the intrinsic advantages of improved thrust, or equivalent power-to-weight ratios, and reduced vibration levels, leading to reduced maintenance costs for both engine and airframe, and the ability to operate efficiently at higher altitudes and greater flight speeds. Unit fuel costs for kerosene (Aftur, Jet A1), the fuel most commonly used, are lower than for aviation gasoline (Avgas), as it is less refined.

4.2 Types of gas turbine engine for aircraft propulsion

4.2.1 Turbojets

The turbojet engine is the simplest gas turbine arrangement, consisting of a compressor connected by a shaft to a turbine, a combustion chamber between the two, and a propelling nozzle at the rear. Some turbojets are configured with two coaxial shafts and a compressor and turbine mounted on each, forming low-pressure and high-pressure spools, each rotating independently of the other. This arrangement enables the compression system to operate at higher pressure ratios (pressure ratio is the ratio of the compressor delivery pressure with respect to the entry pressure) yet still offers the necessary operating flexibility over the rotational speed range of the engine. The use of turbojet engines is applicable to supersonic aircraft and to military fast jets with an air superiority, dog-fighting role.

4.2.2 Turbofans

A turbofan engine is a variation of the basic turbojet. Turbofans, earlier known as bypass or bypass turbojet engines, incorporate a fan mounted forward of the engine compressors. A fraction of the airflow from the fan passes through the core, or main part, of the engine, while the remaining flow bypasses the core. The fan may consist of a single axial flow stage, predominantly used for civil airliner applications, whereas multi-stage fans are most appropriate for military fast jets. In many civil turbofans the fan is connected directly, or by a gearbox, to the low-pressure spool. In the mid 1960s Rolls-Royce uniquely chose, for aerodynamic and engine operability reasons, to drive the fan of the civil RB211 and the later Trent engines from an additional third shaft powered by its own set of turbine stages. Military examples of turbofan engines with multistage fans are the Rolls-Royce Pegasus and Turbo Union RB199 used respectively in the Harrier and Tornado aircraft. Civil turbofan engines are designed to generate most (at least 80%) of the engine thrust from the fan, by employing large bypass ratios (the bypass ratio is the ratio of the bypass airflow with respect to the core airflow). The relatively cool bypass flow and the hotter core flow mix at the rear of the engine assist in reducing engine exhaust jet noise. In subsonic cruise conditions turbofan engines are more efficient than turbojets, since the mean propulsive jet velocity is lower for the former and more closely matched to the aircraft velocity (propulsive efficiency is the ratio of the aircraft velocity with respect to jet velocity). Turbofans are also more fuel-efficient for a given thrust as fuel is burned in only a fraction of the total engine airflow.

4.2.3 Turboprops

A turboprop engine is essentially an unducted turbofan, with a propeller. The propeller is either gearbox-driven from the low-pressure spool or driven by a separate shaft from a power turbine. As with civil turbofans, the turboprop develops most of its thrust from the propeller, with the core exhaust, passed through a propelling nozzle, contributing the rest. Because of the propeller's aerodynamics, turboprop-powered aircraft are most suitable for relatively low-altitude low-speed flight typical of small airliners and smaller transport aircraft. A variation of the turboprop is the turbo-shaft engine. As its name suggests, the turbo-shaft engine is designed to supply power via a shaft or gearbox system, as in a helicopter, for example, where shafts and gearboxes are used to drive the rotor blades. Auxiliary power units (APUs), fitted to aircraft to provide power when the main engines are shut down, are also examples of the turbo-shaft engine. Land-based turbo-shaft engines are used primarily to generate electricity and pump gas and oil, although they can be used to power vehicles. At sea, applications cover both power generation and propulsion.

4.2.4 Afterburners

Afterburning, or reheat, is a method of providing a substantial increase in thrust for little increase in engine weight. Afterburning involves burning additional fuel in the jet pipe downstream of the turbines. Due to its inefficiency, it is only appropriate to use afterburning for short periods of time, for example, on take-off, when climbing and in combat when additional performance is required. Afterburning utilises the unburned oxygen in the exhaust to support further combustion. The considerable increase in exhaust gas temperature results in a much increased jet velocity from the propelling nozzle and, therefore, increased thrust.

4.2.5 Ramjets, scramjets and pulse-jets

The ramjet is the simplest form of jet engine. It is essentially a turbojet without any of the rotating compressors and turbines, and in Britain was originally known as an athodyd (aero-thermodynamic-duct). Effective operation is limited to supersonic flight, usually greater than Mach 1.5, as the air compression necessary for the engine to function is wholly dependent on its high forward velocity. Consequently, its uses are restricted to missile propulsion. Take-off and acceleration to supersonic speed requires assistance, usually by means of solid rocket boosters. The combustion process inside a ramjet takes place at very low velocities, much in the manner of a conventional gas turbine. In some more recent designs, the flow through the combustion chamber is designed to be supersonic and these engines are referred to as scramjets.

A pulse-jet is similar to a ramjet, except that several spring-loaded shutter-type valves are located ahead of the combustion section. In a pulse-jet, combustion is intermittent or pulsing rather than continuous. Air is admitted through the valves, and when combustion begins the valves close to prevent backflow through the inlet. The hot gases are expelled through the propelling nozzle, producing thrust. Then the valves re-open and the process is repeated. The most widely known pulse-jet is the Argus As 014, which powered the German World War II V-1 missile commonly known as the Doodlebug or 'buzz bomb'.

4.2.6 Rocket motors

All the engines described so far are air-breathing; that is, they require atmospheric oxygen to support combustion. The rocket motor is also a jet propulsion engine but differs in that it carries its own oxygen supply in the form of an oxidant and is therefore not dependent on the atmosphere to function. Rocket motors are either solid- or liquid-fuelled. Solid fuels incorporate the oxidant and the fuel in one compound that, when ignited in the combustion chamber, decomposes into a gas at high-pressure and temperature, exhausting through the propelling nozzle at great velocity. With liquid fuels, the fuel and oxidant are kept separate until introduced to each other in the combustion chamber. The thrust from liquid-fuelled rocket motors can be varied during flight by controlling the flow rates of the fuel and the oxidant. The thrust from solid-fuelled rockets cannot be varied once combustion has begun.

4.3 Early jet engine development, before World War II

4.3.1 Research and development in the UK

The first practical proposals for using gas turbine engines date from 1926 when A A Griffith at the Royal Aircraft Establishment (RAE), carried out some theoretical studies. These formed the basis of a report that led to the granting of approval for two series of tests to be carried out to verify the theory. Frank Whittle, while still a cadet at RAF Cranwell, had been investigating quite separately the possibility of gas turbine power for flight. In 1930 his master patent was published for jet propulsion, which he went on to exploit through the formation of a company, Power Jets Limited, in 1936. Thus, in Britain there were two separate organisations aiming to exploit the gas turbine, both led by exceptionally talented individuals. At RAE the team was led by Griffith, until he left to join Rolls-Royce in 1939, while Whittle led the technical activities at Power Jets. The chairmanship of Power Jets was in the hands of an American lawyer, Lancelot Law Whyte, who worked for the investment bank, O T Faulk and Partners, that had provided the company's initial capital.

The private capital on which Power Jets was founded was used to let a contract to British Thomson-Huston (BTH) for construction of an experimental gas turbine engine. BTH was a company experienced in steam turbine manufacture and, therefore, appropriate for gas turbine work. Power Jets occupied part of the BTH works at Rugby. On 12 April 1937, the first-ever test of a jet propulsion gas turbine took place at these works. Shortly afterwards, as BTH expressed concern for the safety of engine testing at Rugby, Power Jets relocated to a disused BTH foundry at Lutterworth. At this time, Power Jets established its headquarters and design activities at Brownsover Hall, not far from Lutterworth.

The gas turbine design that Whittle chose incorporated a centrifugal compressor, as this type of compressor was far better understood at the time than the aerodynamically more complicated and less well developed axial-flow type being advocated by RAE. Whittle's approach was to develop a practical aircraft gas turbine as quickly as possible for service with the RAF, and he appreciated that the additional work and risk involved with developing an axial design could cause delay (Dennis 1999).

Whittle's success in demonstrating the feasibility of the gas turbine concept, with the experimental jet propulsion engine WU ('Whittle Unit'), led the Air Ministry to place a contract with Power Jets in May 1938 to design and build an engine, the W1, for flight testing. The Gloster Aircraft Company was at the same time contracted by the Air Ministry to construct two aircraft for the flight trials under the specification E28/39. The aircraft were known variously as E28, Gloster-Whittle and later, unofficially, as the Pioneer.

The period between 1926 and 1936, when eventually RAE was given authority to construct a multistage axial compressor, had not been wasted at Farnborough. Following Griffith's theoretical work of 1926, two experimental programmes were put in place. The first of these, begun in 1927, involved tests of various blade profiles, in cascade in a wind tunnel. The second programme, starting in 1929, entailed construction of a turbo-compressor unit comprising a single turbine stage followed, on the same shaft, by a single axial-stage compressor. Measurements of stage efficiency were derived by drawing air through the unit. Griffith's first proposal for an aircraft gas turbine, also presented in 1929, was based on a multistage axial contra-flow arrangement, where each stage of compressor blades was tipped by a row of turbine blades. Each row of blades contrarotated relative to the adjacent row. RAE also spent considerable effort furthering the substantial research already carried out on exhaust-driven centrifugal superchargers (turbochargers in today's terms), the turbines of which had considerable relevance to future gas turbine work. At the same time, RAE also established the method of expressing compressor results non-dimensionally, a method used to this day.

In July 1936, the Engine Department at RAE sought and obtained authority to design and have constructed a multistage axial compressor. This marked an important step in government-sponsored research of the gas turbine engine for use in aircraft (Dennis 1999). Hayne Constant summed up the feeling in a well-argued case for further research:

> The simplicity of the internal combustion turbine (ICT) with its freedom from the inherent complications of the reciprocating engine has made it the dream of many engineers. The very magnitude of the advantages which it has to offer, associated with the repeated failures to achieve a practical design have given the impression that the ICT is merely a convenient medium on which to work off the surplus energy of imaginative inventors. In fact, however, the same principles and the same practical experience as have in the past predicted the performance of machines of more novel design, can be applied to determine the success or the failure of the internal combustion turbine (RAE Technical Note E3546, 'The internal combustion turbine as a power plant for aircraft').

The unit, known as 'Anne', was tested in 1939. Its first test was disastrous; a rubbing seal caused it to shed all its blades within 30 seconds of starting. The unit was rebuilt, but was largely destroyed during an air raid on RAE in August 1940; its remains are on display in the Science Museum, London. Anne was the first of the named RAE axial-flow compressors, several others being tested in the next few years. A fruitful collaboration between RAE and Metropolitan-Vickers Electrical Co Ltd started in 1937, leading to the design and construction, under Air Ministry sanction, of the first British axial-flow gas turbine engine. B10, as this unit was called, consisted of a nine-stage axial compressor ('Betty') driven by a four-stage turbine. In today's terms, the engine would be known as a 'proof-of-concept demonstrator' as it produced no useful power but demonstrated the concept of an axial-flow gas turbine. The RAE team concentrated their efforts on developing the axial-flow compressor; despite the major technical challenges, they foresaw its advantages in greater efficiency, coupled with reduced frontal area, as compared with the centrifugal type.

4.3.2 Research and development overseas

In 1933, Dr Hans von Ohain, working at the University of Göttingen, conceived the idea of a continuous-cycle combustion engine, and in 1935 patented a jet propulsion design similar in concept to Whittle's but differing in its internal design. Whittle and von Ohain apparently carried out their researches independently of each other, neither being aware of the other's progress, despite Whittle's patents being widely published in Europe. In September 1937, von Ohain demonstrated his experimental engine, S2, five months after Whittle's. Shortly afterwards, following the successful testing of the S2 he joined Ernst Heinkel and continued with the development of his jet propulsion concepts. Heinkel sanctioned the construction of a flight-standard engine, the HeS3, and the He179 aircraft to flight-test it. This aircraft made its first flight on the 27-August 1939, making it the first jet aircraft to take to the air.

Prof Dr Herbert Wagner began designing the world's first axial gas turbine at Junkers, Magdeburg, in 1938. Wagner's research was continued during World War II under a fellow Austrian, Dr Ing. Anselm Franz, which led to the Jumo 004 axial-flow engine.

In 1939, the Swiss company Brown Boveri completed development, at Baden, near Zurich, of the first modern land-based gas turbine. The turbine was installed at Neuchâtel in the foothills of the Swiss Jura to power a 4-megawatt electrical generator for back-up power, and is still in operation over 60 years later. The factory at Baden also still exists, now part of Alstom Power, one of the one major manufacturing sites of industrial gas turbines.

4.4 Jet engine development during World War II

During the Second World War the development of the jet engine as an aircraft power plant was largely in the hands of Britain and Germany, although they shared the technology with their respective allies, the United States acquiring technology from Britain while Japan's wartime operational jet engine was a result of technology acquired from Germany. Japan, the Soviet Union and Italy all conducted basic research, to less effect. The Soviet Union's efforts were interrupted by the German invasion.

In Britain, test flights of engines developed by Power Jets and RAE took place early in the war. On 15 May 1941, the Gloster E28/39 'Pioneer' with Whittle's W1 engine made its first flight from RAF Cranwell, becoming the first jet aircraft to fly in Britain. The first flight test of the RAE/ Metropolitan-Vickers F2 jet engine took place at RAE in July 1943, the engine being installed in the tail of the prototype Avro Lancaster bomber. Later this engine was installed in a modified Gloster Meteor, first flown on 13 November 1943. The Meteor, which was the first production and operational jet aircraft in Britain, saw active service during the war. Although never used as a frontline fighter, it did destroy a significant number of V-1 flying bombs.

Power Jets Ltd was not in a position to mass-produce the Whittle engines themselves, and to speed up technological development, production and service introduction, Rover Co Ltd was appointed to perform development work on the Whittle engines and prepare for full-scale production. The relationship between Power Jets and Rover was not a happy one, and the Rover plant was transferred to Rolls-Royce in 1943. The collaboration with Rolls-Royce resulted in the Welland engine, powering the Gloster Meteor Mark 1. During the war, the Air Ministry's Gas Turbine Collaboration Committee (GTCC) brought together the main gas turbine protagonists, including Power Jets, RAE and the fledging gas turbine industry (comprising British Thomson-Houston, Metropolitan-Vickers, Rover, de Havilland, Rolls-Royce and Armstrong Siddeley) to share the technology, with the aim of speeding up development, and ultimately production, by avoiding duplication of effort.

In 1940, with the rapid wartime expansion of gas turbine activities at RAE, the accommodation for the gas turbine group in the Engine Department was becoming inadequate in 1940. RAE was given authority to construct a new, purpose-built, gas turbine research station at Pyestock, approximately two miles to the west of their current premises. Pyestock was progressively occupied by the newly formed Turbine Division during the latter half of 1942. At about the same time, the government funded construction of a dedicated gas turbine factory for occupation by Power Jets.

By 1944, the British gas turbine industry was expanding fast and many aircraft companies were formulating their own gas turbine designs. Because of the very small size of Power Jets, now located at Whetstone, Leicestershire, and the industry's rapid growth, concern had been expressed that the company might be subsumed into one of the larger companies and the valuable stream of Whittle's ideas lost, since it was feared that Whittle would not be party to any such restructuring (McKenzie 2002, 4). Early in 1944 the government decided to set up its own gas turbine research organisation competent in all the associated technologies. To achieve this Power Jets was nationalised by buying out the shareholders and it was combined with the Turbine Division of RAE's Engine Department at Pyestock to form, on 1 May 1944, the nationalised company of Power Jets (Research & Development) Ltd. This company continued to operate from both Whetstone and Pyestock, with its headquarters at Pyestock. Dr Harold Roxbee Cox (later Lord Kings Norton) was appointed Chairman and Managing Director of the new company. Within two years of the creation of the nationalised company, it was becoming apparent that it was not achieving its objectives for a variety of reasons and so, in July 1946, the organisation was reconstituted within the Ministry of Supply as the National Gas Turbine Establishment (NGTE), with Roxbee Cox as its Director.

In order to aid the war effort and as part of the Lend-Lease agreement with the USA, the UK agreed to transfer Power Jets' gas turbine technology to the Americans. A small team from Power Jets, which included Whittle, together with the W1X, not a flight-worthy engine, arrived at the General Electric Company at Lynn, Massachusetts, in 1941, in order to facilitate manufacture of jet engines in the USA. The Americans worked fast and a test flight using the Bell XP-59A took place the following year with engines developed directly from the W1. The Lockheed P-80 Shooting Star became the first operational jet fighter in the United States, going into service in 1945. It emerged as the victor in the world's first all-jet combat during the Korean War in 1950.

Germany had successfully flown a jet-propelled experimental aircraft just before the war began (see above). The work of Dr Franz resulted in the Jumo 004 axial-flow gas turbine engine. In July 1942 the world's first operational jet aircraft, the Messerschmitt Me262 'Schwalbe' ('Swallow'), was flown, powered by the Jumo 004 engine. The flight was successful but subsequent development problems (the engine had a rated life of approximately 25 hours), Allied bombings, and cautious Luftwaffe leadership contributed to delays in production. Eventually over 1,400 Me 262s were produced, but fewer than 300 saw combat. Most remained on the ground awaiting conversion to bombers, or were unable to fly because of lack of fuel, spare parts and trained pilots.

The tripartite Axis of Germany, Italy and Japan allowed for the transfer of technology between them, and Germany sent drawings of a complete engine of the BMW 003 type to Japan. This resulted in the development of the Nakajima Ne-20 engine used in the 'Nakajima Kikka' ('Orange Blossom'), a twin-jet fighter based on the German Me 262.

4.5 Jet engine development after World War II

4.5.1 Introduction

The gas turbine engine as an aircraft power plant was one of the most important practical innovations that came out of the Second World War. It greatly influenced military and civil aviation. When in the late 1940s and early 1950s the world's first passenger jet aircraft were built, the de Havilland 'Comet' and the Boeing 707, they revolutionised air transport. The higher power output of the gas turbine engines, combined with advanced aerodynamic design (some learned from German research during the war) enabled military aviation to make tremendous advances in the early 1950s. Newly developed jet fighters were combat tested in the Korean War: the American F-86 and Soviet Mig-15, both of which had been influenced by German aerodynamic knowledge, were the first jet aircraft to meet in combat.

4.5.2 United Kingdom

Britain ended the war with an active gas turbine engine research programme, full-scale gas turbine manufacture and operational aircraft powered by gas turbines. Captured German equipment and German expertise greatly influenced post-war aeronautical developments, especially the combination of advanced German aircraft and engine design. In general, however, advances in engine design in Britain in the early post-war period were largely based on its own research, such as that carried out during the war at RAE and Pyestock (described above). In 1946, a further change in organisation took place when the government decided to dissolve Power Jets (Research & Development) Ltd and bring its work directly under the control of the newly-formed Ministry of Supply, with the formation of the National Gas Turbine Establishment (NGTE). Dr Harold Roxbee Cox, having been Chairman and Managing Director of the nationalised company, remained to be NGTE's first Director.

The construction of major research and test facilities at Pyestock, in what became known as the 'New Site', started in 1949 and continued to the mid 1970s. Over the years, these facilities were used not only by NGTE for intramural research but by the British aero-engine industry and by NATO allies, under contract.

During the Cold War, Britain remained a world leader in many fields of defence technology associated with research at RAE Farnborough and NGTE Pyestock (Bud and Gummett 1999, 3). The Cold War (from at least 1947 onwards) fuelled defence research and spending, and in the UK and the USA more than half of government-funded research and development, and something approaching one quarter of the national total, came from defence budgets. The British Government hoped that these enormous expenditures on investment in science and high technology might yield economic as well as security benefits. British expenditure was larger than that of other European countries, but its economic growth was lower than that of most of its competitors. UK defence research was largely led either by the research establishments or by the government department responsible for them at the relevant time. In Pyestock's case the research programme was administered by the Ministry of Supply and its successors in London until the early

1960s, when the administrative responsibility for the whole engine research programme was transferred to Director, NGTE. Throughout, the scientific staff at Pyestock actually carried out approximately 40% of the research, the remaining 60% being undertaken by the aero-engine industry and by other organisations under government contract.

During this period, with the construction and bringing into service of the engine test cells, the engine test facility at Pyestock became the largest of its type in Europe and NGTE was a leader in many aspects of gas turbine research, both civil and military.

Following the end of the Cold War (in 1989 or soon afterwards), jet engine research in the UK has concentrated less on military and more on civil applications, notably large by-pass turbofan engines such as the Rolls-Royce Trent series. Gas turbine research is largely generic, so the change of emphasis had little influence on gas turbine research topics but did affect funding. Pyestock's research budget was provided not only by the Ministry of Defence but also by the Department for Trade and Industry, the former providing substantially the larger proportion.

4.5.4 United States of America

At the end of the Second World War, the United States lacked the test facilities necessary to ground-test the high-performance jet engines then being planned and developed. To address this, Congress approved in 1949 the creation of an engine test facility, which became the Arnold Engineering Development Center (AEDC), Tennessee, officially opened in 1951. In 1950 the US Air Force began installing the BMW (Bavarian Motor Works) high-altitude engine test plant taken from Germany at the end of the war. The German equipment was modernized and expanded considerably. The first turbojet engine to be tested was a General Electric J-47, which was later used to power the B-47 Stratojet bomber (www.arnold.af.mil).

The AEDC grew to be what is now the largest engine test facility in the world and is the national and international leader in most, if not all, areas of development, testing and evaluation of jet engines. The site has 58 aerodynamic and propulsion wind tunnels, rocket and turbine engine test cells, space environmental chambers, ballistic ranges and other specialized units, 14 of which are unique in the world (www.arnold.af.mil).

In 1941, the National Advisory Committee on Aeronautics (NACA) had opened the Aircraft Engine Research Laboratory at Cleveland, Ohio (www.nasa.gov). Six years later this was renamed the Flight Propulsion Research Laboratory to mark its transition from an engine laboratory to a propulsion research laboratory. The following year it was again renamed, becoming the Lewis Flight Propulsion Laboratory in memory of its late Director, George Lewis. When NACA was dissolved in 1958, the laboratory became part of the National Aeronautics and Space Administration (NASA) and was called the NASA Lewis Research Center. 1999 saw a further change in name, when it became the NASA Glenn Research Center. Pyestock was this establishment's nearest equivalent, both of them being civilian.

4.5.4 Union of Soviet Socialist Republics

After World War II, the Soviet Union captured German scientists, occupied German research facilities and collected industrial and research material. The Junkers Aircraft and Motor Company was completely dismantled and taken to Russia as war booty, and rebuilt exactly as it had stood in Leipzig. Blueprints of German jet and rocket aircraft were also acquired, so that when German 'specialists' (actually prisoners) arrived in October 1946 they were set to work on the new Russian 'Wunder' jets, such as the MiG-15. German technology, thus acquired, formed the basis of the Soviet Union's progress in military technological developments early in the Cold War.

During the 1950s, the Central Institute of Aviation Motors (CIAM) in Moscow extended its test capability to include an altitude engine test facility. During the same period, research was carried out into transonic axial-flow compressor aerodynamics. Further research related to gas turbines appears to have been aimed at the development of variable-geometry engine air inlets and the associated automatic control systems for supersonic aircraft. Research programmes were focused during the 1960s and 70s on such diverse topics as engine noise reduction and hypersonic ramjets and, in recent years, the sphere of fundamental engine research has been widened significantly. CIAM remains the Russian Federation's dedicated centre for aero-engine research (www.ciam.ru).

4.5.5 Other countries

The loss of their research establishments at the end of World War II resulted in a new and slow start for gas turbine research and development and industrial capability in Germany and Japan. A growing civil aviation industry and, during the Cold War, the pressure to continue innovative development of defence equipment led countries like Germany and Japan to rebuild their gas turbine research and industrial capability. The same can be said for France which, after wartime occupation, had to start from scratch.

The French government provides expertise and specialised testing services for major civil and military aeronautical projects, in particular testing at simulated flight conditions, at the CEPr (Propulsion Test Centre), Saclay, near Paris, which is under the control of the Délégation Générale pour l'Armement (DGA). Germany has a long history of organised aeronautical research, beginning with the establishment of an institute at Göttingen in 1907, the creation of the DVL (Deutsche Vesuchsanstalt für Luftfahrt) at Berlin-Adlershof in 1912, and the DFL (Deutsche Forschungsanstalt für Luftfahrt) at Braunschweig in 1936. Research like that at Pyestock is undertaken at Stuttgart by the ILA (Institut für Luftfahrtantriebe) and FPS (Forschungsinstitut für Physik der Strahlantriebe). Elsewhere in the world the Kakuda Space Propulsion Center in Japan, and recently constructed sites in Korea and Taiwan, include altitude test facilities for military and civil purposes.

4.6 Production testing

All the major aero-engine gas turbine manufacturers have their own ground-level test facilities where engine development testing and delivery pass-off tests are carried out. In the UK, until recently, Rolls-Royce possessed altitude test capability (roughly equivalent to Pyestock's Cell 2) at Derby. Significant sites in the USA and Europe include those of Pratt and Whitney at East Hartford, Connecticut, General Electric Aircraft Engines at Peebles, Ohio, Snecma Moteurs at Villaroche, Seine-et-Marne, and Rolls-Royce at Derby and Hucknall. There are many other commercial test facilities around the world to support the gas turbine industry, but most do not have altitude capability.

5 Development of the Pyestock site

5.1 Pyestock 'Old Site' (1942–2001)

Gas turbine engine research started in 1926 at the adjacent Royal Aircraft Establishment (RAE), Farnborough. In 1941–42, the RAE constructed the first engine research facility at Pyestock on what became known as the 'Old Site' to the east of the area currently under redevelopment (Figs 1 and 2), with the purpose of carrying out gas turbine and ramjet engine research. The early, secret, development of jet engines, including significant development of the ramjet, evolved here during and immediately after World War II. A personal memoir by Peter Ashwood (2003) provides a fairly informative personal account of his and others' research carried out at the Old Site in addition to subsequent work at the New Site.

The Old Site, apparently laid out to resemble a village and therefore reduce its vulnerability to air attack (Ashwood 2003, 1), originally comprised a single-storey office block, a workshop and two ground-level test cells each capable of testing engines up to approximately 1500lb static thrust.

From 1944, the newly-nationalised company, Power Jets (Research & Development) Ltd, had its headquarters there (see Section 4, above). When the NGTE (National Gas Turbine Establishment) was created in 1946 under the Ministry of Supply, its remit was largely similar to that of its predecessor, the nationalised company, with one notable exception. The patent administration activities were vested not with NGTE but remained instead with Power Jets (Research & Development).

NGTE inherited two sites, Pyestock and Whetstone, the latter in Leicestershire some 150 miles to the north. Most of NGTE's scientific expertise was located at the former whilst the latter housed the major test facilities and manufacturing capability. To improve efficiency of operation, Roxbee Cox planned to centralise the operation. Eventually Pyestock was selected although it was by no means the first choice. Having put the centralisation plan in place, Roxbee Cox left NGTE in 1948, leaving implementation of the plan to the Establishment's new Director, Hayne Constant. By 1955, all NGTE's activities at Whetstone had ceased and the site was leased to the English Electric Company.

The Old Site's air-moving machinery was housed in a building known as the Compressor House. Air was supplied to a number of independent test cubicles, housing various component test rigs and aerodynamic wind tunnels, and clustered around the Compressor House (DTEO 1996, Sec 1, 3). The air plant provided a compressed air supply but little exhauster capacity, and effectively supported model-scale and limited full-scale tests of components (MoD 1974, 25). Exhauster capacity was provided by two Holland-type exhausters. Air-drying capability was also available, with the capacity to dry air to a dew point corresponding to a temperature of -20°C. At the height of the Old Site's development there was a total of 17 test laboratories, all of which housed experimental test rigs or wind tunnels. These were broadly similar to those that were later installed in the Plant House Building on the New Site, although the latter offered greater operational flexibility (**Bldg 572**, see below) (see MoD 1974, 25–9, 79, for detailed technical information on compressed air supply at the Old Site).

Despite the establishment of the New Site (the present site) to the west in the early 1950s, the testing facilities at the Old Site continued in service and contributed directly to the research programme up to the mid 1970s, when the Compressor House was decommissioned and taken down (MoD 1974, 79). Until 1999 the two sites were linked by a road, The Howf, only part of which still exists between Cells 1 and 2 and the northern ramp of a bridge to the present QinetiQ site. Other than the electricity supply, which was routed via the New Site electrical substation, the Old Site test facility was largely self-contained. (MoD 1974, 79).

Ively Road has subsequently been realigned in a curve to the north, and this effectively severed the New Site from the Old Site. The Old Site was vacated in 1999, after which all its buildings were demolished and the site redeveloped under QinetiQ's ownership.

5.2 Pyestock 'New Site' (1954–2002)

5.2.1 The early years: 1950s

The New Site at Pyestock, which is the focus of the present study, was established in the late 1940s and early 1950s (Figs 1 and 2). The existing area of the site was extended by acquiring 195 acres of land from the War Office, part of which had, until the outbreak of war in 1939, been used by the Bramshot Golf Club (DERA 1996), but was otherwise coniferous plantation or scrub (Ordnance Survey 25-inch map of 1940). Some of the roads on the site were named after the course, such as 'The Fairway' and 'Bramshot Road', while the Tenth Tee (**Bldg 549**) was actually preserved for nostalgic reasons, and lies to the north of the Battle House. The Romany was named after the fourth hole of the course and The Howf after one of the fairway shelters.

Site construction started in 1949 with the building of the site spine road, later named The Fairway, and providing access to the site from Ively Road. This and the south wing of the Main Offices (**Bldg 401**) were finished in 1950, followed in 1952 by the Admiralty Test House (**Bldg 307**), Battle House (**Bldg 543**) and the Power Station (**Bldg 305**).

More advanced altitude engine test facilities required much larger equipment and buildings. In 1952–6, Test Cells 1 and 2 (**Bldg 561**), initially called 'No. 3 Ram Jet Area' (ETD n.d.), were designed and built on the New Site, along with the Plant House (**Bldg 572**) and its component test facilities and ancillary buildings comprising No. 3 Workshop and Stores Building, with a Fire Station and Surgery (**Bldg 405**). Cells 1 and 2 were the first large altitude engine test cells to be built in Britain (DERA 1996). Cell 1 provided a means of directing a supersonic jet of air at an intake and engine to simulate supersonic flight conditions ('free-jet testing'), enabling engine intake performance to be studied. In Cell 2, the air supply was connected directly to the test engine ('connected testing'), which was on a frame to enable thrust to be measured and engine integrity and performance to be tested (DTEO 1996, section 1, 3–5). Cells 1 and 2 are described in detail in the present survey (Section 7, below).

