UNCLASSIFIED

AD NUMBER
AD597184

CLASSIFICATION CHANGES	
TO:	**unclassified**
FROM:	**restricted**

LIMITATION CHANGES

TO:

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FROM:

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AUTHORITY

DSTL ltr dtd 15 Feb 2007; DSTL ltr dtd 15 Feb 2007

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Journal of the

Decl OADR

AD-597184

ROYAL NAVAL

SCIENTIFIC SERVICE

Volume **29**

Number **4**

July **1974**

RESTRICTED

CONTENTS

THE DEFENCE APPLICATIONS OF COMPUTERS*

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Director General Research Weapons MOD

People are conventional; they think of new developments in terms of previous ones. They can hardly do otherwise, but it doesn't always work. A friend of mine was given a pair of water skis for Christmas and he's still looking for a sloping lake.

Some of you may remember the time when Sir Thomas Beecham was having difficulty with a 'cellist during an orchestral rehearsal. " Madam," he said, " you have there between your legs an instrument capable of giving pleasure to millions. Yet all you do is sit and scratch it ! "

The moral is that we should make an effort to know and understand the instruments or tools we use—and one of these is the digital computer.

At one time we fought shy of starting computations which would take a man more than three months. Now we do ones, which by the older techniques, would have taken a man 30 years. Using digital computers we can do them in three months. The actual computing time may be only one hour, but the rest of the three months is spent in writing and proving the programme !

I have so far spoken in terms of the first application of computers, to scientific computation. We now have far wider application, some of which are

Operational research
Elements of weapon systems
Management
Teaching and training
Command and control
Engineering design
Industrial automation

And the well-dressed man must of course carry his HP35 on his hip.

At the lowest level, it may be difficult to distinguish the digital computer in a weapon system from other electronic circuits used in an on/off manner. At the higher levels we can be faced with extremely complex systems. The number of possible states may well increase factorially with the number of sources of data involved; substantial additional variations will be introduced by any men/machine interfaces; it becomes impracticable to forecast and test all the possible situations.

Yet we are faced with a very new technology, with a very limited number of really experienced practitioners—and those often of techniques now being overtaken by new methods. Many countries have had traumatic experiences in this area and I hope that by getting together we shall be doing something to steer each other around some of the pitfalls.

We started thinking that the hardware was the principal problem, with the programming a relatively straightforward task which could wait—indeed would have to wait—until the hardware was working. We even used to advocate selecting a digital computer solution, as against a conventional analogue system, on the grounds that it would be much more flexible and it would be easier to amend the design !

Now we appreciate that more than 50% of our effort will go into the software, that we must start the software work somehow *before* the hardware and that many of our systems are *less* flexible than the older systems—we just daren't change the software for fear of faults that will be exposed and the additional labour to prove it.

Perhaps it's worth quoting some rough figures. George 3, ICL's operating system for the 1900 range, has been said to cost £6 million and 500 man years of effort. The LACES automated cargo handling project for the Customs and Excise Authorities at Heathrow was equally divided between hardware and software and our project LINESMAN is also equally divided.

Why do these problems arise? Perhaps it's because we are attempting to combine men and machines in a task that was previously done by men and was not at all well-defined. But there is another factor. Conventional management techniques also require a reasonable ability to estimate the size of tasks, adequate measurements of the progress of them and satisfactorily precise interfaces between them.

For software, it simply hasn't worked. We have consistently under-estimated the amount of logic needed—even more, that is, than we do in our hardware developments. We haven't the right measures of our rate of progress: we cannot just count the numbers of instructions written, as our total is so poorly known and anyway the real problems may lie ahead when we start testing the apparently complete programme.

The interface problem is also difficult because of the large number of ways in which parts react on each other and, in addition, because they have to operate through what can be the bottleneck of common hardware.

The early definitions of the system are also in everyday language—which is not one with the precision and freedom from ambiguity desired by computers. I am reminded of the General who put the question to DOAE's computer:

" Will the RED forces or BLUE forces win the battle ? "
" Yes " . . .
" Yes, what ? "
and the only elaboration the General could obtain to that question was,
" Yes, *Sir.*"

Just as we need experimental " breadboard models " of hardware, we must develop analogous experimental and more fully engineered models of the software. But we really do not know enough yet of what form these should take.

It would be very nice if our team of programmers behaved like a crystal, all regularly ordered with well-defined bonds; but they all too often have the turbulence of a liquid. With the addition of only a little heat they all acquire completely random motions—and the whole thing turns into gas! Let's hope this symposium will be more than just gas.

Part of our problem arises from our rushing in too boldly into systems of too great a complexity for our current understanding. But another part lies in the fundamental differences between Man and our present machines.

We have designed our computers to be immensely precise—which is not a well known characteristic of man. Yet we must communicate with them. We have done pretty well on the output side with a choice between documents, video displays, graph plotters and, if we wish, spoken output. But that's the easy part of the problem; displaying what is precise and detailed in the computer to Man who is unrivalled for pattern recognition.

The input problem, the instructions to the computer, whether as programme or during-run commands, are more difficult. We have to move from the qualitative views of an imprecise situation, complicated by the individual's wealth of experience which is not held in the computer's store, to a mathematically precise algorithm.

We try to ease this transition by inventing new languages with precise enough syntax to suit the computer yet intelligible enough in human terms for our programmers and operators. We are still trying to raise the " level " of our languages, but I wonder myself if we place too much emphasis on improving the " power " of the language and its ability to run the machine " efficiently ". As our hardware problems are now a diminishing part of the total, perhaps we should be aiming rather at the human side of the coin, improvements to the simplicity and intelligibility of the language.

Even the input of data poses a problem. The 1971 census analysis read three million documents and 36 million cards containing three Gigacharacters. My mind boggles at the wear on fingertips! Logical errors in the data led to nearly a year's delay as well.

So far I have spoken about software, but I should like to ask if we can also in the longer term do something on the hardware side. Is it possible to sacrifice something of the precision in favour of flexibility, learning, pattern recognition, artificial intelligence even?

We can only make guesses at the answer. I am in no doubt that for many applications it will be absurd to sacrifice the precision, and it's hardly economic yet to replicate Man's abilities by electronic hardware even if it was technically feasible. He really is relatively cheap, he heals his faults and can replicate himself—which is fun !

Yet in the use of computers in weapons, there can be significant gains from adaptive operation, adjusting the weapon's behaviour to an unpredicted environment including enemy countermeasures. Our feedback loops already confer an element of homeostasis to our design but the digital computer can do a lot more in this direction if we wish it. We may well require quite different architectures to achieve the improvements in pattern recognition that are desirable. Associative memories and parallel computation are technologies to watch.

I believe that such movements to giving computers more initiative will arise in these more specialised areas.

This is all an exciting subject with almost unlimited potential for the future.

SECOND INTERNATIONAL DIVING CONFERENCE

In 1968 an international diving conference was hosted by the United States Navy in San Diego. It was the first organised international meeting of the diving community and representatives of the navies of UK, Canada, Australia, Germany, France and Sweden (many more were invited) participated. It proved successful as a forum for discussion on a wide number of diving problems and the UK offered to host the next meeting in 1969. Subsequently it was felt that this interval was too soon, by 1973 a renewal of interest was expressed and MOD(N) approval was given to hold the Second International Conference in H.M.S. *Vernon* in 1974. The two day conference was opened by Admiral Sir Derek Empson, K.C.B., Commander-in-Chief, Naval Home Command at 1000 30 July.

Sixteen nations, excluding UK, participated in the Conference and were represented by 44 delegates from Navies, Armies and ' service ' civilians; the latter mainly doctors who were specialists in underwater physiology.

The following papers were presented:

USN: The USN 1600 foot dive—1973
USN Diving Policy
Canada: Current Status of the Canadian Forces Deep Diving Programme
Canadian Institute of Environmental Medicine support for the CDF Deep Diving Programme
Physiological and Medical Studies related to the CDF Deep Diving Programme
FGR: Diving Medicine (supported by a three part film)
Norway: Norwegian Navy Underwater Training Centre
Denmark: An Emergency Bell for Submarine Rescue
France: Underwater Exploration in the French Navy
UK: The RN Saturation Diving System
Maintaining the Efficiency of Divers in Cold Conditions
Offshore Diving Safety.

The paper by Lieut. Commander SA Warner (Rtd)—Inspector of Diving for Department of Energy—presented in simple terms the Offshore Installations (Diving Operations) Regulations 1974, laid before Parliament the previous day. This was of great interest and it was gratifying to see how all nations are watching the UK lead in this field.

The Conference was of great value and gave clear indication that all nations participating were particularly concerned with involvement with commercial diving and the need for legislation to cover diver safety and medical and training standards.

PROGRAMMING LANGUAGE STANDARDS

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Abstract

The highest level of general-purpose programming language would crystallize everything we know about communicating a task to a machine, just as a natural language crystallizes everything we know about communicating with people. Formal computing languages are not yet so well developed that the programmer can stop as soon as his problem has been unambiguously specified, but the higher the level of language, the less is the amount of irrelevant detail he has to give. Language designers aim to raise the level as high as possible. How is it achieved? The two mechanisms of language evolution are:—

(a) to add extra features into an existing language, and

(b) from time to time to make an entirely fresh start.

The first method may increase breadth and versatility, but is apt to depress quality. The second method enables us to re-organise the very structure of a language, and achieve a more expressive (orthogonal) medium of communication. This is the only known way of making really significant improvements in language design. If standards are imposed with the intention of securing uniformity, they may at first raise the level of programming, but later on will hold it down. There is then no escape from the need to permit new standards (e.g. Algol 68) to grow up in parallel with older ones (e.g. Coral 66), if the development of computer science in real-life applications is not to be retarded. Users tend to resist new languages, and need every encouragement to move to higher levels if they are to avoid being tied down by obsolescent ideas. The prime instance of this tendency is the continued use of Fortran, based on ideas first developed more than 15 years ago. You cannot do advanced work in computer programming unless you make use of the most advanced tools.

Languages are fun, and standardization boring. This is the attitude of computing research staff, and I would claim to understand their point of view, but in the military field some degree of standardization is important and has to be faced. I am here to tell you something of our experiences in setting up and maintaining Coral 66 as a standard programming language for on-line operational military computing systems. There is nothing peculiarly military about Coral 66—the language probably has a big future in the civil world of process control—but the special characteristic of military authority is its power to enforce standards. In a rapidly advancing subject, this power can be dangerously exploited, and the real object of this talk is to try to qualify any excessive enthusiasm for adopting Coral 66, or any other language, exclusively. To some of you this may seem a little strange, for if we cannot even agree on common means of communication, a certain amount of chaos can be expected to result. Unfortunately, reality is always a little more complicated than we think, and there can be no rapid progress without a little chaos.

The effort of introducing a computing language is by no means trivial. The machine must be provided with a *compiler* so that it can understand the programmes we give it, and the programmers must be provided with *training and documentation* so that they know what the compiler expects. This exercise cannot begin to pay off until many different people use the language, which then *de facto* becomes a kind of standard. So far so good, but computer science is rapidly advancing. We are continually learning more about languages and how to raise programming to higher levels. The bigger the language basis, the bigger is the initial capital investment, not only in compiler writing but also in the documentation and training for users, which is even more significant than the former. The bigger the initial investment, the wider it must be spread to be economic, until it extends across the boundaries of particular makes of computer and particular classes of work. Once this snowball starts rolling, it tends to exclude alternative standards until it entirely dominates the scene and becomes peculiarly resistant to any major change. There is no shortage of scientific innovators, but for every one man who wants to introduce a new standard, there are a hundred who will resist. At best there will be a committee who will be slow to agree on any action.

Does this matter? If our computing problems remained small in scale, probably not, but I have a theory that with a given level of language, there is a practical upper limit to the size of the programme which can be brought to successful fruition. There are several ways of convincing oneself about this. To take an extreme case, let us imagine we are using machine code. The total programme will then take so long to produce that the requirements will have changed before it has been finished. Or so many men will be employed in parallel that the overheads of organizing their interaction will get out of hand. Another way of looking at it is this: a programme may be put to use whilst it is still manageable in size, but we then find we want to build more on to it. Again a limit will be reached in the attempt to make every addition compatible with what has gone before. Which ever way we look at it, the ultimate size of a working programme depends on the level of language in which it is conceived and written. So, if we are embarking on a big project, the ultimate power of the software will be language limited. The ease of writing in, say, Algol 60, is probably 10 times greater than in assembly code. Who can say that we shall not achieve the same factors again with advances in computing science?

I have spoken about improvements to languages without saying anything of their nature. Improvements are of two kinds. One most naturally thinks in terms of a growing list of facilities to be added. This is one approach—though there is a limit to what you can tack on to an existing language. A compiler is, after all, only a programme, and it has it own limits of "upwards compatibility". There is another more serious objection to adding bits and pieces to a language. It diverts attention from the thought that there might be an entirely new starting point, and I would like to offer very briefly a suggestion on what the next major change might have to offer us.

A language moulds our way of thinking when we are designing a programme. The right way to design anything is to start by thinking in the broadest terms, and attend to details afterwards. An author should not bother about the grammar of his second sentence before he knows the title of his second chapter. Unfortunately, in programming work many of us do start with the detail, because our languages do not help us avoid it. One of the biggest steps in programming was the introduction of the *procedure* in Algol 60, which can be traced back many years before that, but which did not flower fully until Algol 60 put it on a very general footing. The power of the procedure is that it enables you to map out a programme, using the names of procedures before actually writing them. In your mind, you can obey parts of the programme before they are actually written. This is a very big step in the "top-down" approach to programme design But what about data? Everybody who has written a big programme knows how important is the structuring of the data, but languages are here still in a very rudimentary state. In Algol 60, the only data structure is the array. Coral 66 has tables, which are really arrays of simple packed data structures, and Algol 68 has very general means of structuring data. But none of these languages, nor any others, permit one adequately to map out a programme using data structures before defining them. This is the kind of advance we should be looking for—the ability to handle entities like procedures or data-structures in the broad stages of initial programme design, before they are actually defined. In a few years' time, we may see big advances in this direction.

I am indebted to J. M. Foster for making me understand the truth of this matter.

Evolution to higher standards, then, is important, and we must give some attention to the mechanism of achieving it. I cannot claim to know what the answers will be, because in UK defence work we are only just beginning to be confronted by the problems resulting from our own standardization policy. It will be best if I start by telling you how far we have got until now, and I will begin at 1966 (for rather obvious reasons). At that time, I suppose that nearly all programming for off-line scientific computing was already being done in high-level language. At RRE, for instance, Algol 60 was the order of the day, whilst most of the scientific world was—and still is—using Fortran. Even so, the transition to high-level language had been painlessly accomplished, indeed welcomed. In so-called real-time computing, the picture was very different, and it is interesting to speculate why. It was always said that in real-time work, and I quote, " the efficiency of the object programme is of paramount importance ". The phrase was used so often that it became a cliché, and to this day the word " paramount " makes me think of real-time computing. Feelings ran very deep and arguments were emotional. I think we failed to understand that in work such as process control, where the computer is only a part of a larger engineering system, the system designer is an engineer. He is not a physicist wanting to knock up a quick programme to be run once only and take the answers home. He is a man dedicated to the design and production of efficient running machinery, not satisfied unless he has a complete grasp of everything between the control panel and the running plant. His motivation is efficiency in every link of the chain, and in this context the intervention of a compiler is an irrelevance. It tries to do part of the design, and not very well at that. As long as the design is a small effort compared with the stable working life of the system, it is perhaps a valid attitude, but in big computer-based systems, the software design effort is no longer so small, nor does the running system remain stable and unchanging. A revision of attitudes was therefore inevitable, and the introduction of the first standard high-level language was rather easy. I see 1966 as the significant year. By then, the pressure from real-time designers for their own high-level language had reached the point at which we were forced to provide one. At RRE, we re-

sponded to the need by adapting Algol 60 and calling it Coral 66. That is how I would describe Coral 66 to a computer scientist—Algol 60 with a few minor alterations. The fact is, however, that the minor alterations have been the secret of the success we have had in selling the language. Coral 66 has features which are mathematically inelegant, but which respond to users' supposed requirements, such as the ability to produce highly efficient object code. If necessary, the programmer can revert to code anywhere within a Coral programme. He is told something about the storage allocation algorithm, which enables him to by-pass the language rather easily if he wishes. The language allows fixed-point arithmetic, as floating point units were unusual in the types of machine for which it was mainly designed. Changes such as this are what made Coral acceptable, but they are also the very features which will eventually be its undoing.

I have said that Coral was designed in 1966, and a compiler was working by 1967, but the time taken to define it for public use and get it established as a standard was a further three years or so. Only then starts the serious business of providing compilers for a multiplicity of machines. So even now, in 1973, seven years after 1966, we are only beginning to see the language come into practical use, and it is already obsolete !

Where, then, do we go from here ? It would be convenient if we could build on the foundation we already have by making " enhancements " to the language from time to time. I have already remarked that there is a limit to the amount of such treatment a language can stand, because every proposed extra facility becomes more difficult to make compatible with what is already there. In any case, the worst thing you can do to a standard is to alter it slightly, and my policy would therefore be different. Let us keep Coral 66 to the letter for the whole of its life and be working towards an entirely new standard for the future. Most people will accept this idea; they see the progression to new standards as a kind of ladder with a date attached to each rung. The rungs would be at least seven years apart.

Although this is the current thinking in various quarters of the MOD, I happen to think that the idea of dated rungs is not practicable, because you cannot develop entirely new languages to a sufficient extent in the vacuum of

the research laboratory. Computing is an essentially practical art, and new ideas need to be tested in real-life projects. In any case, we should remember that we are concerned with developments which are aimed towards really big projects, too big for the research laboratory. The conclusion which seems inescapable is that, whilst most projects are using the current " standard ", others must be encouraged to break the rule. We have not actually reached this point yet in MOD work, but I expect we soon shall, and the opposition can be expected to be great.

I will conclude by summarizing. Programming languages are of the first importance in software design work. For a big project, one should think hard and independently about the language to be used, because it will set the scene for years to come, and may eventually be the limiting factor for the scale of the whole project. Take professional advice to ensure that the language design is sound and forward-looking, and if there is no very much better idea, use a standard and reap the benefits of conformity. But above all, recognize that languages matter.

References to languages mentioned

" Official Definition of Coral 66 ", " Algol 68-R Users Guide ".
Both of these publications are obtainable from Her Majesty's Stationery Office.

ADMIRALTY OIL LABORATORY—21st ANNIVERSARY

The Admiralty Oil Laboratory will be celebrating its 21st Birthday with Open Days on September 17 - 18, 1974 when the work and facilities of the Laboratory will be put on display. Admission is to be by ticket only.

Admiralty Oil Laboratory was set up in 1953 at Brentford as a result of the Recommendation of the Admiralty Oil Quality Committee under Lord Geddes in May 1951 and its task is to provide the Director General of Ships with the necessary advice and assistance in solving naval fuel and lubricant problems. The range of sophisticated analytical equipment at Admiralty Oil Laboratory is constantly being expanded and close cooperation with both the Universities and Industry is maintained.

A visit to Cobham will prove both pleasant and instructive.

MICROWAVE HIGH POWER TECHNIQUES

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Abstract

This article surveys the field of breakdown in waveguides from the work carried out in the earliest days to the present state of knowledge.

It includes a section on the theory of breakdown and concludes with design criteria and recommendations for future High Power Systems.

Robin Endean obtained an honours degree in physics from the University College of Wales, Aberystwyth in 1966, and a post-graduate diploma in Atmospheric physics in 1967. In 1969 he was awarded a Ph.D. for his studies of anomalous v.h.f. radiowave propagation at Aberystwyth. From 1969 to 1972 he was employed by the Plessey Company as a research engineer on communications projects. Since 1972 he has been working with the Electronic Warfare Division of ASWE.

Introduction

High power breakdown limitations of radar and ECM systems have emphasised the need for further practical and theoretical work to enable a better understanding of breakdown phenomena.

To establish this improved understanding it is necessary to understand the breakdown phenomena, to be able to interpret theoretical results in practical terms, and to utilise a test facility which enables testing to be undertaken up to the breakdown limit. Much work has already been carried out in these areas and is well documented in unclassified publications.

It is convenient to divide this article according to the subjects to which most effort has been applied. The theory of breakdown commands an important section of this article as do the experimental results. However, the most important section is that one covering the conclusions and recommendations.

This is the first known literature review of high power microwave breakdown studies, and it is therefore appropriate to describe the developments that have taken place from the earliest days; this means that only the major trends can be covered, and these somewhat superficially. However, papers dealing more fully with specific aspects of the subjects are referenced, and the reader may use them not only to fill in some of the details, but also as sources of further references.

The conclusions and recommendations necessarily take into account the feasibility of their application in service environments.

Historical Survey

The earliest demonstrations of gaseous breakdown were made on spark gaps at frequencies up to 25 MHz and is well documented by Loeb[1] and Seward[2]. Results indicated that the electric strength of air decreased with increasing frequency up to 1 MHz and increased with increasing frequency between 10 and 25MHz. Beyond 25 MHz no measurements appear to have been made prior to World War II. Loeb, however, suggested that the breakdown stress at frequencies of about 100 MHz would be lower than the value at 1 MHz.

Cooper[3] appears to be one of the earliest experimenters at microwave frequencies (2800 and 9800 MHz). In his experiments the spark gaps used consisted of either coaxial-line or waveguide transmission systems, and the electrical stress was applied in the form of impulses. The behaviour of the spark gap was shown to be dependent on the irradiation conditions of the gap, but a minimum value of breakdown stress existed which was independent of irradiation. Perhaps, Cooper's most important result was his confirmation of Paschen's Law at centimetric wavelengths. Paschen's Law states that the breakdown voltage of a gas depends only on the product of the pressure and the electrode spacing[4]. A corollary of Paschen's Law is that breakdown in waveguide systems used in aircraft will be expected at lower breakdown levels than found in similar ground based systems.

One year after Cooper, in 1948, Moreno[5] was one of the first observers to remark on the fact that the maximum power carrying capacity of waveguides may be a fraction of the theoretical figure due to the presence of line-discontinuities, dirt, dust, high VSWRs etc. Moreno's book remains a classic for microwave transmission design engineers.

The power carrying capacity of various modes within waveguides was examined in 1952 by Barlow[6], who discovered that E modes are capable of higher power flow for a given cross sectional area than are the H modes.

It was also in the early 1950s that investigations started to study breakdown in different gases. Prowse and Jasinski[7, 8] studied breakdown in a cavity resonator using the elemental gases, hydrogen, nitrogen, oxygen and neon. Sutherland[9] carried out some very useful waveguide breakdown studies using air, Arcton 6 and sulphur hexafluoride. His results suggested that the power handling capacity of waveguides may be increased by a factor of 9 to 10·5 if Arcton 6 or sulphur hexafluoride is used rather than air as the dielectric.

Microwave engineers will have noted that the above works (pre 1955) touch upon and suggest solutions for most of their high power problems. More recently, US workers led by Microwave Associates' engineers Gould and Gilden[10-15] produced a viable breakdown theory, proved it and also produced refinements to the solution of practical problems. Many other useful publications from the United States have appeared on the subject of breakdown, since 1955. One of the most recent publications was that of Acampora and Sproul[16]; they investigated waveguide breakdown effects at high average power and long pulse lengths.

Some recent high power design studies have been carried out at ASWE, notably that of Martin Collar who investigated safety factors in a specific high power waveguide system with a bias towards a naval environment.

Breakdown Theory

The primary ionisation of the gas due to the electron motion is the only production mechanism which controls microwave gas discharge breakdown. Breakdown occurs when the rate of electron production *via* ionisation exceeds the combined rate of electron loss through the processes of attachment, diffusion and recombination. These processes are defined by the electron continuity equation as follows:

$$\delta n / \delta t = v_i\, n - v_a\, n + \nabla^2 (Dn) \ . \ . \ . \ . \ (1)$$

Equation (1) states that the net number of electrons produced per second, $\delta n / \delta t$, is equal to the number of electrons produced per second by ionisation, $v_i\, n$, less the number of electrons lost per second by attachment, $v_a\, n$, and the number of electrons lost per second by diffusion, $- \nabla^2 (Dn)$. The coefficients v_i, v_a and D can be obtained as a function of the applied electric field or average electron energy from d.c. measurements of drift velocity, average energy, Townsend ionisation coefficient and attachment coefficient. A solution of equation (1) is feasible provided the correlation between electron energy and the applied microwave field has been established. At low pressures or short wavelengths, the mean electron energy can be considered as independent of time. Thus, the high frequency field can be related to an effective d.c. field defined as:

$$E_e = E_{rms}/[1 + (w/v_c)^2]^{\frac{1}{2}}$$
$$= E_{rms}/[1 + (C/P_o\lambda)^2]^{\frac{1}{2}} \qquad \ldots (2)$$

The coefficient C has different values for each gas and for air is 36. The factor $[1 + (w/v_c)^2]^{\frac{1}{2}}$ is a measure of the efficiency of energy transfer from the microwave field to an electron. The efficiency of energy transfer decreases as the pressure or wavelength decreases, with the efficiency factor becoming significantly smaller than unity for $P_o\lambda$ less than 200 in air. The coefficients in equation (1) can be determined from d.c. measured values by considering E_e as an equivalent d.c. field. The effect of energy modulation is to significantly increase the net average rate of electron production.

The electron continuity equation, equation (1), can be solved for the breakdown conditions in waveguide systems. The boundary conditions are that the electron density is zero on the waveguide walls. Under uniform conditions when D and V_{net} (which is $V_i - V_a$) are constant in space, functions are sought for n such that:

$$\frac{\nabla^2 n}{n} = -\frac{1}{\Lambda^2} \qquad \ldots (3)$$

where Λ is a constant depending upon the size of the volume and is termed the characteristic diffusion length. Typical values of Λ will be discussed in a following section, *e.g.* $\Lambda = d/\pi$ for a parallel plane region. With the previous assumptions and definitions, the solution to equation (1) becomes:

$$n = n_o \exp\left[\frac{V_{net}}{P_o} - \frac{DP_o}{P_o^2 \Lambda^2} \right] P_o t \qquad \ldots 4$$

It is seen that n can grow exponentially when the exponential growth factor is positive. Thus an essential condition for breakdown is:

$$\frac{V_{net}}{P_o} - \frac{DP_o}{P_o^2 \Lambda^2} \geq 0 \qquad \ldots (5)$$

The cw breakdown condition, since the time for exponential growth can be infinitely long, is that the left-hand side of equation (5) be zero. Since both V_{net}/P_o and DP_o are functions of $(E_e/P_o)n$, Equation 5 defines a relationship between $(E_e/P_o)n$ and $P_o\Lambda$. This relationship is shown in Fig. 1 for air. For large values of $P_o\Lambda$, where attachment is the dominant loss mechanism, V_{net}/P_o is zero and the value of $(E_e/P_o)n$, and consequently DP_o becomes independent of the dimensions of volume. In the pressure range where attachment dominates, the familiar linear relationship between break-
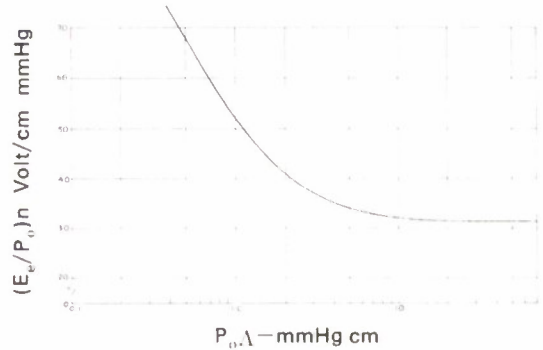

FIG. 1. Universal breakdown curve for air.

down field strength and pressure (or breakdown power and the square of the pressure) holds. As diffusion becomes more important this linear relationship fails.

Non-uniform breakdown is what is experienced in most practical situations. In such cases the electric field intensity is not uniform within the volume and at certain walls, the values are zero. Under some conditions the gas temperature or P_o is also not uniform in the volume, then the variables V_{net} and D cannot be considered as constants and equation (1) becomes non-linear necessitating numerical or computer solution techniques. Solutions for a number of these problems are discussed in reference 14. Since net ionisation only takes place in a portion of the region under non-uniform conditions, solutions for breakdown simply yield values for characteristic diffusion lengths which depend upon the size of this region and the maximum value of E/P_o. As a rough approximation to allow application of a universal breakdown curve, the smallest dimension of the region in which net ionisation is taking place, divided by 3, may be used for Λ. This is particularly useful for considering the effect of small discontinuities or highly localised regions of ionisation in waveguides.

Under single-pulse breakdown conditions, unlike those for cw, the exponential growth of the electron density (Equation 4) must reach the critical value within the individual pulse duration τ independent of ionisation remaining from the preceding pulses. The breakdown condition for the exponential growth factor thus becomes, from Equation 4:

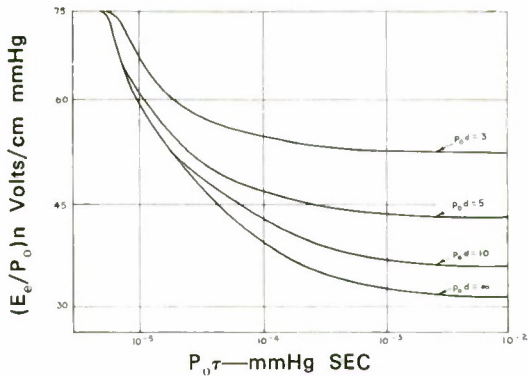$$\frac{V_{net}}{P_o} - \frac{DP_o}{P_o^2 \Lambda^2} = \frac{\ln\left(\frac{n_h}{n_o}\right)}{P\tau} \qquad \ldots (6)$$

FIG. 2. Normalised single-pulse breakdown curves for Air in a parallel plane configuration

TABLE 1.
Relative Breakdown Strength of Gases.

Gas	Relative Breakdown Power
Air	1·0
Nitrogen	0·9
Freon 12	18
Sulphur Hexafluoride (SF_6)	20
Freon 114	49
Freon C 318	60

relative power handling capability of the gases are displayed in Table 1.

The values for Freon 12 and SF_6 are substantiated by ionisation and attachment data. However, none was available for Freon 114 and Freon C 318.

[The theory in this section has been largely a summary of that found in Reference 14].

Waveguide Characteristics

There is a limit to the power which can be carried by any transmission line. In an air-filled waveguide there is no loss in the air, and the power dissipated in the walls is seldom the only limiting factor. However, even in a perfect system there exists the limit set by voltage breakdown in the air or gas-filling of the waveguide, e.g. dry air at atmospheric pressure breaks down when the electric stress reaches a value of about 30 kV/cm. To avoid breakdown the electric stress is usually limited to half the above value.

Empirically it has been found that a value of n_b/n_o of 10^8 yields good agreement between theory and experiment. Because the logarithm of this ratio appears in Equation (6), the values of breakdown field strength are insensitive to this ratio (an order of magnitude change in n_b/n_o changes the breakdown field by only a few per cent). Fig 2 shows a normalised single-pulse breakdown curve for a parallel plane gap for various values of $P_o d$. The normalised effective field is plotted as a function of $P_o\tau$. For large values of $P_o\tau$ the values of $(E_e/P_o)n$ approach the cw values. For small values of $P_o\tau$, $(E_e P_o)n$ rises indicating that greater peak powers can be handled in a given geometry with decreasing values of $P_o\tau$. In addition, for small values of $P_o\tau$, Fig. 2 shows that breakdown becomes independent of values of $P_o d$ (i.e. electron diffusion becomes unimportant). This can be seen from Equation 6 by noting that as τ is decreased, the right-hand side of the equation can only increase significantly through an increase in V_{net}/P_o, therefore, the term involving $P_o \Lambda$ eventually becomes negligible. A theoretical extension of Fig. 2 using available data and some approximation is given in Fig. 3 for $P_o d$ approaching infinity.

A number of gases in addition to air are used in waveguide systems, primarily, to increase power handling capability. Although these gases intrinsically have relatively high dielectric strengths, they are rarely realised in practice. Results of microwave measurements on breakdown in a parallel plane geometry are given in Fig. 4. Values of E_{rms}/P_o are used because insufficient data is available to compute $(E_o/P_o)n$. The normalised breakdown field strengths are illustrated in Fig. 4 and the

TABLE 2.