In 1955, the facilities at the New Site were further expanded in response to developments in engine size and performance. More sophisticated test facilities were needed to simulate high and low temperature operating conditions (DTEO 1996, section 1, 5). The main Air House compressor-exhauster plant (**Bldg 621**) was built at this time to pump high-pressure air to the engine test chambers to simulate the required altitude flight conditions. Research laboratories such as the Metallurgical Laboratory (**Bldg 303**) and the Dynamics Laboratory (Bldg 304) and infrastructure buildings such as the Assembly Hall (**Bldg 301**), which contained a restaurant, were also built, reflecting the expansion of the facilities at the site. The British government's concern for defence against the USSR and its allies during the Cold War undoubtedly drove this expansion, particularly after the Soviet Union's first atomic bomb test in 1949. From about 1950, rearmament began in Britain; the physical fabric of research stations throughout the country shows that investment in their infrastructure peaked during the 1950s, as it was understood that the Cold War confrontation would probably be protracted (Cocroft and Barnwell 2003, 7–10). During this decade, more than half of total government spending on research and development was allocated to defence, and by 1961 this represented more than 15% of the total defence budget (ibid 2003, 237).

Apparently it was standard practice in the Pyestock Drawing Office, as in other drawing offices at this time, to destroy outdated site plans to ensure that contractors and others worked to the most recent version (Marion Pennell, pers. comm.). Nevertheless, three pencilled 1:500 scale layout and topographic survey drawings of the site, dated 1956–8, were discovered in the archive. These drawings show the outlines of buildings and indicate that most of the site as it appears today was developed by this time, other than the area north of Constant Road, then under construction, which is shown as cleared ground (Fig 3). The drawings do not show Cell 3, although this part of the site is marked as cleared but 'not yet levelled' in preparation for its construction. The drawings also show development on the northern side of The Howf, which linked the Old and New Sites, in the form of the Oil Tank Farm (**Bldgs 502** and **503**), Glen Test House (**Bldg 500**) and the Water Treatment Plants (**Bldgs 261** and **252**).

The Pyestock site is roughly triangular. Roads were clearly set out aligned from north to south and from west to east. The Fairway served as the principal north-south road, with

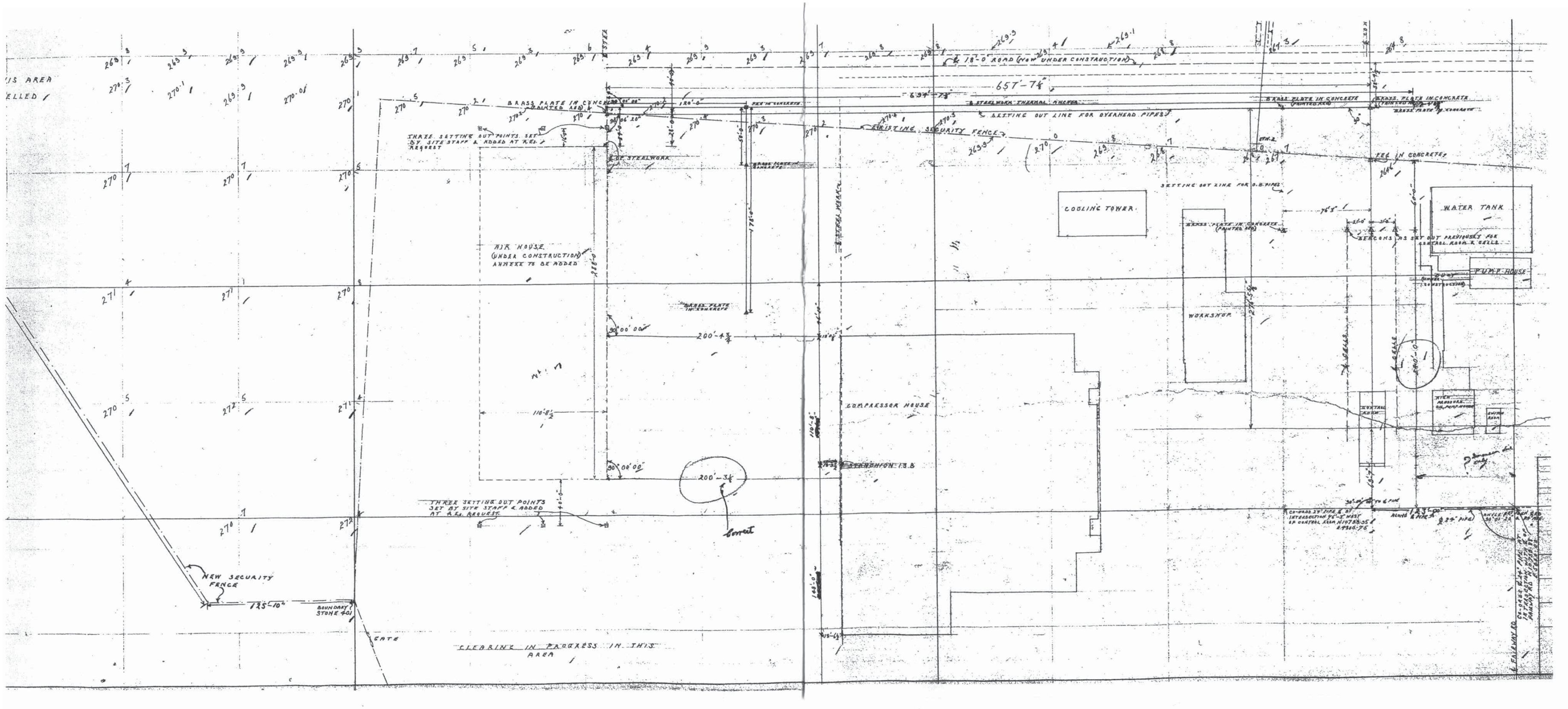

Fig 3 Survey of the northern part of Pyestock 'New Site' dated Feb 1956 (Drg No. LSG41). The survey shows that the site only extended as far north as Constant Road, with the Air House under construction. The topographic levels data indicates that the land to the north was soon to be developed.

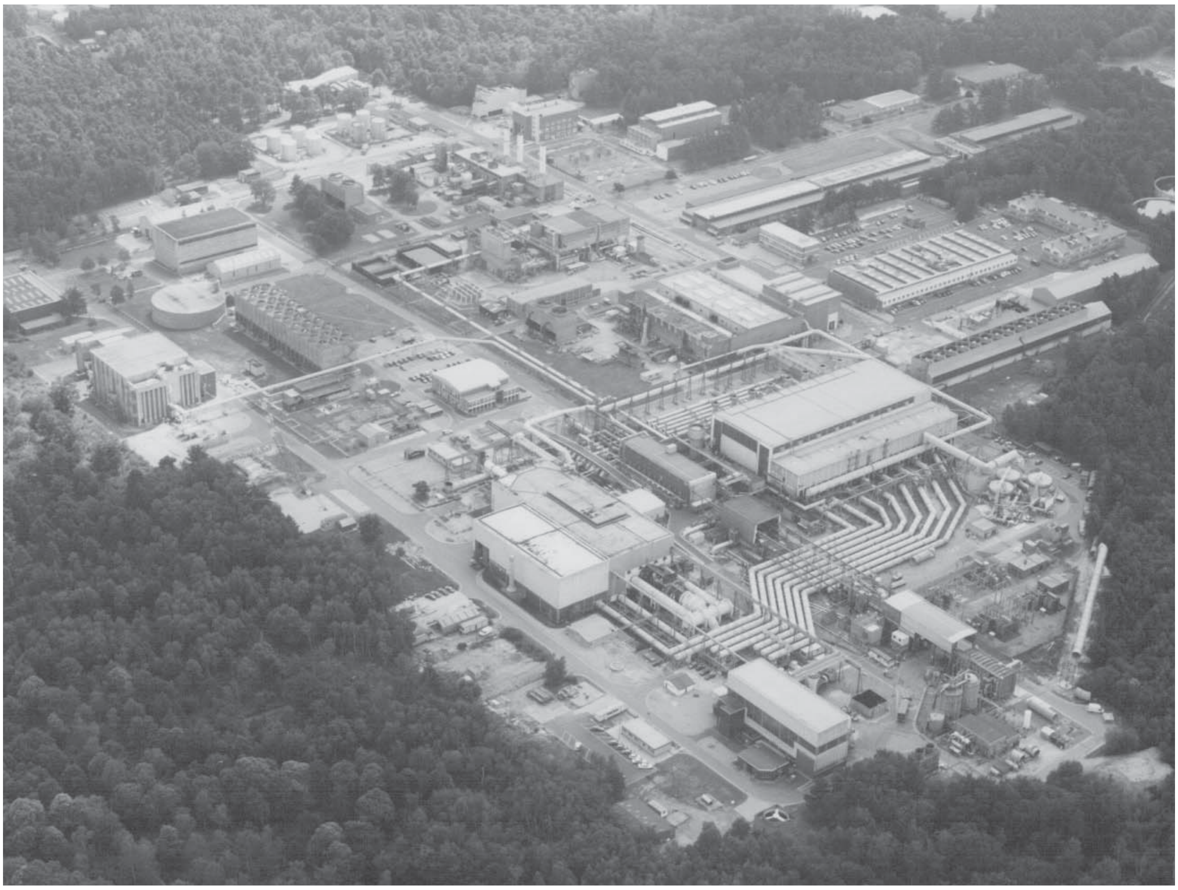

Fig 4 Aerial photograph of Pyestock, before the construction of Ively Road, looking southeast

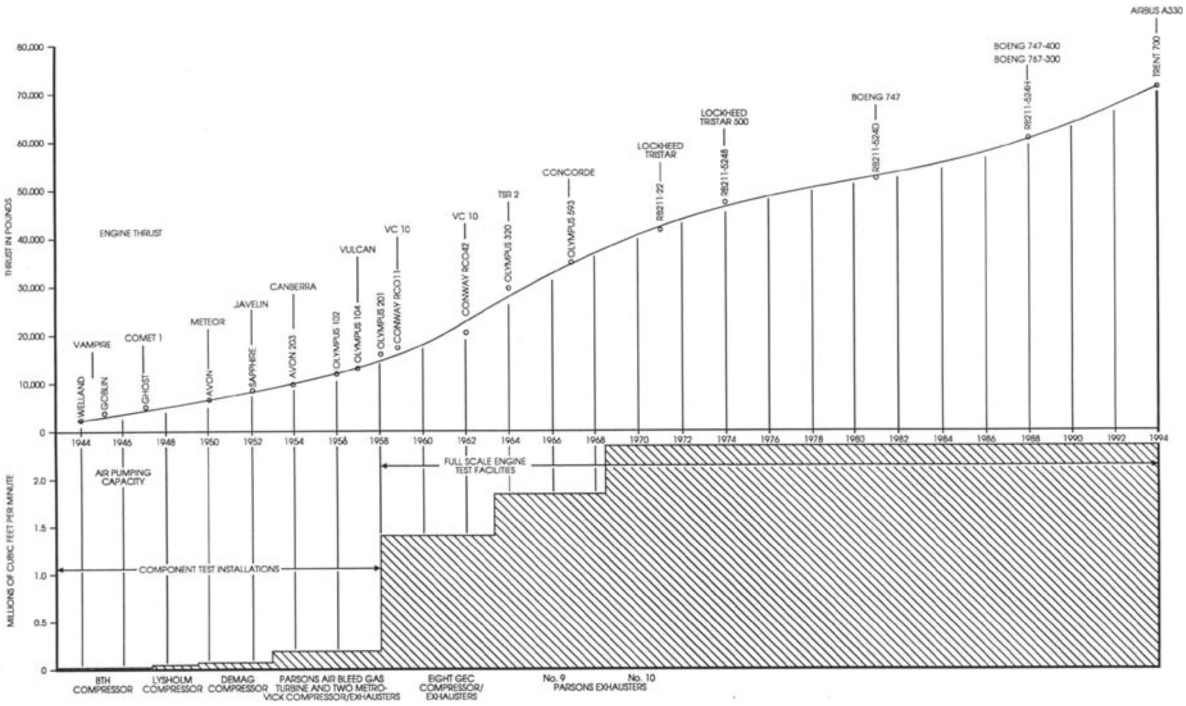

Fig 5 Growth of Pyestock's engine testing plant, 1944–1994 (DTEO 1996, fig 1.1)

	PLANT CAPACITY										CELL CAPACITY									
	Capacity of compressed air supply equipment. Total flow available				Capacity of sub-atmospheric air exhauster equipment. Total flow available					Capacity of dry air supply			Cooling water supply				Fuel system equipment			
Engine test plant	No. and type of machine	Weight flow kg/s (lb/s)	Pres-sure ratio	Delivery temp. range °C	Type of plant	No. of units	Weight flow kg/s (lb/s) per unit	Inlet pressure mm Hg Abs. (in. Hg Abs.)	Inlet temp range °C	Flow kg/s (lb/s) & Absolute humidity kg/kg (lb/lb)	Inlet air pressure range	Inlet air temp. °C	Closed circuit softened water: litre/hr (gal/hr)	Closed circuit softened water: Temp. range °C	Raw water injection system: litre/hr (gal/hr)	Raw water injection system: Pressure m/head (ft/head)	Flow litre/h (gal/hr)	Max press-ure in kPa (lbf/in²)	Method of instrum-entation	Special remarks relating to test equipment
ETF No. 1 Cell	3 GEC	204.1 (450)	9:1	70 to 225 see remarks	GEC driven ejectors	4	14.5 (32)	88.9 (3.5)	15 to 100	272 kg/s at 0.001 for 2.4h 136 kg/s at 0.0002 for 4h (600 lb/s at 0.001 for 2.4h 300 lb/s at 0.0002 for 4h)	1/5 to 9 atm	30 to 350	1,091,040 (240,000)	86 to 38	Two systems, one 818,280 l/hr at 24.4 m (180,000 gal/hr at 80 ft) head. The other 863,740 l/hr at 38.1 m (190,000 gal/h at 125 ft) head. Both supplied from two 1,363,800 litre (300,000 gal) reservIors. Water extract capacity 981,935 litre/hr (216,000 gal/hr).		Two systems available: 54,552 l/hr at 9653 kPa & 27,276 l/hr at 13,790 kPa. (12,000 gal/hr at 1,400 lbf/in² 6,000 gal/hr at 2,000 lbf/in²). Hot fuel: 95°C continuous on all systems. 1660 l/hr at 150°C on one system only.		Direct reading instrum-entation. Real-time data recording acqui-sition and proces-sing.	Delivery temperature of 10 to 15°C can be achieved with flows of up to 91 kg/s (200 lb/s). Engine air may be blown by compressor plant or sucked from atmosphere. Air heating by 3,000 kW electric heater and/or 3,000 kW gas heater.
	2 M.V.	54.4 (120)	6:1	30 to 245																
ETF No. 2 Cell	3 GEC	204. (450)	9:1	70 to 225 see remarks	GEC driven ejectors						1/5 to 9 atm	30 to 350								
	2 M.V.	54.4 (120)	6:1	30 to 245																
ETF No. 3 Cell	3 GEC	272.1 (600)	9:1 —or— 3:1	70 to 225 / 50 to150	GEC as exhaust	8	65.3 (144) Performance with outlet temp. of 15°C 10% lower at 75°C	76.2 (3.0)	30 to 75	272 kg/s at 0.001 for 2.4h 136 kg/s at 0.0002 for 4h (600 lb/s at 0.001 for 2.4h 300 lb/s at 0.0002 for 4h)	1/10 to 5 atm	-70 to 200	11,365,000 (2,500,000	57 to 27	Raw water, 2,727 litre (600 gal) de-mineralised also available		30,000 l/hr at 103-689 kPa. (6,600 gal/hr at 15-100 lbf/in²). Hot fuel at 65°C with same flow. 250 litres (56 gal) single shot at 95°C.		Direct reading instrum-entation. Real-time computer data recording acqui-sition and proces-sing	Sub-zero temp. produced in cold air plant of 45 kg/s (100 lb/s) capacity at -70°C. Super cooled droplet plant: 673 litre (148 gal) at 20 micron.
					Parsons exhaust	2	48.5 (107)	76.2 (3.0)	40											
ETF No. 3 Cell West	2 M.V.	54.4 (120)	6:1	30 to 245	GEC as exhaust	8	65.3 (144) Performance with outlet temp. of 15°C 10% lower at 75°C	76.2 (3.0)	30 to 75	18 kg/s (40 lb/s) approx. via torch air main.	1/10 to atm	-37 to ambi-ent	1,818 (400)	57 to 27	545,520 l/hr (120,000 gal/hr) at 42.6 m (140 ft) head		2,7276 l/hr at 103 to 689 kPa. (6,000 gal/hr at 15 to 100 lbf/in²). Hot fuel: 5455 litres (1200 gal) at 60°C with same flow.		Direct reading instrum-entation. Real-time computer data recording acqui-sition and proces-sing	Sub-zero temperature pro-duced by 30% aqueous ammonia plant designed to cool 363 kg/s (800 lb/s) of air to -37°C for a period of 60 min. when ambient air is at 7°C and relative humidity.
					Parsons exhaust	2	48.5 (107)	76.2 (3.0)	40											

Fig 6 Pyestock's capacity for engine testing (DTEO 1996, table 3.1)

The Romany as the principal west-east road, the eastern end of which connected with The Howf and the Old Site. Testing facilities were located in the centre of the site, with support infrastructure – the main workshop, offices, and assembly bays – in the site's southern half.

5.2.2 The 'golden years': 1960s–1970s

Pyestock remained in the forefront of jet engine technology research throughout this period. In 1961, Cell 3 (**Bldg 630**), the largest and most comprehensive altitude engine test facility in Europe, was commissioned. The new cell provided a much-enhanced altitude test capacity than hitherto available and was used mainly for military testing (DERA 1995), described in more detail below (Section 9.1).

In 1965, Cell 4 (**Bldg 635**) was brought into service, and officially opened by the Prime Minister, Harold Wilson, in 1967. This cell, which took nearly ten years of effort to design, develop and construct, was designed to simulate supersonic flight conditions over a wide range of speeds, enabling the interaction of intakes and engines to be studied under steady state and rapidly changing conditions of pitch, yaw and Mach number. In parallel with the construction of Cell 4, additional suction facilities were provided by the installation of Parsons No. 9 exhauster plant and, in 1968, the No. 10 exhauster plant (DTEO 1996, Sec 1, 5), which provided additional exhauster capacity for Cell 3 West. Cell 4 is described in detail in the present survey (Section 8, below).

A 1:1250 scale site survey drawing and very detailed 1:500 scale survey drawings, dated 1968, show the layout of Pyestock at this time. New development, additional to that shown on the survey of 1956–58 described above, comprises all buildings on the northern side of Constant Road and in the north-west of the site, along with the Sooty Water Plant (**Bldg 263**) north of The Howf. The plans show Test Cells 3 and 4, the Transformer Park (**Bldg 625**), Parsons No. 9 and No. 10 exhausters (**Bldgs 635** west and **638**), and the Computer Building (**Bldg 574**). The plan also shows the very northern part of the site, north of the existing Kerr Road and Davidson Road, as open and undeveloped. This rough, unmetalled area was unofficially known as 'Dodge City', as it contained several timber sheds used by the site construction contractors, giving an impression of the Wild West! It remained little changed at the time of the survey, in 2005.

In 1969, the last test cell to be built at Pyestock was constructed. Cell 3 West (**Bldg 649**) was designed to test turbofan engines in the 50,000lb thrust class, such as the Rolls-Royce RB211 for the civil Lockheed Tristar airliner. The requirement here was for a facility capable of testing very large diameter power plants of high thrust and air mass flows but at subsonic altitude conditions. A large multi-tube air cooler installed at the cell inlet enabled the simulation of representative altitude air temperatures. Cell 3 West was also used for simulating icing conditions on both engines and full-scale helicopter fuselages (DTEO 1996, Sec 1, 5). Cell 3 West is described in more detail below (Section 9.2).

Pyestock occupies a significant place in the context of post-war defence research. It was a beneficiary of the spending of the 1960s, reflecting Harold Wilson's vision, first expressed in 1963, of an ultra-modern Britain that would be forged in the 'white heat of technological revolution' (cited by Cocroft 2003, 237). In his memoir, Peter Ashwood provides evidence for the liberality with which resources were made available for research at Pyestock:

'What strikes me most when looking back is the freedom that existed to define subjects for research and follow them through to experiment, even on occasion to full-scale flight trials. I had been at Pyestock for perhaps ten years before the question of cost was even mentioned. I can honestly say that throughout my whole career there was never an occasion when I was not allowed to follow a line of research on the ground of cost provided no new items of capital equipment were involved' (Ashwood 2003, 23).

The capacity of Pyestock grew in relation to specific research and development projects (Fig 5). By 1975, Pyestock had reached its maximum extent and employed over 1500 people. A 1:1250-scale site survey dated 1975 (Fig 2) shows development of the land in the northernmost part of the site, including the anechoic chamber of the Noise Test Facility constructed for research into the reduction of engine exhaust jet noise, built in 1974–5 (**Bldg 590**). Pyestock was home to the largest altitude engine test facility in

Europe (Fig 6) and the work carried out was respected throughout the world. The gas turbine research carried out then, and continuing to this day in QinetiQ was, and remains, world class.

5.2.3 Reorganisation and decline: 1980s–1990s

In 1976, NGTE was involved in a rationalisation programme promulgated by the Controller of Establishments and Research at the Ministry of Defence. The plan involved bringing most naval engineering work within NGTE. The establishments affected included the Admiralty Engineering Laboratory (AEL) at West Drayton, London Borough of Hillingdon, the Admiralty Oil Laboratory (AOL) at Cobham, Surrey, and the Admiralty Marine Establishment at Haslar, Hampshire. Some of the staff and activities at these establishments relocated to Pyestock but practicalities ruled out full relocation. The relocation of AEL's submarine work brought marine diesel engine testing to Pyestock, using refurbished test cubicles in the Plant House. In 1979, there was a review of the management and staffing levels at NGTE. This did not come up with any significant proposals for improvement, but it provided the basis for the continual questioning of the Establishment's raison d'etre. Concern was expressed in the MoD that NGTE was too independent with respect to the choice of research topics and that it should contribute to the solution of more immediate problems, although nothing really came of this (Ashwood 2003, 17). Cell 4 was closed in 1980 but kept in a 'care and maintenance' condition until all the site's test facilities were decommissioned.

In 1983, NGTE was subsumed into the Royal Aircraft Establishment (RAE). Although this brought some disruption, it meant that a much larger pool of money was available for funding capital projects. One project in particular was to enable research to continue, in conjunction with the University of Oxford, into turbine blade cooling. A testing facility was constructed for measuring heat transfer effects and aerodynamic performance on a full-scale model of an engine high-pressure turbine (McKenzie 2002, 5).

In 1991, the organisation of Pyestock was radically changed. A further review, as part of the government's 'Next Steps' initiative, had recommended that the four main non-nuclear research establishments should be formed into an executive agency. Thus, on 1 April 1991, the Defence Research Agency (DRA) was vested in the MoD. Initially, DRA funding came from the parliamentary defence vote, but later DRA became a trading fund whose income came solely from its customers. After a year, DRA divested itself of all its major test facilities, including the engine test facility at Pyestock, returning them to MoD. The effect on Pyestock was that the site, as a whole, returned to MoD under the Directorate-General Test and Evaluation (DGT&E) while the remaining gas turbine research element remained part of the DRA as a 'lodger unit' at the site (McKenzie 2002, 5). In 1995, the Defence Evaluation and Research Agency (DERA) was formed from DRA and DGT&E, with a new divisional structure. At Pyestock, the former DGT&E activities now fell within the new Defence Test and Evaluation division (DTEO), while DRA, still encompassing the Pyestock research group, became a division in its own right.

DERA Pyestock operated for six years, during which its research programmes proceeded more or less as normal. Engine testing projects included, among others, the EJ200 engine development programme for the Typhoon Eurofighter and the Rolls-Royce Trent and BMW Rolls-Royce BR700 civil aircraft engine development and certification programmes. DERA then divided in 2001 into a public limited company, QinetiQ, incorporating approximately three-quarters of DERA while the remaining quarter, which included the militarily sensitive elements of DERA, was formed into the Defence Science and Technology Laboratory (DSTL) operating as a trading fund within the MoD. Pyestock's activities fell within the remit of QinetiQ, which initially was a fully government-owned public limited company (McKenzie 2002, 5). QinetiQ sold a proportion of its equity to a strategic financial partner in 2002 with the future intention of an initial public offering on the London Stock Exchange.

5.2.4 Present day: 2000–2005

By 1999, all but Cells 3 and 3 West had been placed on 'care and maintenance' and by April 2002, these two cells had also been closed. Cell 3 West would have required major modification to accommodate the increased diameter of the Rolls-Royce Trent 800, and the even greater diameter of its derivatives, Trent 900 and 1000, prevented their installation. Faced with this position, Rolls-Royce determined to contract their testing to AEDC in the United States. The MoD was reluctant to fund more testing of EJ200 in Cell

3, considering the mature position of that engine's development programme. Under these circumstances, QinetiQ took the decision to decommission the remaining engine test facilities at Pyestock. As part of the redevelopment of the Old Site and the realignment of the Ively Road, the main administration block (**Bldg 401**) and the Metallurgical Laboratory (**Bldg 303**) were both demolished. At the same time, the Glen Test House (**Bldg 500**) also became surplus to requirements and was dismantled and sold to the Score Group, who reconstructed it at Peterhead, Aberdeenshire, for pass-off testing of industrial gas turbines. Cells 3 and 4 were used in 2004 as sets for a Hollywood film, 'Sahara' (released March 2005). In preparation for filming, partial and fairly minor alterations included repainting and the installation of minor structures and a false roof on Cell 3. This was not the first occasion that Pyestock had been used for filming; episodes of 'The Bill' were filmed in 2004, episodes of 'Red Dwarf' were filmed in Cell 4 in the mid 1990s, and as long ago as 1968 location shots for a minor film 'Some Girls Do' were filmed in and around the test facilities.

At the time of writing, almost all of the original buildings are extant, with the distinctive network of pipes carrying air, fuel and water to the test cells. Most buildings are fairly utilitarian structures of either brick or steel frames with cladding. Many contain the remains of highly specialised and complex equipment, including engine test cells and control rooms, air compressing and exhausting machinery, and component test facilities. Smaller and more serviceable equipment has been almost entirely removed from the control rooms, test facilities, workshops and offices since the site was decommissioned and the interior of the rooms bears little resemblance to that shown in archive photographs. The general appearance of the site is nevertheless impressive and the physical remains and extensive archive provide evidence of what was, until relatively recently, a world-leading research establishment. Several facilities in the northern part of the site are still in operation, such as the 'Sigma Aerospace' pass-off engine test facility on the northern side of Kerr Road, which is run by a private company, and the anechoic chamber of the Noise Test Facility (**Bldg 590**), operated by QinetiQ. The ejector seat test rig, sited to the west of the Noise Test Facility, was dismantled in April 2005. The laboratories of the QinetiQ Fuels and Lubricants Centre (**Bldg 442**) are sited in a separate enclave towards the southern end of the site.

6 Pyestock at work

6.1 Test preparation

Test programmes were often very complex, and the preparation and execution of a full-scale engine test in one of the large test cells required the cooperative effort of approximately 30 people, who covered a wide range of scientific and engineering disciplines (Ashwood 2003, 15). The person with overall responsibility for installing an engine in a test cell was the cell engineer. His responsibilities also included the design and manufacture of any ducting and other fittings and fixtures that were required. This senior individual was a chartered engineer and had at his disposal design draughtsmen, engineering supervisors and craftsmen. The choice of cell to be used for a particular test depended on a number of factors such as the type of test, engine size and operating parameters, and would be determined by discussion between the Trials Group, which supplied the scientific effort including the test controller, and Cells Engineering.

During installation, the craftsmen carrying out the work were responsible for the quality of their own work and all took great pride in what they were doing. Safety in the engine test facility was of paramount importance and the site operated a 'permit to work' system. On the day of a test run, the permit to work on the cell would be closed by the engineering supervisor in the Test Area Office and instructions would be issued for the plant systems to be set up. During this process, the test controller and his team would arrive in the control room and ready themselves for the test. On completion of the set-up, the checklists used by the craftsmen for setting up would be checked by the cell engineer and passed to the test controller. Once he was satisfied that all was in order, responsibility for the operation and safety of the cell would pass to the test controller by means of signatures on a form (Geoff Timmins pers. comm.). Following completion of the test run, the test controller would sign off and responsibility would revert to the cell engineer, who would then arrange for the raising of a new permit to work. The physical act of creating a permit to work in the test cells took, on average, three quarters of an hour. The effectiveness and efficiency with which the test cells operated was very much down to the strong ethos of team-work that existed at Pyestock (Geoff Timmins pers. comm.).

Pyestock staff managed the testing facilities and associated equipment, while the manufacturers (mostly Rolls-Royce) looked after their particular engine and would usually have their own engineer attending the test. Test engines delivered to the site for Cell 3 West would be unloaded using a 60-ton crane in the 'Palladium' stores building (**Bldg 584**), unofficially so called after the London Palladium, the theatre with the largest stage in London (Geoff Timmins pers. comm.). The engine was transported to the cell by means of a hoverpad assembly mounted on a trailer.

The common dependence of the test cells and test cubicles on the air pipe system meant that scheduling of tests was essential to avoid interference. To that end, a weekly rota system was adopted, allowing each cell to operate effectively with respect both to its own programme and to the programmes of other cells and test rigs (MoD n.d., 31).

6.2 Data collection

Testing procedures developed considerably from the early days, as Peter Ashwood recalls: 'The process of reading instruments by eye, with the observations recorded using paper and a pencil and with calculations made using a slide rule, has given way to digital data acquisition systems linked to computers which can handle several hundred individual measurements…' (Ashwood 2003, i).

The instrumentation was constantly updated to incorporate technological changes. Instruments in the test cells measured temperature, pressure, load, speeds and flows from 'steady state' tests, where the test conditions were predefined and fixed, and from 'dynamic and transient' tests, where conditions were changed during the test to simulate manoeuvres in the air, such as dives (DTEO 1996, Sec 4, 4).

Data gathering was carried out in stages:

Data collection from numerous transducers fitted to the test engine along with numerous plant inputs

Transmission of the data from the test cell to the Data Centre

Receiving and processing of data using the appropriate altitude test facility (ATF) computer

Reproducing processed data to the client.

Technological developments meant that for some test cells, data from the test could be transferred directly not only to the central control room, but also to Rolls-Royce in Derby (Geoff Timmins pers. comm.).

6.3 Essential services

Testing in the cells required vast quantities of air, fuel, electricity and water. The sections below describe how the demand for these resources was met. The technical information and the illustrations are almost entirely derived from the Defence Test and Evaluation Organisation brochure, *Pyestock test facilities* (DTEO Jan 1996), with additional comments from Geoff Timmins. The brochure provides a good overview of the facilities at Pyestock and much technical information, the salient points being summarised here.

6.3.1 Air supply

The main feature of air supply facilities at Pyestock was the ability of its air machines to compress atmospheric air to high pressure and to exhaust the air from the test cells in order to simulate altitude conditions (DTEO 1996, Sec 2, 3). The main air facilities comprised:

The Air House (**Bldg 621**) (Figs 7 and 8). This was constructed in 1955 in order to produce compressed air for supersonic and subsonic testing in the test cells. It originally contained four compressors; four more compressors were added later (Fig 9). Each of the eight GEC machines, which were *in situ* at time of writing, consists of three centrifugal compressor stages (each of 3:1 pressure ratio) mounted in line with a 30MW synchronous electric motor at one end of the connecting shaft (Figs 10 and 11). The compressors could be used for either compressing or exhausting (but not simultaneously) at overall pressure ratios of 3:1, 9:1, 1:3 and 1:9. These were originally brought up to speed using steam turbine engines. The steam was provided by three marine boilers located in the Battle House (**Bldg 543**). More recently, the compressors were started with an electronic variable frequency power source.