Guide Size	Frequency Range GHz	Attenuation dB/m	CW Power Rating MW
WG 15	6·57 - 10·0	0·08	0·35
WG 16	8·2 - 12·5	0·11	0·20
WG 17	9·84 - 15·0	0·13	0·17
WG 18	11·9 - 18·0	0·18	0·12

The power rating used in Table 2 is based on $E_{max} = 15$ kV/cm.

Clearly such power ratings are calculated only for ideal conditions. Under realistic or service conditions problems frequently occur at levels of the order of 20 dB below those predicted in Table 2, therefore these results should not be assumed to suit every system.
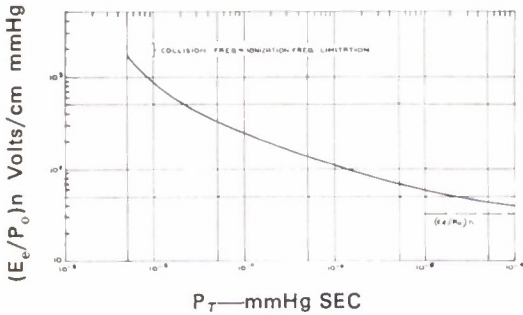
FIG. 3. Extrapolation of pulse-breakdown curve to large values of E/p for air
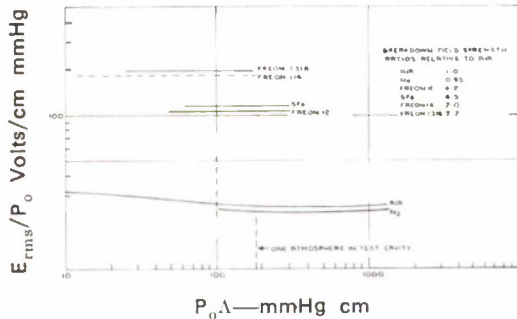

FIG. 4. Dielectric strength of gases

A comparison between coaxial cables and rectangular waveguides shows that for the X-Band region, the dimensions of the coaxial cables would be inconveniently small if the higher modes are to be avoided. The attenuation is also higher than for the waveguide, even though, unfortunately, its power carrying capacity is an order of magnitude better.

Circular waveguides offer significantly higher power carrying capacities than rectangular waveguides, but suffer the disadvantage of almost proportionately restricted frequency ranges.

For the dominant (TE_{11}) mode in a circular waveguide the maximum power carrying capacity may be calculated from the following equation:

$$P = E_{mnx}^2\ 1 \cdot 99 \times 10^{-3}\ a^2\ (\lambda/\lambda g) \quad \ldots\ (8)$$

An example of X-Band results is contained in Table 3.

TABLE 3.

Frenquency Range GHz	Attenuation dB/m	CW Power Rating MW
9·68 - 11·1	0·13	0·38

(Again using a power rating based on 15 kV/cm.)

For Type WG 16 waveguide (8·2 — 12·4 GHz) a power of 1·05 M watts would be transmitted at 10 GHz if the maximum value of the electric field, E_{max}, were 30 kV/cm. If E_{max} were at the safety level of 15 kV/cm, then the power transmission would be reduced to approximately 250 kilowatts.

The maximum value of mean power which can be handled without breakdown can be calculated for a TE 10 wave as:

$$P = \left(E_{max}\right)^2 \frac{a\,b}{480\,\pi}\left(1 - \left(\frac{\lambda}{2\,a}\right)^2\right) \text{watts}$$

$$\ldots\ (7)$$

a   is the width of the waveguide
b   is the height of the waveguide
E_{max} is the electric field measured halfway across the guide.

In the case of a pulsed system P is the short period mean value of the peak power attained during the pulse. With pulses of the order of one microsecond, average pulse powers sufficient to cause voltage breakdown are readily obtainable.

When short pulses are applied, the field at which breakdown occurs is to some extent dependent on the pulse duration and its repetition rate. This is because there is a finite delay between the application of the field sufficient to cause breakdown, and the actual occurrence of breakdown. Hence the value of electric field at which breakdown occurs increases as the pulse duration is decreased.

The choice of dimensions for a rectangular waveguide requires the consideration of the following factors:

(i) Frequency range.
(ii) Desired mode (TE_{10}).
(iii) Critical wavelength of this and other modes.
(iv) Attenuation due to conductor loss.
(v) Power carrying capacity.

From these considerations, details of Type WG 15 to 18 waveguides are as in Table 2.

The practical bandwith of the circular waveguide is less than a rectangular waveguide due to the proximity of modes. For the dominant TE_{11} mode to be transmitted and the next (TM_{01}) mode to be kept below cut off, the maximum theoretical frequency range is 1·31 : 1. The practical necessity of avoiding very high attenuation close to cut-off frequency reduces the working range to about 1·15 : 1. Clearly this attenuation may be minimised by using the high conductivity materials essential for use in high power carrying systems.

Theoretically, the working range of circular guides can be considerably extended by the use of mode filters, which will permit one mode to operate but suppress others.

It is not necessary here to discuss in detail dielectric waveguides without metal walls, suffice it to say that such waveguides are not suitable for high power work because of their high inherent radiation losses. However, the effect of dielectric within metal waveguides does deserve a mention.

If a waveguide is filled with a dielectric; primarily, there will be losses introduced by the dielectric, and in addition, the copper losses will be affected by the presence of the dielectric material. In general, the losses in the dielectric are so high that the space reduction, achieved by dielectric insertion, is more than compensated for by the increased attenuation. If it were possible to insert a very low loss dielectric, high power side benefits may be obtained in that the introduction of arc-inducing particulate matter into the system would be impossible. Typical dielectric losses range from $1 \cdot 00$ down to as low as $0 \cdot 00001$ for polystyrene foam. A good account of the effect of dielectric material inserted into waveguides is given in Frank's Waveguide Handbook[22]. Even the existence of very low loss dielectric within a waveguide may cause as much as one third of the incident power to be reflected if stringent design principles are not adhered to; this property is, of course, frequency dependent which limits the bandwidth of solid dielectric insertions and the power carrying capability of the system.

Localised Breakdown

Much of the previous work has concentrated on the solution of volume breakdown problems. In fact, one of the main problems, of high power microwave engineers, is that of localised breakdown. Localised breakdown means the reduction of the breakdown threshold resulting from localised electric field enhancement or localised heating effects due to the presence of small particles within the waveguide system. According to Gilden and Pergola[13] localised breakdown can also be due to localised heating of the waveguide system, although Beust and Ford[18] found that severe local heating (waveguide wall approaching dull red) did not result in waveguide arcing. Whatever the reason for breakdown, heat is almost certain to be a contributory factor and ionisation will be necessary to initiate break-

down. In a constant pressure system the field strength at which ionisation begins to occur is inversely proportional to the absolute temperature of the gas. Localised heating therefore causes localised ionisation and breakdown. These conditions of non-uniformity in temperature, gas density and ionisation mean that some of the constants in the electron continuity equation (see theory) become non-linear. The solution of this equation is no longer simple and numerical techniques or computer solutions are required. Solutions for several of these problems are discussed in Gilden's Handbook[14].

According to Gilden, a detailed examination of the breakdown theory shows that the electron continuity equation remains valid for non-uniformities in the electric field; but for non-uniformities in gas density it is no longer valid. The corrected, more general equation for gas breakdown is:

$$\frac{V_{net}}{D} \Phi \psi + \Phi \nabla^2 \psi + (\nabla \Phi)(\nabla \psi) = 0 \quad \ldots (9)$$

where Φ is the inverse of the relative gas density and

$$\psi = \frac{Dn}{\Phi}$$

is the normalised electron density. The equation reduces to the more familiar one for Φ constant. Gilden goes on to state that the electric field strength is increased locally by the presence of small metal objects or distortions of the waveguide walls. For non-uniformities ranging from a hemicylinder to a sphere on the surface the maximum increase in field strength ranges from 2 to $4 \cdot 2$. These values of electric field enhancement are useful for estimating the reduction in peak power capability in components, however, it is the small inadvertent irregularity that is most troublesome.

Another form of non-uniformity arises from temperature gradients in the gas and thus in the gas density. These gradients arise as a result of particles or surfaces becoming heated. (For very small heated regions even though the rate of ionisation may become large, the small size of the region allows the electrons to be lost rapidly by diffusion with the result that breakdown may become inhibited). Gilden gives an example of the transition from a highly localised breakdown to a main volume breakdown for measurements on a small hemisphere.

Gilden states that although enhanced values of E/p generally oeeur at small diseontinuities or loealised heated regions, the effect on the breakdown threshold frequently does not appear until high pressures are reached, where the eleetron diffusion rate has been sufficiently redueed. He points out that some care must be exercised in attempting to predict system failures from measurements made at lower power levels.

Continuing on the subject of localised breakdown due to the presence of loose partieulate matter, microseopic in size and noisy at miero-wave frequeneies; Acampora and Sproul[16] deseribe an experimental and analytieal proof of the meehanisms responsible. They used short duration diseharges " processing " to break up partieles, thereby increasing the system's power handling eapaeity.

The presence of loose particles causes a local reduction in the moleeular density of the gas, reducing the field strength necessary for breakdown and locally enhancing the electric field. Aeampora and Sproul derive the eleetric field enhaneement faetor and the equations for temperature rise at various levels of average power. Using these results and their equation for the breakdown power threshold they show that correlation between theory and experiment is good, see Fig. 5.
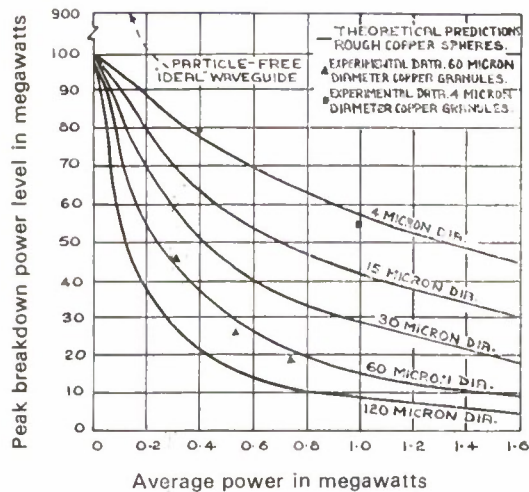

FIG. 5. Effect of particles on breakdown

Acampora and Sproul observed from Fig. 5 that, within the range of particle sizes investigated:

(i) Peak breakdown power levels at very low levels of average power, are inde-

pendent of particle size and are below that of ideal waveguide beeause of field enhancement only.

(ii) As the average power increases, the presence of heated particles causes further reduction in power handling eapability due to localised reduction in gas density. Larger particles cause a greater reduction in power handling capability beeause they are heated to higher temperatures.

The analysis from which Fig. 5 was derived is applicable when the partiele dimensions are small eompared with the waveguide dimensions and large compared with the eharacteristic diffusion length of the gas. It should not be inferred that particle indueed arcing cannot occur above 100 M watts, since particles with dimensions smaller than the diffusion length will, say Acampora and Sproul, cause breakdown to oeeur above this level. An analysis of particle behaviour in this region was not considered.

The above work neglects intrapulse heating since long pulse lengths and high average powers would probably not have been obtainable if water-cooled waveguide, pressurised with SF_6 were not used at S-Band frequencies.

In an earlier artiele, Platzman and Huber Solt[21] studied mainly theoretieally, microwave breakdown of air in non-uniform electric fields. Two speeifie eases were considered in detail; firstly, a rectangular microwave cavity with a small hemispherieal boss on one of its walls and a similar cavity without a boss. Their theoretical results were found to be in good agreement with observed experimental data. Whilst this article is not directly relevant to the present problem of waveguide breakdown, it is mentioned here as one of the earlier attempts at recognising and solving problems associated with non-uniform conditions.

Microwave breakdown near a hot surface in a waveguide system was studied by Gilden and Pergola[13] to determine its dependence upon the thiekness of the adjacent film of hot gas and its associated temperatures. The study shows that, although the breakdown threshold of a waveguide system is lowered by the presenee of a hot surfaee, a suffieiently rapid flow of the bulk gas tends to restore the threshold as a result of the reduction in the thickness of the film of hot gas. The effect appears to occur in addition to that resulting from cooling the surface.

Gilden and Pergola's work appears to be an interesting academic exercise which may not be so practical in service-type conditions. It is probable that any gas flow system will suffer from the passage of moisture and particles through the waveguide system, these must be removed using air driers and filters if the breakdown threshold is to be maintained. In fact, service systems are usually space limited and complexities such as pumps, driers and filters would be undesirable. In particular, a gas flow system may also be difficult to maintain using say a pressurised SF_6 system. One final point that Gilden and Pergola have omitted is that work done by Beust and Ford[18] several years earlier actually suggested that severe local heating in waveguides (to a dull red heat) did **Not** contribute to a significant reduction in the breakdown power level.

Gilden[14] and Acampora[16] above, have both studied the effect of loose particulate matter in waveguide systems. Collar[20] also studied this subject at ASWE from the point of view that contamination of the waveguide by comparatively large particles of electrically lossy material might easily happen under service conditions. His investigation was purely practical and was carried out by inserting samples of contaminants (approximately 0.2 in^3) into the waveguide system and testing at 1 kW CW at X-Band. Collar concluded from these tests that the most dangerous types of contaminants were found to be those with a large hydrocarbon or ferrous particle content.

Localised breakdown remains one of the biggest sources of failure in high power waveguide systems. Clinical cleanliness within the system remains the most important solution.

Experimental Work

Many parameters affect the power handling capacity of microwave systems. It will be appropriate to discuss individually, the experimental results obtained during the study of each parameter. Several of the parameters are combined in the breakdown power threshold equation derived by Acampora and Sproul[16]:

$$P = \frac{d_1 \, d_2}{4 \, Z_0} \quad \frac{C^2}{\beta^2 \, K^2 \, T^2} \quad p^2 \qquad \dots \dots (11)$$

P = breakdown power threshold
d_1 = waveguide cross section dimension, height
d_2 = waveguide cross section dimension, width
Z = wave impedance

C = constant, dependant on the dielectric gas
β = field enhancement factor
K = Boltzman's constant
T = absolute temperature
p = absolute gas pressure

For constant temperature, this is the familiar relationship between peak power breakdown and the square of the absolute pressure, known to be valid in the high pressure region where electron loss by diffusion is negligible. These parameters and others will be discussed in greater detail in the following sections, followed by a brief mention of experimental techniques.

Perhaps, the most easily understood parameter is volume. As seen from the previous equation the power threshold is directly related to the volume of the waveguide *i.e.* voltage breakdown is a linear measure, volts/cm and power breakdown is proportional to the square of the voltage, the unit therefore becomes Watts/cm^2. This applies for rectangular or circular waveguides. Clearly, the power capability of a waveguide system may be increased by using the largest volume waveguide system possible, consistent with the efficient transmission of the desired mode.
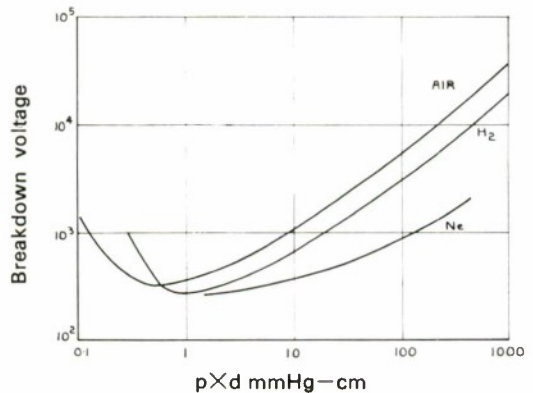

FIG. 6. Uniform field breakdown voltages for several gases as a function of p×d

Breakdown power, or voltage is usually linked with pressure in terms of Paschen's Law. This states that the breakdown voltage of a gas in a uniform field is proportional to the product of the pressure of the gas and the distance between the electrodes. In fact, this law only holds for high pressures[23]. The curve in Fig. 6 illustrates this for air, hydrogen and neon over the entire range of vacuum to high pressure, showing that at some point a minimum

occurs. For air the p.d minimum occurs at 0·5 mm Hg-cm. Below the minimum the breakdown potential increases because the electron strikes very few atoms on its way to the anode. Above the minimum the electron has increasing difficulty in accumulating ionising energy before losing it by excitation collisions with the more closely packed gas molecules.