Parsons No. 9 (northern part of **Bldg 635**) and No. 10 exhauster sets (**Bldg 638**). These were constructed to provide additional exhauster capacity for Cells 3, 3 West and 4. The former is a three-stage axial exhauster driven by a 27.5MW synchronous electric motor with a constant operating speed of 3,000 revolutions per minute, producing an overall pressure ratio of 1:13.5; the latter is a two-stage axial exhauster (pressure ratio 1:9) driven by a 25MW synchronous induction motor. One machine could be used if the other was being serviced, or they could be used in parallel when maximum output was required.

The Plant House (**Bldg 572**). Originally designed for component testing, it also supplied air to the first test cells, Cells 1 and 2. The Plant House contained four electrically driven compressors: two Metropolitan-Vickers axial compressors (pressure ratio 6:1), each driven by a 6.6MW motor, available for either compressing or exhausting; a Reavell compressor (pressure ratio 2.5:1) with a 447kW variable speed induction motor (compression only); and a Broomwade low flow compressor (pressure ratio 10:1) with a 201kW electrically-driven motor (compression only, also serving the auxiliary plant). The air was fed from the hall into research

Fig 7 Exterior of the Air House (Bldg 621), looking west. Each of the eight vertical exhauster stacks serves one of the sets of air compressors inside the building (CNV00025-F1-24.jpg)

Fig 8 Interior of the Air House, looking north-east, showing the southernmost set of air compressors at an upper level inside the building. Service piping and machinery is underneath at ground level. The space in the foreground is a loading bay (MoLAS 015/05/02)

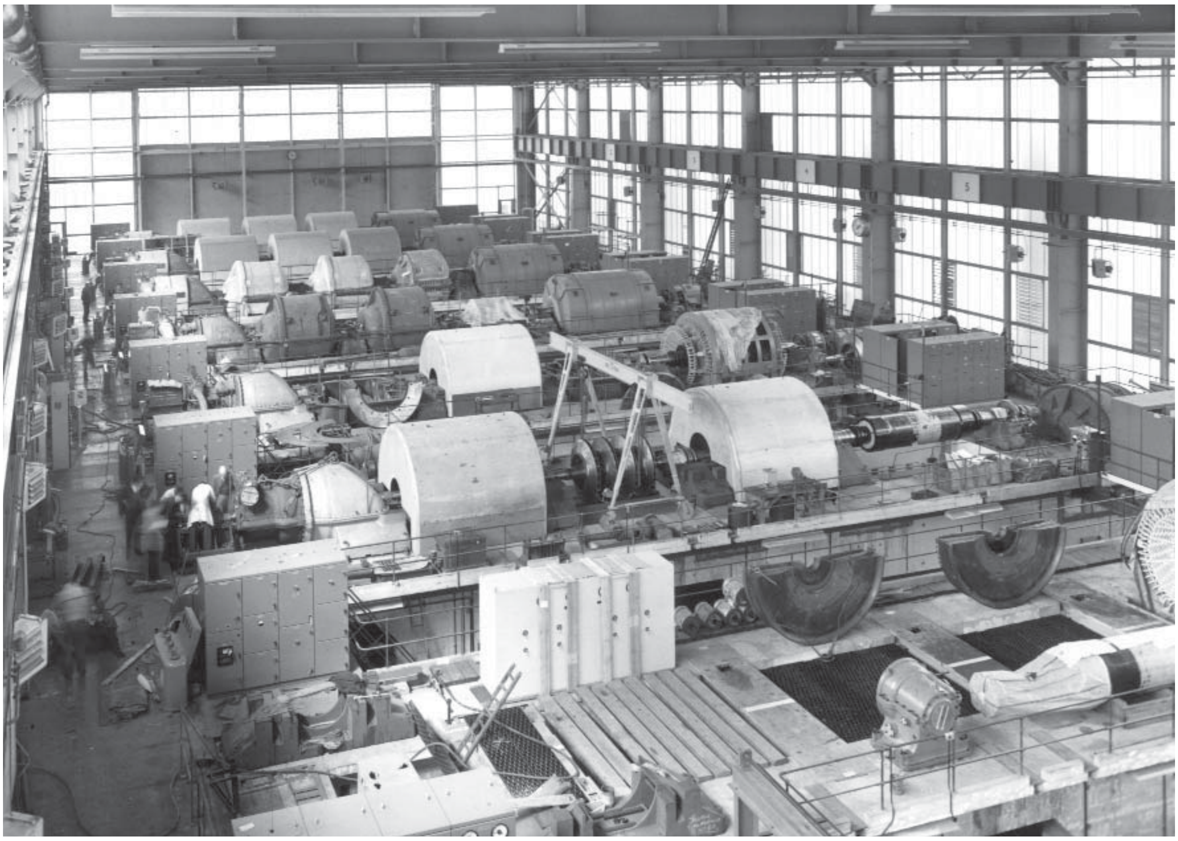

Fig 9 Compressors being installed in the Air House (NGTE 19699)

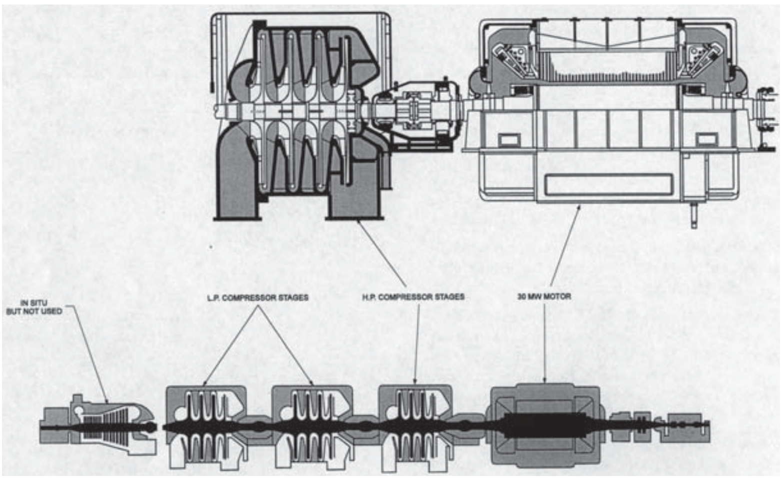

Fig 10 Sectional view of a GEC machine in the Air House (DTEO 1996, fig 2.4)

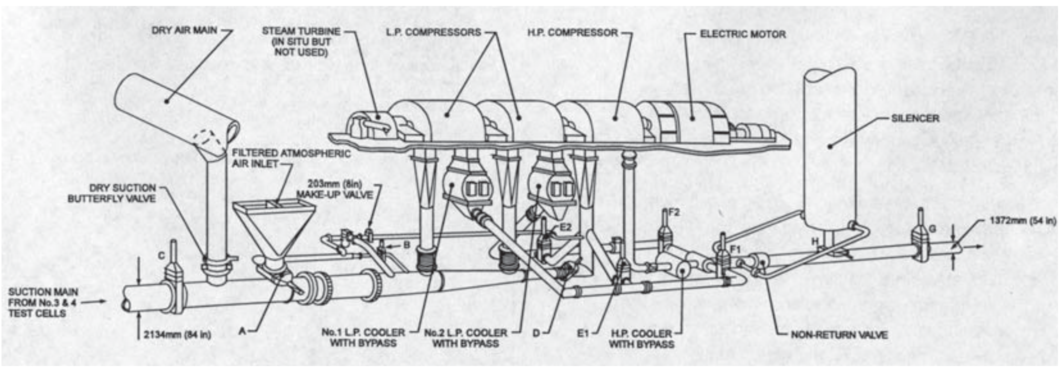

Fig 11 Perspective view of a GEC machine in the Air House (DTEO 1996, fig 2.5)

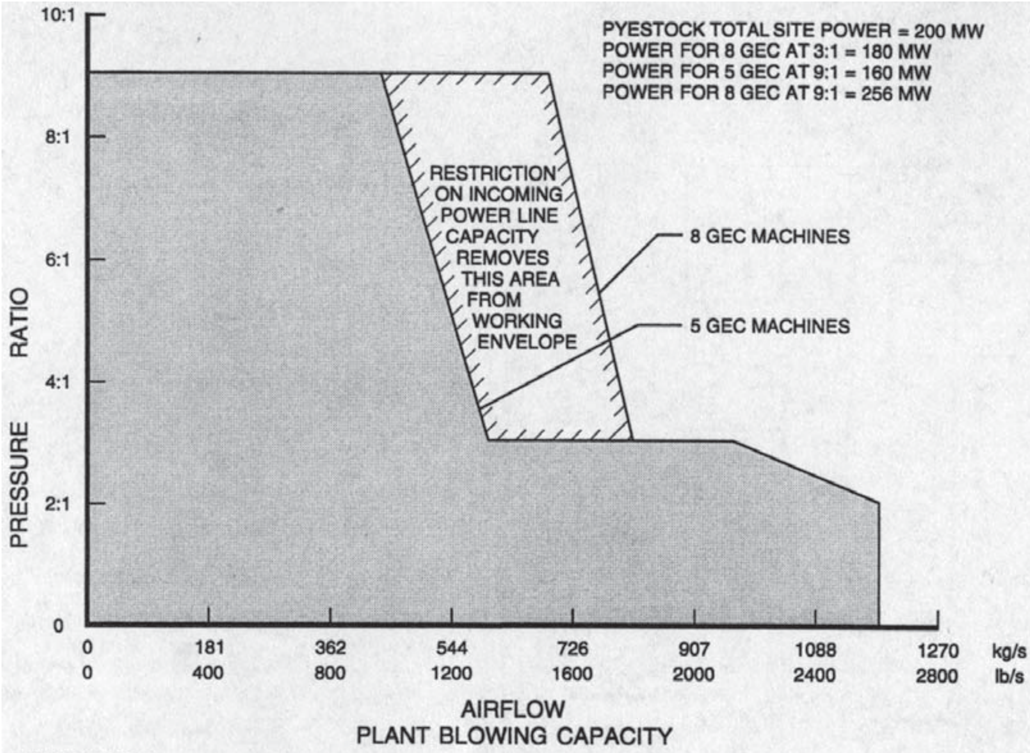

Fig 12 Total compressing performance of Air House (DTEO 1996, fig 2.2)

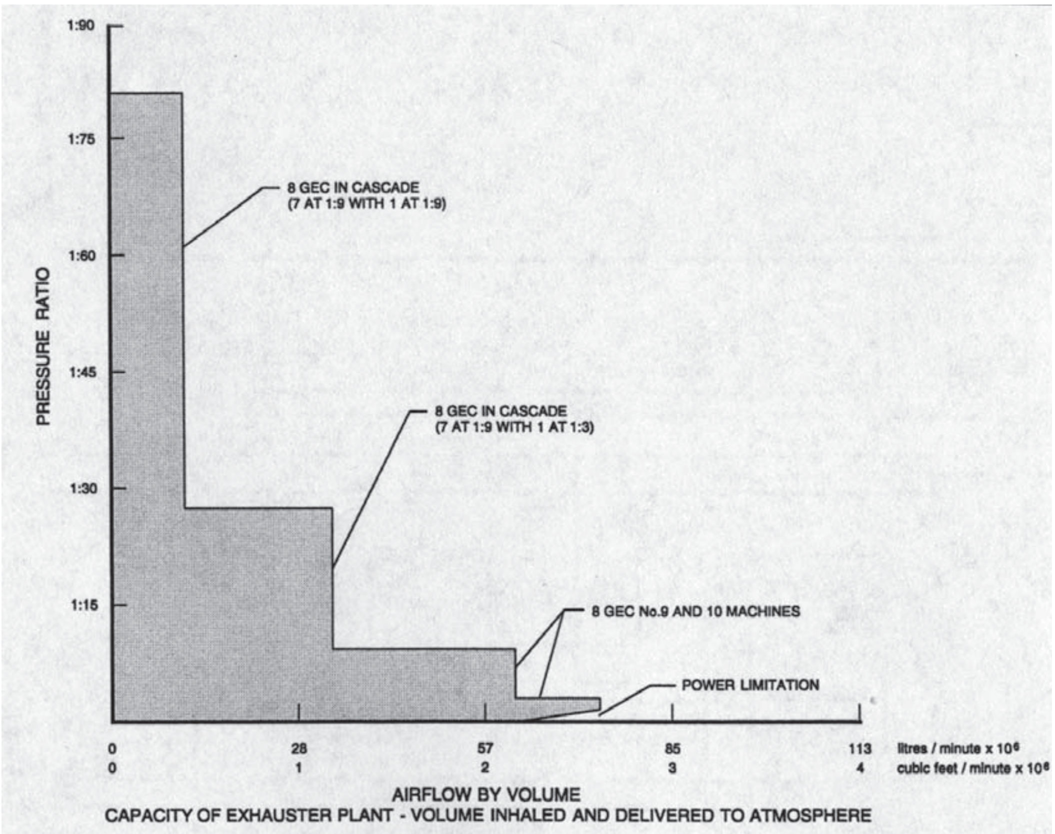

Fig 13 Total exhauster performance of Air House and No. 9 and No. 10 machines (after DTEO 1996, fig 2.3)

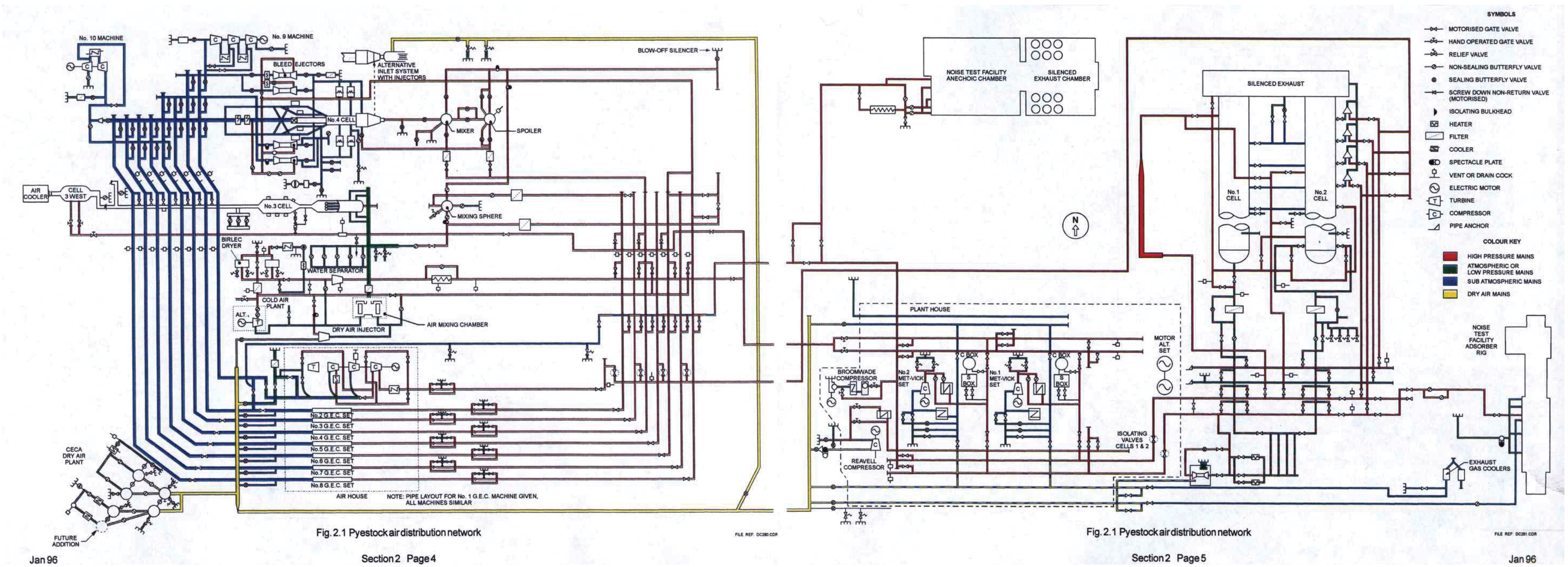

Fig 14 Air distribution at Pyestock (DTEO 1996, fig 2.1)

> cubicles on the north and south sides of the building, by lines of pipes in valve bays on either side of the hall. A Parsons air-bleed gas turbine (compressing only) was also installed supplying air at a pressure of four atmospheres. This machine, rarely used due to its unreliability, was finally taken out of service in the 1980s.

When all eight GEC compressors in the Air House were working in unison, configured for a pressure ratio of 3:1, a maximum flow of 2,600lbs of air per second was possible, but aerodynamic losses reduced the available pressure ratio to 2:1 (Fig 12). Although the electrical power demand to operate all eight sets simultaneously was within the site's capacity, there was no practical advantage. For extreme altitude conditions, all the compressors could be run as exhausters in parallel, by operating seven sets at 1:9 cascaded into the eighth set operating at 1:3, to produce an overall exhauster pressure ratio of 1:27. Alternatively, operating the cascaded eighth machine at 1:9 would provide 1:81 overall. The total exhauster, or suction, performance of the eight machines plus that of Parsons No. 9 and 10 machines was 25 million cubic feet per minute (Fig 13).

The air was distributed around the site by a system of large-diameter ducts, which allowed wide operational flexibility, and the ducts were controlled by valves to ensure that there was no conflict between the various test cells (Fig 14). The pressure ducting was lagged to maintain air temperature whilst the suction mains to the Air House and the overhead dry suction main from the Ceca dry air plant (see below) were unlagged and painted light blue. The ducts were constructed with flexible couplings to cope with the demands of changing air pressure and temperature (Figs 15 and 16).

Dry air could be provided when tests required it by means of an atmospheric air drying plant, the Ceca Plant (**Bldg 623**), situated to the west of the Air House. This plant comprised two individual units each containing a filter, and a combined total of four absorbers each containing 54 tons of silica gel for drying the air sent through it. Reactivation of the silica gel, which could take up to 9 hours, was usually carried out overnight to minimise the impact on testing. Each plant provided a throughput of 90.7kg/sec (200lb/sec), making a total of 272kg/sec (600lb/sec) dry air available. A second, smaller dry-air plant, the Birlec Dryer, was constructed earlier during the building of Cell 3. This contained 42 tons of silica gel for use exclusively for cold air testing in Cell 3 and was situated immediately to the south of this cell.

6.3.2 Power supply
Testing at Pyestock made use of a variety of power supplies: electricity, gas and steam. Testing and, in particular, the use of the compressors required a vast amount of electrical power (Fig 17).

Until 1984, steam was used extensively to start the GEC machines in the Air House (**Bldg 621**), for powering the test cells and for heating buildings (DTEO 1996, Sec 5, 5). Steam was also used for powering two further steam turbines sited in the Power Station and the Battle House. The former powered an alternator that could generate up to 12.75MW to provide peak-load lopping capability. The 11.2MW Battle House steam turbine formed part of the compressor test facility in that building and was used to power research compressors. In 1984, two variable frequency starting systems, manufactured by the Brush Electrical Engineering Company, were installed for starting all the large air-moving machinery, much reducing the site demand for steam. Steam was produced by three boilers in the Battle House (**Bldg 543**), so called because the first two boilers had been salvaged from the Battle Class destroyer HMS *Namur* broken up after World War II (Geoff Timmins pers. comm.). Additional steam was provided by five generators, manufactured by Babcock Robey, located in the West Annexe of the Air House and used exclusively for regenerating the silica gel in the Ceca Plant.

As very large electrical demands and changes in demand were common, potentially up to 100MW within a five minute period, close liaison with the electrical supply provider was essential. In 1994–5, DGT&E negotiated an agreement with Southern Electric that allowed for a maximum summer and winter capacity of 129MW and 160MW respectively, via the Southern Electric substation at Pyestock (**Bldg 625**). An additional 45MW was also available from the DRA facility at Farnborough (DTEO 1996, Sec 5, 3). One former member of staff estimated that in the 1970s Pyestock accounted for as much as 3% of the total demand for electricity in southern England (Ian McKenzie pers. comm.).

Fig 15 Flexible support for overhead air pipe near Cells 1 and 2 (MoLAS 021/05/20)

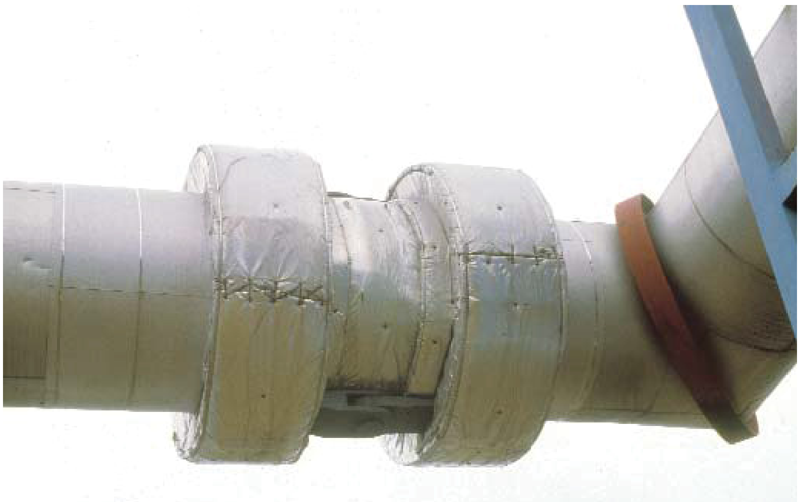

Fig 16 Lagged flexible coupling on overhead air pipe near Cells 1 and 2 (MoLAS 021/05/21)

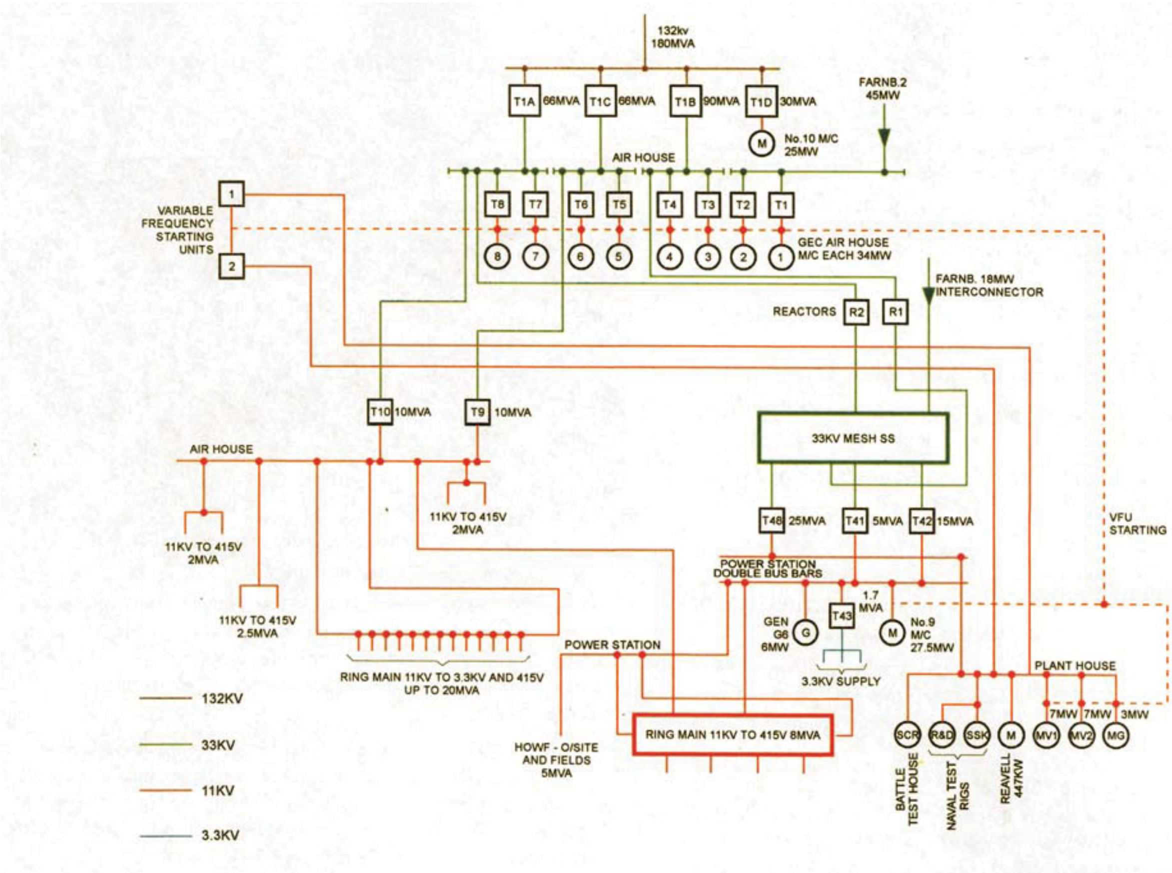

Fig 17 Electrical distribution at Pyestock (DTEO 1996, fig 5.2)

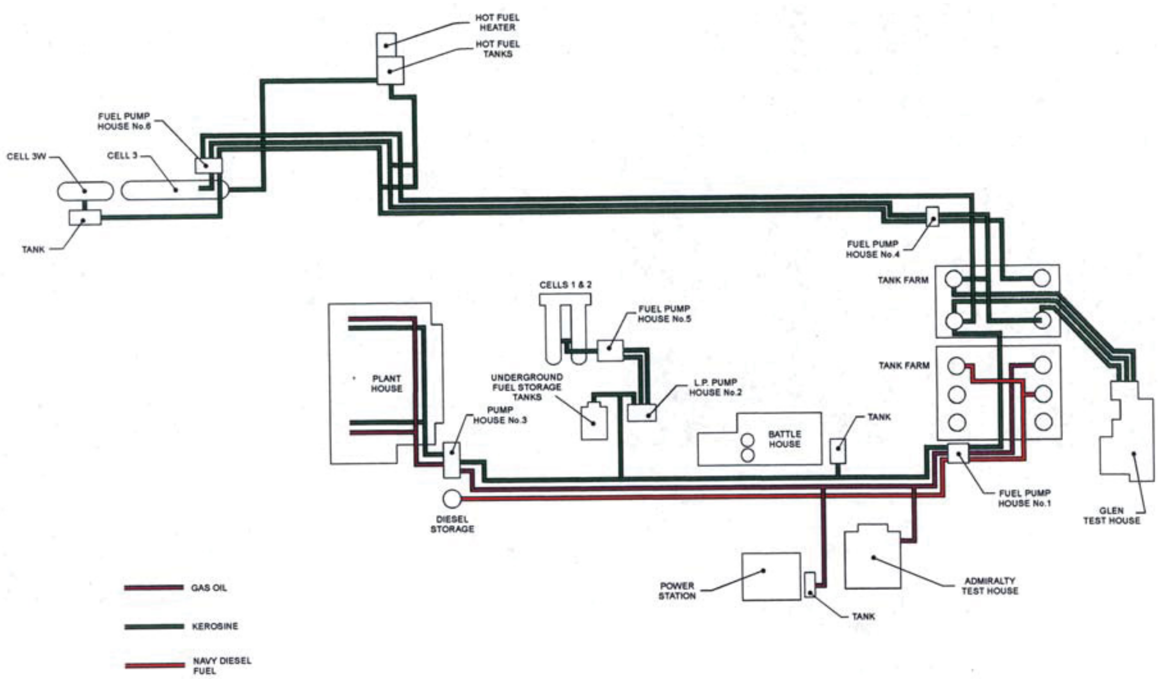

Fig 18 Fuel distribution at Pyestock (DTEO 1996, fig 5.5)

Fig 19 Fuel pipes and other pipes laid in an open conduit forming a 'safety zone', looking west between Cells 3 and 4 (MoLAS 021/05/14)

Fig 20 Water tanks north-east of Cells 1 and 2, to store water for cooling; looking south-west. Note water-level gauge on the nearest corner (MoLAS 021/05/10)

Gas was supplied to the Pyestock site via two pipelines, and was used for heating buildings and also fuelling the air heater for two combustion test rigs in the Battle Test House (**Bldg 543**). Hydrogen, required for reheat testing in Cell 2, was delivered to the site in special purpose-built trailers. These were parked adjacent to the cell and, when required, were connected by armoured flexible hoses to two gas-unloading stations (DTEO 1996, Sec 3, 7).

6.3.3 Fuel supply

Several types of fuel were used at Pyestock: Navy diesel, Avtur (Jet A1 aviation kerosene), Avtag (wartime gas oil) and, until the marine boilers in the Battle Test House (**Bldg 543**) were decommissioned in 1994, heavy fuel oil. The Navy diesel was used for testing at the Admiralty Test House (**Bldg 307**) and for some combustion testing in the Plant House (**Bldg 572**). The fuel supply to the Power Station (**Bldg 305**) had been disused for many years. (Geoff Timmins pers. comm.).

Ten 80,000-gallon tanks in the Tank Farm on the eastern edge of the site (**Bldgs 502** and **503**) were used to store fuel, which was then distributed to local tanks and fuel systems in the facilities according to demand (Fig 18). Distribution was by 6-inch and 3-inch pipes, through six pump houses (DTEO 1996, Sec 5, 7). These pipes were contained in open trenches or conduits, forming a 'safety zone' (Fig 19).

6.3.4 Water supply

A vast amount of water was required primarily for cooling purposes during altitude testing. The vast majority of the water was used to cool the engine and cell exhaust gases. Additional water was used for the air moving machinery intercoolers and after-coolers when operating in the compressor mode, to regulate the delivery air temperature to that required for the tests. The site steam plant also used considerable quantities of water. Raw, untreated water was originally drawn from the Basingstoke Canal, but was later drawn exclusively from the Mid-Southern Water Company mains. From these mains it passed through, and was stored in, a system of water treatment plants, reservoirs, cooling towers, pump houses, pipe circuits and tanks (Figs 20 and 21). A total of about eight million gallons of water could be stored at Pyestock (Geoff Timmins pers. comm.).

Water was treated before it was used, as this was beneficial in economic terms (DTEO 1996, Sec 5, 10). Treatment entailed softening the water at two plants, to reduce alkalinity, and demineralisation at one plant, where minerals and silica were removed. The latter was required when very pure water was needed, as in icing trials and the direct injection of water into experimental engine compressors. Softened water was held in one of three tanks, the Bramshot Reservoir (**Bldg 581**) or Nos 1 and 2 'Pondpenny' Reservoirs (**Bldgs 406** and **423**).

Most of the test facilities had their own water cooling towers, with a cooling pond that collected the water as it dropped through the tower, which held additional supplies of softened water. The cooling towers are characterised by sections of wooden slats along the sides of the structures, which allowed a free flow of atmospheric air to pass into the tower to assist in cooling the water (Fig 22).

Contaminated water was reused by passing it through the oily and sooty water treatment plants on the northern side of The Howf (**Bldgs 261** and **263**; Fig 23). The Old Site used separate water supplies, although its contaminated water was treated in the New Site oily water treatment plant.

6.4 Support workshops

The Main Workshops (**Bldg 407**), containing standard workshop equipment (drills, lathes, etc), consisted of two separate support sections, comprising the instrument workshop and the electronics workshop. These workshops provided equipment required by the scientists and technicians for the site tests, although each of the main testing facilities also had its own workshop that produced bespoke fittings (Geoff Timmins pers. comm.). Until the closure of the Main Workshops in 1994, in-house manufacture accounted for less than half of the site's requirements, the remainder being sourced under sub-contract from external engineering manufacturers.