Inter-related with pressure is, of course, altitude[5]. For most practical purposes the power carrying capacity of unpressurised transmission lines obeys Paschen's Law. Since pressure decreases in an exponential-type relationship with height, therefore breakdown voltage decreases exponentially with altitude, see Fig. 7. This curve has been proven to be on the pessimistic side since laboratory tests have indicated that a reduction in pressure to an equivalent altitude of 41,500 feet would reduce the power carrying capacity of a waveguide to about 10% of its sea level value, at 9 GHz. The conclusion to be drawn from this information is that, especially at altitude, a pressurised waveguide system has distinct advantages for the carriage of high power.
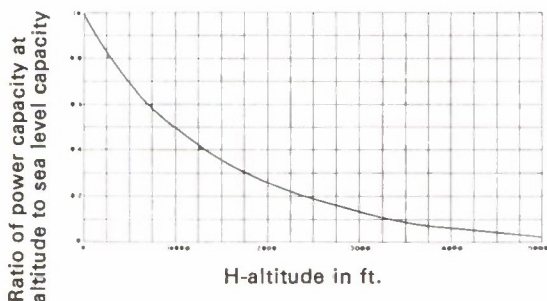
FIG. 7. Variation of power—carrying capacity with altitude of unpressurized, air-dielectric transmission line

One of the most important factors contributing to breakdown is the temperature of the gas in the waveguide. Gas temperature is directly related to gas density, this in turn directly affects electron production, attachment, diffusion and recombination rates.

Waveguide temperature is generally the parameter studied since it is more easily measurable and controllable and in any case the internal gas should be in temperature equilibrium with the adjacent waveguide. In fact, power carrying capacity is inversely related to the square of the (absolute) temperature of the waveguide gas.

$$P = P_o \left(273/(T-20)\right)^2 \qquad \ldots . (12)$$

(T is measured in °Absolute and P_o is assumed to be the breakdown level at 20°C).

Relatively high humidity levels appear to have little effect on the power carrying capacity within a waveguide system, more important is the effect of condensation due to changes in humidity with environmental temperature. Bandel and MacDonald[24] discuss the electron collision phenomena and breakdown field strengths in air plus water vapour.

As opposed to the previous parameters which are difficult to optimise in a fixed waveguide system, waveguide cooling is a simple task. In addition to using high conductivity waveguide materials (silver or copper) to reduce waveguide power attenuation[25-27] and absorption, black body radiation techniques, cooling fins and water cooling are often utilised to maintain low waveguide temperatures for high power capacity.

The replacement of air in a waveguide system by a high dielectric strength gas can dramatically lower the probability of breakdown. Sulphur-hexafluoride is a commonly used gas, this can theoretically increase the power handling capacity of a system by a factor of 20. Whilst this gas is an arc inhibitor, Beust and Ford[18] point out that it would dissociate in the presence of very hot particles reducing ferrite particles to a fluorine salt and possibly damage the entire waveguide system. Further details of the dielectric strengths of gases relative to air may be found in Table 1 in the previous theoretical section, and in Fig. 4.

Standing waves on a transmission line degrade its power handling capacity. Such waves may be caused by discontinuities in the line or unmatched terminations. The amount of degradation appears to be debatable depending on whether the breakdown power is taken as the net transmitted power or the power carried only by the forward component of the standing wave, reference[14]. It is safest to make the first assumption in which case the power carrying capacity of the line is inversely proportional to the VSWR existing on the line.

$$P = P_o/VSWR \qquad \ldots . . (13)$$

If, as in most practical systems, the VSWR is less than 2 : 1 the inverse VSWR equation approximates in any case to the forward-only power flow equation.

Harmonic power and spurious mode power can cause resonances and the breakdown effect is similar to the previously mentioned VSWR example. According to Gilden[14], even a few per cent of relative power in a harmonic or at a spurious frequency causes a significant reduction in the breakdown threshold for VSWRs greater than 10 : 1. Unlike VSWR, spurious signals cannot be easily equated to the power carrying capacity of transmission lines.

The CW breakdown level imposes a lower limit on the breakdown power whereas single pulse breakdown imposes the upper limit. The intermediate condition is governed by the equation.

$$P_{average} = \text{Repetition Rate} \times \int P_{peak} dt \quad \dots \dots (14)$$

However, a quantitative treatment of the effect of repetition rate on breakdown power does not appear to be available because of the lack of information concerning the inter-pulse electron removal mechanisms. Measurements do indicate that there exists a wide range of repetition rates in which the single pulse breakdown conditions are valid, see Fig. 8. It has also been experimentally determined that for pulse lengths greater than 2 microseconds the breakdown threshold may be considered to be the CW level[14].
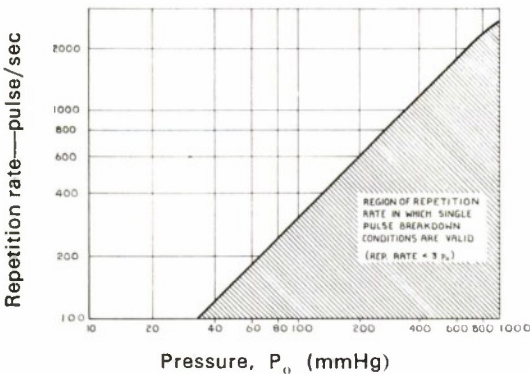

FIG. 8. Repetition rate/pressure validity graph

It has been experimentally proven that in most cases where unusually low breakdown levels are experienced, the presence of loose particulate matter in the system is the root cause. There is no general rule governing this parameter other than, the cleaner the system the higher its power carrying capacity. Beust and Ford[13], have shown that by itself severe local heating does not contribute to waveguide
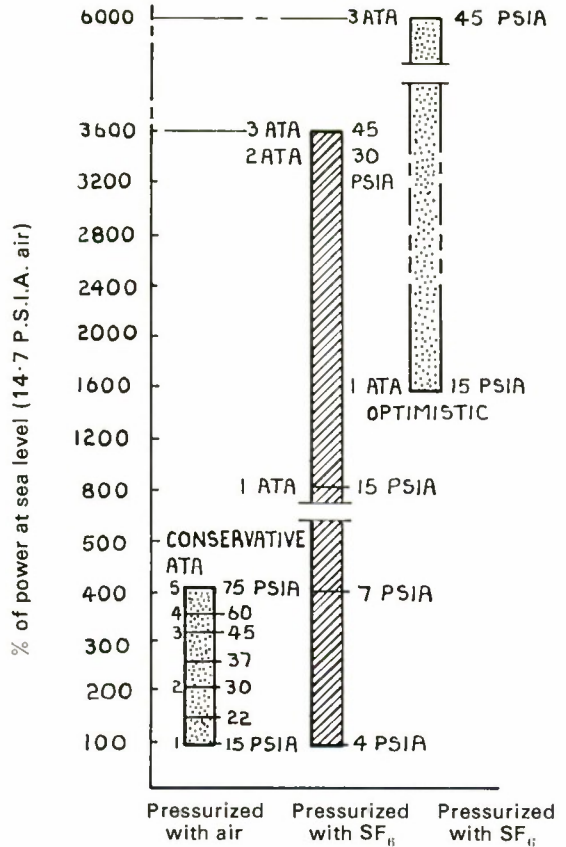

FIG. 9a. Ciavolella power handling chart

arcing. Acampora and Sproul[16] in a more recent paper have studied in some detail the effect of particles on breakdown and experimentally verified results illustrated in Fig. 8. They also suggest that because of the importance of this problem, a form of rf processing of the system should be undertaken before making a system operational. This rf processing would be intended to burn out offending particulate matter rendering it harmless.

Ciavolella[17], Fig. 9b, proposes a guide to breakdown power levels affected by dirt which appears to err on the optimistic side.

Waveguide components are often the other root cause of anomalously low waveguide system power capacities. Again, Ciavolella provides a guide to the reduction in power carrying capability imposed by the use of a a variety of components. This guide is in general agreement with the figures presented by other workers e.g. Gilden[14]. However, what is not stated, is that these figures almost cer-
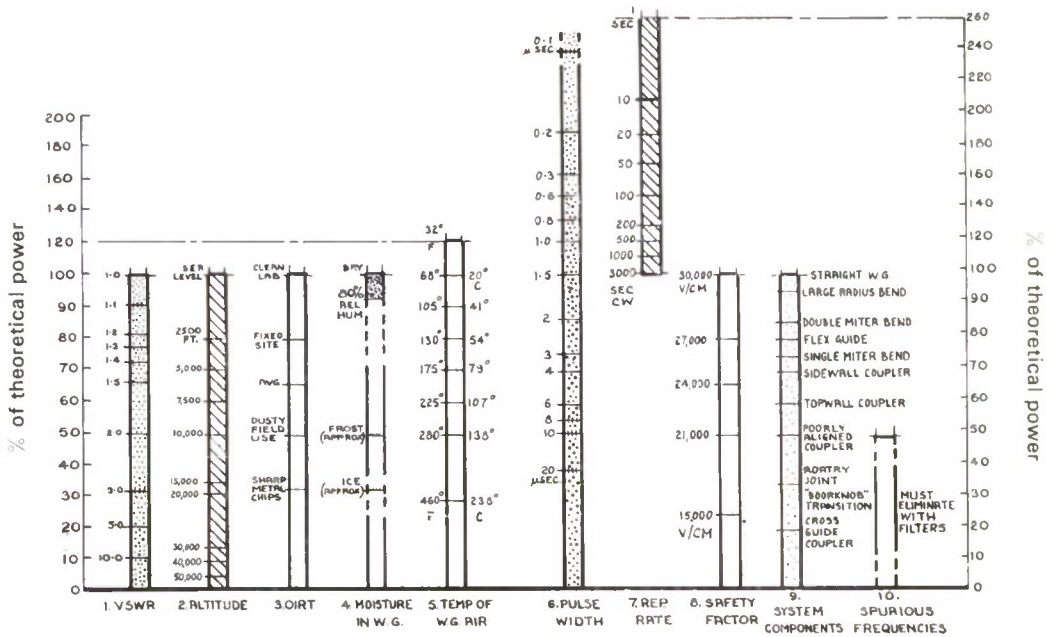
FIG. 9b. Ciavolella system parameter chart

tainly apply to well-designed components; only too often badly designed components are inserted into waveguide systems. Rigorous design and rigorous testing should not be neglected particularly when the components are intended for long period unattended use as in service environments.

The most common tool for high power testing appears to be the travelling wave resonator. This waveguide ring circuit facilitates at least a 10 dB gain on the maximum forward power already available (and no reverse power!) for the extra complexity of only an extra piece of waveguide circuitry. In addition it is often possible to obtain the gain in forward power required for breakdown inside the ring, when normal breakdown is impossible. Of course, when the breakdown occurs, the power in the ring is attenuated and large areas of damage are avoided. The theory of operation of the travelling wave resonator is well documented[28-31]. To prove its usefulness, Maltzer and McCune[19] constructed and proved a 250 KW X-Band travelling wave resonator with power gains of the order of 30, and without waveguide pressurisation. References 20 and 32 describe experimental work on travelling wave resonators that has been carried out within ASWE.

In order to design or use a high power microwave system it is necessary to understand the formation and, in particular, the performance of arcs. It is widely understood that arcs are formed in regions where for some reason or other the voltage gradient exceeds the breakdown threshold of the medium. However, what is less understood is that arcs, once formed, can exist under conditions of reduced power and can also travel at great speed through waveguide systems with disastrous consequences.

During arcing experiments, Beust and Ford[18], determined that approximately 75% of the transmitted power is absorbed in the arc, the remainder being reflected. The absorption factor is variable dependent upon the power level, waveguide size, temperature and pressure within the waveguide. Once struck, the arc tends to move towards the power source with a velocity proportional directly to the incident power and the frequency, and inversely proportional to the internal pressure and the dielectric strength of the internal gas, see Figs. 10, 11 and 12, respectively.

It has been noted that the arc moves with a velocity relative to that of the surrounding gas, thus it may be possible to control the movement of the arc by controlling the flow of gas.

However, this control is only useful for low incident powers, it does not detract from the need for adequate arc protection safety devices.
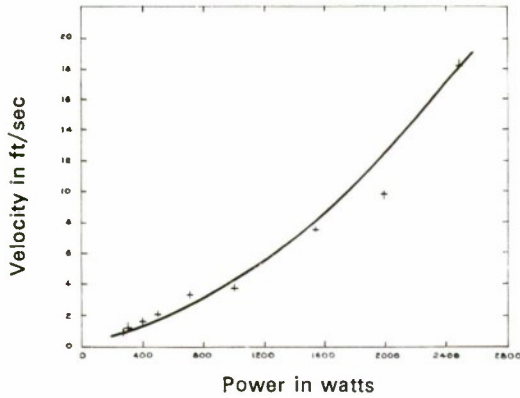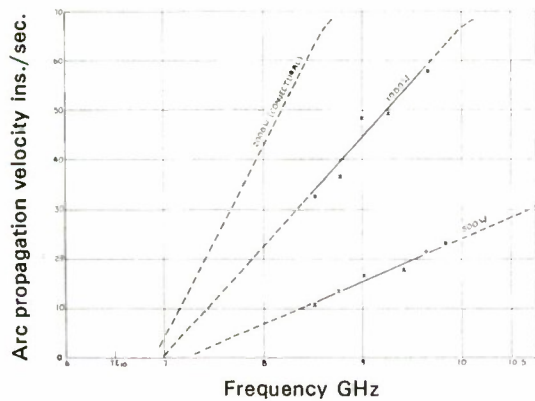

FIG. 10. Arc velocity vs source power
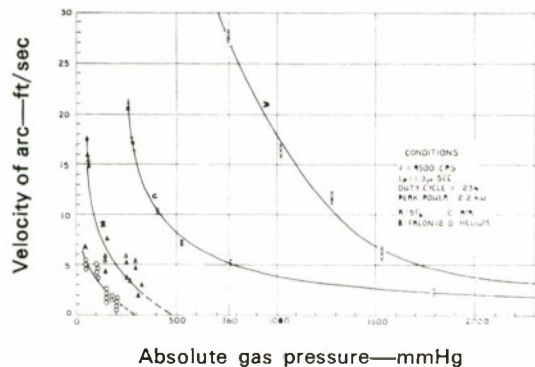

FIG. 11. Arc velocity vs frequency

FIG. 12. Arc velocity for different gases

Design Parameters and Criteria

This review has already described the state of the art in high power microwave breakdown theory and experimentation. There only remains to be summarised the design parameters, and the criteria for high power microwave design applications, that the afore-mentioned works have suggested.

The conventional task of the microwave designer is to explain why the practical power handling capacity of a waveguide system is only a few per cent of its theoretical capability. The conventional solution to this task is to consult numerous reference sources which can represent thousands of pages. Ciavolella[17] recognised this problem and formed his own solution—two reference charts, Figs. 9 (a) and (b). By glancing at these charts, the microwave system designer can now determine in a matter of seconds the practical limitations of his system to a close approximation.

Whilst Ciavolella's charts form a landmark in microwave design applications, they cannot detract from the excellent work of the researchers whose efforts formed the basis for the charts.

A contrast to the brevity of Ciavolella's article is the equally classic work of Gilden in his " Handbook on High Power Capabilities of Waveguide System "[14]. This handbook could be described as 100 pages of material that every microwave designer should be acquainted with. Included in the 100 pages are 11 pages of design considerations for waveguide systems. Gilden suggests a number of useful measures for obtaining acceptable high power performance:

(i) Pressurisation with air or high dielectric strength gases. This measure can increase the peak power level by factors of 10 to 100. The power level is normally proportional to the square of the pressure and SF_6 is recommended as the best gas to use.
    Evacuation can also increase the peak power level when the pressure is reduced to the range of 10^{-4} mm Hg. An advantage of evacuation is that even if arcing occurs there is not normally enough gas for a destructive breakdown. On the other hand, leaks are more troublesome and multipactor discharges are likely to occur.