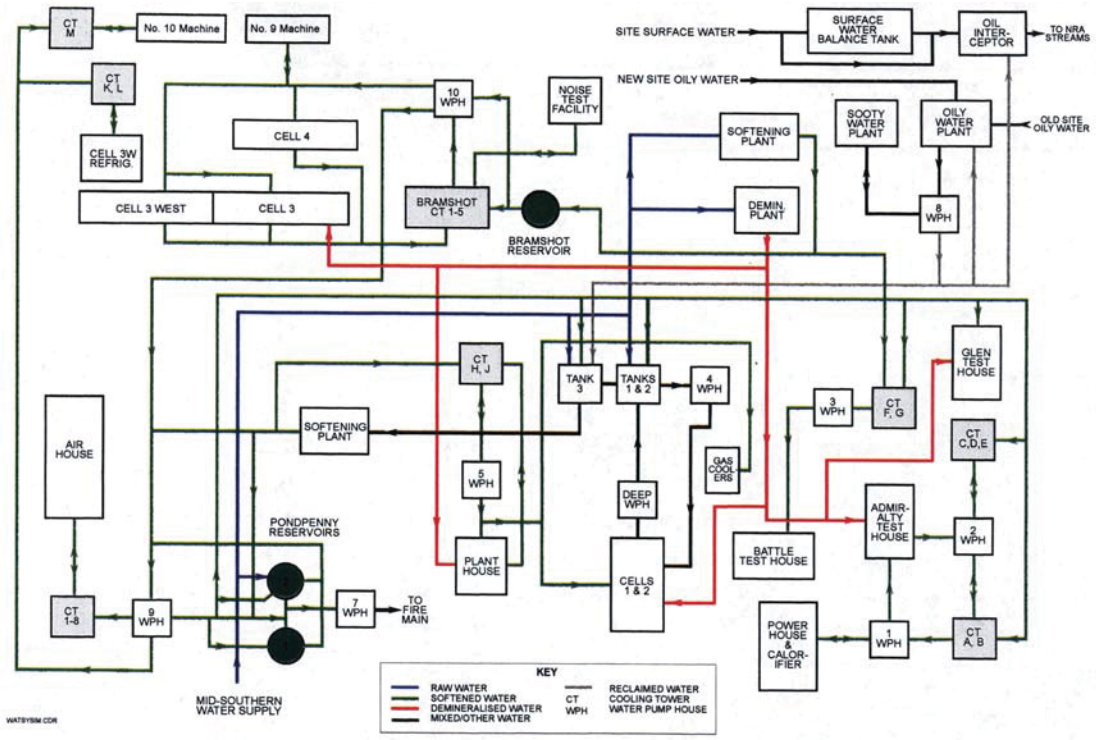

Fig 21 Water distribution at Pyestock (DTEO 1996, fig 5.6)

Fig 22 Water cooling towers under construction south-west of Cells 1 and 2, in the mid 1950s, looking south-west (NGTE 10395)

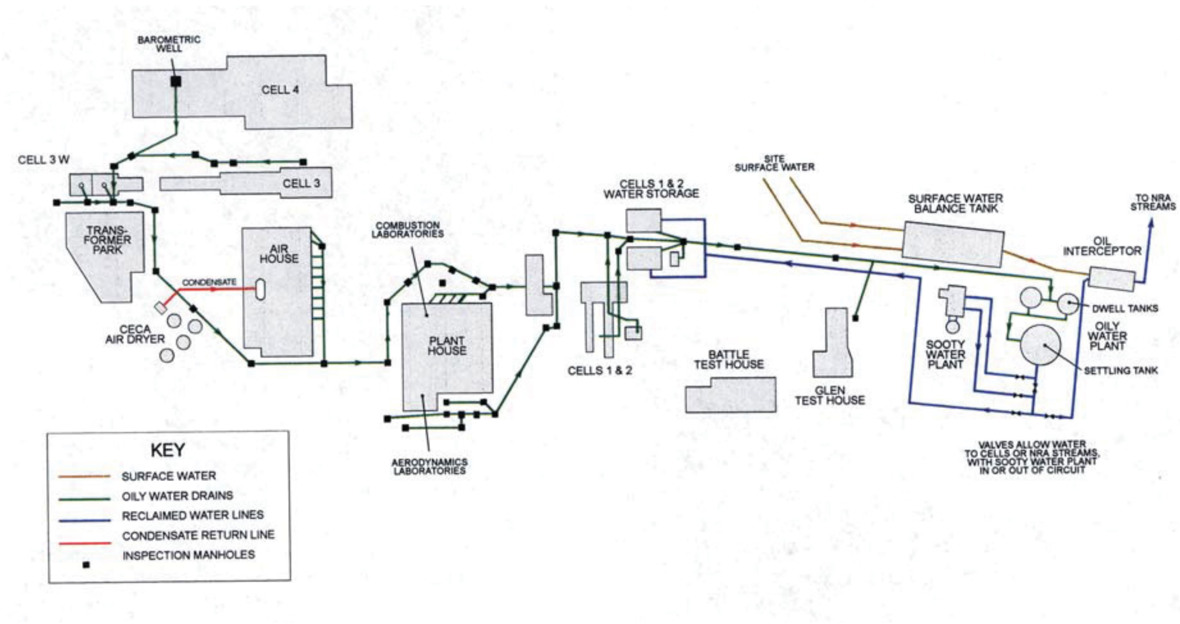

Fig 23 Drainage and effluent system, incorporating recycling of water (DTEO 1996, fig 5.12)

Fig 24 Cycle sheds north of the Computer Building, looking east, typical of many on the site (MoLAS 021/05/18)

6.5 Other infrastructure

The Assembly Hall (**Bldg 301)**, also known as the Canteen, catered for the industrial, research and directorial staff. It contained a restaurant-canteen and was situated at the south-eastern end of the site, outside the security fence, so that it could be used for social functions and indoor sports activities during out-of-office hours (Ministry of Supply 1955, 2). The building overlooked the Sports and Social Club (**Bldg 300**), the sports fields and a bowling green to the east.

A fire station and minor surgery were located at the northern end of the Main Workshops (**Bldg 407**).

Bicycles were used to get around the site, and a number of cycle sheds are shown on the 1970s site layout map (Fig 24). The site was served by its own bus stops, one being located outside the Main Workshops on the opposite site of The Fairway (Fig 25). Due to Pyestock's isolated location, with no public transport available, a network of coach services brought NGTE employees to work from the surrounding towns and villages.

6.6 Safety

As with other industries, heath and safety procedures have evolved considerably from the mid 20th century to today's stringent standards. Although such procedures were paramount at Pyestock, Geoff Timmins recalls one fatality in the early days, when a technician was sucked into the air system. Peter Ashwood recalled the fact that safety goggles were never worn during observations of combustion testing, which resulted in 'a scale of eye and nose-watering intensities corresponding to combustion intensity' (Ashwood 2003, 20).

A safety procedure was, however, put in place that ensured that all valves were correctly set according to the particular test requirements and appropriate safety instructions were put into affect both before and during every test (MoD n.d., 31). The procedures were aimed not only at protecting personnel working in or around all sections of the test cells and air pipe network, but also at safeguarding the valuable plant (DTEO 1996, Sec 2, 6). The responsibility for each test, including safety, was signed over to the test controller before the test took place. With the size and complexity of the engine test facility, the risk of accident could be significant. These days, all large engineering operations routinely operate a safety system known as 'permit to work'; Pyestock was one of the sites chosen by the government to pilot the concept more than forty years ago.

Small concrete sheds marked 'Eyewashes' were noted on the MoLAS site visit beside Cells 1 and 2 and Cell 3 West, as well as simple outdoor showers for emergency douching (Fig 26), necessary because of the use of fuel and chemicals. Warning signs were also noted in various places indicating that ear protectors should be worn (Fig 27). Archive photographs show staff in the control rooms wearing intercom sets, to allow control room personnel to communicate with other facilities during testing. A safety ring was noted on a hook on the outside wall of the Barometric Well, presumably in case anyone fell down it.

Small one-storey buildings housing lavatories and wash-rooms, built to a standard design, were also distributed around the site (Fig 28).

Fig 25 Bus shelter on the east side of The Fairway, looking south-east (MoLAS 021/05/02)

Fig 26 Emergency showers outside the Air House, looking west (MoLAS 028/05/09)

Fig 27 Warning to wear ear protectors, between Cells 3 and 4, looking west (MoLAS 028/05/24)

Fig 28 Standard lavatory and wash-room building east of Cell 4, typical of several on the site, looking south-west (MoLAS 021/05/16)

7 Cells 1 and 2

7.1 Background and purpose

These cells, in Building 561, were designed from about 1952, and built from about 1954 (MoD 1974, 3; Fig 29)). The purpose of this building and its equipment was to be able to conduct two kinds of test on jet engines under development, which necessitated test cells of two different kinds. One, 'free-jet testing', required a means of blowing air at supersonic speed at an engine to simulate an aircraft's forward movement, in order to study mainly the performance of an engine's air intake. Second, 'connected testing', required a means of blowing compressed air directly into an engine, while compensating for the engine's thrust, to investigate engine performance and integrity (DTEO 1996, 3). Two test cells were therefore constructed parallel to each other and almost side-by-side, using the same sources of air, fuel, water, etc (Fig 30). They shared a single control room, which was therefore positioned between them, and a single exhauster stack, where the air left the cells, positioned at their rear. Each test cell consisted of a steel tube, 12 ft (3.65m) in diameter and about 100ft long, strong enough to withstand extremes of pressure and temperature. Air was blown into these cells through large-diameter pipes, which entered near the southern end of the cells (Fig 31). The exhaust air and gases left the cells at their northern end. Various well-insulated apertures permitted signals to be transmitted by cable from instruments inside the cells, measuring conditions there and the performance of the engines. The cells could also be opened up at their southern ends and near the northern ends to install the engines and then resealed (Fig 32).

At the time of construction, these cells were situated at the northern edge of the site, and were known at first as the 'Northern Test Area', the 'Ramjet Test Area' and 'Test Area 39'. Early design drawings (e.g. AK-39/1, dated 11 March 1952) suggest that the basic layout of the two cells and their ancillary equipment was clearly established. One oddity was that initially the free-jet test cell was to be to the east, and the 'connected rig' test cell to the west; later in the design process, their respective positions were reversed. The cells were apparently not called by numbers until a third test cell was built later, when they became known as Cell 1 (for free-jet testing) to the west and Cell 2 (for connected rig testing) to the east.

In Cell 2, the test engine was mounted on a thrust-measuring frame with its air supply connected directly to it via a plenum chamber fed from the compressed air supply (Figs 33 and 34). A slip-joint in the air ducting just forward of the engine provided the necessary axial movement of the thrust frame to facilitate thrust measurement.

7.2 Description

Cells 1 and 2 and their ancillary structures cover an area roughly 70m from south to north and 40m from west to east (see plans AK-39/8 of 1953 and AL 39/3 of 1954, and sections MD 39/105 of 1959, XB39/2 and XB39/4). The control room is situated in the centre of this area, in a block about 18m long from south to north and 8m wide. The control room is on two floors, a raised ground floor containing control desks and instruments (Fig 35), with a basement below containing instrument connections and electrical relays in cabinets (Fig 36). This block is constructed of steel-reinforced concrete, cast in situ integrally with the foundations and supports for the test cells to either side. The supports include concrete platforms and walls above the control room for air intake pipes, and intake chambers containing filters and splitters to reduce noise. A steel door gives access to the control room at the southern end of its east wall. A set of double doors in the centre of the north wall (now sealed shut) is approached externally by steps up from ground level; these doors may originally have been the main entrance.

According to design drawings (e.g. AB-39.7/4 and AB-39.7/5, dated 29 November 1954), the reinforced concrete base of the control room incorporates a layer of cork ¾ inch (19mm) thick, labelled 'isolation layer', presumably to minimise vibration. Other aspects of the design indicate that considerable trouble was also taken to keep noise and gases out of the control room. The concrete walls are a minimum of 9 ins (0.23m) thick, all the openings are specified as having to be sound-proof, and the existing door at the

Fig 29 Exterior of Cells 1 and 2 (Bldg 561), looking north-west (CNV00001-F1-01.jpg)

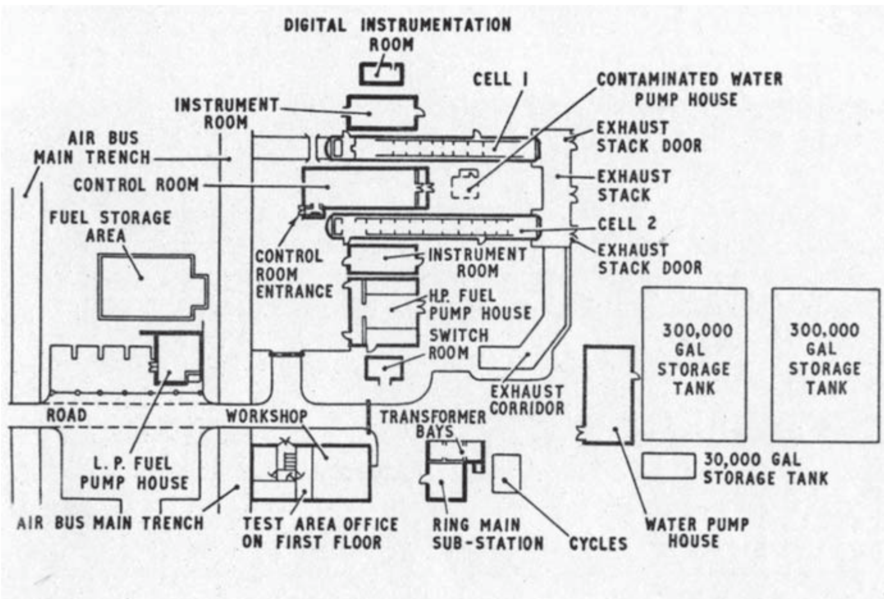

Fig 30 Schematic plan of Cells 1 and 2 and ancillary structures (MoD 1974, fig 39)

Fig 31 Air pipes in a conduit approaching Cells 1 and 2, looking east. The test cells are at ground level, beyond the edge of the photograph to the left (MoLAS 021/05/15)

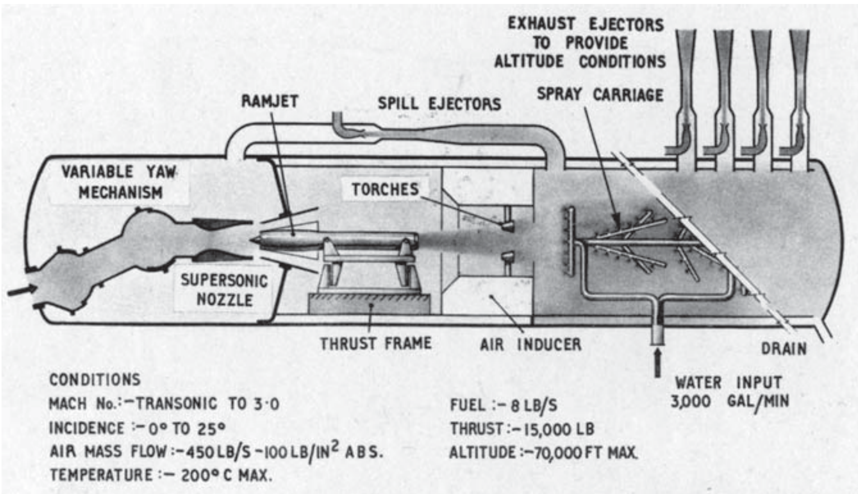

Fig 32 Schematic longitudinal section through Cell 1 (MoD 1974, fig 40)

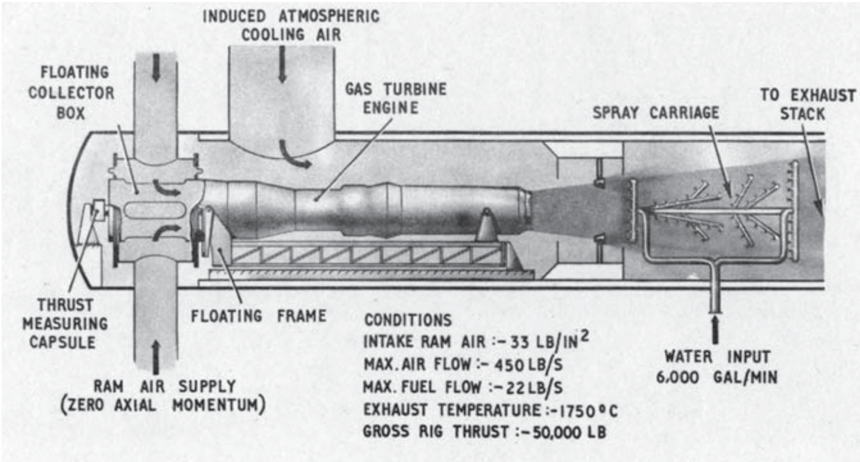

Fig 33 Schematic longitudinal section through Cell 2 (MoD 1974, fig 41)

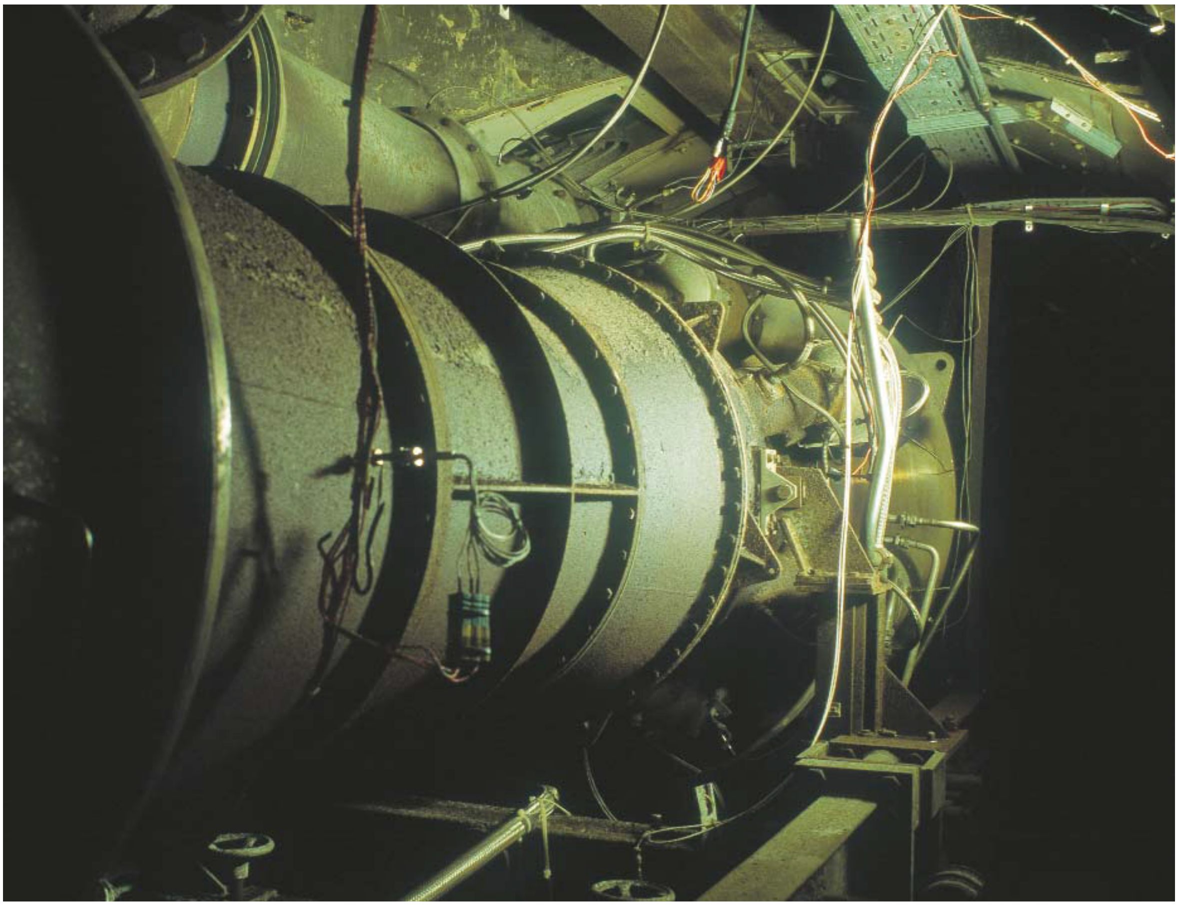

Fig 34 Engine mounted inside Cell 2, looking north-west (MoLAS 021/05/27)

Fig 35 Cells 1 and 2 control room in 2005, looking south (CNV00001-F2-01.jpg)

Fig 36 Basement under Cells 1 and 2 control room, looking north-west (MoLAS 021/05/29)

south-east corner is a heavy, thick steel door with bevelled internal edges. A large 'ventilating plant room' is drawn as being directly above the control room for air-conditioning.

The interior of the control room has a rubber floor and false ceiling, and is enclosed by false walls, which are set forward of the concrete external walls by nearly 1m to allow access behind them to instruments fixed in them. On both the long external walls of the control room are long, narrow windows of armoured glass, facing the test cells. The narrow space behind the false walls also contains at least two steel ladders down to the basement.

The tubular steel test cells are supported at ground level through much of their length, but they overhang pits at both their southern and northern ends, in which pipes for air, fuel and water are carried. The pits at the southern end, for instance, appear to be vertically sided, about 3m wide and 6m deep, and constructed of reinforced concrete cast *in situ*. They are covered partly with concrete duct slabs at ground level to allow access to the control room. Other areas, such as the upper part of the cells and pipes, with valves and junctions, are reached by steel cat ladders and steel grating catwalks (Fig 37).

Steel stanchions along the outer edges of the cells support a steel lattice-framed roof running from south to north over the control room, cells and piping. The roof is surrounded by short curtain walls, forming, in effect, a high, open-sided shed (see AB 39.14/3). Both the roof covering and the curtain walls are probably of corrugated asbestos sheeting. The roof, about 14m above ground level and about 20m wide, also shelters a travelling overhead crane. The gantry for this crane travels from south to north, its west and east ends running on rails at the sides of the shed. A similar travelling crane runs from west to east over the northern part of the cells, just to the north of the control room.

Further to the north, the exhauster forms a tower of reinforced concrete, about 10m wide from west to east by 4m north to south, in plan, and some 15m high (Fig 38). This tower is apparently surrounded by a much larger concrete base, at ground level. Steel ladders on the south side of the tower give access to its top, which is surmounted by vertical concrete panels, and a steel mesh net projects from its walls about 10m above the ground. Drawings (e.g. MD-39-10/31, dated 11 November 1952) show a concrete-lined shaft some 10m deep, housing a water pump, situated between the control room and the exhauster tower.

Ancillary one-storey buildings are ranged to west and east in line with the north end of the control room. These buildings are apparently of reinforced concrete frame construction, infilled or faced with brick and on concrete foundations, and are flat roofed. Immediately to the west and east of the cells are buildings containing instrumentation for their respective cells, and further to the east is a pump house for fuel.

Deep, wide conduits with concrete floors and brick walls run to the west and south, containing large-diameter pipes. These conduits are bridged for road access around the cells. Overhead air pipes run to the north.

Exposed structural steel framing and the overhead air pipes are painted light blue.

7.3 Alterations and developments

One drawing, (MD-39-192/1, dated 12 March 1954) outlines the stages to be followed in constructing the cells. The concrete foundations and supports, control room and the fuel pump house were to be built first. The cells were then to be assembled. Both cells comprise three separate lengths or sections, each section weighing between 40 and 63 tons. The sections were to arrive in turn by road transporter at the eastern side of the buildings, to be off-loaded and moved by crane first to the west, and then to the south along the line of the respective cell. The west cell was assembled first, from its southern end northwards, followed by the east cell, after which the bases for the roof columns and crane gantries, the exhauster and ejector duct, and the instrument houses could be built. The total weight of a cell is some 165 tons. The stanchions for the roof and crane structures are detached from the buildings adjoining them, the walls of the instrument

Fig 37 Gap between Cell 2 (right) and control room (left), looking north, showing the mountings for the test cell separate from the steel frame for the shelter overhead (MoLAS 021/05/33)

Fig 38 Exhauster tower at north end of Cells 1 and 2, looking north-east (CNV00016-F1-15.jpg)

Fig 39 Cells 1 and 2 under construction, probably early in 1956 (NGTE 14704)

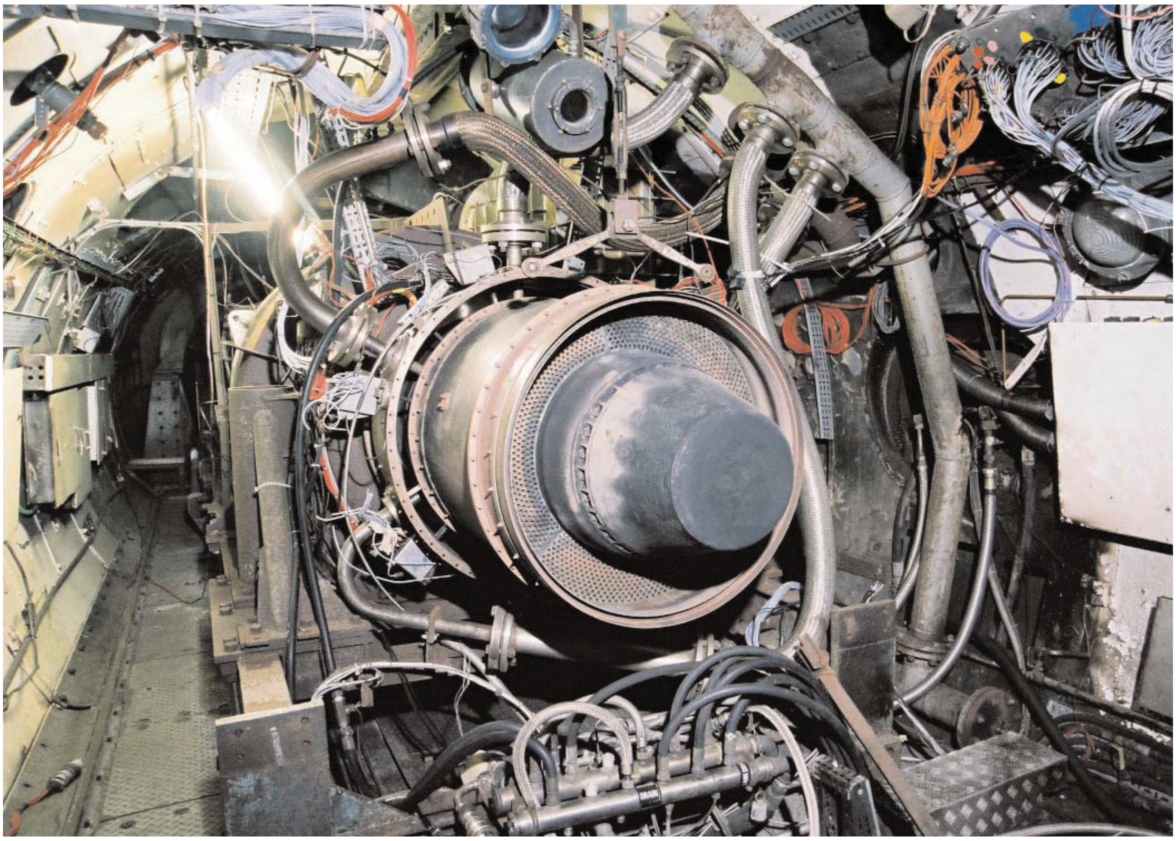

Fig 40 Exhaust outlet of engine inside Cell 2, looking south-west (CNV00005-F2-03.jpg)

houses, for instance, being recessed around them, presumably to minimise the transmission of vibrations.

Photographs show successive stages of construction, starting early in 1956 with construction of the reinforced concrete base and pits (13720). The installation of the steel sections of the cell appears (Fig 39) and, shortly afterwards, the steel frame was constructed (14869). The latter photograph is fortunately dated May 1956. Other, undated views show construction of the exhauster and its reinforced concrete tower, and completion of the steel framework to enclose the cell (15316, 16094, 16098, 16100). The interior of the control room, with functional consoles facing windows in the side walls, is in another photograph (16107). The close run of numbers given to these photographs suggests that they may all have been taken at the same time, perhaps in or soon after November 1956, as this is the date of two views of the interior of Cell 1, which have slightly lower numbers in the same sequence (15583, 15584). The associated cooling towers (Bldg 417) are shown as almost completed in a photograph dated June 1957 (see Fig 22).

The exhauster was designed to include a large ejector duct to one side, and later possibly both sides. This was designed to extract air from the cell, creating low-pressure conditions inside the cell, and was fitted and shaped to reduce noise. On early drawings, the exhauster is called 'exhaust silencer block' and 'exhaust silencing chambers'.

The control room has been modified slightly, although the initial design is still evident. On both sides, the false wall is splayed outwards to form the reveals of a large window, which looks directly out on to one or other of the cells. One drawing, (AB-39.7/3, dated 29 November 1954) labels each of these as an 'observation window', with a 'control desk' immediately under it. Downstream of each window (i.e. to the north) was to be a 'steel angle-framed periscope duct', suggesting that initially the cells and control room were linked closely so that the tests could be observed directly from inside the control room.

From an early date the tests were observed remotely, and recorded using film cameras and closed circuit TV (MoD 1974). Cell 2, entered by a steel pressure door near its southern end, contains the reheat rig still installed in the cell following the long finished EJ200 engine reheat development programme (Figs 34 and 40), testing military engine after-burners (Geoff Timmins pers. comm.). Lamps and a camera housing, pointing at the outlet of the engine, are evidently protected from temperature and vibration, the camera housing being enclosed in a water-jacket to keep it cool. The only drawing noted referring to communications is dated 18 April 1955 (EL-39-5/1), entitled 'Intercommunication and telephone layout'. Another (PYE/MK-39.6/2), showing altered arrangements of the engine test frame inside 'ram jet cell', is dated 19 December 1957. A third drawing (MD-39-6 & 8/130), showing 'internal and external applied loads on vacuum cells [i.e. Cells 1 and 2] and foundations', drawn initially on 4 August 1953, was presumably so important and heavily used that it was reproduced by tracing on 4 July 1960.

Since its original construction the south-eastern entrance to the control room has been extended outwards a short distance by screen walls in brick, enclosing steps, perhaps to make the entrance easier to use while tests were in progress. This alteration, evident in the fabric of the building, is shown on a drawing (PYE/AK-39/1) dated November 1957. The northern entrance to the control room may have been even less easy to use during tests, and may have become disused altogether.

7.4 Technical details of working processes

7.4.1 Introduction

The following section is largely based on information from an official brochure (DTEO 1996, Sec 3, 4-9) with additional technical detail and explanations provided by Ian McKenzie.

Cells 1 and 2 are adjacent to each other and are separated by a single dual control room. They also shared the surrounding services and fuel and air supply equipment, water and fuel stores and the exhausting stack. Air driven ejector plant, rather than the later Air

House and Parson's No. 9 and No. 10 compressors used for compressing and exhausting air at the other test facilities, provided simulated altitude conditions of up to *c* 50,000ft. Ejectors work by blowing air or steam through a nozzle centrally positioned within a draught tube, creating a low-pressure area and thereby causing large quantities of air to be drawn into the tube. The technical details of the processes are discussed below.