(ii) Waveguide joints should be avoided where possible and low toleranced where impossible. Joints represent one of the most serious sources of failure problems. The restrictions on narrow gaps and lossy interfaces also apply more generally to ferrites cemented to waveguide walls.

(iii) Electric field enhancement must be minimised. Avoid high Q structures and large standing waves, by rounding all corners and maintaining smooth surfaces.

(iv) Heat removal should be assisted from the waveguide system by using the principles of liquid cooling, convection cooling, or even black body radiation cooling.
The internal flow of gas is not recommended for effectiveness because of the low thermal capacity of gases.

(v) The system should be free of foreign matter such as metal particles or bits of lossy material which can either increase the fields to the breakdown point or cause excessive heating until localised breakdown occurs.

(vi) Harmonic or spurious resonances are to be avoided, these can result in field strengths exceeding that of the main mode, and absorption of as much as 50% of the line power can occur in the resonant section.

(vii) Arc movement should be prevented to protect vulnerable components. Arc detectors should be used as a means for rapidly turning off the transmitter.

Components designed within the above principles should result in peak power capabilities at least within 10% of the associated waveguide value. Gilden tabulates the peak power capabilities of some high power components.

TABLE 4.

Component	Relative Capability to Waveguide
H. Plane bend	0·6 - 0·9
E Plane bend	0·97
90° Twist	0·8 - 0·9
Cross Guide Coupler	0·21
Rotary Joints TM_{01}	0·14
Coax	0·15

(All measurements made at X-Band and 15 p.s.i. in air).

Also discussed in Gilden's handbook is the theory of breakdown. A theory developed capable of predicting the breakdown field as a function of pressure, frequency, pulse-width and geometry. Their theory has been verified experimentally for breakdown power in uniform field geometry, non-uniform effects in parameters have also been studied in depth in this report.

The field of high power design has been covered so comprehensively in Gilden's Handbook that many other references, which would normally deserve a mention in such a review, will have to be obtained from the text if they are to be studied in greater detail.

Whilst Gilden's work describes well the theoretically possible results as seen in Table 4, it does not explain the large departures from these figures which become evident when operating at high powers in a service environment.

However, there are several other approaches to the subject which should be noted in passing. Beust and Ford[18] suffered the problem of consistent arcing in their 2 kW CW X-Band transmitter (after no arcing at all in a 1 kW system). They applied the now-recognised cures for the trouble and noted some interesting experimental results whilst doing so. Firstly they found that SF_6 had doubtful practicality under conditions of high temperature since any particle at red heat would dissociate the SF_6 liberating fluorine which combined with the waveguide metal. Therefore, arcs could be eliminated by SF_6 but in eliminating them, the entire waveguide system may be sacrificed. Secondly, they noted that severe local heating did not contribute to arcing, but when an arc was produced a shock wave was reported. Beust and Ford concluded that the most practical methods of preventing breakdown were to obtain a state of clinical cleanliness within the system and to use detectors to shut off the power for 25 to 50 milliseconds in order to burn the offending particle from the system. This quenching system gave complete protection from the destructive effect of arcs as long as a thick $(\lambda/2)$ ceramic window was used immediately in front of the thin klystron output window.

Acampora and Sproul[18] confirm that loose particulate matter at high temperatures results in local rarification of the dielectric gas, field enhancement at the particle boundary and hence breakdown at unexpectedly low power levels. They extended the work on "quenching" started by Beust and Ford. They state

that "quenching", now known as "processing", prevents excessive energy dissipation which can cause waveguide melting. However, processing requires a dielectric gas which rapidly recovers its dielectric strength, sulphur hexafluoride is suggested as ideal and possibly the only practical choice. The result of this processing is that the power handling capacity is considerably increased.

The conclusions of Maltzer and McCune's work[19] prove that system cleanliness and some mechanical modification can result in very high power capabilities. Clinical cleanliness was obtained by heating the waveguide to 800°C in a wet hydrogen atmosphere or by chemical cleaning, it was then hermetically sealed and kept pressurised with a few pounds per square inch of dry nitrogen. By using an eight hole rectangular flange instead of a four hole square flange, and by using careful design techniques, Maltzer and McCune succeeded in attaining power levels of 250 kW in an X-Band travelling wave resonator, without waveguide pressurisation or the use of high dielectric strength gases. [250 kW is close to the theoretical maximum for this size of waveguide].

Maltzer and McCune's 250 kW resonator demonstrates the advantages of good laboratory facilities. They secured clinical cleanliness, used size 15 waveguide and water cooled components. However, there exist circumstances where these conditions are not possible. For example, in ship system engineering it is doubtful whether such a state of cleanliness is possible and problems of size and complexity may rule out large size waveguides and water cooling. Some research work has been carried out at ASWE by Collar[20] under these conditions. In contrast to the 250 kW previously found possible, Collar concludes that 2 kW CW appears to be the upper limit for uncooled size 16 waveguide components, particularly flexible waveguides. Using water cooling, he maintained flexible guide to above 5 kW CW and solid components to beyond 10 kW CW. Collar's final recommendation on this subject was that all X-Band equipments, whose mean transmitted power exceed 1 kW, should be fitted with an arc protection system.

Recommendations

The multifarious breakdown problems that have been discussed earlier in this review emphasise the need for efficiency, simplicity and cleanliness in any high power waveguide system.

(i) Efficiency means the use of waveguide and components that have minimum VSWR and attenuating properties and very high power capacity. Each part of the system should be carefully scrutinised and tested before being inserted because, like a chain, a transmission system's power carrying capability is purely related to that of its weakest component.

(ii) Reducing the number of components and waveguide sections in a system to the minimum increases its simplicity and its breakdown threshold. Ideally, the system and in particular the waveguide runs should be tailor-made; *i.e.* fewer joints reduce the likelihood of connections loosening, positioning the antenna closer to the generator is another solution which has obvious benefits.

(iii) Cleanliness is equally important; the the introduction of moisture and particulate matter may easily reduce the power handling capacity by a factor of 10. If cleanliness were obtained by sealing the system and pressurising it with a gas such as SF_6, the safety factor of the system would almost certainly exceed the power levels required in most service equipments.

In addition to the above suggestions, there are several other useful techniques to aid system designers. The use of water cooling and black body radiation techniques can increase the power handling capacity. However, the extensive use of water cooling would hardly satisfy the simplicity requirement, therefore it should be restricted to the most vulnerable components.

Despite the inclusion of many of the above principles in the design of a high power transmission system, unforeseen problems are still likely to occur. Therefore the final and perhaps the most important advice is to provide an arc protection and arc processing facility within the system. Such a facility would be relatively inexpensive and easy to fit as well as allow the system to be safely operated much nearer its full power capacity.

References

[1] L. B. Loeb, "Fundamental Processes of Electrical Discharges in Gases", John Wiley & Sons, New York, 1939.
[2] E. W. Seward, "The Electric Strength of Air at High Frequencies", *Journal IEE*, 84, p.288, 1939.

(3) R. Cooper, "Experiments on the Electric Strength of Air at Centimetre Wavelengths", *Journal IEE*, 94, Pt. III, p. 315, 1947.

(4) P. Parker, "Electronics", p. 596. Edward Arnold, 1950.

(5) T. Moreno, "Microwave Transmission Design Data", McGraw-Hill, 1948.

(6) H. M. Barlow, "Power Carrying Capacity of High Frequency Waveguides", *Proc. IEE*, 99, Pt. III, p. 21, 1952.

(7) W. A. Prowse & W. Jasinski, "Observations on the Electrical Breakdown of Gases at 2·8 GHz". *Proc. IEE*, 98, Pt. IV, p. 101, 1951.

(8) W. A. Prowse & W. Jasinski, "Observations on the Electrical Breakdown of Gases at 2·8 GHz". *Proc. IEE*, 99, Pt. IV, p. 194, 1952.

(9) J. W. Sutherland, "Electrical Breakdown in Waveguides at 3 GHz. *Electronic Engineering*, p. 538, December 1954.

(10) L. Gould, "Handbook on Breakdown of Air in Waveguide Systems", *Microwave Associates*, April 1956.

(11) L. Gould, "Microwave High Power Breakdown Study", *Microwave Associates*, June 1956.

(12) L. Gould and L. W. Roberts, "Breakdown of Air at Microwave Frequencies", *J. App., Phys.* 27, No. 10, October 1956.

(13) M. Gilden and J. Pergola, "Microwave Breakdown Near a Hot Surface", *IEEE Trans* on *Microwave Theory and Techniques* MTT-12, 1, p. 26, January 1964.

(14) M. Gilden, "Handbook on High Power Capabilities of Waveguide Systems", *Microwave Associates*, June 1963.

(15) C. Buntchuh and M. Gilden, "Nanosecond Pulse Breakdown Study at Microwave Frequencies". *Microwave Associates*, July 1964.

(16) A. S. Acampora and P. T. Sproul, "Waveguide Breakdown Effects at High Average Power and Long Pulse Lengths", *Bell System Tech. J.*, Vol 51, 9, p. 2065, November 1972.

(17) J. Ciavolella, "How to Take the Hassle out of High Power Design", *Microwaves*, p. 60, June 1972.

(18) W. Beust and W. L. Ford, "Arcing in CW Transmitters", *Microwave Journal*, p. 91, October 1961.

(19) I. Maltzer and E. McCune, "A 250 kW X-Band Travelling Wave Resonator", *Microwave Journal*, p. 57, February 1964.

(20) M. D. Collar, "Project P 9123", ASWE/RACAL Report, 1970.

(21) P. M. Platzman and E. Huber Solt, "Microwave Breakdown of Air in Non-uniform Electric Fields", *Physical Review*, 119, 4 p. 1143, August 1960.

(22) W. H. Frank, "Waveguide Handbook", M.I.T. Radiation Laboratory Sect, Rept 9, September 24, 1942.

(23) F. J. Campbell, "Putting Pressure on Paschen's Law", Proc. 9th, EL Ins. Conf., Boston 1969, p. 81.

(24) H. W. Bandell and A. D. MacDonald, "Microwave Breakdown in Air Plus H20", *J. App. Phys.*, 41, No. 7, p. 2903, June 1970.

(25) F. A. Benson, "Attenuation and Surface Roughness of Electroplated Waveguides", *Proc. IEE*, 100, Pt. III, p. 47, 1953.

(26) H. C. Baeyer, "The Effect of Silver Plating on Attenuation at Microwave Frequencies", *Microwave Journal*, p. 46, April 1960.

(27) J. Allison and F. A. Benson, "Waveguide Surface Finish and Attenuation", *Electronic Engineering*, p. 482, November 1956.

(28) L. J. Melosevic and R. Vautey, "Travelling Wave Resonators", *IRE Trans.*, MTT-6, April 1958.

(29) S. J. Miller, "The Travelling Wave Resonator and High Power Testing", *Microwave Journal*, p. 50, September 1960.

(30) R. E. Hall, "A Method of Testing High Power Waveguide Components", *RAE Tech. Memo.*, Rad 667, July 1964.

(31) P. J. Sferrazza, "A Travelling Wave Resonator" Proc. NEC, p. 968, October 1955.

(32) R. P. J. Endean and M. A. Hammond, "A Travelling Wave Resonator Study", *ASWE* Working Paper, W.P.—XCB—7409.

DANGER—MEN AT WORK

The complementing of tasks from the line managers point of view

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Introduction Assuming that a line manager has a given work force and the broad outlines of the tasks to be performed, it is one of his prime functions to find the necessary work force to perform these tasks.

For many years, it was thought that all that was required when manning a job was to find a person with the necessary skills and order him to perform that particular task. Nowadays much more thought should be, and in many cases is, given to this problem of complementing before a particular task is assigned to a particular man or group of men.

The number of tasks or occupations where certain personal characteristics are needed for a person to perform that task are great but the number where they are essential is much more limited. In the past little attention was paid to fitting the "round hole" personality t o the "round hole" situation but it is now gradually being recognised that people are individuals and therefore should be treated as such and not as cogs in a machine.

Why People Work

Before considering the placement of people in a job, it is desirable to consider why they work at all.

At the turn of the century the style of management was based on the "Economic man" of "Scientific Management" school of thought which stated that men worked only for financial reward and to increase efficiency the only requirement was greater financial stimulus.

This was found not to be the case and in fact other factors were involved. The "Hawthorn Experiment" at the Western Electric Corp. USA demonstrated that the human values of interest and sympathy had a large effect on productivity.

The psychologist A. H. Maslow developed a theory of human motivations in which he stated that there were five categories of human needs and that there was a definite order of priority to them.

i.e. (1) Physiological—basic needs of food, drink, shelter, sex etc.
(2) Safety, stability and security
(3) Belongingness and love
(4) Self esteem and the esteem of others
(5) Self-actualization

Whilst financial reward would take care of the needs in group (1) and to a certain extent group (2), it would not have a marked effect on the needs of groups (3), (4) and (5). Although financial reward is a large factor in the reason why people work, it is not the only one, especially in the condition of today's "welfare state" and those reasons which fulfil. the needs of groups (3), (4) and (5) have also a great bearing on it. However once a need has been satisfied, it is necessary to try and draw on a higher unsatisfied one to further motivate the person concerned.

Evaluate The Job

The job itself obviously has strong influences on the problem of complementing and must therefore be evaluated. Nearly every task differs by a number of factors such as:—

1. Essentiality
2. Magnitude
3. Urgency
4. Types of skills and aptitudes required
5. Profitability
6. Duration

and thus it is essential that a job analysis be carried out. This is a very skilled operation best carried out by an expert for complicated and high duration tasks, but when it has been completed, a detailed specification, defining the exact job and the qualities needed to complete it, can be drawn up.

Next it is necessary to draw up a list of these jobs and set them out in order of their priority. This list might possibly alter as the jobs progress and thus must be continually updated. The priority of a job can, in general, be thought to be made up of four factors.

1. Value
2. Cost effectiveness
3. Urgency
4. Importance

Care must be taken in evaluating these factors, as for instance an important job need not necessarily be a valuable one, or an urgent job an important one.

The time that the task is going to take must be borne in mind, *i.e.* the time that a valuable man or piece of equipment is going to be tied up. This factor with the priority must be considered in determining the constraints put on the freedom of choice of the resources, both human and equipment, and their redeployment if and as when the list of priorities alters.

The Man Himself

The description of the task provides the wherewithall to define the sort of person required to perform it. A variety of factors must be taken into account:—

1. Education, training and qualifications
2. Direct or related experience
3. Skills, knowledge and special aptitudes
4. Degree of success and attainment in previous work
5. Versatility — more than one skill or aptitude
6. Uniqueness — the only one with certain skills etc.
7. Administrative skills — able to lead a group
8. Personal factors—
   (a) sex
   (b) age range
   (c) physical fitness
   (d) appearance, speech and manner
   (e) social qualities—acceptability, co-operativeness
   (f) qualities of intelect—judgement, perception
   (g) qualities of integrity—honesty, industriousness
   (h) qualities of temperament—stability, persistence, drive

Once this evaluation of the men has been completed, their value to the organisation and their fitness for the various tasks, can be assessed.

Manning The Job

Having now evaluated the job and defined the value and capabilities of the various members of the work force it is now possible to consider manning the job.

"One Man Only" Tasks

Consider first a task that requires only one man to perform it.

If no man is suitable, then it will be necessary to

(a) recruit a new man
(b) retrain an existing man
(c) abandon the task altogether

Which alternative the line manager adopts depends on the value and priority of the job itself.

When only one man is suitable to perform the task then there is no choice and he must be assigned to it, unless this is thought to be such a gross misuse of this man that it is better to consider that no man was suitable and act accordingly. Care must be taken with these "one man only" situations that, especially with tasks of long duration, a versatile and unique man is not so tied up that the flexibility of the work force is seriously impaired. Again under these conditions it might be considered a better solution that no man was suitable and the appropriate action again taken. It is also worth noting that sometimes the job can be modified or adapted to fit a man, thus giving a freedom of choice from the other men. It is also possible that by a small amount of retraining another man could be made suitable for the task, thereby releasing the first choice for other possible "one man only suitable" situations.