Various transducers that provided data on engine performance were fitted to the test engines for steady-state and transient tests. The information from the test was gathered, recorded and processed by a real time (i.e. data available at time of testing) computer system.

The chambers which contained the test engines are still in place, although access is restricted due to health and safety considerations. The control room has been stripped of equipment, but desks and some controls survive.

An archive photograph (DTEO 1996, fig 3.9) shows at least seven individuals at work in the control room, all of whom are wearing intercom headsets. Two people are manning the main desk in the centre of the room, one of whom is the test controller, with the remainder sitting or standing by various control panels at the side of the room. The engine driver is sitting directly in front of the test controller. A reheat development test appears to be in progress in Cell 2.

7.4.2 Air pressure
The Air House or the Plant House provided compressed (as opposed to extracted) air to the cells. The former was connected using a 54-inch (1.37m) diameter pipe restricting the air capacity to the output from three of the GEC compressors. The odd-numbered machines (Nos. 1, 3, 5 and 7) were normally used although, when these were unavailable, the even-numbered compressors could be used by means of interconnecting crossover pipes at the Air House (see Fig 12). In addition to supplying the needs of engines under test, pressure air was used to create the altitude conditions in the cells by operating ejectors connected to the rear portion of the cell downstream of the test engine. Interconnecting ducts between the two cells allowed both chambers to be exhausted simultaneously. (Ejectors function by driving high-pressure air through an axially aligned primary nozzle within the ejector and, by so doing, low pressure air from the cell is entrained through the body of the ejector and exhausted to atmosphere.) Each ejector consumed 100lbs per second of driving air (see Figs 10 and 11).

Sometimes, when high altitudes were simulated, the pressure of the air entering the test engine was less than atmospheric, and consequently the engine requirements were drawn from the atmosphere through a silenced air intake.

7.4.3 Heated air
When test conditions demanded, for example, the high temperatures required to simulate the kinetic heating effect of supersonic flight, the engine inlet air could be preheated using a Metropolitan-Vickers 3MW electric heater. These were built in two 1.5MW sections, each of which could operate independently and when combined with the output of a 3MW gas heater could produce a maximum temperature of 350°C.

The reheat (afterburner) development testing carried out in Cell 2 required higher airflow temperatures than those possible with the existing reheat rig. To enhance the capability of this rig, a hydrogen fuelled section was installed downstream of the kerosene fuelled combustor to provide the required temperatures at entry to the reheat jet pipe (see section 6.3.2 regarding supply). The system was controlled by two GEC Minigem programmable logic controllers (PLCs) at a mimic, or diagrammatic control, panel located in the control room. This provided the necessary control valve sequence required for hydrogen injection and subsequent nitrogen purging. The PLCs also provided automatic trailer selection, shutdown sequences and safety interlocks.

7.4.4 Cooled air
Air could be supplied from the Air House at a minimum temperature of 70°C. If colder air was required, it could be routed through the Cold Air Plant at Cell 3, to produce a temperature of 30°C (10°C during the winter months), at a maximum air mass flow of

200lbs per second. Cell ventilation for cooling purposes was achieved by inducing atmospheric air into the chamber from a top-mounted vent.

The engine exhaust also had to be cooled. This was achieved by direct water injection through spray nozzles. Two systems were available, giving maximum injection rates of 180,000 gallons per hour at a pressure head of 80ft, and 190,000 gal/h at 125ft head respectively. The maximum amount of cooling water injected for a particular test was governed by evaporation losses and the capacity of the cell water extractor pumps (216,000gal/h). A total water storage capacity of 330,000 gallons (72,300 litres) was available and the cells operated on a recirculatory basis so that only evaporation losses needed to be made up. During testing the water vapour in the plume from the exhaust stack at the northern end of the cells was visible for miles around (Geoff Timmins pers. comm.).

7.4.5 Air filters
The inlet pipe work to both cells was fitted with an air filter to reduce component wear and reduce engine performance degradation. The filter could handle a throughput of up to 450lbs per second at a maximum temperature of 250°C. The filter removed 99.5% of all particles greater than 0.5 micron in size. The filter pressure vessel could withstand up to 12 atmospheres.

7.4.6 Fuel system
The plant fuel system could deliver fuel to run engines in both cells at flows of up to 54,552 litres (12,000 gallons) per hour at pressures of up to 98.4kgf/cm^2 (1,400 lbf/in2). A secondary plant fuel system was also available that could deliver 27,276 litres (6,000 gallons) per hour, at pressures of up to 140kgf/cm^2 (2000 lbf/in^2).

Steam, supplied from the steam generators in the Air House West Annexe, was used to raise the temperature of the fuel entering the Cell 2 reheat rig jet pipe on the colander, gutter and vaporiser sections, forming the reheat system. Fuel heating took place in three heat exchangers, one for each section, located beside the test rig. With all three heat exchangers in use, the fuel temperature could be raised to 95°C, providing a combined fuel flow of 22,275 litres (4,900 gallons) per hour. In this operational mode, with the over temperature limits reset to each section in turn, fuel temperatures of 150°C and up to 1,659 litres (365 gallons) per hour in one section have been achieved with the other two sections unheated. The hot fuel process was controlled from a mimic panel located in the control room.

7.5 Research undertaken at Cells 1 and 2

The free-jet capability of Cell 1 gave NGTE the ability to develop its ramjet technology more efficiently than had been possible hitherto with free-flight testing. The Cell 2 connected capability was installed largely at the behest of the British aero-engine industry following the poor altitude performance of some of its early post-war jet propulsion gas turbine engines when measured in the BMW high-altitude test facility at Oberwiesenfeld near Munich. The British aero-engine companies were keen that a government-funded altitude test facility be established that would be available to all manufacturers, and NGTE at Pyestock was considered an appropriate, neutral location.

7.5.1 Cell 1
Test activities in Cell 1 concentrated exclusively on supersonic free-jet testing. A large proportion of the early work concentrated on ramjet research, replacing the need for flight-testing using free-flight vehicles such as the NGTE-Napier ramjet test vehicle. These flight tests were launched from Aberporth, south Wales, and the vehicle, after the flight, had been recovered from the Irish Sea. Conducting the same tests in the controlled conditions of Cell 1 was much quicker and easier.

The Bristol Engine Division of the Bristol Aeroplane Company (later operating separately as Bristol Siddeley and currently part of Rolls-Royce) exploited NGTE combustion chamber and reheat technology during the development programmes for both the Thor and Odin ramjet engines. Both engines were tested in Cell 1. Thor had initially suffered from combustion instability until, with the assistance of NGTE, it was redesigned. Thor was installed in the RAF's Bloodhound surface-to-air missile, where two engines were pod-mounted to either side of the missile body. A single centre-mounted Odin was used in the Royal Navy's Sea Dart missile.

Concorde featured highly in NGTE's research and development activities, which concentrated on maximising the effectiveness of the complete power plant system (intake, engine and exhaust). Much of the work was aimed at understanding and optimising the engine intake's variable geometry. At supersonic speeds, a large proportion of the power plant's total air compression was achieved by the intake alone, due entirely to the pressure rise across the intake shock waves. The two-dimensional (rectangular in section) intake design developed for Concorde is of the external compression type, the shock wave pattern being entirely outside the enclosed portion of the intake duct. The position of the shock waves was important for efficient operation at supersonic speeds. For several years during the late 1960s tests were carried out in Cell 1 to investigate the optimum intake geometry using small-scale intake models, which were fitted with a plug valve at the rear to simulate the throttling effect of the engine. The effects of varying flight Mach number, intake yaw, intake ramp angles and the air-mass flow swallowed by the intake could all be studied. The data from these tests fed directly into the full-scale Concorde power plant tests carried out in Cell 4, and subsequently the aircraft's supersonic flight test programme.

7.5.2 Cell 2

In the early days of Cell 2, tests were carried out on the Bristol Proteus turboprop engine fitted to the Britannia passenger aircraft. These tests formed part of an investigation into the problem of icing of the inlet duct, which had caused a flameout of all four engines in the prototype aircraft, leading to a forced landing on the mud flats of the Bristol Channel. Other development testing included the reheated version of the Rolls-Royce Avon for the English Electric Lightning, the Bristol Olympus 320 for the BAC TSR2 tactical strike and reconnaissance aircraft (cancelled in 1965) and the Pegasus vectored-thrust engine eventually used in the Harrier. The relatively large diameter of the Pegasus, with the protuberance of the vectoring nozzles at each side, made it a tight fit. The nozzles were locked in the fully aft position for these performance tests, and large deflector plates were provided to prevent the jet exhausts damaging the walls of the cell.

Cell 2 also played its part in Concorde engine development, being used for engine integrity tests to assess the damage tolerance of the Rolls-Royce Olympus 593 engine, by simulating oil system failure and engine fires. Rather than use actual 593 engines, which were few in number and valuable, for these potentially destructive tests, surplus type 320s were used that were sufficiently similar for these tests to be representative.

An interesting, but fruitless, test programme was carried out on the Olympus 320 using a digital engine control system. The normal Olympus control amplifiers employed analogue control architecture, but Bristol Siddeley created a prototype digital system anticipating, correctly, that this would offer far better control on reheated engines where there are a significant number of control parameters. Unfortunately the trial failed, as the control technology was too immature. After a major collaborative research programme started in the late 1960s between NGTE and the control system industry, digital engine control is now standard on all modern aero-engines.

When the government decided, in the 1960s, to purchase the McDonnell Douglas Phantom strike bomber from the USA it was agreed that the aircraft would be powered by a reheated version of the Rolls-Royce Spey. As part of the service entry requirements, an endurance test programme was carried out in Cell 2.

The Turbo Union RB199 reheated turbofan engine for the Tornado multi-role combat aircraft incorporated a sophisticated reheat system, which required considerable development. To enable this work to progress in parallel with the main engine development programme, a reheat rig was manufactured and installed in Cell 2. The rig simulated the reheat entry conditions of the engine without the added complication of running an as-yet incompletely developed engine. The engine jet pipe, including the reheat system, was attached to the rear of the rig. With some modification, the rig also provided a suitable test vehicle for reheat development for the EJ200 engine for the Eurofighter Typhoon.

7.5.3 Testing: the human element

The expense of carrying out tests in the cells was considerable and maximising the test output called for a disciplined team of test personnel. NGTE managed to combine this discipline with an efficient but relaxed approach to testing that proved over the years to be most effective. A test controller was in charge of a test. He, or she, had absolute authority, with responsibility for the safe operation of the facility and, most importantly, the safety of all those involved in the test. The remaining test team numbered approximately six in the control room with mechanical, electrical and electronic support staff on call should technical problems arise. Other staff were in the Plant House and Air House operating the site's air-moving machinery.

Conditions in the control room could be fairly noisy because of its proximity to the cell. This was particularly the case when testing large military engines such as the Olympus 320, operating at maximum reheat. To combat this, and to enable communication among the test team, noise reduction headsets were worn. The early headsets incorporated throat microphones that were attached around the neck by an elasticated strap which, after an hour or so of use, became very uncomfortable. In later years, these were replaced by more comfortable modern equipment.

The large amount of electrical power needed to operate the test cells dictated that a large proportion of testing occur during the evenings, with test shut-down scheduled at 10.30 p.m. To cover this, the industrial labour force worked two shifts a day, while the scientific and professional engineers involved worked overtime, which could make for quite long days.

8 Cell 4

8.1 Background and purpose

In the late 1950s and early 1960s Cell 4 was designed and constructed on the then northern edge of the site for free-jet testing of gas turbine engines, on a larger scale requiring greater air compression and exhauster capacity than in Cell 1. From 1956, development of a large supersonic aircraft was under official consideration in Britain, and design studies had been in progress from 1959. To develop such an aircraft, whether civil or military, it was essential to test the intake-engine combination at supersonic speeds. Cell 4 was designed specifically for such testing. Although much larger than Cell 1, the basic principles of the design and operation of Cell 4 for free-jet testing were the same. A significant difference between the cells was that Cell 4 exhausted directly to the exhauster plant and therefore required substantial plant cooling and fuel inhibition systems. The eight compressor-exhauster sets in the Air House had already been brought into service for Cell 3, but additional exhauster capacity was required for the tests in Cell 4. To meet this, No. 9 Machine was constructed.

The only large supersonic aircraft being developed in Britain was a civil airliner, which, from 1961, became a collaborative project between Britain and France, eventually named 'Concorde'. The engines for this aircraft were jointly designed by Rolls-Royce (the Rolls-Royce Olympus 593) and Snecma (responsible for the reheat and propelling nozzle systems). The engine intake was the responsibility of the British Aircraft Corporation (BAC).

The new cell had to be capable of measuring the interaction of air intake and engine at different simulated altitudes and speeds while, at the same time, simulating the effects of aircraft yaw and pitch on intake performance. By comparison with the other cells, Cell 4's air system was relatively complicated with a series of large pipes and ducts running around and behind the cell's working section and engine capsule, containing the intake and engine respectively. Most of the airflow from the supersonic blowing nozzle entered the intake and engine. Approximately 4% of the air, however, was creamed off by the outboard entry surfaces of spill diffuser ducts within the working section, and routed via the working section bleed ducting to the plant exhausters. The remaining air spilt around the intake was directed through two separate spill diffuser ducts passing through the working section and lying above and below the engine capsule (Figs 41 and 42).

The earliest drawings available (e.g. AB9/19/1, dated March 1962), indicate that the design of Cell 4 was well advanced by the early 1960s, and construction was under way in 1963. As originally constructed, and for the early commissioning tests, Cell 4 had been configured for a different and much smaller power plant. Fairly major modification to the cell were required for the Concorde tests involving new blowing nozzle spill diffuser ducts, engine capsule and ducting for the intake ramp bleed and dump door airflows.

Manufacture of prototype engines and airframes for Concorde began in 1965. (The first of four prototype Concorde aircraft flew in 1969, a total of 16 production aircraft were made from 1973 to 1979, and the aircraft last flew in 2003.)

8.2 Description

Cell 4 (Bldg 635) and its ancillary structures cover an area roughly 200m from east to west and 60m from south to north. The new cell was situated directly to the north of, and parallel to, the existing Cell 3, in order to be connected with the same air supply and suction pipes running from and to the Air House, to the south of Cell 3. The direction of the flow of air in Cell 4 was therefore, like that of Cell 3, from east to west. A single large building containing the test cell, near the east end of this area, is some 70m long from east to west, 35m wide from south to north, and its roof is about 17m above ground level. Air supply pipes approach the east end of this building from the south, and a gantry carrying a travelling overhead crane runs from south to north over these pipes, next to the cell building (Figs 43 and 44). Several exhaust pipes run from the west end of the building for a distance of about 75m further to the west, where they connect with the suction pipes running obliquely towards the Air House to the south (Figs 45, 46 and 47).

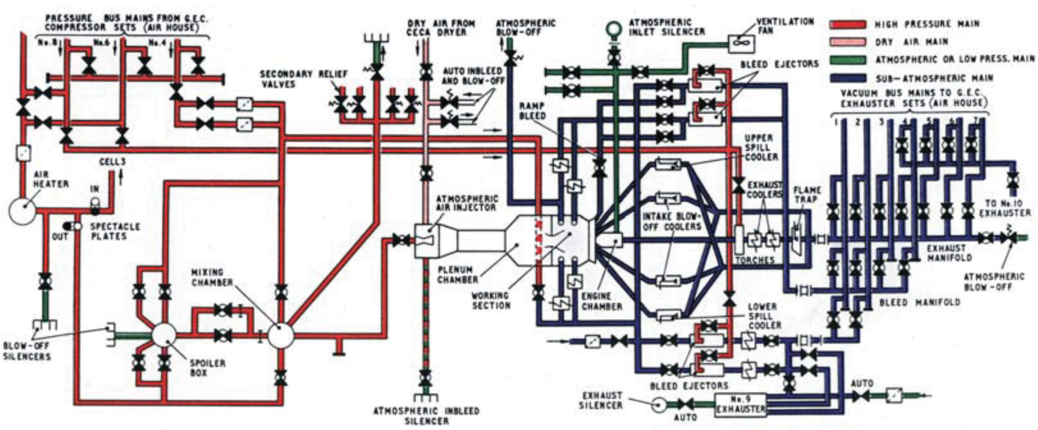

Fig 41 Diagram of air flow in Cell 4 (MoD 1974, fig 72)

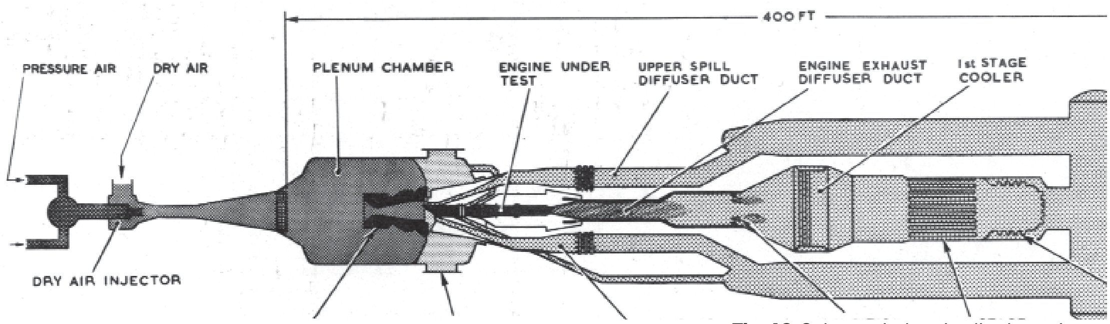

Fig 42 Schematic longitudinal section through Cell 4 (MoD 1974, fig 74)

Fig 43 Exterior of Cell 4 (Bldg 635), at its east end, looking north-west (CNV00014-F5-14.jpg)

Fig 44 Exterior of Cell 4, east end, looking north (MoLAS 028/05/12)

Fig 45 Air pipes at the west end of Cell 4, looking north-west. The cell's outlet pipes (white) are mainly at a low level, connecting with overhead pipes (blue) to the Air House (CNV00008-F5-08)

Fig 46 Air pipes at the west end of Cell 4, looking north-west (MoLAS 028/05/27)

Fig 47 A series of air pipes running overhead from the west end of Cell 4 towards the Air House, looking north-west. Large areas of the site are gravelled and possibly sprayed with weed killer, presumably to minimise maintenance (MoLAS 028/05/26)

The pipes to the west of the cell building, and the base of the building itself, are situated in a wide basin, the floor of which is some 4.5m below surrounding ground level. The sides of this basin slope, at least to the north and east, where their top edge is some 7m from the walls of the building. To the west, the sides of the basin are vertical. Cell 4 is thus partly below ground, in a kind of reinforced concrete-lined basin open to the air, unlike Cell 3, which is situated in a deep trench, lined massively with reinforced concrete.

Another constraint on the position of Cell 4 was the existence of a 'photographic instrumentation building' (Bldg 692) to the north of Cell 3. This was retained, and was connected to Cell 4 immediately to its north.

The control rooms of Cell 4 are ranged along, and attached to, the south side of the main cell building, on the side nearer the rest of the site. These rooms are on three floors, in a block consisting of a steel-reinforced concrete frame, precast concrete slab floors and mainly brick infill walls. The lowest floor, or basement, is at the level of the base of the concrete basin and the floor of the main building, and therefore some 4.5m below surrounding ground level. The basement, against the south wall of the basin, contains a 'motor control centre' (according to drawing AB9/19/1). To the east of the latter is a staircase, 'auxiliary control room', 'workshop area' and 'compressor room', and to the west, another staircase, a 'workshop and fitting bay'; these basement rooms have direct access to the lowest level of the main cell building to their north, and a single external entrance to the floor of the basin to the east.

The ground floor contains an 'instrumentation and valve control console room', flanked to the east by a 'safety interlock room' and staircase, and to the west by 'industrial lavatories' and the other staircase. Both staircases have an entrance giving direct access from ground level to the south. Further to the east are 'offices', 'male' and 'female' lavatories, and a 'mess room'. Further to the west is a 'workshop', 'battery room' and, entirely separate and entered from the exterior, a switch room, with transformers beyond it. The 1st floor contains the 'control room', with a staircase and air conditioning plant to its east. The staircase to the west stops at ground level, and the space above it at 1st-floor level is marked on the drawing as being for future expansion. The control room, measuring about 20m long by 7.5m wide, is jettied out slightly to the south, oversailing the ground-floor wall below (see Fig 43). The north wall of the control room, which is simultaneously the south wall of the main cell building, is of steel-reinforced concrete and contains two 'armoured observation ports' each about 1m wide. Presumably, the greater protection on this side was in case of a major structural failure of the cell.

The main cell building consists of a steel frame on concrete foundation blocks, and a steel lattice girder roof structure with a central raised clerestory lantern (Fig 48). The steel frame incorporates the rails for an internal travelling overhead crane, which runs from east to west, the rails being some 14.5m above floor level. The walls are clad with asbestos panel sheeting, above brick walls at basement and ground-floor level, and the roof of the structure, 19m above floor level, is covered with wood wool slabs, a half-inch cement screed and layers of bituminous felt. Similar materials cover the flat roofs of the control room block. The central lantern is some 2.5m higher than the rest of the roof, and provides natural light through wired glass in its walls, as do wired glass panels in the walls at the north-east corner of the building. Steel sliding folding doors, 8m high, at the east end of the north wall, and reached by a concrete bridge from the exterior, give access to a working platform of reinforced concrete in the north-east corner of the building, slightly above external ground level, which was the main loading bay.

The interior of the building is dominated by the apparatus of the cell, which runs along a line slightly nearer the south than the north wall. A series of steel vessels and pipes, some of them extremely large, runs from east to west. They are surrounded and accessed by steel mesh walkways and platforms at various levels (Fig 49). Successive separate steel frames, called 'portals' in the drawings (e.g. AB9/19/1 and ML9/19.427/0100), founded on massive concrete stanchions below floor level, support the central pipes and cylinders of the cell. The main inlet pipe from the east wall had been removed during cell decommissioning when it was placed under care and maintenance, leaving the entrance to the 'plenum chamber' open. The plenum chamber, the first part of the cell to which air was supplied, is the largest vessel, about 30 ft (9m) in diameter and 36 ft (11m) long, with curved corners; it can be entered by a pressure door half-way up its north side (Fig 50; see also NGTE 29095). Inside this chamber the outlet towards the next vessel, called

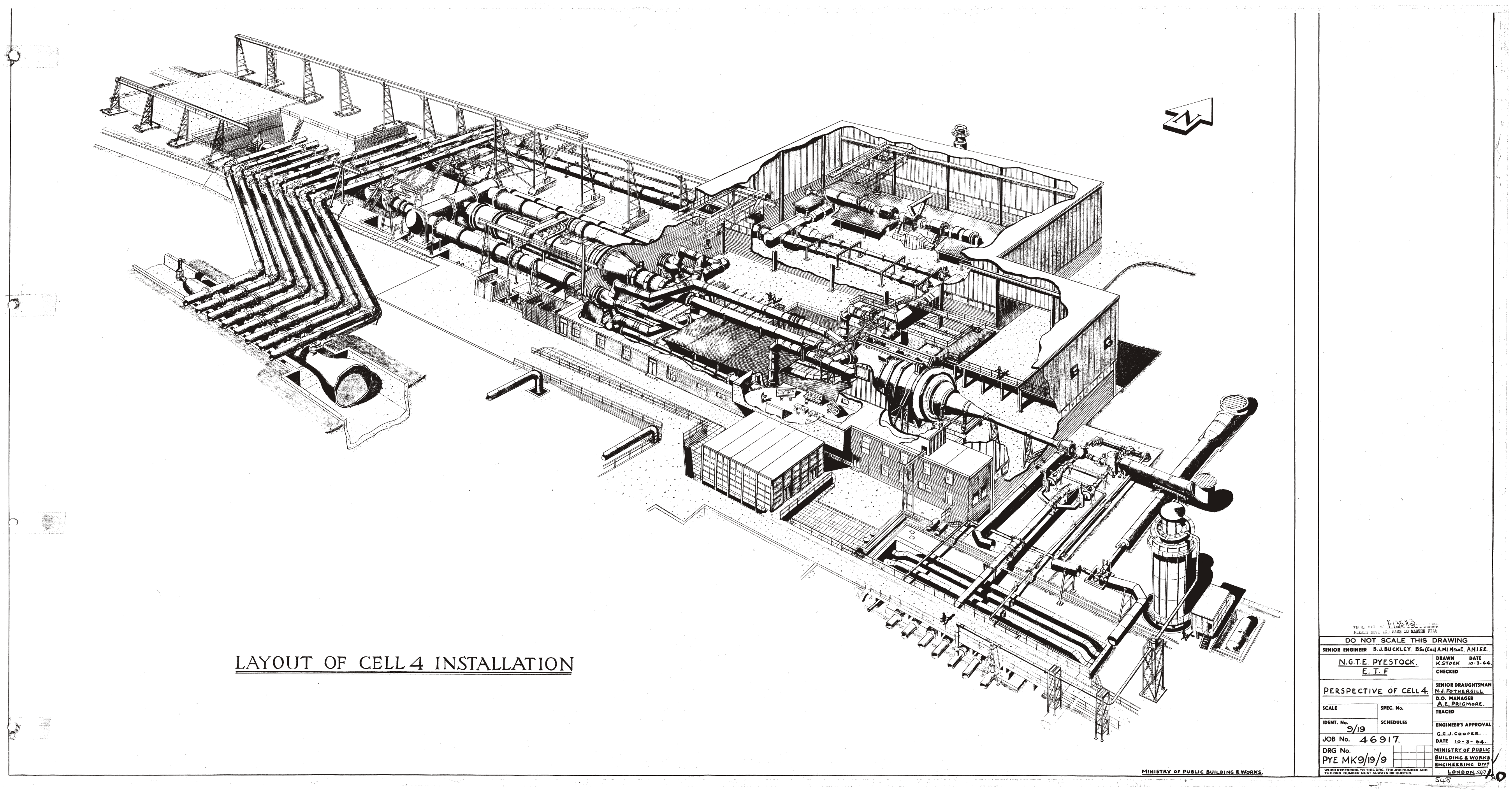

Fig 48 Perspective cut-away drawing of Cell 4, dated 1964, looking north-west (PYE MK9/19/9)

Fig 49 Interior of Cell 4, north side, looking west. The lower pipes and ducts shown here had been removed by the time of the survey (CNV00014-F2-08.jpg)

Fig 50 Cell 4 plenum chamber, looking south-west. The intake has been disconnected, to the left (CNV00011-F2-07.jpg)

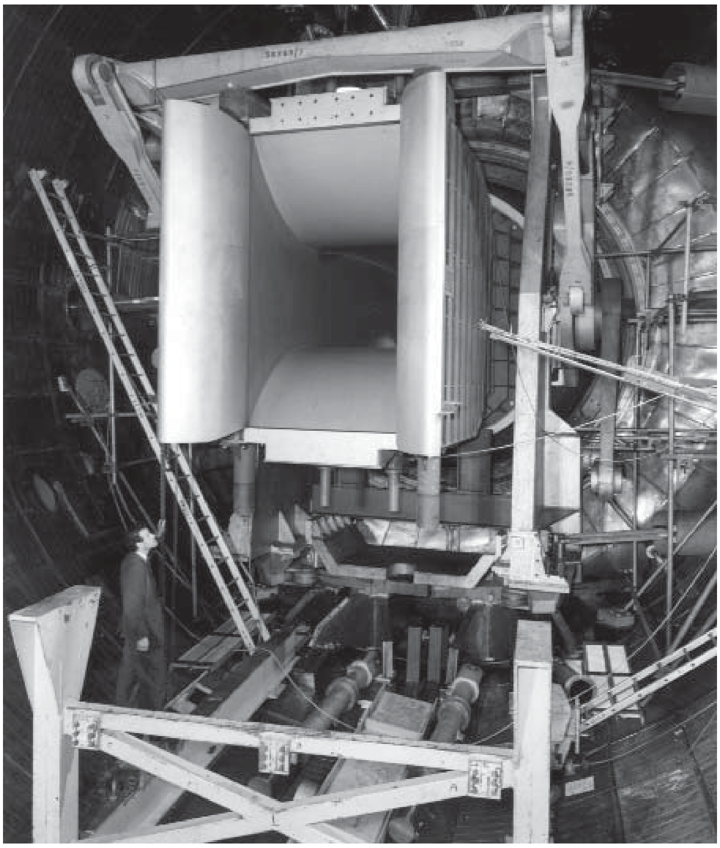

Fig 51 Cradle and blowing nozzle inside the plenum chamber of Cell 4, during construction, looking west (NGTE 31947)

Fig 52 Pressure door to engine capsule in Cell 4, looking south (MoLAS 028/05/45)

the ‘working section’ in drawings (e.g. MoD 1974, 56, fig 74), is behind a large steel cradle, which projects eastwards into the chamber. This cradle held a large rectangular steel funnel-shaped supersonic blowing nozzle, called the ‘adjustable Mach nozzle’, since removed (Fig 51); the cradle and blowing nozzle together weighed 75 tons. The cradle could be moved hydraulically, causing the blowing nozzle to direct the supersonic flow of air at the test intake in the working section from different directions to simulate aircraft manoeuvring. The working section contained the test intake for the engine, which necessarily was fixed in position and directly connected to the engine, which was itself positioned in the engine capsule.

The working section is about 9m in diameter and 3.2m long and effectively forms the rear of the plenum chamber. Surplus air that did not enter the intake could be directed from there through two spill ducts, above and below the ‘engine capsule’, the next main vessel to the west. The latter is about 3m in diameter and 5m long, and can be entered by pressure doors on either side (Fig 52). The tubes and pipes further to the west are mainly to do with cooling the exhaust gases from the engine and directing them and other various flows of air out of the cell. The main ‘exhaust diffuser’ tube, about 1.5m in diameter and 17m long, is at the level of a steel plate and mesh platform, and can be unbolted and rolled to the south on this platform for servicing and to install and remove the engine and intake (Fig 53). A cross-section of the cell at this point (ML9/19.27/0114) specifically shows this for the original, pre-Concorde, arrangement and shows the engine capsule positioned to the north. The drawing also shows the engine capsule installed with its gull-wing doors open This part of the cell is shown in elevation (ML9/19.427/0100 sheet 1), several cross-sections and a photograph (NGTE 33096).

The upper and lower spill ducts branch to either side of the exhaust diffuser and four ducts run alongside the cooling stages through the west end of the cell building (Fig 54). The first stage exhaust cooler, outside the building, is a steel vessel 8m in diameter, and the second stage is 5.5m in diameter, for a total length of 32m (ML9/19.27/0118 sheet 1). The first stage includes torches to ignite any unburned fuel still in the engine exhaust, removing the risk of explosion in the exhauster machinery during compression to atmospheric pressure. The exhaust gases passed through a matrix of tubes containing coolant, which in this case as elsewhere on the site was water. In the second stage, the gases flowed in tubes surrounded by coolant, and water was also sprayed directly into the gases; at the end of this stage is a flame trap. Water was also sprayed into the spill air (some of the numerous small tubes pointing into the upper and lower ducts can be seen in Figure 53 and NGTE 33096), and all water in the air flows was collected and drained to a barometric well north-west of the cell building, some 12m deep and lined with steel-reinforced concrete.