When several men are suitable, then there is a freedom of choice and other points have to be taken into account before the job is assigned to any one particular person. Care must be

taken when assigning one particular person to
a task that the situation is not created whereby
there is no job left suitable for another man.
It is essential that the man suitable only for
one job is assigned first and the more versatile
man left for other jobs or to maintain a flexible
reserve labour force. It is quite possible, that
by assigning this "only one job suitable" man
to a particular task, an exactly similar situa-
tion is created for another man, so the pro-
cedure is repeated until all this type have been
given jobs. It is also possible that a "no job
suitable" situation has been created, in which
case if it is desirable that he be retained, then
a new job will have to be found or created. If
not then he will have to be removed from that
work force.

Having now assigned all the "one job only"
men the remaining staff can be assigned to the
various tasks bearing in mind that the most
versatile and unique men are better employed
on tasks of short duration, so forming a better
flexible and versatile reserve to meet possible
changes in the order of priorities of new un-
foreseen eventualities but also at the same time
making sure that they are not under or ineffi-
ciently occupied.

Group Tasks

Up to the present, tasks only requiring one
man have been considered but in a very great
number of cases many men, or in other words
a group, working together, is required.

There are different kinds of groups, with
different styles of leadership and the type of
group set up can have a marked influence on
the effectiveness of that group. The two main
types are the organisational or imposed group
and the informal group. The imposed group
can be further subdivided into

1. Command groups
2. Task or work orientated groups.

Command Group

The command group is composed of a
superior plus subordinates and has a rigidly
fixed hierarchial structure. Leadership under
these conditions tends much more towards the
autocratic style. Types of leadership are dis-
cussed later. The superior himself is a sub-
ordinate of the group above and the organisa-
tion is composed of interconnecting groups.

Task Orientated Group

The task group sometimes coincides with the
command type but essentially in a task group
the group has a definite objective and each
member has a definite function within that
group to achieve the common goal. Leadership
in this type tends towards the democratic style.

Informal Group

Besides the imposed groups, informal groups
are created within the organisation and these
are not constricted by the boundaries of that
organisation. A wide variety of reasons can be
found for the formation of these, such as:—
Similar age. Common interest—quite often
outside the work situation. Education, Poli-
tical beliefs, and many others.

In this type of group the leadership is not
imposed by the organisation but, by the con-
sent of the membership, he is elected, often
based on his personal characteristics *e.g.*
respect, popularity etc.

Leadership

Any group must have a leader whether it be
one appointed by the organisation or one
elected by the group itself. When appointing
a leader care must be taken over the possibility
of the unofficial leader being in competition
with and sometimes working against the
official one. It is possible sometimes to make
these two types one and the same man but if
this is not feasible the official leader can often
make skilful use of the unofficial one as a con-
fidant and a channel of communication.

Types of Leader

The types of leader range from the auto-
cratic at the one extreme to the democratic at
the other and the situation can call for different
types at any given time.

A leader may be a man who:—

1. Identifies the problem, decides the solu-
   tion and then gives the orders. The sub-
   ordinates don't participate in the decision
   making at all.

2. Identifies the problem, decides the solution
   and then sells it to the subordinates.

3. Identifies the problem, decides the solu-
   tion, asks questions but still confirms his
   original decision.

4. Identifies the problem, tentatively makes suggestions for a solution, asks for suggestions and criticism and does not make a final decision until he has had the feed back.

5. Outlines the problem, lets the subordinate make the first suggestion of a solution but then makes the final decision.

6. Outlines the problem and lets the subordinates decide the solution.

7. Conveys the problem to the group from an outside source (*e.g.* Board of Directors) and lets the subordinates make the decision.

As the style of leadership approaches the democratic so the subordinates become increasingly involved in the process of decision taking.

Qualities Necessary in a Leader

Although there is no prescription for a leader, the qualities and methods varying with the situation, he must have certain basic qualities. He must, as an absolute essential, possess integrity and should have a fairly comprehensive knowledge of the subject which he should know when and how to apply. He should have human sympathy so that he is able to take a balanced view between concern for the members of the group and the task. To a certain extent he should be tough minded to enable him if necessary to overcome opposition, withstand the temptation of short-term compromise and overcome personal disappointments. He must also be able to communicate both up to his superiors and down to his subordinates, and they with him.

Type and size of group to be set up

Knowing the task, priorities etc., it is now possible to consider the size and type of leadership of the group to be set up to perform it.

Sometimes it is necessary such as when time is of the essence, that the group are of the command type so that a decision and its implementation can be arrived at quickly. In general most tasks are carried out with the optimum efficiency by the task form of group. At all times however it must be remembered that superimposed on that group and overlapping into other groups will be the informal types which sometimes can interfere with and disrupt the official one. There should be an identity of aim between the policy of the organisation and

the group codes of both the formal and informal groups and if management can influence these factors to work for them then there is power throughout the group which is much more effective than power over the group.

The size of the group merits attention as well. The job specification itself determines to a large extent the size of group required but within that constraint smaller groups have in general the best team spirit because they are more involved and have closer personal contacts. The group however should not be so small that the absence of one or two members has a marked effect on the performance of the rest.

The Men Forming the Groups

Once the type, size, task, etc. of the group has been determined, attention can be paid to the personnel required to form and lead it. Not only the effect of the man on the group but also the effect of the group on the man must be considered. As noted earlier Maslow stated "that man needs to belong". In some men this need is fulfilled outside of the work situation and these men are in fact most efficient when working on their own. Groups can sometimes have a restrictive effect on this type by such means as—forcing him by its norms to behave in a manner alien to him, possibly restrict his ideas *e.g.* he does not want to be thought of as a company man, etc. This type of person therefore should not be included unless absolutely essential to a group and even then should be removed at the first opportunity. Other men need this feeling of belonging *i.e.* to be able to identify with a group, to be satisfied in the work situation. The supportive contact *e.g.* shown the ropes, restricting the speed of learning to his rate, sharing the responsibility, etc. help him to be more efficient. It may also ease innovation as it can give him a feeling of some degree of control over his environment. This type of person is well suited to be a group member and will probably work best in this manner.

Placement of Men in the Groups

Now knowing from the job specification and priorities, etc. what type size, form of leadership, skills and aptitudes, are required, which men are best suited to work in groups and noting at the same time the effects of any informal groups and leaders which might occur and any possible interaction between individual

members of a group, the complementing of the required groups can be considered. All the precautions noted in the "one man only" type of task equally apply to the group situation and must be taken into account, so that situations like "no job suitable" do not occur. The composition of the group should also be such that as many skills etc. as practicable are included. This can be achieved by using the versatility of the individuals so that any problems and tasks which might arise are covered and queue forming avoided.

Conclusion

Whilst this article deals only briefly with some of the many aspects facing a line manager it does illustrate the fact that there is "Danger" when men are at work and attempts to show some of the pitfalls that the unwary can fall into if he does not stop and consider carefully before manning a job. He should no longer just give a job to a man and tell him to get on with it but try to fit a "round peg" into a "round hole" and by so doing get the most efficient use of his human resources.

NAVY'S NEW NUCLEAR SUBMARINE COMMISSIONS

H.M.S. *Sovereign,* the Royal Navy's eighth nuclear-powered Fleet submarine, commissioned on Thursday, 11th July at Barrow-in-Furness, where she has been built by Vickers Limited Shipbuilding Group.

Laid down in January 1970 and launched in February 1973, she is the second of the modified Swiftsure-class to come into service, and will join the Second Submarine Squadron in Devonport for operational duties, after completing a 'work-up' programme with the Clyde-based Submarine Sea Training Organisation.

H.M.S. *Sovereign* displaces 4,400 tons on the surface. She has an underwater speed in excess of 20 knots, and can stay submerged several weeks. She is 272 feet in length, with a beam of 32·2 feet. She has a complement of about 100 men, of whom 12 are officers.

Her sister ship and class leader, H.M.S. *Swiftsure,* has been in commission more than a year, and three more submarines of the class are now being built—*Superb, Sceptre* and one other.

Lady Ashmore, wife of Admiral Sir Edward Ashmore, Chief of the Naval Staff and First Sea Lord, as the guest-of-honour named the vessel on 11th July.

H.M.S. *Sovereign* is commanded by Commander A. J. B. Laybourne, R.N., of Wickham, Hampshire.

TRIBOLOGY BRONZE MEDALS 1973

Dr. R. A. Onions

In September, 1969, the Institution of Mechanical Engineers announced the establishment of a Tribology Trust, the purpose of which was to be the acknowledgement of outstanding achievement and the furthering of interest and study in the new science and technology of friction, wear, lubrication and associated subjects.

The main award is the Tribology Gold Medal. This is an international award presented at minimum intervals of a year to a person or persons in recognition of supreme achievement in the field of tribology.

In addition, no more than three Silver and Bronze Medals may be awarded each year.

The Silver Medal is a national award in recognition of a major contribution to the subject.

The Bronze Medal is a national award for technical contributions by students and others who have not completed their formal education and training.

On Tuesday, February 5th, 1974, Dr. I. Maddocks, Chief Scientist, Department of Trade and Industry presented the first three bronze medals at the Institution of Mechanical Engineers. One was awarded to Mr. (now Dr.) R. A. Onions for his research work on pitting in gears and the theory of surface contact, carried out during 1968 - 72 at the University of Leicester and Thornton Research Centre.

Dr. R. A. Onions is now employed on wear problems and in the field of hydraulic fluids, as a Higher Scientific Officer in the Applied Physical Chemistry Division of the Admiralty Oil Laboratory, Cobham.

Following graduation in 1968 with a First Class Honours degree in Engineering, Dr. Onions remained at the University of Leicester to undertake Post-graduate research in the Department of Engineering and the Industrial Lubricants Division of Thornton Research Centre, Shell Research Limited, Chester.

Undertaking the trial of a new scheme designed to place post-graduate students into an industrial situation, Dr. Onions's work centred on the pitting of gears. The main aim of the programme was to determine whether the concept of the 'D' ratio, *i.e.*, ratio of surface roughness to the lubricant film thickness, was directly applicable to gears. Results of great practicable significance were obtained. Further work included a theory of contact of random surfaces using models and computer simulation of contact through elastohydrodynamic films.

Though some time will be required to fully develop the techniques for the computer work this, along with the other areas covered, is capable of widespread application.

Failure due to pitting fatigue was investigated under controlled laboratory conditions. The investigations used both a realistic laboratory test rig using $\frac{1}{2}$in. face width gears and the geometrically simpler simulation of gears using a disc machine. The results obtained substantiated earlier work of Way and Dawson. The initiation and propagation mechanisms were generally considered to hold true. However, the gear tests showed that failure could occur much more readily than with discs and therefore the application of disc tests to gears must be viewed with caution. The results suggest a fundamental difference between the pitting behaviour of gears and discs.

The second part of the thesis was of a more theoretical nature. A theory of surface contact was developed along the lines of that by Greenwood and Williamson using a surface model developed by Whitehouse and Archard. These results show that the influence of a distribution of asperity curvatures increases the probability of plastic deformation. The plasticity index was re-defined in terms of a convenient two parameter definition of surface topography.

The theory was applied to results obtained from a typical ground surface of hardened steel; when the anisotropy, which is part of such surfaces, was taken into account it was shown that only a small proportion of plastic flow occurs. The limitation of this form of model was discussed and a second approach put forward using digital techniques. Theory was developed to enable surface profiles to be brought together in a computer and the interference areas so formed related to the real Hertzian deformed areas of two rough surfaces. The approach is equally applicable to run-in surfaces which are not represented by existing models.

One paper[1] has been published so far on this work and two others are in preparation [2, 3].

Dr. Onions continued in the field of tribology and is now involved with the evaluation of the lubricating properties of hydraulic fluids. The bulk of the work has been carried out using pin and disc machines to simulate sliding conditions occurring in pumps and motors.

Further work envisaged will be of a more fundamental nature studying metallic contact conditions which exist when there is an inadequate oil film between mechanical components.

References

[1] Onions, R. A. and Archard, J. F. The contact of surfaces having a random structure. *J. Phys.D. Appl. Phys.,* **6,** pp. 289 - 304. 1973.

[2] Onions, R. A. and Archard, J. F. Pitting of gears and discs. To be submitted.

[3] Archard, J. F., Hunt, R. T. and Onions, R. A. Stylus profilometry and the analysis of the contact of rough surfaces. Invited paper to be presented at Symposium of Mechanics of Contact between Deformable Bodies. International Union of Theoretical and Applied Mechanics (IUTAM). Technological University of Twente, Netherlands. August 20 - 23, 1974.

SUPERPLASTIC METALS TECHNOLOGY

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S. J. Thurlow started his career in the Instrument Group at ARL working on the development of an Oxygen-in-Helium meter for use in the deep diving ship H.M.S. *Reclaim*, special purpose cameras and a steering aid for assistance in shallow water minesweepers. He then joined the forerunner of the Applied Psychology Unit and carried out trials investigating noise hazards in H.M. Ships and shore stations involving protracted trials at R.A.E., Aberporth and on H.M.S. *Girdleness*. Latterly, prior to the work on Superplasticity he was engaged on the evaluation of a signal processing system for an underwater environment.

Abstract

This article gives an elementary description of the phenomenon of Superplasticity in metals, together with a brief history of the technology involved in its utilization.

It further describes the work done on a study carried out to examine the possibility of using the techniques for engineering purposes at Admiralty Research Laboratory.

Introduction Superplasticity is the somewhat unscientific label given to a property which enables some metallic materials, when heated to a particular temperature, to deform and flow quite readily under low stress. The behaviour of such material is similar to glass, which when heated, can be pulled or stretched to a fine thread. These metallic materials can, after heating, be extended up to 2000 per cent, thinning down uniformly length wise without the customary " necking " accompanying the more conventional metals.

The phenomenon was first recorded in 1920 when certain eutectic alloys were seen to behave differently from normal crystalline behaviour in the manner described above. For a number of years this behaviour was mainly of laboratory interest. However, in the last 15 years or so, over 20 materials or alloys have been shown to exhibit superplastic (SP) behaviour, and, as knowledge increases, more are being " discovered " or " tailored " to suit requirements, and much has been written on this subject[1].

Definition of Superplasticity

Metals that are characteristically superplastic are fine grained alloys which retain their structure even while being worked at high temperatures. Superplastic deformation is characterised by a flow stress which is highly sensitive to the rate of straining, that is, by a high "strain rate sensitivity".

Stress/strain relationship can be expressed by the equation

$$S = ke^m$$

where S is the stress or force (load) per unit area

k is a constant

e is the strain rate, or relative extension per unit time

m is the measure or index of superplasticity, called "strain rate sensitivity".

The latter index constitutes the main difference between those materials which are superplastic, and those which, for want of a better name are called "normal". In the latter, the index 'm' is small, less than 0·2 irrespective of strain rate and temperature. In superplastic materials, however, at the requisite elevated or "critical" temperatures and very low strain rates, 'm' varies, reaching a maximum between 0·5 and 0·8.

The deformation of a superplastic metal is a viscous flow phenomenon, not a "stretching" of the material, consequently there is no residual stress to cause "springback" on removal of the deforming load.

This valuable property, inherent in these materials, can be used to significant advantage when forming strong metals under relatively low load applications. Whereas conventional forming requires the application of high loads at ambient temperatures, or alternatively, the high temperatures associated with casting.

Objectives of the Study

Interest was aroused within the Engineering Department of the Admiralty Research Laboratory, with regard to the possible engineering applications of superplastic metals. Consequently a study of the subject was instigated.

This entailed investigations regarding the most suitable, available and practical material to use, familiarisation with the technologies involved, and development of handling techniques.

Materials available

Among the materials which, in recent years, have been demonstrated to have superplastic characteristics there are:

some titanium alloys, notably Titanium 318,
some steels of varying compositions, including a high strength stainless steel IN 744, and various alloys of aluminium/copper and zinc/aluminium.

These various alloys exhibit superplastic behaviour at temperatures which are in excess of half the absolute melting point peculiar to the alloy concerned. Thus the temperatures associated with (a) titanium and steel are in excess of 900°C, (b) aluminium/copper alloys in excess of 500°C and (c) zinc/aluminium alloys in excess of 250°C.