Beyond the cooling stages, all the air outlets combine in a ‘trident manifold’, and over a further distance of about 32m are connected to seven of the eight suction pipes leading to the Air House (ML9/19.27/0118 sheet 2; MoD 1974, 58).

The vessels, pipes and ducts of the cell are supported by steel frames independently of the superstructure of the building around them. Inside the building, a 60-ton travelling overhead crane runs from east to west (Fig 55), and outside the building to the west another similar crane runs further from east to west, over the cooling stages and exhaust pipes there. The equipment was built by Vickers Ltd (Fig 56).

8.3 Alterations and developments

The initial design (drawing AB9/19/2, dated May 1962) had the spill ducts rejoining the main exhaust diffuser before the two-stage exhaust cooler was reached. In the event the spill and exhaust flows, and other air flows, join each other beyond the cooling stages (as described above), although the date of this alteration is unclear.

Provision was left for expansion to the north of the main cell building, for an ‘in-bleed ejector extension’ (according to AB9/19/1, dated March 1962). This was built, apparently at an early date, as it is shown in a perspective cut-away view of Cell 4 (PYE MK9/19/9) dated March 1964 (Fig 48). The arrangement shown there is for the working section bleed, the original scheme. In the event, the actual position of the bleed ejectors was in the cell basin, and the extension was built to house No. 9 Machine. An early addition to

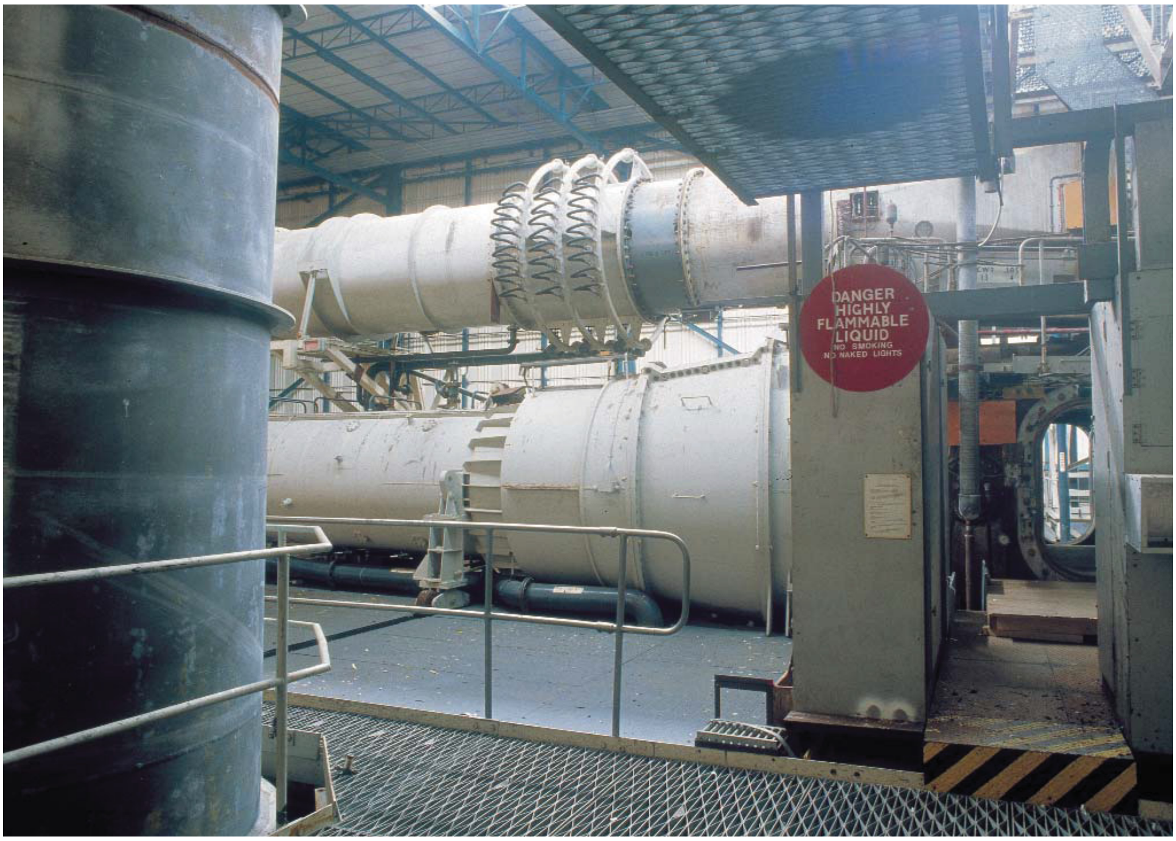

Fig 53 Engine capsule in Cell 4, leading to the main exhaust diffuser (to left), and upper spill duct above, looking north. The diffuser can be unbolted and rolled sideways to install and dismantle engines. Note water spray pipes entering the spill duct (MoLAS 028/05/40)

Fig 54 Spill ducts and exhaust diffusers leading to cooling stages in Cell 4, looking north-west (MoLAS 028/05/47)

Fig 55 Central part of travelling overhead crane inside Cell 4 building, looking east. The sign was added for a film, 'Sahara' (MoLAS 028/05/56)

Fig 56 An authentic sign in Cell 4, for Vickers Ltd (MoLAS 028/05/46)

the main building structure, in all aspects of its structure and materials the extension is similar to the main building, and its roof is at the same height as, and flush with, the roof of the latter. Sliding folding steel doors like those in the main building give access at the east end of its north wall to a loading bay. Inside, the cut-away drawing shows a travelling overhead crane running from east to west, as in the main building. The wall between these two parts of the cell building is mainly glazed at basement level, where there are also doors, but largely asbestos panel sheeting above.

The method by which the cell was constructed is not explicitly recorded, although an early drawing (AB9/19/1, March 1962), suggests that a road along the north side of the site (now Road G) was to be a construction road. It is annotated to the west, 'Construction road (dry lean concrete)', and to the east, 'Ex-construction road to be reformed to permanent construction on completion of 4th cell'. A short spur road at the west end of the line of the cell is labelled 'Access road' and to its north is an 'Off-loading area', the latter covered by the overhead crane. In the area noted as being for future extension to the north, a ramp is drawn running from ground level down to the floor of the basin, annotated 'From temporary ramp down for plenum chamber', suggesting that the components for this arrived separately from this direction. The first stage of construction was excavation and construction of the basin. Photographs show Cell 4 at various subsequent stages of construction, although unfortunately few are dated. One (NGTE 25606), dated December 1963 (Fig 57), shows the 'altitude chamber', by which is meant the plenum chamber, looking east. The walls and roof of the main cell building around it also appear, although these would perhaps have been built after the plenum chamber was fabricated on to site. A steel mesh platform on bolted girders extends to the west of the plenum chamber, partly above the level of the outlet of the chamber, and it is possible that this was a temporary platform. Much steel scaffolding is visible, as well as a long wooden ladders. The scaffolding to the east of the plenum chamber may have been important, as, according to numerous drawings, this marked the setting-out point for construction of the cell. This photograph also shows steel frames to support pipes and ducts along the north side of the cell only. The plenum chamber is also shown from the other direction (NGTE 26122), looking south-west, and this view of both the inlet and outlet sides of the chamber without anything immediately adjoining them confirms that it was installed first. A view of the plenum chamber from below, possibly looking south-east, is difficult to place exactly (NGTE 25711).

Another photograph (NGTE 25780), annotated 'by-pass ducting from exhaust side', shows the rear of the plenum chamber at a slightly later stage, looking south-east, with more supporting frames erected and an isolated length of the upper spill duct in position. Other lengths of similar piping lie on the ground below. Another photograph (019), possibly taken at the same time from a position slightly further to the west, looking east, is annotated 'test cell section from exhaust side'. This indicates that the plenum and working section pressure vessel was brought to the site in sections for site fabrication. One section is shown shackled to a girder suitable for lifting by crane, using lifting eyes on the inside of the section (presumably left *in situ* afterwards), the open part of the section being held open by metal stays apparently welded in place, and therefore temporary. The nearly completed cell appears in NGTE 33096 (Fig 58) and NGTE 29095 (Fig 59).

It is worth noting that the provision of different lavatories for the workshops and the control room attached to Cell 4. This was not a conscious social discrimination between two groups of workers; rather that the control room was essentially a clean office-like environment and the lavatories were designed accordingly with provision made for both men and women. The lavatories adjacent to the workshops were fitted out to suit the needs of a workshop and were only for men. Women are shown in photographs of the control room for Cells 1 and 2 (MoD 1974, 37, fig 48), but not in the only available photograph of the control room for Cell 4 (29710) as by chance no women were ever involved in Cell 4 activities.

8.4 Technical details of working processes

8.4.1 Introduction

Ashwood (2003, 13) states that the designing of Cell 4 began in 1960, and at first it was intended purely as a research cell rather than to support specific engine development projects. At the time of conception and for many years afterwards, the scale

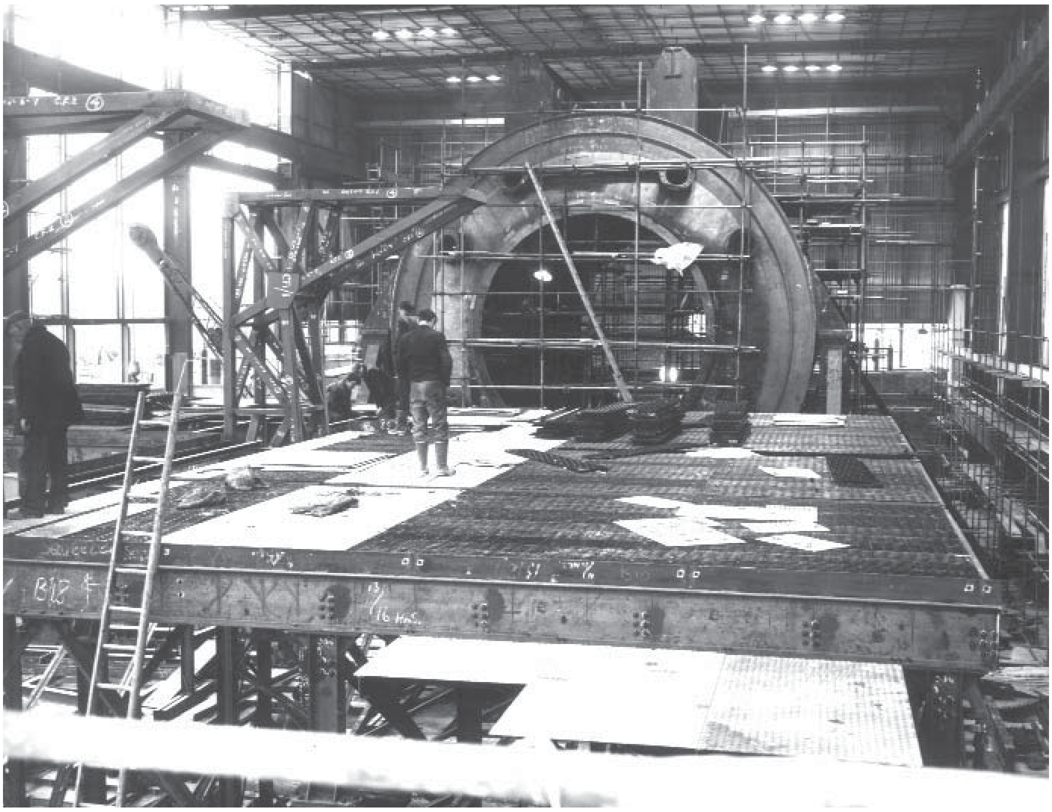

Fig 57 Cell 4 plenum chamber under construction, December 1963 (NGTE 25606)

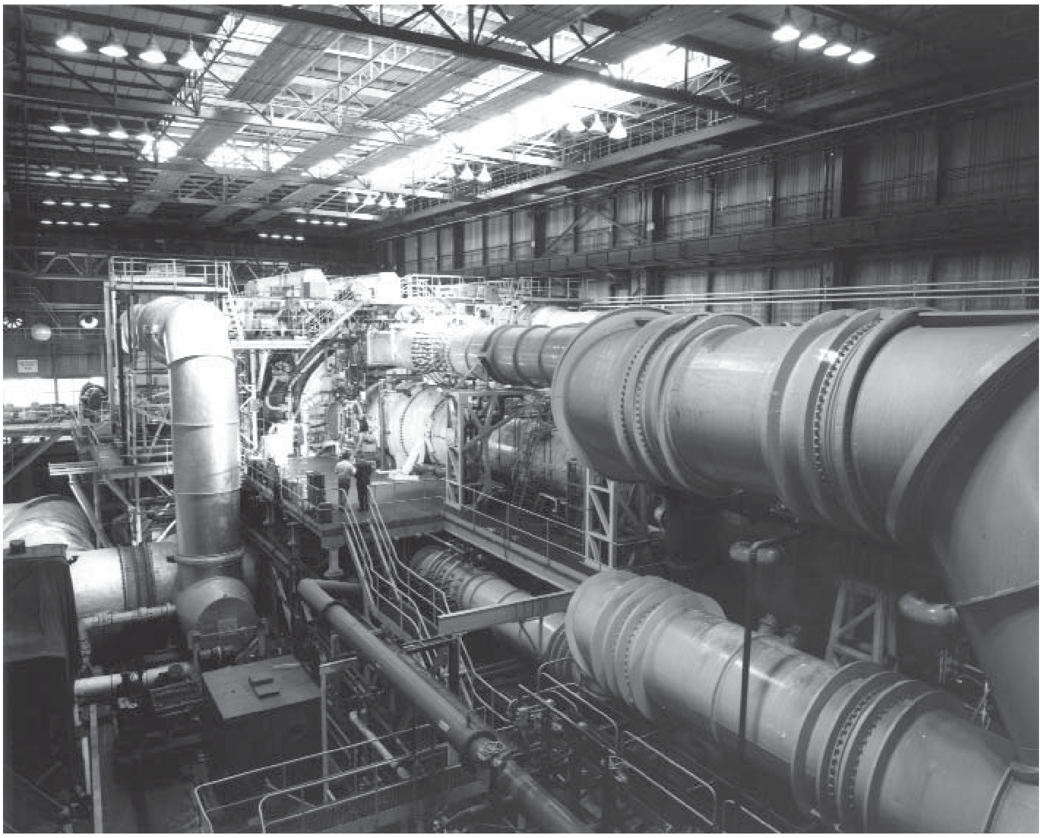

Fig 58 Interior of Cell 4 nearly completed, looking south-east towards by-pass ducting (NGTE 33096)

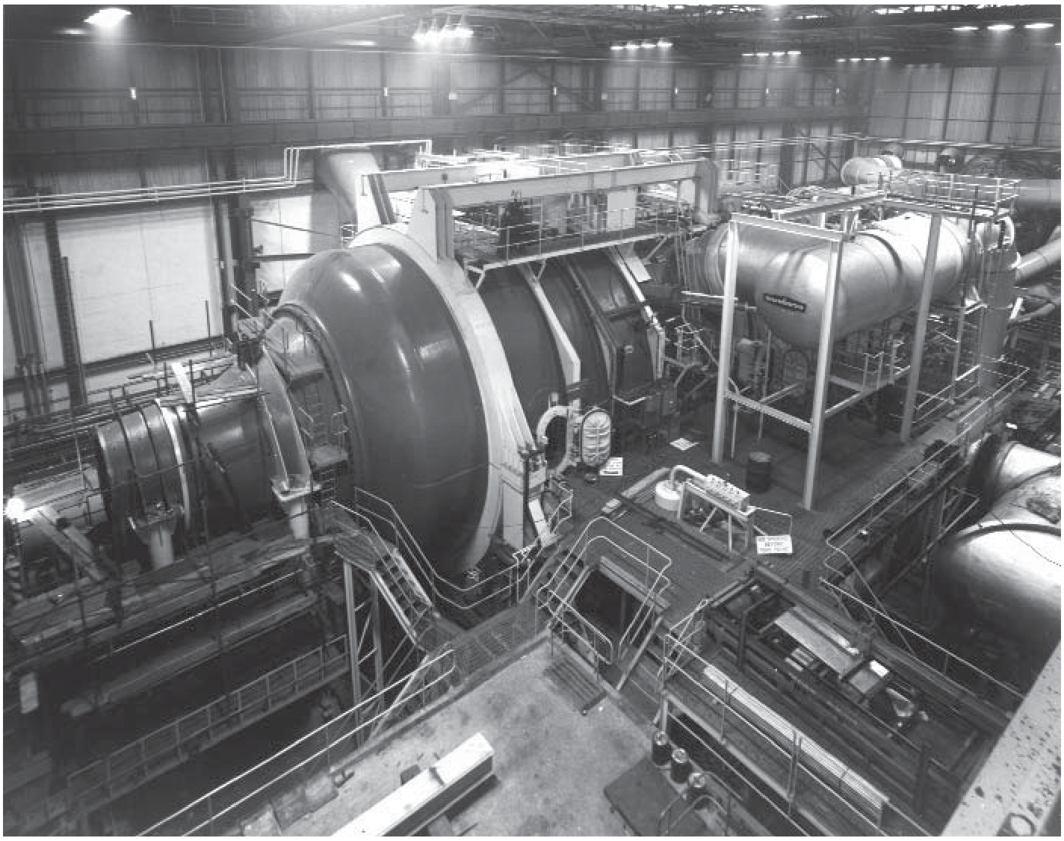

Fig 59 Interior of Cell 4 nearly completed, looking south to the plenum chamber (NGTE 29095)

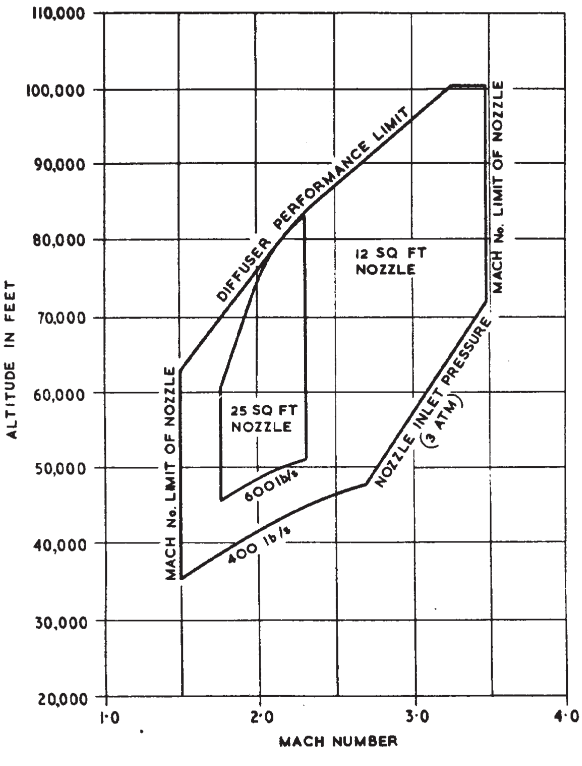

Fig 60 Performance limits for Cell 4 (MoD 1974, fig 68)

and capability of Cell 4 for supersonic free-jet testing made it unique in the world, and it was greatly envied by the US engine-testing fraternity. The existence of Cell 4 was cited to the US Congress as evidence supporting the case for constructing a comparable facility at AEDC. Specifically, Cell 4 was designed to simulate supersonic airflows at full-scale over a wide range of speeds, to enable the interaction of intakes and engines to be studied under both steady-state and rapidly changing conditions.

Cell 4 required additional exhauster capacity for the Concorde test programme, and this was provided with the installation of Parsons No. 9 exhauster plant immediately to the north of the cell (**Bldg 635** north extension), commissioned in 1966.

Cell 4 proved invaluable for testing Concorde's engine intake performance and developing the variable geometry control laws associated with it. In particular, to investigate simulated transient aircraft yaw and the adverse effect this might have on the remaining engines following a single engine failure. Obviously, this was too dangerous a condition to attempt during a full-scale flight test (Ashwood 2003, 14). Other projects supported by Cell 4 included intake-engine compatibility tests of the Tornado power plant incorporating the Turbo Union RB199 engine (DERA 1995), subsonic free-jet sets on an Adour engine and the intake for the Jaguar, and on the power plant of a Sea Dart missile (Ashwood 2003, 14).

8.4.2 Air pressure

Cell 4 was designed to handle supersonic airflows with a maximum airflow of 400lb per second under pressure conditions, the output of two GEC compressors, or up to 600lb/s at lower pressures by use of the injector system. The maximum inlet pressure did not exceed three atmospheres absolute with a temperature range of between 70°C and 470°C. The Ceca Plant (**Bldg 623**) provided the dry air that was essential for supersonic testing, avoiding condensation shocks in the free jet that would have invalidated the tests.

The supersonic free jet in Cell 4 was created by means of a blowing nozzle with a remotely variable throat area to vary the flight Mach number. The nozzle passage was rectangular in section with flexible upper and lower walls within fixed side walls. Flexure of the upper and lower walls varied the nozzle throat area. In longitudinal section, the nozzle was initially convergent as far as the throat, followed by a carefully designed divergent profile to the exit. Supersonic flow was achieved when the ratio of the entry and exit pressures was such that the flow was accelerated to sonic velocity at the throat, the point of minimum area. Supersonic expansion then occurred, creating the desired supersonic flow in the divergent section. The Mach number achieved was the ratio of the exit and throat areas of the nozzle, the smaller the throat area the greater the ratio and, therefore, the greater the Mach number (Fig 60).

Flight simulation was achieved by directing the air jet from the blowing nozzle at the test intake. Two blowing nozzles were constructed, the first, with an exit cross sectional area of $12ft^2$ was used for the initial commissioning tests and operated over a Mach number range of 1.5 to 3.5. The second, larger nozzle ($25ft^2$ exit area) was installed for Concorde and functioned between Mach 1.7 to 2.5. (Mach number is the ratio of the speed of a vehicle with respect to the local speed of sound).

The nozzle was mounted on a universal carriage (weighing, with the $25ft^2$ nozzle, a total of 75 tons) to enable simulation of aircraft pitch and yaw at angles of up to 10° and at rates up to 20° and 10° per second respectively for the $12ft^2$ nozzle and somewhat more slowly with the larger nozzle. The engine intake was mounted in the working section immediately downstream from the blowing nozzle, with the engine coupled in the narrower engine chamber behind (MoD 1974, 55).

The two spill diffusers collected the majority of the air spilt around the test intake and were designed to convert the kinetic energy of the flow to pressure energy by reducing the flow velocity and increasing its pressure. In so doing, the exhauster requirements for the cell were greatly reduced. The required cell altitude was achieved by setting the necessary pressure level at entry to the blowing nozzle.

The spill diffusers, apart from the function described above, creamed off the low-velocity, low-energy boundary layer of the supersonic jet, approximately 4% of the total cell flow, and directed it into the working section from where it was extracted by the working section bleed. No. 9 Machine, in the northern extension of the building, was used for this duty with the additional help of four working-section bleed ejectors.

The geometry of the Concorde engine intake required additional ductwork in order to accommodate the ‘ramp bleed’ and ‘dump door’ flows, which are a characteristic of this intake design. This additional ductwork routes these flows to the main exhaust circuit of the cell.

8.4.3 Cooled air

As in all altitude tests, the exhaust air needed to be cooled. In Cell 4, this took place in several stages after the air had passed six ‘flame torches’, which were to ignite any unburned fuel and reduce the risk of explosion further along the line. The first stage entailed cooling the exhaust from 1,700°C to 1,000°C by passing it over cooling tubes. In the second stage, the exhaust was taken through the tubes, with the temperature being further reduced to 150°C. In the third and final stage, direct injection water sprays were used as evaporative cooling in order to reduce the temperature to 50°C, the maximum acceptable temperature for the GEC exhausters. Excess water from the sprays was drained from the ductwork into the barometric well (**Bldg 636**). The total recirculating flow of all cooling water systems in Cell 4 under hot running conditions was 2.5 million gallons per hour. Up to 170,000 gal/h were lost through evaporation, leakage and contamination. The exhaust cooling system was made of ferrous materials, which required continuous maintenance.

8.4.4 Fuel system

Cell 4 shared its fuel system with Cell 3, which was possible because both testing facilities did not run at the same time. The fuel flow rates were up to 100 gallons per minute for the engine system and 200gal/min for the reheat system, at a set pressure of 25lb/inch^2, although this could be increased to 100lb/inch^2, if required.

8.5 Research undertaken in Cell 4

Cell 4 was essentially a larger and more capable version of Cell 1, being designed originally for free-jet testing of supersonic power plants with engines sized up to 150 lb/s ground level airflow. The commissioning tests of the complete cell started in January 1965. For these initial test, the 12ft^2 supersonic blowing nozzle was installed, providing a Mach number range of 1.5 to 3.5. Initially, the test vehicle consisted of a simple Pitot intake connected to a dummy engine sized to replicate the Bristol Siddeley (formerly de Havilland) PS50 Gyron Junior engine. The dummy engine consisted of a simple duct that connected to the intake at its forward end, with an axially translating plug valve at the rear to adjust the airflow swallowed by the intake. Its use enabled intake performance to be evaluated, and the optimum intake control laws (for intake variable geometry) to be established, more quickly and over a wider range of intake conditions than the complication and limitations imposed by an engine would have allowed.

It was during these initial tests that the cell operated in the supersonic mode for the first time, at Mach 1.8. In addition to the basic commissioning tests, controlled by staff from the Ministry of Public Buildings and Works in association with NGTE staff, NGTE added additional test points to gather information regarding the Mach number distribution across the blowing nozzle and the performance of the spill diffuser system. Both these systems had been the focus of considerable aerodynamic study, both theoretical and experimental at model scale, by NGTE scientific staff for a considerable number of years prior to the final engineering design definition of the cell in 1962. The results from the Cell 4 tests correlated very closely with the earlier NGTE studies.

The Pitot intake was replaced by the Bristol Type 188 centre-body intake for the next series of tests although the dummy engine was still retained, thus allowing attention to concentrate on the intake performance. The PS50 Gyron Junior engine (employed in the type 188) was then installed, firstly without reheat and then with reheat, the latter providing the opportunity to demonstrate the effectiveness of the exhaust coolers under the higher engine exhaust gas temperatures associated with reheat. The cooler design was another area of significant design attention by NGTE staff and necessitated the construction of a test model to validate the heat transfer calculations used in the design.

Following the conclusion of this phase of the commissioning programme, the cell was extensively adapted for the Concorde tests. This entailed changing the supersonic blowing nozzle to the 25ft^2 unit, adapting the inlet portions of both spill diffuser ducts by removing approximately 20ft of the original ducts and replacing them with new ducts, installing a larger engine capsule and bringing on line No. 9 exhauster machine to cater for the increased requirement for working section bleed.

The Concorde test began initially with the installation of a dummy engine, following which the Rolls-Royce (Bristol Siddeley) Olympus 593 was installed. In total, more than a dozen separate test series were run on the Concorde installation between 1965 and the mid 1970s, during which the variable geometry intake and its control system were progressively developed. Testing involved identifying the limiting yaw angles and maximum Mach numbers to which the intake could be subjected before the onset of engine surge (surge being a condition when an engine compressor ceases to function as a compressor due to excessive blade stalling). Test data were recorded in both steady-state and transient conditions with the objective of defining the safe operating limits for the intake. This control system was based on analogue computer technology. It became apparent late in the programme that this analogue architecture was not precise enough to raise intake performance to the level required for the aircraft to cross the Atlantic safely with the amount of fuel it could carry. Thus, only a couple of years before entry into service, the control amplifiers were redesigned with digital computer architecture. This change was only possible at such a late stage due to the considerable research work already carried out elsewhere at NGTE on digital engine control systems.

Starting in the early 1970s and interleaving with the later Concorde tests was an extensive programme in support of the Panavia Tornado. The Turbo Union RB199 engine and intake were somewhat smaller than those of Concorde and required modifications to both the blowing nozzle and the spill diffuser ducts. The blowing nozzle exit area was reduced from 25ft^2 to approximately 22.5ft^2, and the entry geometry of the spill diffuser ducts was modified to compensate for the horizontal offset of the Tornado intake with respect to the engine centre line. Much of the Tornado programme led on from the experience gained with Concorde.

Following the completion of the Tornado programme, the supersonic blowing nozzle was replaced with a simple fixed-geometry convergent nozzle to carry out subsonic trials on the SEPECAT Jaguar intake, firstly with a dummy engine and then with the Rolls-Royce/Turbomeca Adour engine. The final programme to run in Cell 4 before it was stood down on a care and maintenance basis in 1980 was a series of subsonic tests on the Sea Dart propulsion system.

Cell 4 was a complicated cell to operate so, in addition to the test controller who was in overall charge, there was an assistant test controller (Fig 61). The test controller had absolute authority with responsibility for safe operation of the facility. The workload of controlling was shared, the assistant controller being responsible for starting up and shutting down the cell, these process taking about three-quarters of an hour and half an hour respectively, while the test controller took charge of the actual test programme. All intercom conversation was recorded on magnetic tape with every command and action recorded by a log-keeper in a large A3-size logbook. In addition to these three, the remaining test team numbered a minimum of twelve in the control room, as well as two in the auxiliary control room, two floors below in the basement. Crew members were also located in the Data Centre, where the data reduction computers were operated, and in the Air House and in No. 9 Machine Hall, where they operated the site’s air-moving machinery and the oil-fired air heater, the latter providing the high air inlet temperature required to simulate the kinetic heating effect of supersonic flight. In total, approximately 26 people would be directly involved in a test, with mechanical, electrical and electronic support staff on call should technical problems arise.

Although sited adjacent to the test hall, little noise penetrated the control room to disturb the air of quiet calm typical of the environment during testing. It was certainly not possible from what noise could be heard to determine whether the cell was operating supersonically. The only indications of this were the shock waves visible on a television monitor viewing the intake shadowgraph system, and the levels of the mercury manometers connected to the blowing nozzle and spill diffuser ducts, positioned adjacent to the operating desk for the spill diffuser.

Communication between all members of the test team was by means of lightweight intercom headsets so, to the casual visitor, no conversation was audible. In addition, the light level in the control room was much reduced during test operations to prevent eyestrain and assist concentration. Every so often the silence would be interrupted when the engine on test surged. A surge would occur when the limit of stable operation was deliberately exceeded to identify the engine's operating limits. Even then, only a mild vibration of the floor was noticeable, and a flash of flame would be visible in black and white on another television monitor. If the engine was running on reheat, an additional roar could be heard as the large increase in unburned fuel was burned off by the inhibition torches in the cell exhaust.

Cell 4's electrical power consumption during testing was approximately 80MW. This dictated that a large proportion of testing occurred during the evenings, with test shut down scheduled at 10.30 p.m.

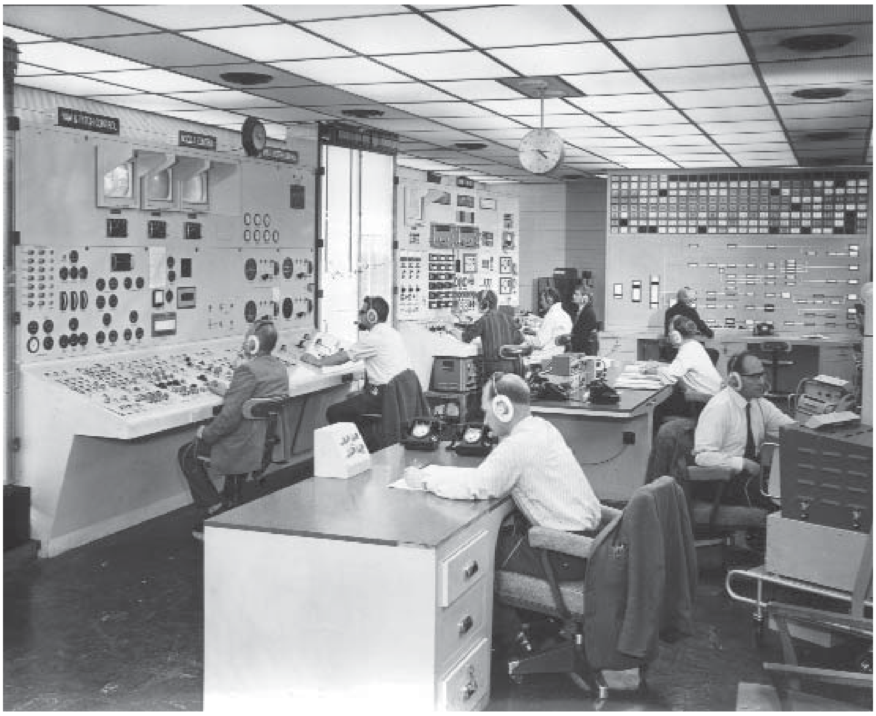

Fig 61 The control room for Cell 4 (NGTE 29710)

9 Other test facilities at Pyestock

9.1 Cell 3 (Bldg 630)

Cell 3 was put into commission in 1961 in order to test the performance of turbine engines over a wider range of inlet air temperatures and altitude conditions than possible hitherto. Testing was carried out in the connected mode. The cell is 97m long and was constructed entirely in a concrete trench below ground level in order to contain noise and to limit collateral damage should a structural failure of the cell occur. It comprises several discrete sections, (Fig 62). A substantial portion of the cell was taken up with engine exhaust cooling. In 1979, additional improved inlet air filtration was installed to prevent the blockage of the small cooling passages in the air-cooled turbine blades of modern aero-engines. The cell shared the suction mains, and exhaust manifold and valves, with Cell 3 West, but was otherwise independent. The control room was sited on the 1st floor of the main Computer Building (**Bldg 574**), approximately 100m to the east of the cell.

Unlike Cells 1 and 2, which used air ejectors, Cell 3 used the newly constructed Air House GEC compressors (**Bldg 621**), and later the Parsons Nos 9 and 10 exhausters (**Bldgs 635** west and **638**), to provide the altitude conditions. The air was supplied to the test engine through an extensive system of pipes. Both hot and cold air processing plants were available to achieve the required engine entry air temperature. Air temperatures available raged from -70°C to +250°C. A supercooled water droplet plant was also installed to test the performance of engines under atmospheric icing conditions. Elevated fuel temperatures occur in aircraft where the fuel is used as a heat sink for cooling aircraft systems. To simulate this in the cell, steam from the steam generators in the Air House West Annex was passed through heat exchangers, before the fuel entered the cell, raising the temperature of the fuel to 60°C. For special tests, a fixed quantity of 250 litres in a holding tank could be heated to 95°C (DTEO 1996, Sec 3, 9-16).

During the 1970s, tests carried out here supported three major British projects, Concorde, the Tornado and the Harrier. Tests were also conducted on the US Avco Lycoming ALF turbofan and on the Japanese FJR 710 turbofan (Ashwood 2003, 16).

9.2 Cell 3 West (Bldg 630)

Cell 3 West was the largest test cell to be constructed at Pyestock in terms of airflow throughput, with an internal diameter of 7.9m and a working section 9m long (DTEO 1996, Sec 3, 16). This cell, brought into service in 1969, was designed to carry out connected tests on turbofan engines in the 50,000lb thrust class. This type of testing required substantial exhauster capacity, greater than that available from the eight GEC sets in the Air House. To supplement the latter, No. 10 Machine was constructed and put into commission in 1968. The air entry to the cell was from the atmosphere, whence the air passed through a large air cooler to reduce the temperature to the required level consistent with the test altitude. Subsequently, ducting was installed between the cell inlet and the Ceca dry air plant (**Bldg 623**) to control the humidity of the air entering the cell. At the time it was thought that this thrust class was the upper limit of engine size, but by the beginning of the 21st century engines of twice this thrust are considered normal (Ashwood 2003, 14). The test engines were attached to a thrust frame supported by flexible rods attached to the roof of the cell.

The Cell 3 West inlet air cooler was an air-over-tube heat exchanger consisting of 33 modules. Air-cooling is achieved by passing refrigerated aqueous ammonia coolant through the heat-exchange tubes. During use, the coolant is circulated through the air cooler and two 500-ton cold store holding tanks (**Bldg 609**), with a refrigeration plant (**Bldg 607**) used to reactivate the cold store between test runs. Using one cold store tank, the cooler can provide a maximum of 800lb/s of cold air to the cell at 37°C for 30 minutes at, on entry, a dry bulb temperature of 7.3°C and 100% relative humidity.

A wide variety of tests were carried out in this cell. A very extensive test programme, early on, involved the Rolls-Royce RB211 turbofan for the Lockheed Tristar civil airliner. The programme included altitude relighting tests, oil and control system tests, cold starting, and verification of performance guarantee points. The last of these tests carried important financial implications. Both Rolls-Royce and Lockheed collaborated closely with Pyestock, analysing results from, for instance, Tristar flight trials in California, and ground-level engine tests at Rolls-Royce's facilities at Derby and Hucknall and Lockheed's test bed at Palmdale, California.

Because of Cell 3 West's cold air capability (DTEO 1996, Sec 3, 3), the opportunity was taken early in the life of the cell to carry out subsonic free-jet icing trials on a Sea King helicopter. The success of these trials led to others, on the Lynx helicopter and the power plants of both Concorde and the Tornado (Ashwood 2003, 15). Cell 3 West established a world reputation for cost- and time-effective icing trials, as it could operate largely independently of the prevailing climate.

9.3 Admiralty Test House (Bldg 307)

The Admiralty Test House was built in 1951–2 specifically to test marine gas turbine engines about to enter service with the Royal Navy. It consisted of a flat test bed, supplied with fuel, compressed air and cooling water. The engine under test was installed in a cubicle to represent the ship installation and was connected to typical marine inlet and exhaust ducting. A dynamometer absorbed the power from the engine power turbine. The facility had equipment that enabled salt water to be injected into the engine inlet, to simulate conditions at sea. The test house was extensively modified in the mid 1990s in order to test the Northrop Grumman-Rolls-Royce WR21 engine for the US Navy, and for the Royal Navy's new Type 45 destroyer.

9.4 Glen Test House (Bldg 500)

The Glen Test House was used to test gas turbine engines under sea-level conditions, 'Glen' being an acronym for 'ground-level engine nacelle'. The infrastructure was not as complicated as that needed to simulate altitude flight conditions (MoD 1974, 59).

The plant was originally installed for engines with an inlet mass flow up to 250lb/s and 28,000lb of thrust, although engines of 320lb/s and 35,000lb of thrust were tested here, such as the Olympus 320 engine for the TSR2, and, in 1974, there were plans to increase this to accommodate engines of 435lb/s and 43,500lb of thrust. The cell was used extensively to develop the design rules for digital engine control, particularly on reheated engines where the greater number of input parameters complicates the control system. To reduce noise emissions from the facility, the Glen Test House incorporates sound-absorbing air inlet splitters and an exhaust detuner. During reheat operation the exhaust gases are cooled to avoid the detuner overheating.

9.5 Engine component test facilities (Bldgs 303, 304, 405, 415, 442, 539, 543, 572 and 590)

In addition to the facilities for testing complete engines, there were comprehensive facilities at Pyestock to test engine components. These ranged from model-scale or laboratory rigs to support fundamental research, at one extreme, to large, full-scale facilities to test engine compressors, turbines and combustion systems used in support of major aerodynamic, heat-transfer and combustion research programmes, at the other extreme. In the latter years, many of these were supported by European Union funding.

A number of small wind tunnels, both subsonic and supersonic, supported aerodynamic research, providing the means of designing supersonic engine intakes and compressor and turbine blade profiles, and of developing other aerodynamic devices, such as purpose-designed pressure and temperature-measuring probes for use in other test facilities. The ideas developed at model-scale were then tested and evaluated at full-scale in the large component test facilities.

Comprehensive high-temperature materials research laboratories were available for supporting research on high-temperature metal alloys. In addition to incorporating the usual creep and tensile testing equipment, one laboratory included a foundry supporting research into blade-casting techniques, with the aim of improving turbine blade life by controlling the crystalline form of the blade, as it cooled, to enhance its creep properties. This research led, during the late 1970s, to the first manufacture in Europe of single crystal turbine blades.

Research into the reduction of jet engine noise was, and continues to be, supported by the largest anechoic chamber of its type in Europe. This facility, which is still fully operational, has recently undergone a major enhancement programme and will continue to support research into reduction of engine noise for many years to come.

In terms of test activity, these component test facilities and laboratories accounted in total for many more testing hours and manpower allocation over the years than the major engine test facilities.

Fig 62 Cell 3 under construction in January 1958, looking east (NGTE 17348)

10 Conclusion

The facilities at the Pyestock New Site are associated with key developments in jet engine technology in the second half of the 20th century. Engines tested included those for military aircraft and missiles, commercial aircraft and marine engines. In its heyday in the 1960–70s, Pyestock employed upwards of 1500 people. It was the largest gas turbine engine test facility in Europe and at times was the world leader in aspects of gas turbine engine research. It occupies a significant place in the context of post-War defence research and development.

A DERA brochure produced in 1996, titled 'Pyestock, A Celebration of the Gas Turbine Engine' provides a useful summary of key achievements:

> Research into engine noise reduction, for which Pyestock and Rolls Royce received the Queens Award for Industry in 1990.
>
> Pyestock produced the first European nickel alloy single crystal turbine blade in 1967, now used in all new British gas turbine engines.
>
> The early development of the axial compressor by Griffith and Constant.
>
> The key engine tests – the Pegasus vectored thrust engine for the Harrier jump jet, the Olympus 593 for Concorde, the RB199 for the Tornado.
>
> The icing tests for the RB211 and Trent engines.
>
> Marine gas turbine testing covering development and endurance trials for various engines prior to their entering service with the Royal Navy.

Whilst the site has great historical and scientific significance, it has been accepted by the local planning authority and English Heritage that the facilities themselves are not suitable for reuse and they will be demolished in advance of redevelopment of the site.

This report and the accompanying gazetteer and CD provide a record of the buildings and facilities of NGTE Pyestock, as required by the local planning authority and English Heritage. As part of this project, the story of jet engine research on the site will be publicised in a series of articles for a more general audience at both local and national levels.

It is also proposed that the archive of drawings and manuals relating to the test facilities should be deposited with an appropriate public archive to ensure that this valuable collection is maintained for future historical research. At the time of writing it is proposed to transfer ownership of the archive to the Farnborough Air Sciences Trust (FAST), who already have an extensive collection of photographs and material from the site. In the long-term it is proposed that FAST will be able to curate the material under the auspices of the Royal Aeronautical Society's proposed National Aerospace Library (NAL) at Farnboough. If this solution is not achievable for any reason, the National Archives at Kew will curate a selection of the material. The present report (including gazetteer and CD) and accompanying material (brochures, and a small selection of copies of archive drawings) will be deposited with the Aldershot Military Museum (Accession No. R2005.5) in Hampshire.

Fig 63 Marion Pennell and part of the archive of drawings at Pyestock (MoLAS 028/05/05)

11 Acknowledgements

MoLAS would like to thank Astral Developments, which commissioned the work. The authors and project manager wish to thank all those who helped with different aspects of the project, especially Geoff Timmins, former Pyestock Senior Engineer and member of FAST, who kindly provided a very interesting and informative tour of the site; Marion Pennell, of the former Pyestock Drawing Office, who made copies of a selection of relevant drawings; Jim Dearcove of QinetiQ who provided copies of Pyestock brochures, photographs and video footage; and Brian Luff, Collections Manager at FAST, who helped with the use of FAST's prints. Many thanks are due to Stephen Appleby of Hampshire County Council and Dr John Schofield of English Heritage for their advice and encouragement, and we would also like to thank Mick Corby, of DL&E, for providing access to the site and much practical assistance there.

Section 3, above, indicates how different parts of the project were carried out. Ian McKenzie, a former Pyestock Senior Engineer and now a member of QinetiQ's Trusted Expert group, provided significant contributions to the narrative on jet engine development and the history and operation of Pyestock. Research on the archived photographs and drawings was conducted mainly by Chris van Schaardenburgh. Other documentary research was carried out, and the first draft of the report was written, by Jon Chandler. The descriptions of Cells 1, 2 and 4 were written by Andrew Westman. The MoLAS photographs were taken and scanned by Maggie Cox. The design of this report was by Kenneth Lymer.

12 Bibliography

Ashwood, P F, 2003 *Pyestock, Farnborough, Hants., where aero-engine research flourished: a personal memoir by Peter F Ashwood*. Unpublished memoir.

Bud, R, and Gummett, P, 1999 *Cold War, hot science: applied research in Britain's defence laboratories, 1945–1990*. Science Museum. London.

Clark, K, 2001 *Informed conservation: understanding historic buildings and their landscapes for conservation*

Cocroft, W D, and Thomas, R J C (Barnwell, P S, ed), 2003 *Cold War: building for nuclear confrontation, 1946–1989* (English Heritage)

DERA [Defence Evaluation and Research Agency], 1995 *Pyestock:* a *celebration of the gas turbine engine*, brochure.

Dennis, R, 1999 *Farnborough's jets: an account of early jet engine research at the Royal Aircraft Establishment Farnborough and at Pyestock.* Footmark Publications. Hampshire.

DTEO [Defence Test and Evaluation Organisation], Jan 1996 *Pyestock test facilities*. Brochure.

DoE [Department of the Environment], 1990 *Planning Policy Guidance 16: archaeology and planning (PPG16)*

DoE, 1994 *Planning Policy Guidance 15: planning and the historic environment*

ETD [Engine Test Department], n.d. [*c* 2000] *A memento: Pyestock 1947–2002*. Unpublished memento in photographs

English Heritage, 1991 *Management of archaeological projects* (2nd edition)

English Heritage, 1999 *Conservation area practice… guidance on the management of conservation areas*

English Heritage, [2000] *The presentation of historic building survey in CAD*

Francis, P, 2003 *National Aeronautical Establishment Bedford: Wind Tunnel Site.* CGMS client report.

Golley, J, 1987 *Whittle, the true story*. Airlife. England.

Harris, A, Sept 2003, *Cultural heritage – built environment: Pyestock North*, ES Technical Volume. CgMs Ltd client report

IFA [Institute of Field Archaeologists], 1998 and 1999 *Standard and guidance for archaeological investigation of standing buildings or structures*

McKenzie, I, 2002, *60 years of gas turbine research at Pyestock*, FAST Newsletter article, December 2002

MoD [Ministry of Defence], [1974] *Engine and component test facilities at the National Gas Turbine Establishment*. Issue 3, Copy no. 296. Ministry of Defence, Procurement Executive, brochure.

MoD, n.d. *Engine and component test facilities*. Issue 3, Copy no. 1200. Ministry of Defence, Procurement Executive, brochure.

Ministry of Supply, Sept 1955 *National Gas Turbine Establishment, Pyestock, Hants. Visit of the press, Sept 1955. Notes on buildings.* Unpublished report.

Ministry of Supply, May 1955 *National Gas Turbine Establishment, Pyestock, Hants. Show Week, 1955 (16th–19th May 1955).* Unpublished report.

Ministry of Aviation, May 1960 *National Gas Turbine Establishment, Pyestock, Hants. Show Week, 1960 (23rd–27th May 1960)*. Unpublished report.

MoLAS [Museum of London Archaeology Service], 2003 *Health and safety policy*

MoLAS, 2005 *National Gas Turbine Establishment, Pyestock: an environmental impact assessment.* Client report

Museum of London, 1994 *Archaeological site manual* (3rd edition)

Reed, T, and Turnhill, R, 1980 *Farnborough: the story of RAE*. Robert Hale. London

RCHME [Royal Commission on Historical Monuments, England], 1996 *Recording historic buildings: a descriptive specification*

Archive drawings and plans

(All drawings obtained from the Pyestock Drawing Office Archive unless stated otherwise.)

Ordnance Survey 25 inch map. Hants sheet XX.4 (1940)

Pyestock NGTE ETF Site. Drwg no. LSG41, dated Feb 1956

Pyestock NGTE. Survey of area north of Howf Road for record purposes. Drwg no. LSG46, dated Aug 1957

Pyestock NGTE. Survey of area east and west of Fairway for record purposes. Drwg no. LSG49, dated June 1958

National Gas Turbine Establishment 1:1250 site survey. Drwg no. E252/23, dated June 1968.

National Gas Turbine Establishment 1:500 site survey. Drwg no. E252/28 sheets 1–11, dated June 1968.

National Gas Turbine Establishment 1:1250 site survey. Drwg no. A0/662/1, dated Aug 1975.

National Gas Turbine Establishment 1:1250 site survey. Drwg no. A0/662/1, dated 19/1/95

Internet sources

www.arnold.af.mil	(Arnold test facility, USA)
www.ciam.ru	(Russian test facility)
www.nasa.gov	(NASA test facility)
www.saclay-scientipole.org	(French test facility, Saclay)
www.ila.uni-stuttgart.de	(University test facility, Stuttgart, Germany)
www.ista.jaxa.jp	(Japanese test facility)
www.snecma.com	(Company test cells, Snecma)
www.pratt-whitney.com	(Company test cells, Pratt & Whitney)
www.geae.com	(Company test cells, General Electric)
www.rolls-royce.com	(Company test cells, Rolls Royce)
www.sverdrup.com	(Jacobs Sverdrup, test cell engineering)
www.dstl.gov.uk	(Defence Science and Technology Laboratory)
www.nationalarchives.gov.uk	(The National Archives, Kew)

Appendix 1

List of holders for Cells 1, 2 and 4 within the Pyestock drawing archive

Cells 1 & 2 (Bldg 561)

Drawing Holder no.	*Drawing Holder title*
179/ 1 of 2	Air Mains & supplies
179/ 2 of 2	Air Mains & supplies
180	Air Inlet & Heaters
181	Air Inlet & Splitters
182	Air by pass Filter NGTE & Firms
183	Ejector & Exhaust
184	Exhaust Stack
185/ 1 of 3	Site Layout & Foundations
185/ 2 of 3	Foundations Ducts & Steelwork
185/ 3 of 3	Foundations Ducts & Steelwork
186	Buildings
187	Handrails Ladders & Platforms
188	Misc. Valves & Mechanisms
189	Schedules
190	Hydraulic Systems
191/ 1 of 2	Instrumentation
191/ 2 of 2	Instrumentation
192/ 1 of 7	Test Cells – Layout & Detail
192/ 2 of 7	Test Cells – Structural Detail
192/ 3 of 7	Test Cells – General Detail
192/ 4 of 7	Test Cells – General Detail
192/ 5 of 7	Test Cells – Floor Plates
192/ 6 of 7	Test Cells – End Covers Ports Doors Windows Periscope
192/ 7 of 7	Test Cells – Nozzle Yawing Mechanism
193/ 1 of 3	Fuel System, Layouts & Fuel Jettison Pipe Detail
193/ 2 of 3	Fuel System, No. 5 HP Fuel Pump House & Gen. Mech. Layouts
193/ 3 of 3	Fuel System, No.2 Booster Pump House
194	Fire Precaution
195/ 1 of 3	Water System, No. 4 Water Pump House
195/ 2 of 3	Water System, Water Pump House Underground Inc. Contaminated Water System.
195/ 3 of 3	Water System – Water Valves & Regulators Orifice Plates Tanks & P/work
196	Service Layouts
197	Drainage
198	——
199	Lifting Equipment
200	Assembly Bay & New Fitting Shop
201	Bldg 547 & 565: Missing
202	Bldg 547 & 565: Missing
203	Bldg 547 & 565: Electrical
204	Bldg 547 & 565: Electrical
205	Bldg 547 & 565: Electrical
206	Bldg 547 & 565: Electrical
207	Bldg 547 & 565: Electrical
208	Bldg 547 & 565: Electrical

Cell 4 (Bldg 635)

Drawing Holder no.	*Drawing Holder title*
513	Electrical Drwgs. Vickers-Halls
514	Electrical/ Safety Interlock& Plant Alarm systems
515	Electrical/ Control room
516	Instrumentation
517	Instrumentation
518	Electrical, Air Valves
519	Air valves
520	Lighting and Small Power
521	Electrical
522	Fire Prevention
523	Engine Capsule
524	Fuel and Torch systems
525	Electrical Water& Comp. Air Systems
526	Water Systems- Valves, Vickers- Arm.
527	Heating & Ventilation
528	Electrical General File
529	Electrical
530	Nozzle Balancing System
531	Electrical Spill Diffuser
532	Schedule of Identification Numbers

Drawing Holder no.	*Drawing Holder title*
533	Vacant
534	Schedule of Identification Numbers
535	Schedule of Identification Numbers
536	Schedule of Relays- A. Coils
537	Relay Schedules
538	Vacant
539	Vacant
540	Cable Schedules
541	Cable Schedules
542	Cable Schedules
543	Cable Schedules
544	chedule of Ident. Numbers
545	Schedule of Ident. Numbers
546	Schedule of Relays
547/ 1 of 2	General Layout
548/ 2 of 2	General Layout
549	Air Inlet System General
550	Hot Air System
551/ 1 of 3	Medium Temp. Air System
552/ 2 of 3	Medium Temp. Air System
553/ 3 of 3	Medium Temp. Air System
554	Balance & Ejector Air Systems
555/ 1 of 4	Plenum Chamber & Working Section Vessel
556/ 2 of 4	Plenum Chamber & Working Section Vessel
557/ 3 of 4	Plenum Chamber & Working Section Vessel
558/ 4 of 4	Plenum Chamber & Working Section Vessel
559	Nozzle Actuation
560/ 1 of 8	Nozzle & Carriage
560/ 2 of 8	Nozzle & Carriage
560/ 3 of 8	Nozzle & Carriage
560/ 4 of 8	Nozzle & Carriage
560/ 5 of 8	Nozzle & Carriage
560/ 6 of 8	Nozzle & Carriage
560/ 7 of 8	Nozzle & Carriage
560/ 8 of 8	Nozzle & Carriage
561	Ramp Bleed System & 24 Butterfly Valve
562	Assembly of Plenum Inlet Cone & Carriage
563	Vacant
564	Exhaust & Cooler Section- Foundations
565	Vacant
566	Nozzle Pressure Balance System
567	Nozzle Pressure Balance System
568	Nozzle Pressure Balance System
569/ 1 of 3	Throat & Exit Angle Actuation
570/ 2 of 3	Throat & Exit Angle Actuation
570/ 3 of 3	Throat & Exit Angle Actuation
572/ 1 of 14	Pitch &Yaw Actuation
572/ 2 of 14	Pitch &Yaw Actuation
572/ 3 of 14	Pitch &Yaw Actuation
572/ 4 of 14	Pitch &Yaw Actuation
572/ 5 of 14	Pitch &Yaw Actuation
572/ 6 of 14	Pitch &Yaw Actuation
572/ 7 of 14	Pitch &Yaw Actuation
572/ 8 of 14	itch &Yaw Actuation
572/ 9 of 14	itch &Yaw Actuation
572/ 10 of 14	Pitch &Yaw Actuation
572/ 11 of 14	Pitch &Yaw Actuation
572/ 12 of 14	Pitch &Yaw Actuation
572/ 13 of 14	Pitch &Yaw Actuation
572/ 14 of 14	Pitch &Yaw Actuation
573	Flow Visualisation
574/ 1 of 4	Engine Capsule
575/ 2 of 4	Engine Capsule
576/ 3 of 4	Engine Capsule
577/ 4 of 4	Engine Capsule
578/ 1 of 3	Engine Chamber
579/ 2 of 3	Engine Chamber
580/ 3 of 3	Engine Chamber
581/ 1 of 3	Spill Diffuser System
582/ 2 of 3	Spill Diffuser System
583/ 3 of 3	Spill Diffuser System
584/ 1 of 2	Blow-off Ducts
585/ 2 of 2	Blow-off Ducts
586/ 1 of 3	Exhaust Diffuser
587/ 2 of 3	Exhaust Diffuser
588/ 3 of 3	Exhaust Diffuser
589/ 1 of 3	Make up Section
590/ 2 of 3	Make up Section
590/ 3 of 3	Make up Section
592/ 1 of 2	ransition Cone
593/ 2 of 2	Transition Cone

Drawing Holder no.	*Drawing Holder title*
594	Inhibition Torches
595/ 1 of 2	First Stage Cooler
596/ 2 of 2	First Stage Cooler
597/ 1 of 2	Intermediate Section
598/ 2 of 2	Intermediate Section
599	Second Stage Cooler 10ft.
600	Second Stage Cooler 20ft.
601	Bleed Ejector & Atmospheric Inbleed System
602	Ejector Bleed Duct Work
603	Valves-Valve Details
604/ 1 of 3	North & South 100ft Spill Ducts
605/ 2 of 3	North & South 100ft Spill Ducts
606/ 3 of 3	North & South 10ft Spill Ducts
607	Flame Trap Section
608/ 1 of 2	Trident Manifold
609/ 2 of 2	Trident manifold
610	Engine Exhaust Suction Manifold
611	Vacuum Mains
612	Fuel System
613	Cold Air Extension
614/ 1 of 2	10ft CW Supply Gen, Treated Water Delivery & Return Mains, Carriage Actuation
615/ 2 of 2	10ft. CW. Supply Gen, Treated Water Delivery & Return Mains, Carriage Actuation
616/ 1 of 2	Bleed – Spill Blow Off & Ejector, CW. System- Bulkhead- Balance Jack
617/ 2 of 2	Bleed – Spill Blow Off & Ejector, CW. System- Bulkhead- Balance Jack,
618	Spray Cooling-Spill Blow Off & Ejector
619	First Stage & Intermediate Cooler, Second Stage Cooling, Flame Trap Water Supply
620	Vacant
621	Domestic- Emergency- & Misc. Water Supplies, Spherical Cap Steal & Nozzle Drive Box Cooling, Dosed Water System
622/ 1 of 4	Superstructure Bldg.
623/ 2 of 4	Superstructure Bldg.
624/ 3 of 4	Superstructure Bldg.
625/ 4 of 4	Superstructure Bldg.
626	Dunbar
627	Dorman Long Ltd.
628	Dorman Long Ltd.
629	Cell Support Structure- General
630	Cell Support Structure- General
631	Heating& Ventilation
632	Barometric Well General
633	Compressed Air Supplies, Comp. House Acoustic Structure
634	Fire Protection Systems
635	Site Services
636	Engine Handling
637/ 1 of 2	Cranes & Handling Equipment
638/ 2 of 2	Cranes & Handling Equipment
639/ 1 of 4	Access Ladders & Platforms
640/ 2 of 4	Access Ladders & Platforms
641/ 3 of 4	Access Ladders & Platforms
642/ 4 of 4	(Empty)
643	MICA Installation
644	M.R.C.A. Installation
645	Gen. Layout & Schemes MRCA
646	White & Riches Ltd.
647	Vacant
648	Gloster Aircraft Co. & Armstrong- Whitworth

Appendix 2

Index of selected scanned archive drawings on the CD accompanying this report

Subject	*Drawing Title*	*Drawing No.*	*Date*
Air Dryer Plant	Control House To Air Dryer Plant	AB.97/1	2.9.1958
	Staircase for access to roof of filter house (for access to valves)	MD.97/2	8.4.1960
	Lay out of comp. Air main to receiver adjacent to air- drying plant	ML.80.3/38	ND
	Air drying plant foundation details	XB.97/1	15.5.1958
Air House	Air House plans	AB.80.3/1	1.7.1955
	Air House Elevations, sections	AB.80.3/2	1.2.1956
	Annexe on W. side of Air House	AB.80.3/3	Not readable
	Air House Plans Sheet 2	AB.80.3/4	19.5.1957
	Air house elevations	AK.80.3/2	9.6.1955
	Lay-out of equipment of West wall bays 7&8 and loading bay	ML.80.3/12	31.3.1956
	Longitudinal section looking east in annexe bays 4,5&6	ML.80.3/16 28	3.1957
	Plan at 24 foot level in annexe & bays 1,2&3	ML.80.3/20	15.3.1957
	GA of turbo-compressor unit North Side elevation	ML.80.3/63	4.3.1957
Assembly bays	Proposed Metal Tube Store	AB.87.1/1	21.9.1959
	Foundation Plan	AB.87/1	9.9.1955
	Ground Floor & Mezzanine Plan	AB.87/2	7.10.1955
	Elevations& sections	AB.87/3	17.10.1955
Admiralty Test House	Admiralty Test House& workshop, ground floor plan.	AB.32/1	10.1.1950
	Admiralty Test House& Workshop, upper floor plans.	AB.32/2	18.1.1950
	Admiralty Test House& workshop, elevations	AB.32/3	24.07.1950
	Admiralty Test House& Workshop, details of exhaust diffuser tanks etc	AB.32/4	25.2.1952
Battle Test House	14.000 HP Turbine test house, first floor plan	AB.34/2	5.10.1950
	14.000 HP Turbine Test House, roof & site plans	AB.34/3	4.10.1950
	14.000 HP Turbine Test House, sections	AB.34/4	4.10.1950
	14.000 HP Turbine Test House, elevations	AB.34/5	11.9.1950
Cells 1&2	Booster Pump House	AB39.10/1	13.5.1953
	Assembly Bay Offices & Lavatories	AB.39.12/1	4.9.1953
	Test Area (North end of site) cooling water pump house	AB.39.3/1	27.4.1953
	Control Room Basement Plan	AB.39.7/2	29.11.1954
	Control Room Ground Floor Plan	AB.39.7/3	29.11.1954
	Control Room Sections	AB.39.7/4	29.11.1954
	Control Room Elevations	AB.39.7/5	29.11.1954
	Ram Jet Test Area, Preliminary Scheme/ Site plan	AK.39/1	11.03.1953
	Ram Jet Test Area, Preliminary Scheme/ Site plan	AK.39/2	11.03.1953
	Test Area Preliminary Scheme	AK.39/4	24.03.1952
	No Title	AK.39/5A Drawing N3	ND
	General Arrangement N. of bus main duct	AK.39/8	17.11.1953
	Preliminary site plan of test area, north end of Site	AL39/1	3.04.1952
	Layout Plan	AL.39/3	25.5.1954
	Test Area North end of test cell installation (Transverse elevations)	AL.39/3m	16.7.1959
	For off-loading of test cells	MD39/192	12.3.1954
	General arrangement of (unreadable)	MD.39/84	ND
	Lay-out of fuel pipe work in tank farm area.	MD.39.10/125	7.7.1953
	Detailed arrangement & lay-out of oil fuel booster pump house	MD.39.10/31	15.12.1952
	GA pumps pipe work etc. Cooling water underground pump house	MD.39.15/352	20.9.1954
	Layout of compressors and air pipe work in cooling water pump house	MD.39.3/108	4.5.1952
	Arrangement of cooling water pump house	MD39.3/50	11.6.1952
	Centralised test cell installation	MD.39.5/119	3.5.1953
	External& internal applied loads on vacuum cells and foundations	MD.39.6&8/30	31.8.1953
	Additional Access ladders and platforms Ram Jet Test Cell	PYE/AK.39/1A	1.11.1957
	Amended lay-out of huts for contractors	PYE/AL.39/1	24.02.1955
	Arrangement of engine test frame in Ram jet cell	PYE MK 39.6/2 Sht.1	28.01.1958
	Arrangement of engine test frame in Ram jet cell	PYE MK 39.6/2 Sht.2	28.01.1958
	Foundation Longitudinal sections	XB.39/2	01.01.1954
	Control Room Walls Details of Sub-Frame for hole S.3 in south wall	XB.39/33	27.04.1955
	High-pressure oil pump house RC details	XB 39/36	01.10.1954
	Foundation Longitudinal Sections	XB.39/3	01.01.1954
	Foundation cross sections	XB.39/4	01.01.1954
	General Arrangement of Storage Tanks and Tank farm	XB.39.10/1	ND
	General Arrangement No.1 Gantry Structure		ND