It was therefore considered that, despite the attractiveness of the higher strength (*e.g.* Titanium, steel and copper al.) alloys mentioned, the temperatures were too high for an initial low cost venture into a relatively unknown area. Consequently those zinc/aluminium alloys, having medium strength and lower critical temperature came within the scope of practical investigation.

There were two of these alloys available, one known as Superplastic Zinc (SPZ), basic composition 78% wt zinc 22% wt Aluminium; and the other a Zinc Aluminium Magnesium alloy basic composition, zinc from 70 to 82 wt%, magnesium 0·05 to 0·2 wt% copper up to 2 wt% and balance aluminium, known as ZAM. (Ref. 1d).

The latter are a range of alloys developed and patented by the Chemical and Metallurgical Branch, Royal Military College of Science, and are based on the zinc/aluminium eutectoid, but their resistance to corrosion, and creep at room temperature is very much superior to that of the simple binary alloy (SPZ).

Properties of ZAM

Density	(gm/cm³)	5·9
Elastic Modulus	(N/mm²)	69000
Electrical Conductivity		
	(ohm cm 30% IACS)	5·7 x 10⁻⁶
Hardness Hv.		
Superplastic structure		115
After Superplastic deformation		110

At 21°C the stress to give 10^{-4} secondary creep strain in 1000 hours is 12·5 N/mm^2 compared with 1·6 N/mm^2 for the binary alloy (Ref 1d).

However, in their Superplastic condition the characteristics are similar, and since SPZ was more readily available in commercial quantities, the choice of this material for preliminary investigation was obvious.

As manufactured in the cast state, neither of these alloys are in a Superplastic condition. Both, however, can be transformed into the desired state by application of a combination of heat and manipulation. In the case of SPZ, either heat treatment or manipulation will suffice. Thus, to produce sheet material, the rolling process, which involves heat treatment, will perform the transformation effectively. However, if it is required to produce bar or rod in the Superplastic condition the two alloys require different treatments.

SPZ will transform quite readily if an " as cast " billet is held at 360°C for periods of time dependent upon the mass of the material and then quenched in iced brine. The alloy will transform with an exothermal reaction into the Superplastic state.

ZAM, however, in addition to the heat treatment, requires deformation by some 60 - 70% while heated, to carry out the transformation.

When in the superplastic state, both alloys will extrude quite readily under the temperature conditions described earlier, and under quite low applied load. Additionally, ZAM, after extrusion, or thermoforming can be simply heat treated to give a combination of properties such as those quoted in the table opposite (Ref 1d).

Room temperature tensile properties of heat treated ZAM strain rate 0·2/mm

These heat treatments are similar to those given to high strength aluminium alloys. The combination of properties obtainable depends upon ageing temperature and time. Support of sheet formed material during heat treatment may be required if distortion is to be avoided, but this is not serious in solid formed components.

Thermoforming Techniques

(a) *Forming with sheet material.*

All of the thermoforming techniques applicable to thermoplastic sheet are applicable to these alloys. Consequently those more readily adaptable to the existing capabilities and services of the laboratory were the initial subjects of the investigation. On balance it was considered that blow thermoforming techniques were the most suitable because conventional workshop air services were readily available. At the outset, a fairly ambitious programme was envisaged, so a permanent aluminium female mould was cast into a simple hemisphere 368mm diameter. The inner surface was machined and polished. Heating elements were fixed to the exterior as a precaution against chilling of the sheet as it was blown into the cavity.

Properties of ZAM after extrusion thermo-forming.

Treatment Heat	O·2 Proof Stress N/mm^2	UTS N/mm^2	% elongation
HT1	390	475	17
HT2	400	510	14
HT3	420	550	8
HT4	—	680	4
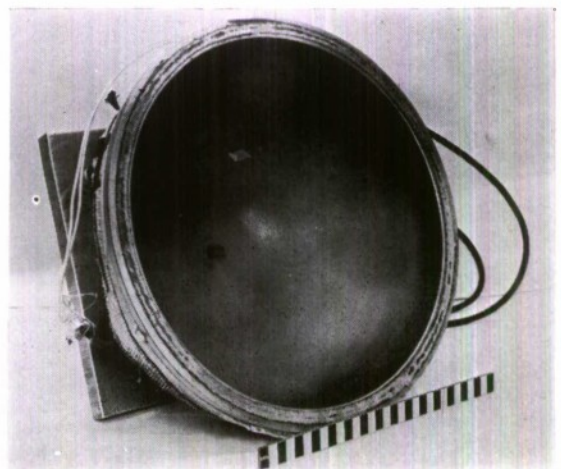
FIG. 1. Cast aluminium heated forming tool

An electrically heated platen 140mm square was placed in the base small hydraulic press.
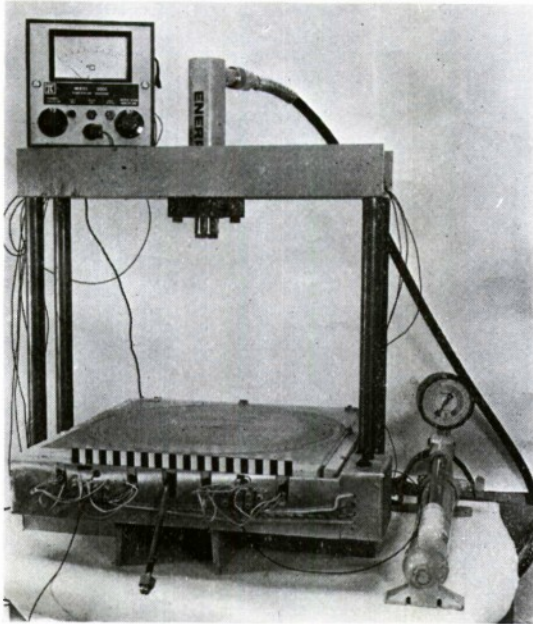
FIG. 2. Bench press, heated platen and temperature indicator

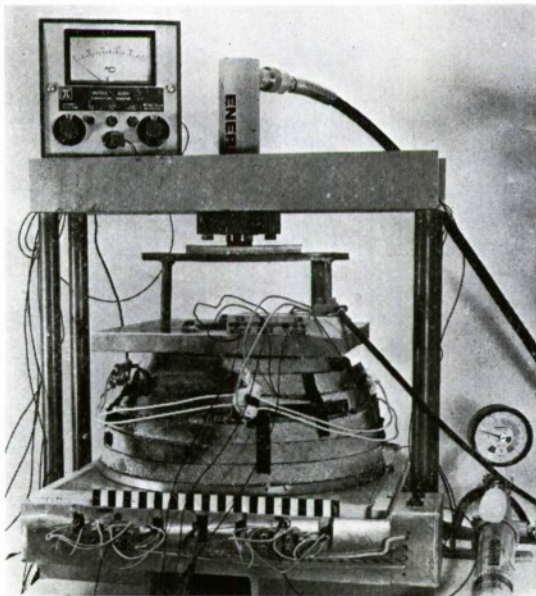A sheet of SPZ alloy was laid on the platen, and the hemispherical mould put in place as in Fig. 3.

FIG. 3. Heated forming tool positioned on press

Thermo couples, connected to a meter, were placed strategically on both the platen and the tool to ensure that the critical thermoforming temperature was achieved but not exceeded.

When the critical temperature was achieved, pressure was applied through the press to the tool to ensure a gas tight seal, and also clamp the edges of the plate. Air pressure of 35 kN/M² rising to 50 kN/M² was applied to the sheet through a bleed hole in the centre of the platen. The sheet was blown into the hemisphere, completely filling the cavity in 15 seconds. The displaced air in the cavity was permitted to leak through a vent hole in the top in which had been placed a mushroom shaped gauging bar, as a guide to the completion of the forming process.

Measurements of thickness distribution were taken, and these are shown in the table as % thickness strain defined as

$$\% \text{ Thickness strain } (\Delta) = (1 - \frac{T_2}{T_1}) \times 100\%$$

where T_1 = Original or nominal thickness (0·050 ± 0·002 in)

T_2 = Thickness of section after forming
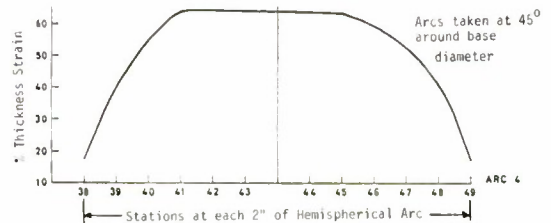
Per cent thickness strain distribution graph of one arc of measurement

Distribution graphs of the other arcs is not included but are typical of that shown.

Subsequently three sheets of ZAM 0·050 in. thick were consecutively formed into hemispheres under similar conditions and strain rates. The time taken after initial heating of the platen and tool to form the three was 10 minutes, which included stripping, placing fresh material and reheating to critical temperature in each case. One of these is shown in Fig. 4.

ARC 1			ARC 2			ARC 3			ARC 4		
STN*	T_2†	Δ	STN	T_2†	Δ	STN	T_2†	Δ	STN	T_2†	Δ
1	41	18	14	41	18	26	41	18	38	41	18
2	31	38	15	29	42	27	31	38	39	30	40
3	24	48	16	23	54	28	23	54	40	23	54
4	20	60	17	20	60	29	20	60	41	18	64
5	18	64	18	18	64	30	18	64	42	18	64
6	18	64	19	18	64	31	18	64	43	18	64
7	18	64									
8	18	64	20	18	64	32	18	64	44	18	64
9	18	64	21	18	64	33	18	64	45	18	64
10	20	60	22	20	60	34	19	62	46	20	60
11	24	48	23	24	52	35	23	54	47	24	52
12	30	40	24	31	38	36	33	34	48	31	38
13	40	20	25	43	14	37	41	18	49	41	18

* STN = Stations at each 2 inch of hemispherical arc.

† T_2 = Final thickness in 0·001 inch.

FIG. 4. First hemisphere formed from ZAM sheet

FIG. 5. Shape blown into Pyrex glass bowl

To demonstrate the need for heating the tool to the required temperature an attempt was made to thermoform into the unheated tool. Because the tool was relatively cool when the sheet made contact with it, heat was conducted from it, and superplasticity was lost. Flow of metal ceased and a deformed conical shape ensued.

The flow of metal was later observed visually by forming into a " PYREX " glass bowl. The sheet extends from the centre to the farthest extremity of the tool, and then flows outwards and fills the sides. This demonstration was a fairly extreme case of blow forming in that the depth/diameter ratio is 1·15, Fig. 5.

Joining techniques

It had been anticipated, from information gathered, that it would be a relatively simple matter to edge weld two hemispheres together, so fabricating a sphere. Unfortunately welding tests exposed great difficulties, and consequently the Welding Institute undertook a programme of work intended to determine suitable welding methods, covering Tungsten Inert Gas (TIG), Metal Inert Gas (MIG), and some form of solid state or diffusion welding. (Ref 2). The main conclusions arrived at from the results of this programme are that the welding of these zinc/aluminium alloys SPZ and ZAM is possible but not at all easy.

TIG with filler using a.c. argon or helium shielded arc have shown the greatest promise. There was no success with MIG and only limited success with diffusion bonding.

Attempts were made to soft solder two hemispheres together, using KYNAL flux and 60/40 soft solder, as advised by Messrs. Fry's Metals Ltd. There was little difficulty in soldering small flat items, but an item of the size and shape as that under consideration posed great problems. These problems proved insurmountable because of the inability to establish a satisfactory soldering technique for this particular application.

Consequently, a sphere 138 mm diameter was fabricated (Fig. 6) with the use of Araldite 123 with Hardener 953B.
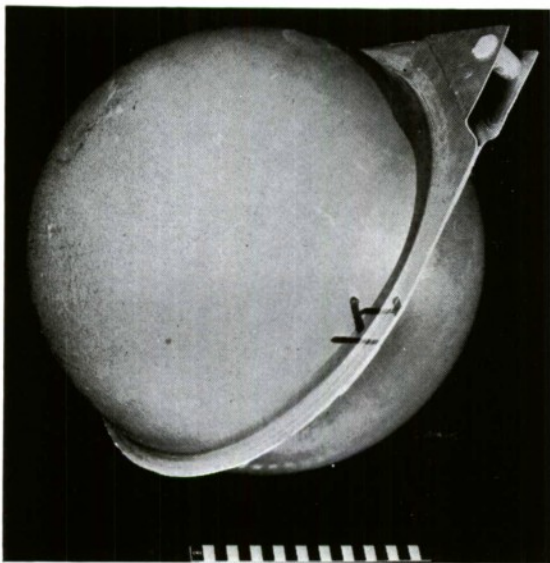
FIG. 6. Fabricated sphere (Araldite adhesive)

(b) *Extrusion*

As stated previously, these alloys will, under the correct conditions, extrude quite readily. However since ZAM, in billet or bar form, was virtually impossible to obtain, and further because of the lack of facilities in the laboratory for the transformation of ZAM cast billets, scraps of SP2 were melted and cast into small cylindrical billets suitable for use in a small closed extrusion die. These billets were transformed into a superplastic state by the method described earlier.

A small closed die in the form of an elementary blade with circular root was made. Fig. 7.
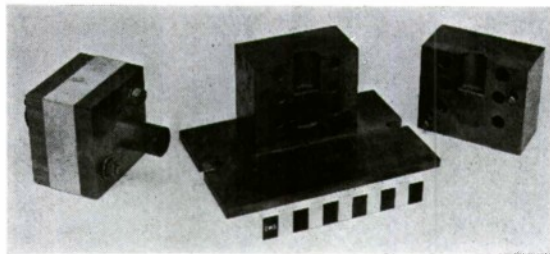
FIG. 7. Closed die and punch for extrusion

The tool was heated to 270°C, the billet was placed in the cavity, and the ram pressed home by the hydraulic press. An initial pressure of $16 \cdot 2$ MN/m² was applied at the ram, this was allowed to fall until steady at 11.2 MN/m². The pressure was increased to $13 \cdot 8$ MN/m² to ensure filling the die, then released.

Two blades were extruded, the first (Fig. 8) shows a great deal of "flash", evidence of a weakness in the die. The die was strengthened before the second work piece was made. However it was satisfactory to note that the smallest surface marks on the die were faithfully repeated on the work piece.

CMs

FIG. 8. First blade extrusion

A section was made of the second extrusion, and this showed, on microscopic examination, that the "blade" and "root" junction were sound, with no evidence of stress mark-

ing. There was, however, indications of " piping " and " porosity " in the root. This was caused by inclusion of the oxides in the flow, probably through insufficient cleaning of the billet prior to extrusion, and insufficient quantity of material being placed in the die. These faults can be easily rectified and the result was considered satisfactory in that it demonstrates the facility of extrusion.

Assessment

The results so far are quite encouraging, it having been demonstrated that, using the correct approach, the manipulation of these materials is not difficult. As observed, there are problems in the area of joining techniques, but these are not altogether insurmountable.

No work has been done at Admiralty Research Laboratory with regard to corrosion, but the Royal Military College of Science has made a study and report (Ref 3).

The characteristic of superplastic forming is that the metal suffers viscous flow rather than stretching, therefore there is no " springback " as in normal press techniques. Additionally deep draws can be executed in one operation, albeit slowly, whereas normal deep drawing requires several operations, alternated with annealing and stress relieving operations. Tool costs are reduced in comparison with normal because only one half of the form is required. Further, because gas pressures involved are low, tools are not highly stressed.

In comparison with thermoformed plastic sheet, the processes are comparable, but the great advantage with a superplastic metal is that it will not burn as plastics will, often with toxic effluents.

Since this work was carried out, further developments have been made in the use of aluminium/copper alloys by Superform Metals Ltd. of Worcester. This company has been formed by Tube Investments Ltd. and the British Aluminium Co. Ltd., to manufacture custom products with the use of an aluminium/ copper alloy " SUPRAL 150 ". This has otherwise the mechanical qualities similar to the NS 3/4 range of aluminium alloys. Full details can be obtained on request from the company.

The conclusions to be derived from this study are fairly obvious. Because of the comparatively simple tooling and manipulation techniques, superplastic materials technology could make a very useful contribution to the engineering manufacturing side of the work of the Admiralty Research Laboratory.

This applies particularly to those areas of work where complex three dimensional shapes have to be produced in medium quantities. By using the materials of higher strength, such shapes could be produced with the major expenditure being incurred on the production of the relatively simple tooling.