Subject	*Drawing Title*	*Drawing No.*	*Date*
Cell 3	Altitude Test Cell Plan	AB.83/1	Not readable
	Altitude test cell plans	AB.83/2	01.10.1956
	Longitudinal section on ¢ of cell, looking north.	AB.83/3	1.11.1956
	Longitudinal section on ¢ of cell, looking south.	AB.83/4	1.11.1956
	Altitude test cell	AB.83/5	01.01.1957
	Altitude test cell elevations	AB.83/6	01.02.1957
	Housing for ice making plant	AK.83/11B	24.11.1958
	Access ladder to travelling crane	AK.83/11	01.06.1957
	General Arrangement	XB.83/1	01.03.1956
Cell 3 Area	5MW HV substation	AB.83.7/1	14.2.1958
	CO2 cylinder housing	AB.83.7/2	22.6.1959
Cell 3 West	GA. of cell 3 west	G380.00	31.3.1970
	Perspective view cell internals	G380.00.003	ND
	Cold Air System	G380.00.013	2.3.1970
	General site layout (plan)	G380.11 (1 of 4)	20.11.1967
	General site layout (major elevations)	G380.11 (2 of 4)	22.11.1967
	Control room& transformer park elevations	G380.11 (3 of 4)	24.11.1967
	General site layout of works	G380.11 (4 of 4)	22.10.1967
	Cell 3 layout of roads	G380/12/003	ND
	GA. of ducting Cell 3 West	G380.21.000 (1 of 3)	23.3.1970
	Ident. System for Air (main duct)	G380.21.202	6.3.1970
	General Arrangement of ladders and platforms	G380.41	24.3.1970
Cell 4	General Plan	AB9/19/1	01.03.1962
	Elevations& sections	AB9/19/2	01.05.1962
	Elevations & Cross sections	AB9/19/4	5.02.1962
	Extension to control house of air dryer plant	AB9/19/5	01.02.1964
	Pump house for closed water tank	AB9/19/6	01.07.1964
	In bleed Ejector Exton plan, sections & elevations	AB9/19 ext/5	21.8.1963
	Fuel pump & meter house	AK9/19/5	ND
	GA. of Capsule Vickers Armstrong Drawing	CW.14703	1963
	Barometric well and sump	Fig. 2.5.2.	
	N.B. this drawing has been scanned backwards	MB9/19.32/0100	
	Assembly of engine chamber	MB9/19.432/0100	29.9.1967
	Arrangement of cooling water system for No.4 Cell engine exhaust	MD9/19.6/132	15.2.1967
	Pipework & Valves	MD9/19.6/130	15.2.1967
	Part Sectional Elevation Near Cell	ML9/19.27/0112 Sht.2	8.9.1966
	GA of No 4 Cell. Part sectional Elevation near cell.	ML9/19.27/0112 Sht.3	8.2.1966
	GA of No 4 Cell	ML9/19.27/0113	8.9.1966
	Cross Section of Cell 4	ML9/19.27/0114	8.9.1966
	Cross section Cell 4	ML9/19.27/0116	ND
	Cross section of Cell 4	ML9/19.27/0117	8.9.1966
	GA. Side Elevation	ML9/19.27/0118 (Sht 1)	8.9.1966
	GA of side elevation	ML9/19.27/0118 (Sht 2)	8.9.1966
	GA of Concord Installation Cell 4	ML9/19.427/0100 (Sht 1)	21.8.1967
	Perspective of Cell 4	PYE MK9/19/9	10.3.1964
	Cell 4 Installation	PYE MK84/48 4	10.1961
Computer Building	Control Building Basic Drawing	AB90/1	17.8.1956
ETF Offices	ETF Office block. Plans& sections	AB/9/35/1	17.4.1962
	ETF Office block. Elevations & window details	AB/9/35/2	01.05.1962
Glen Test House	Engine Test Bed Plans	AK 79/2	25.8.1955
	Engine Test Bed Elevations	AK 79/3	23.8.1955
	Engine Test Bed Sections	AK 79/4	25.8.1955
	Revised Rough Sketch Plans	AK 79/5 Sht 1	6.2.1956
	Acoustic Treatment to Test Chamber	AK 79/5 Sht 2	21.9.1955
	Elevations	AB 79/2	30.4.1956
	Plant House Building	AB 79/3	28.6.1956
Main offices	Office Block	AB 30/1	23.02.1950
	Elevations to office block	AB 30/2	9.12.1949
	Temporary boiler House & rear of new office block	AB 30/3	12.12.1949
Main Tank Farm	Pump House & Oil and Fuel Installation	AB 35/1	9.05.1954
Main Workshop	Test Area Workshop	AB 31/1	1.12.1949
	Test Area Extension	AB 31/3	19.6.1950
Metallurgical Lab	Metallurgical and mechanical test laboratory	AB 78/1A	ND
	Metallurgical and mechanical test laboratory	AB 78/1	27.04.1954
MoPBW Offices	New Site offices	AD88/1	01.09.1955
Number 10 machine	General arrangement of exhauster & associated equipment	MD9/123/143 (1 of 2)	31.1.1967
	General arrangement of exhauster& associated equipment	MD9/123/143 (2 of 2)	31.1.1967
	NGTE Pyestock, newer exhaust building/ Elevations	XB9/123/6	24.1.1966
	NGTE Pyestock, newer exhaust building/ Elevations	XB9/123/7	21.1.1966
	Details- Annexe buildings	XB9/123/8	01.01.1966

Subject	*Drawing Title*	*Drawing No.*	*Date*
Number 9 House	Diagrammatic arrangement of pipes & valves 96520 uncoloured	MD9.19.17/90	4.8.1964
	Diagrammatic arrangement of pipes & valves	MD9/19.17/90	4.8.1964
Plant & general stores	Structural steelwork General arrangement Elevations	XB9/125/2	16.12.1966
	Elevations	XB9/125/7	16.12.1966
Plant House	Plant compressor house, Aero cubicles	AB38/11	1.8.1952
	Plant compressor house, elevations east and west	AB38/14	8.8.1952
	Plant compressor house, aero cathedral plans	AB38/16	1.9.1952
	Plant compressor house, ground floor plan	AB38/1	20.08.1951
	Plant compressor house, main hall first floor plan	AB38/2	22.10.1951
	Plant compressor house, main hall second floor plan.	AB38/3	22.10.1951
	Plant compressor house. Main hall sections	AB38/4	22.10.1951
	Plant compressor house. Main hall sections	AB38/5	22.10.1951
	Plant compressor house, Combustion cubicles	AB38/6	29.7.1952
	Plant compressor house, Combustion cubicles	AB38/7	29.7.1952
Power Station	General arrangement of 10.000 KW gas turbine alternator	2910/S/L2047 (1 of 3)	10.8.1951
	General arrangement of 10.000 KW gas turbine alternator	2910/S/L2047 (2 of 3)	10.8.1951
	General arrangement of 10.000 KW gas turbine alternator	2910/S/L2047 (3 of 3)	10.8.1951
	10.000 KW Gas turbine power station, sub station & control	AB 36/1	28.6.1950
	10.000 KW Gas turbine power station, plans	AB 36/2	3.1951
	10.000 KW Gas turbine power station, plans	AB 36/3	1.3.1951
	10.000 KW Gas turbine power station, sections	AB36/4	1.3.1951
	Calorifier room adjoining 10,000 KW Power Station	AB36/6	7.4.1952
Site survey	Master diagram of ETF air mains	AO/102/30	ND
	1/1250 Site Survey (metric edition)	AO/662/23	5.1.1988
	1/1250 Site Survey (metric edition)	AO/662/1	17.01.1978
	1/1250 Site survey (metric edition)	AO/662/1	19.01.1995
	1/1250 Site survey	E252/23	01.06.1968
	Survey of area north of Howf Road for record purposes	LSG/46	3.10.1957
	Survey of area east & west of fairway for record purposes	LSG/49	18.07.1958
Sports& Social Club, Canteen & Assembly Hall	New canteen Plans, sections & elevations	AB72/1	8.3.1954
	New canteen details of entrance and lavatories at north end	AD72/1	1.12.1953
	New canteen main sections	AD72/2	1.12.1953
Stores & Work Shops	New workshop No 3	AB 71/1	1.10.1953
	New workshop No 3	AB 71/2	21.11.1953
Water treatment plant	Water treatment plant house	AB83.4/1	25.6.1958
	Access layout to building	AD83.4/5	20.1.1959
	Water treatment plant house	AK83.4/1	20.2.1958
	GA of starvation water treatment plant	ML83.4/3	9.4.1958

Appendix 3

Index of selected scanned archive prints on the CD accompanying this report

These photographs are mainly of NGTE buildings under construction and in use (from the FAST collection). Large (8 x 10 inch) prints of the photographs listed here have been scanned and copied as .tif images to a read-only CD. Most of the prints bear a number and short description on the back, transcribed here. Note that the numbers by which the images are identified on the CD are not always exactly the same as the numbers listed here. [bold image no. = reproduced in report]

Subject/Building	*Print description*	*FAST collection: negative number*	*CD number*	*Date*
Cells 1& 2 Bldg 561	Test cell under construction at Marshall, Gainsborough. Section No. 1 free jet cell has satisfactorily completed the vacuum tests.	Ministry of Works G6001/10	G6000110.tif	28.10.1955
	The yawing machine erected on a test rig, jacked to its central position with the forward end in line.	Ministry of Works G5889/1	G58871.tif	12.9.1955
	Test cell section on the road. Transportation to Pyestock, for final assembly.	NGTE 14423	14423.tif	15.2.1956
	Cells 1 and 2 in place at Pyestock. Control Room structure. View towards south-west.	NGTE 16098	16098.tif	No date
	Air supply ducting under construction. Looking south-east towards the power station (Bldg 305), cell 2 can be seen in the right hand corner.	NGTE 16100	16100.tif	No date
	Roof structure under construction. Looking east. One test cell in place and under assembly. BTH (Bldg 543) in operation in the background.	14704	14704.tif	No date
	Roof structure under construction, crane in place. Valves and ducting in foreground. Looking towards north-east.	NGTE 14869	14689.tif	24.5.1956
	Cells 1 and 2 test area under construction. Viewed from top of BTH (Bldg 543). Looking north-west. Also in picture (Bldg 547). Temporary structures in foreground.	NGTE 15316	15316.tif	11.9.1956
	Cells 1 and 2 under construction, looking south-east.	NGTE 13720	13720.tif	No date
	Close-up of Cell 2. Looking north-west.	NGTE 16094	16094.tif	No date
	Cells 1 and 2 control-room under construction. Looking from the entrance towards the back. Some instruments in place.	NGTE 16104	16104.tif	No date
	Inside of Cell 1 looking at the adjustable nozzle. Looking south.	NGTE 15584	15584.tif	29.11.1956
	Inside of Cell 1 looking towards the exhaust end. Looking north.	NGTE 15585	15585.tif	29.11.1956
Cell 3 Bldg 630	Superstructure Cell 3 under construction. Looking north-east	NGTE 16394	16394.tif	18.6.1957
	Section of test cell under construction in underground test cell bay. Looking west.	NGTE 17893	17893.tif	No date
	Cell sections under construction in test cell bay. Looking east.	NGTE 16889	16859.tif	No date
	Cell sections under construction in test cell bay. Looking west.	NGTE 16606	16606.tif	No date
	Cell under construction, different sections being assembled. Looking east.	NGTE 17348	17348.tif	13.1.1958
	Superstructure under construction, looking south-west.	NGTE 18764	18764.tif	No date
	Cell 3 Control Room	No number	83.tif	No date

Subject/Building	*Print description*	*FAST collection: negative number*	*CD number*	*Date*
Cell 4 Bldg 635	Cell 4 under construction, test cell section. Looking from the exhaust side of the building.	No number	019.tif	No date
	Cell 4 under construction, Plenum Chamber. Looking from the intake side of the building. Looking towards the west.	NGTE 26122	26122.tif	No date
	Cell 4 under construction, the altitude chamber. Scaffolding at side of the test cell.	NGTE 25711	25711.tif	No date
	Cell 4 under construction, the altitude chamber. Looking towards the north-east.	25606	25606.tif	19.12.1963
	Cell 4 under construction, looking at the exhaust and by-pass ducting. Looking west.	No number	002.tif	No date
	Cell 4 under construction. By-pass ducting. Looking from the exhaust side.	25780	25780.tif	No date
	Cell 4 Adjustable Mach Nozzle. Used to produce supersonic flow in the test section. The pivoted framework surrounding the nozzle enables it to be pitched or yawed, thereby changing the angle of flow on to the intake under test. MoD Photograph	31947	31947.tif	No date
	Cell 4 nearing completion, looking south-east. Looking at the cell from the exhaust end. The ducts removing the air from the spill diffuser system are on the right. One of the four large working section bleed ducts is on the left. MoD Photograph	33096	33096.tif	No date
	Cell 4 nearing completion. Looking at the 9m diameter Plenum Chamber which houses the variable mach No. nozzle. Mod Photograph	29095	29095.tif	No date
	Cell 4 Control Room during a test run. The Test controller is seated at the desk to the right centre of the picture; the log keeper is at the desk in the foreground and on the right is the transient data recorder. The control consoles on the left operate the nozzle producing the supersonic air stream and the spill diffusers. On this panel are the three television monitor screens, which show engine and other views of cell equipment.. The engine and intake are controlled from the desk at the centre background with, on the panel, the television monitor showing the intake shock system.	?	29710.tif	?
Cell 3 West Bldg 649	Test Cell 3 West and cooler unit. Looking north-east. MoD Photograph	32703	32703.tif	No date
	Sea King helicopter fuselage being installed in the 7.6 m diameter chamber in preparation for a series of tests to examine the possibility of ice building up on the front fuselage, windscreen and engine air intakes. Looking north-east	NGTE 33824	33824.tif	No date
Anechoic Test Facility Bldg 590	This view shows the large silencing splitters through which ventilating air is induced. This air and the exhaust from the test rig are discharged through a silenced exhauster system at the rear of the building. Looking north-east. MoD Photograph	5150	5150.tif	No date
	This view of the inside of the chamber is taken from within the exhaust duct, looking upstream. The ventilating air enters through the vertical splitters on either side of the rig room. A nozzle is being installed for acoustic tests. MoD Photograph	6053/3	60533.tif	No date

Subject/Building	FAST collection: Print description	negative number	CD number	Date
Air Cooling Towers Bldg 417	Air Cooling Towers under construction. Looking west.	NGTE 14880	14880.tif	1.6.1956
	Air Cooling Towers under construction. Looking south-west.	NGTE 15498	15498.tif	No date
	Air Cooling Towers under construction. Looking south-west.	NGTE 10395	10395.tif	18.6.1957
No.3 Workshop/ Stores Building with Fire Station and Surgery Bldg 405	Stores Building, Fire Station and Surgery. Looking at the fire station side. Looking south-west.	NGTE 13452	13452.tif	No date
Fuel Farm Bldg 502	Fuel Farm under construction, looking south-east.	NGTE 9421	9421.tif	No date
Transformer Park Bldg 625	Transformer Park under construction, looking west.	NGTE 16115	16115.tif	No date
Dynamics Laboratory Bldg 304	Dynamics lab after completion, looking north-east.	NGTE 8716	876.tif	06.12.1951
Plant House with Combustion Cubicles 'A' ('The Cathedral') and 'C' Bldg 572.	Plant house and fuel farm after completion, looking north-east.	NGTE 13288	13288.tif	No date
	Plant house inside, air bleed turbine installation. Looking north-east (?).Metropolitan-Vickers Machinery.	Photograph No. 22222	22222.tif	No date
	Plant house inside, air bleed turbine installation. Metropolitan-Vickers Machinery.	Photograph No. 22223	22223.tif	No date
	Plant house under construction, turbine under assembly.	No number	034.tif	No date
Battle House (or Battle Test House) Bldg 543	Boiler removed from Battle Class Cruiser at Portsmouth harbour. Ready for transport to Pyestock.	NGTE 5110	5110.tif	No date
	A boiler in place inside the Battle Test House. Looking north-east.	NGTE 13258	13258.tif	No date
	Battle Test House (with two funnels) looking north-east over the Fairways Transformer Park (Bldg 312)	NGTE 13254	13254.tif	No date
	Turbine test hall with a Rolls-Royce Avon turbine rig connected to one half of the Heenan and Froude 25000 hp dynamometer.	NGTE 15362	15362.tif	8.10.1956
	14000 hp Brush Steam Turbine installation. Proteus Compressors installed.	NGTE 13688	bh34.tif	11.08.1955
	Turbine test hall with the Heenan and Froude 25000 hp dynamometer.	NGTE 13687	13687.tif	No date
	Control room.	NGTE 10417	10717.tif	No date
Air House Bldg 621	Air house under construction,	NGTE 19699	19699.tif	No date
	compressors being installed. Drawing of GEC compressor unit.	10273	10673.tif	No date
Aerial views	NGTE, looking north-east.	NGTE No. 9	9.tif	No date
	Power Station (Bldg 305), Admiralty Test House (Bldg 307) and Cooling Tower (Bldg 308), looking south-west.	No number	25.tif	?
	NGTE, looking south-west.	No number	22.tif	No date
Old Site (?)	Workshop, machine shop.	WS/H/0646	0646.tif	?

Appendix 4

Index of images from MoLAS photographic survey submitted with archive
(**bold** = reproduced in report)

MoLAS Image number	*Bldg No./location*	*Direction of view*	*Description*
15/05/01	621 (Air House)	E	Interior. G loading bay, external doors, overhead crane
15/05/02	**ditto**	**NE**	**Interior. Series of compressors etc (No. 8) on 1F deck, N side of loading bay, roof framing, glazed E wall (landscape)**
15/05/03	ditto	NE	ditto (portrait)
15/05/04	ditto	E	Interior. At 1F level. Space between two series of compressors, etc (Nos. 6 and 7). Latter has covers removed; parked on G in space between
15/05/05	ditto	W	Interior. Steel control cabinet on 1F level walkway to W of compressors etc
15/05/06	630 (Cell 3)	NW	Exterior. From N side of upper roof of 621 (Air House). Background: 649 (Cell 3 W), SW corner 635 (Cell 4)
15/05/07	ditto	NW	ditto (close-up)
15/05/08	619	NE	Exterior. From N side of upper roof of 621 (Air House). 619 is a tall, circular tank, of riveted steel plates, with overhead crane on top
15/05/09	635 (Cell 4)	NNE	Exterior. From N side of upper roof of 621 (Air House). E end 635 (Cell 4). Background: 644 (ejector seat test crane)
15/05/10	572 (Plant House), 570 (cooling tower) ENE		Exterior. From N side of upper roof of 621 (Air House). Rear of 572 (cubicles). Background: Farnborough Airfield (hangars, control tower) visible on tree line
15/05/11	ditto	ENE	ditto (close-up)
15/05/12	621 (Air House)	SE	Exterior. From E side of upper roof of 621 (Air House). Top of exhauster stacks (Nos. 6 and 7)
15/05/13	ditto	SSE	Exterior. From E side of upper roof of 621 (Air House). Top of exhauster stacks (Nos. 6 and 7), with gangway from roof
15/05/14	ditto	SE	Exterior. From E side of upper roof of 621 (Air House). Exhauster stack, compressed air outlet pipes below
15/05/15	417	S	Exterior. From S side of upper roof of 621 (Air House). Top of 417 (cooling towers)
15/05/16	ditto	S	ditto (with more of skyline)
15/05/17	417, 415	SSE	Exterior. From S side of upper roof of 621 (Air House). SW end of 415 (Assembly Bldg)
15/05/18	621 (Air House)	NW	Exterior. From W side of lower roof of 621. Eight exhaust pipes approaching 621. Background: 649 (Cell 3 W), 638 (No. 10 Exhauster House)
15/05/19	623	W	Exterior. From W side of lower roof of 621 (Air House). Top of 623 (Ceca air driers)
15/05/20	ditto	W	ditto (close-up)
15/05/21	ditto	W	Exterior. G-level
15/05/22	ditto	NW	ditto
15/05/23	621 (Air House)	NE	Exterior. S side of 621, workshops and offices. Foreground: overhead air pipe
15/05/24	ditto	N	Exterior. E side of 621, exhauster stacks, overhead crane. Foreground: overhead air pipe
15/05/25	ditto	NW	Exterior. E side of 621, exhauster stacks
15/05/26	ditto	NW	Exterior. S side and SE corner, exhauster stack
21/05/01	561 (Cells 1 and 2), 579	NW	Exterior. Exhaust tower at rear of 561. Background: 579 (Bramshot cooling towers)
21/05/02	Rear of 543 (Battle House)	E	Exterior. Close-up of sign about '10th golf tee' (543 not visible)
21/05/03	ditto	N	Exterior. E end of 550 (cooling tower)?
21/05/04	ditto	S	Exterior. W end of 543. Background: 561 (Cells 1 and 2)
21/05/05	307 (Admiralty Test House)	SE	Exterior. N equipment entrance. Doorway, offices, site of flagstaff
21/05/06	ditto	E	ditto
21/05/07	543 (Battle House)	W	Exterior. S side of 543 facing The Howf
21/05/08	305	S	Exterior. 305 (power station), site of 312 (transformers), grass-sided trench containing pipes
21/05/09	543 (Battle House)	SE	Exterior. Rear of 543
21/05/10	**558, 560**	**SW**	**Exterior. Water tanks for Cells 1 and 2. NB external float gauge at E end of N side of 560, brick base walls**
21/05/11	570	SE	Exterior. Exhaust tower at N of Cells 1 and 2. NB steel mesh around tower about two-thirds of way up
21/05/12	635 (Cell 4)	SW	Exterior. Large doors on N side of 635 facing road
21/05/13	579	S	Exterior. N side of 579 (Bramshot cooling towers). Foreground: pipes overhead along road (Davidson or J Road)
21/05/14	**630, 635**	**W?**	**Exterior. From G Road. Overhead air pipes and pipes in sunken conduits between Cells 3 and 4**

MoLAS Image number	*Bldg No./location*	*Direction of view*	*Description*
21/05/15	**561 (Cells 1 and 2)**	**E**	**Exterior. W side of Cell 1. Foreground: pipes in sunken conduit**
21/05/16	**634**	**SW**	**Exterior. 634 (standard WC block). Background: 635 (Cell 4)**
21/05/17	575	SE	Exterior. 575 (standard bicycle sheds) at rear of 574 (computer bldg)
21/05/18	**ditto**	**E**	**ditto (close-up of 575)**
21/05/19	543	W	Exterior. Footbridges over sunken pipe conduits. N side of The Howf. NB road sign. Background: 543
21/05/20	**561 (Cells 1 and 2)**	**N**	**Exterior. Detail of cradle supporting overhead air pipe, N of Cells 1 and 2, W of 560**
21/05/21	**ditto**	**NE?**	**Exterior. Detail of ?expansion joint in overhead air pipe, N of Cells 1 and 2, W of 560**
21/05/22	543	W	Exterior. Sign on N side of the Howf: 'Tank farm manual call point'. Background: 543
21/05/23	574, 579	NE	Exterior. SE corner of 574 (computer bldg). Background: car park, 579 (Bramshot cooling towers)
21/05/24	562 (Cells 1 and 2)	S	Interior. Control room
21/05/25	ditto	N	Interior. Doors at N end of control room (sealed shut)
21/05/26	ditto	S	Interior. Narrow space at W side of control room. NB thick glass window looking on to Cell 1
21/05/27	**ditto**	**NW**	**Interior of pressure vessel of Cell 2. Engine in position to test after-burners? (looking towards outlet to N)**
21/05/28	ditto	S	Interior. B, cabinets housing relays and other instrumentation. Ladder in background rises to E side of control room
21/05/29	**ditto**	**N**	**Interior. B**
21/05/30	ditto	N	ditto (AW recording)
21/05/31	ditto	E	Interior. B. Detail: labelled keys locking relay box etc, 'men at work'
21/05/32	ditto	SW	Interior. B. Detail: relay boxes
21/05/33	**ditto**	**N**	**Exterior. Space between Cell 2 and control room block**
21/05/34	ditto	NW	Exterior. S side of control room, under shed roof and overhead crane
21/05/35	ditto	N	Exterior. S end of Cell 1 pressure vessel
21/05/36	644	NW	Exterior. Preparing test of ejector seat
21/05/37	ditto	NW	ditto (close-up)
21/05/38	ditto	NW	ditto (control room in shed to W)
21/05/39	ditto	N	Exterior. Adjusting dummy (landscape)
21/05/40	ditto	N	ditto (portrait)
21/05/41	ditto	N	ditto (close-up of dummy)
21/05/42	ditto	NW	ditto (close-up of test crane rig)
21/05/43	ditto	NW	ditto (full height of crane rig)
21/05/44	ditto	NW	ditto (close-up, lights)
21/05/45	407 (office, workshops etc)	SW	Exterior. Car park, flowering cherry on E side of the Fairway, road signs, zebra crossing
28/05/01	407	NE	Exterior. Bus shelter and flowering cherries on E side of the Fairway
28/05/02	**305**	**E**	**Exterior. Bus shelter and flowering cherries on E side of the Fairway. Background: 305 (power station)**
28/05/03	ditto	SE	ditto (better view of bus sign, pipe trenches)
28/05/04	407	N	Interior. Archivist's G-level office (Marion Pennell)
28/05/05	**ditto**	**S**	**Interior. Hanging drawings, 1F archive. Archivist (Marion Pennell)**
28/05/06	572 (Plant House)	NW	Exterior. S and E sides of 57228/05/07 567 NE Exterior. 567 (fuel tanks on SE corner of 572). Labelled 'AVTUR', 'AVTAG' and 'NAVY DIESEL'. Background: Cells 1 and 2
28/05/08	572 (Plant House)	N	Exterior. S side and SW corner of 572
28/05/09	**621 (Air House)**	**W**	**Exterior. W end of S side of 621. Detail: emergency shower. NB drain in ground**
28/05/10	ditto	NW	Exterior. E side of 621 28/05/11 623 NW Exterior. Ceca air driers
28/05/12	**635 (Cell 4)**	**N**	**Exterior. E side of 635. NB some inlet air pipes removed**
28/05/13	ditto	NE	ditto
28/05/14	ditto	S	ditto
28/05/15	435	NW	Exterior. Rectangular section air pipe dismantled (originally was carried overhead to 623). NB chain-link fence
28/05/16	624	N	Exterior. 624? (control room), site of 625 (transformers). Background: Cell 3 W
28/05/17	649 (Cell 3 W)	NW	Exterior. NB Moveable section opened
28/05/18	ditto	NW	ditto (close-up)
28/05/19	ditto	NW	ditto (W end, air supply)
28/05/20	ditto	NW	ditto. NB baffles to smooth air flow
28/05/21	ditto	E	Exterior. Air outlet (portrait)
28/05/22	ditto	E	ditto (landscape, includes wheels and rails)

MoLAS Image number	*Bldg No./location*	*Direction of view*	*Description*
28/05/23	610?	SE	Exterior. Electricity substation N of Cell 3 W? NB sign 'no loitering'
28/05/24	**649**	**S?**	**Exterior. Detail: sign 'use ear protectors'**
28/05/25	635 (Cell 4)	E?	Exterior. SW of Cell 4. Exhaust air pipes going over sunken road
28/05/26	**ditto**	**SW**	**ditto. NB sign 'keep off the stones' (gravel surfacing)**
28/05/27	**ditto**	**NW**	**Exterior. W of Cell 4. Sunken air pipes and junctions. NB corrugated plastic shelter over manual valve? (portrait)**
28/05/28	ditto	NW	ditto (landscape)
28/05/29	ditto	NW	ditto (portrait, including B-level piping)
28/05/30	630 (Cell 3)	E	Exterior. W end of Cell 3 (landscape)
28/05/31	ditto	E	ditto (portrait)
28/05/32	ditto	W	Interior. Roof of Cell 3 pressure vessel open at G level. Background: entrance, Cell 3 W (portrait)
28/05/33	ditto	W	ditto (landscape, no background)
28/05/34	ditto	E	ditto (NB pressure vessel roof parked in background at G level)
28/05/35	ditto	E	Exterior. Detail: sign next to entrance 'Danger, do not loiter...'
28/05/36	635 (Cell 4)	SW	Interior. E end of N side of cell, pressure vessel enclosing air inlet
28/05/37	ditto	S	ditto
28/05/38	ditto	SW	Interior. W end of N side, pressure vessel divided into two. NB water spray pipes attached to upper pipe
28/05/39	ditto	SW	ditto (includes entrance to pressure vessel)
28/05/40	**ditto**	**N**	**Interior. W end, S side, pressure vessel divided into two. S entrance to pressure vessel**
28/05/41	ditto	E	ditto (NB rollers on deck to move section of lower pressure, to insert test rig etc)
28/05/42	ditto	W	Interior. E end, N side of pressure vessel. NB manufacturer's sign
28/05/43	ditto	W	ditto (AW recording)
28/05/44	ditto	S	ditto (detail of warning signs, closed door to pressure vessel etc)
28/05/45	**ditto**	**S**	**Interior. W end, N side of pressure vessel. Door open. Warning signs**
28/05/46	**ditto**	**S**	**Interior. W end, N side of pressure vessel. Detail: Vickers Ltd sign**
28/05/47	**ditto**	**W**	**Interior. W end, S side of pressure vessel**
28/05/48	ditto	SE	Interior. E end. Air inlet pipe removed from wall of bldg to pressure vessel. NB redecoration for filming
28/05/49	ditto	E	ditto
28/05/50	ditto	E	Interior. E wall of bldg from S of pressure vessel
28/05/51	ditto	SW	Interior. N side of pressure vessel, B level
28/05/52	ditto	W	ditto (rubbish left by film company)
28/05/53	ditto	NE	Interior. Gantry over E end of pressure vessel. NB warning sign about hoist
28/05/54	ditto	W	Interior. Air pipe S of pressure vessel. NB warning sign 'fragile'
28/05/55	ditto	W	(close-up)
28/05/	**ditto**	**E**	**Interior. Overhead crane at E end of bldg. NB French manufacturer's sign**
28/05/	630 (Cell 3)	W	Exterior. E end of Cell 3. Overhead air pipe. Road bridge runs W-E between Cells 3 and 4