Indeed, when it is realised that the costs of zinc alloys is increasing very rapidly, the trend should be towards using some of the other materials mentioned, particularly SUPRAL 150, and it is probably in this area that future prospects of this technology lie.

References

(1) a. Johnson, R. H. Electricity Council Research Centre, Capenhurst. 'Superplastic Metals' Design Engineering, March 1969.
b. Cornfield, G. C. and Johnson, R. H. ECRC. 'The forming of Superplastic Sheet Metal'. Int. J. Mech. Sci., Vol. 12, 1970, pp. 479-490.
c. Holt, David L. Dept. of Metallurgy and Material Science, Massachusetts Inst. of Tech. 'An Analysis of the Bulging of a Superplastic Sheet by Lateral Pressure'. Int. J. Mech. Sci., Vol. 12, 1970, pp. 491-497.
d. Smith, A. E. W., Hare, G. A., Belk, J. A. Royal Military College of Science. Dept. of Chemistry and Metallurgy. 'New Superplastic Zinc Alloys.. A summary of Thermoforming and other properties'. Dec. 1970.
e. Fields, D. S. (Jnr.) and Stewart, T. J., IBM Corp. USA. 'Strain Effects in the Superplastic Deformation of 78 Zn. 22Al'. Int. J. Mech. Sci., Vol. 13, 1971, pp. 63-75.
f. 'Engineer' Report 'Superplastic Alloys ready for Industrial Use', The Engineer, 27 May, 1971.
g. Goff, W. E., 'Superplasticity' Flight International. 3 Aug., 1972.
(2) 'Diffusion Welding', Welding Handbook, Vol. 3a, Ch 52.
(3) Burridge, D. P., RMCS. Department of Chemistry and Metallurgy. 'Some observations of the Corrosivity of ZAM Alloys in Accelerated salt spray tests and short term field tests. Technical Report MET/R8/73.

# OPEN DAYS AT ADMIRALTY UNDERWATER WEAPONS ESTABLISHMENT 13—19 MAY 1974

The Admiralty Underwater Weapons Establishment held its first Open Days on the 13-19 May 1974 when the work of the establishment was put on view for some 7000 visitors.

A large selection of hardware and pictorial displays illustrated the great breadth of research and development with which AUWE is concerned. Visitors from the MOD, the Services, Universities, Industry and relatives of the staff of AUWE were able to gain an insight into the many and complex problems associated with the defence requirement in the Underwater area and there is no doubt that some of the technology will ultimately find an application on the domestic front.

It is expected that as a result of the Open Days, AUWE will derive benefits both locally and nationally, but more importantly, that UK industry will gain information and contacts which will help their drive for new markets in the Underwater field.

Dr. Hutchinson (left) with Frank Judd, M.P.
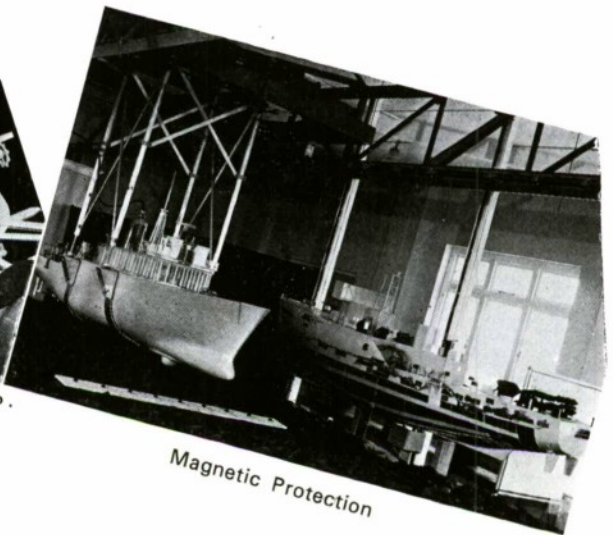
Magnetic Protection
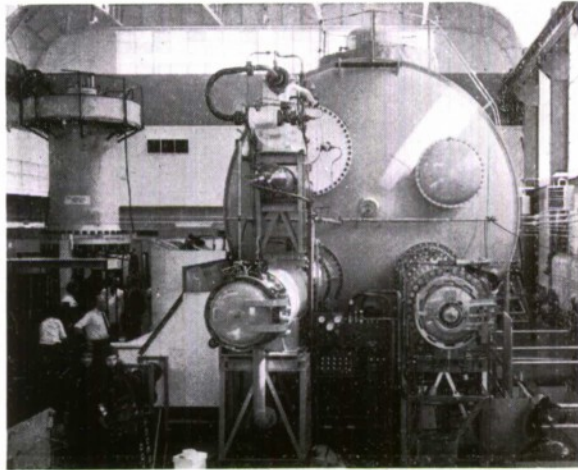
Submarine weapon launch test facility

Sea bed roughness investigations
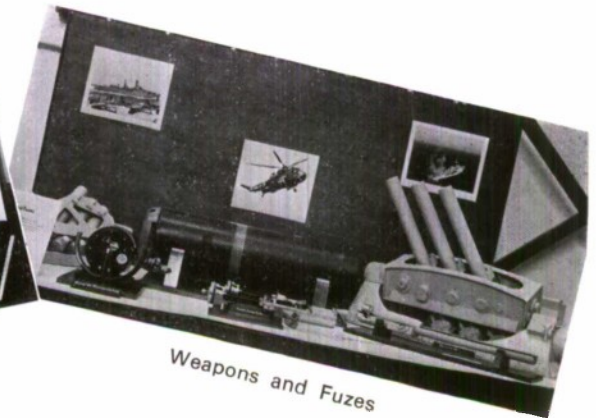
Weapons and Fuzes
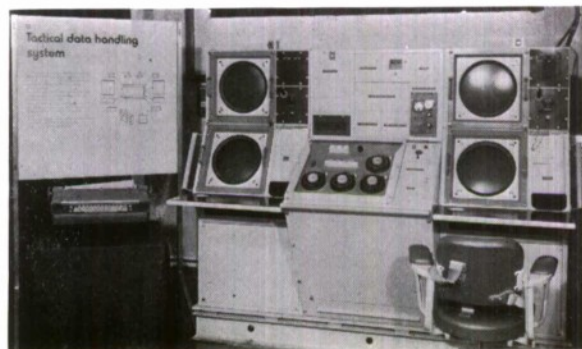
Submarine tactical data handling system

NOTES AND NEWS

Admiralty Surface Weapons Establishment

Mr. A. L. C. Quigley read a paper at the University of Birmingham on 15th May 1974 on "An Application of Kalman Filtering to Radar Data Processing ". The paper was presented as part of one of the University's Bosworth Courses on Radar. Mr. J. F. Goodey read a paper entitled "Antenna and Conducting Screen on a 'lossy' Ground " at the NATO AGARD Electromagnetic Propagation Panel Meeting held at the Hague at the end of March.

Congratulations are due to Mr. H. P. Mason, SSO, who has been awarded the *Marconi* Premium for his paper on " Multiple-Channel UHF Reception on Naval Ships ". This paper was considered to be the outstanding contribution to the Institution of Electronic and Radio Engineer's Journal during 1973. (Radio and Electronic Engineer, Vol. 43, No. 5, May 1973, p. 299 - 311). Mr. Mason has decided to take the premium valued at £50, in the form of books.

Dr. M. Darnell visited the shore-station H.M.S. *Mauritius* for a few days at the end of April in connection with some high-frequency sounding trials. Mr. G. W. Ross, Mr. M. H. A. Smith and Mr. K. G. Hambleton attended a course on "Advanced Methods of Modern Radar Analysis Systems " held in Zurich at the end of June.

Recent visitors to the establishment have included Admiral P. White, CBE, who is to be the new Chief of Fleet Support, and Mr. E. W. J. Satchell, C.Eng., F.I.E.E., F.I.E.R.E., F.I., Mar E., the Head of the Royal Naval Engineering Service.

Mr. D. S. G. Mullens, SSO, of ASWE died suddenly in the early hours of the morning of Sunday, 12th May, 1974 at Colyton, Devon.

Mr. Mullens was born in 1922, and joined ASRE in 1945, working first at Haslemere, and from 1949 at Funtington, and finally in 1951 at Portsdown where he worked on the mechanical aspects of the high power modulator of the Type 984 radar, and later the aerials of the Type 901 radar.

In 1969 he joined the research effort studying the effects of air blast on radomes, which was then a new field to ASWE. He was the leader of trials teams which participated in large scale TNT explosion trials under TTCP auspices at Alberta, Canada in 1970, and Colorado, USA in 1972. At the conclusion of this work, he transferred to the ship system engineering division as leader of two sections one of which is concerned with the installation of weapon systems training equipment in shore establishments, and the other with communication and radar equipment in RN air stations.

Don Mullens gave much of his time to welfare and community work. He was a very active member of the ASWE Civilian Staff Mutual Aid Fund committee. Outside the establishment he was a Councillor of Fareham UDC for several years, where he was the Residents representative, and also served on the Education Committee. In this latter capacity he was Governor of four schools in Fareham.

Recently his main outside interest had been his thatched cottage at Colyton which he had been renovating with the assistance of his wife and two daughters.

Admiralty Underwater Weapons Establishment

Mr. L. S. Brodie, PSO, retired in January 1974 after a long and varied career approaching 38 years in Government Service, most of it in support of the Royal Navy.

John (as he was always known to his friends) obtained a 1st Class Honours B.Sc. (Eng.) at London University in 1934. He then joined the Ministry of Transport as a Junior Assistant in the Experimental Roads Department where he stayed for a couple of years before casting his eye around for something new. The Standard Telephone & Cables Co. appears to have attracted him but his stay "outside" was short and the year 1937 found him back in Government Service at the Admiralty Compass Observatory as a Junior Scientific Officer. Here he concerned simself with the design and development of navigational instruments. In the 1946 reconstruction he was assimilated as a Senior Scientific Officer.

In 1950 he took the double step of getting married and transferring to HMUDE at Portland where he was promoted to PSO in 1952. He first worked in, and later ran, an acoustics group which supported homing torpedo development. This work seems to have introduced him to submarines and he took over the development of submarine sonars in 1952. In 1961 he had acquired a wide experience of underwater matters and if there was anything required to be known about sonar John Brodie was as good a man to ask as any. Indeed it appears to have been considered that Commander British Navy Staff (Washington) might benefit from such experience and away he was despatched to the USA as Scientific Adviser (U/W) in 1961.

On his return to Portland in 1963 he took charge of mine countermeasures for a while but was soon back again leading a group responsible for new projects in the field of sonar and associated equipment for submarines. Here he developed close contacts with some European countries particularly France and the Netherlands and did an enormous amount to foster good relations and collaboration with these countries. For the past few years he has concerned himself with the broad overall control and planning of the research and development programme at AUWE.

At his retirement John's colleagues entertained him to a farewell lunch and presented him with a radio as a parting gift. In return he regaled them with a good helping of his well known and much loved wit and humour. He will be sadly missed not only at AUWE but also in many countries abroad and wherever sonar matters are discussed. He was quite a "character", full of good commonsense, practical experience, gentle humour and a friendliness and helpfulness which endeared him to all. His friends and associates wish him and Mrs. Brodie a long and happy retirement.

Mr. Niall Macdonald, Senior Scientific Officer at AUWE retired recently after 46 years service.

He joined the RN Torpedo Factory, Greenock (later the Torpedo Experimental Establishment) as a boy of 14 in 1928 and served an apprenticeship as a coppersmith. In 1940 he moved to the heat treatment shop and was put in charge of it two years later. He became an Assistant III in 1944, Senior Assistant (Scientific) in 1947, Experimental Officer in 1953, and Senior Experimental Officer in 1964. He was awarded L.I.M. in 1956 and A.I.M. in 1973.

He is an authority on many facets of metallurgy. As early as 1947 he was developing foundry techniques for high strength alumi-

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BOOK REVIEWS

Marine Physics by R. E. Craig, Academic Press, London and New York, pp. vii + 83, £1·90.

This introductory text treats the topics of physical aspects of the oceans and seas in a very readable manner. The chapters are arranged such that each deals with separate and sensibly complete treatment of the subject matter such that any one may be studied without reference to any other.

The first chapter concerns density currents in the sea, discussing pressure and coriolis effects and the second deals with diffusion currents, both in a very readable manner.

Chapter three deals quite well albeit at a simple level, with wind currents in deep water.

The fourth chapter deals in a qualitative manner with physical oceanography, principally with bounded water movements.

Waves and tides are treated in chapters five and six again in a very readable manner and being summarised with coastal tide effects and a discussion of accuracy of tidal predictions.

The penultimate and final chapters treat optics and accousties respectively at a fairly elementary level and the book is concluded with a short appendix listing some properties of sea water and other constants.

A general summary of the text is that it is a well written and useful introductory text to a complex and little known subject and the bibliography provided at the end of each chapter forms a comprehensive basis for more detailed study of any particular aspect dealt with in the book. This book should attract a large readership if available within a reference library along with the bibliography references.

D. Robson

Ocean Engineering Wave Mechanics. M. E. McCormick. John Wiley and Son 1972; 179 + xix pages, 8¼ inches × 5¼ inches; £6·25.

At less than 30 pages to the pound this book is "pricey". For that money a work of high quality is expected. The title (shades of Shrodinger) lives up to expectations, the contents do not. The book is based on the class notes used in a one-semester senior post graduate course—good in concept, but requiring a more thorough treatment to make a satisfactory book.

Chapter 1—Review of Hydromechanics, is a sheer waste of expensive pages. Fortunately not so great as it might have been since Hydrostatics, Inviscid and Viscous Flows, Lift and Drag occupy only 14 pages, plus nine pages of examples and problems. The reader who is not already familiar with these topics will not find the treatment adequate.

Chapter 2—Surface Waves, contains a routine account of the theory of regular waves, including waves in deep and shallow water, group waves and non linear waves. The energy concepts, which often give difficulty to the student, receive only cursory treatment. (The cost of the pages so far is within sight of buying Lamb's Hydrodynamics).

Chapters 3 and 4 provide the material for which the book would be bought, and they cover a good deal of ground. Chapter 3—Fixed Structures in Waves covers the forces on vertical and sloping barriers, forces on a pile, wave induced vibrations and drag. Chapter 4—Floating Structures in Waves covers coupled heaving and pitching, moored and towed bodies. Both chapters include experimental studies and examples. These are complicated phenomena which the author attempts to

present briefly and simply. Unfortunately the resulting treatment is superficial to the point of error in several places.

Of the Appendix on Fortran IV the less said the better. Perhaps one of the pages is missing.

The Figures are excellent and references plentiful.

Students of the US Naval Academy, Annapolis, will no doubt find the book invaluable.

T. B. Booth

Certificate Mathematics. Volume 1. N. Abbott. English Universities Press Ltd. 1972. Price £1·25.

National Certificate Mathematics Volume 2 was first published in 1938, and the many succeeding impressions, with periodical updating to suit changing examination requirements, indicate that it has become accepted as a standard work. This third edition is the result of further modification, it has been retitled Certificate Mathematics Volume 1, and re-written in SI units.

The chapters introduced into this volume for the first time are those on the laws of probability, iterative methods, statistics, desk calculators, rounding errors and the slide rule. In the other chapters surds, indices, logarithms, quadratic equations, graph plotting, progressions, the binomial theorem, trigonometrical ratios, differentiation, and integration are described, and examples given of their use.

The level achieved in such a wide field is little more than introductory, but there is enough information for a great many applications. Each topic is developed from first principles and there are few formal proofs since these are not now usually required in examinations, the emphasis shifting from memory to understanding. There is a plentiful supply of exercises, with the answers at the back of the book.

This is a well produced book and is recommended to students who should find it very useful. It should fufil requirements for a number of years, although the chapter on hand-cranked desk calculators, included for the first time, must be almost out of date following the rapid development of comparatively cheap electronic machines.

J. B. Spencer

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Date of Search: 15 February 2007

Record Summary:
  Title: Journal of the Royal Naval Scientific Service
  Covering dates 1974 Jul 01 - 1974 Jul 31
  Availability Open Document, Open Description, Normal Closure before FOI
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