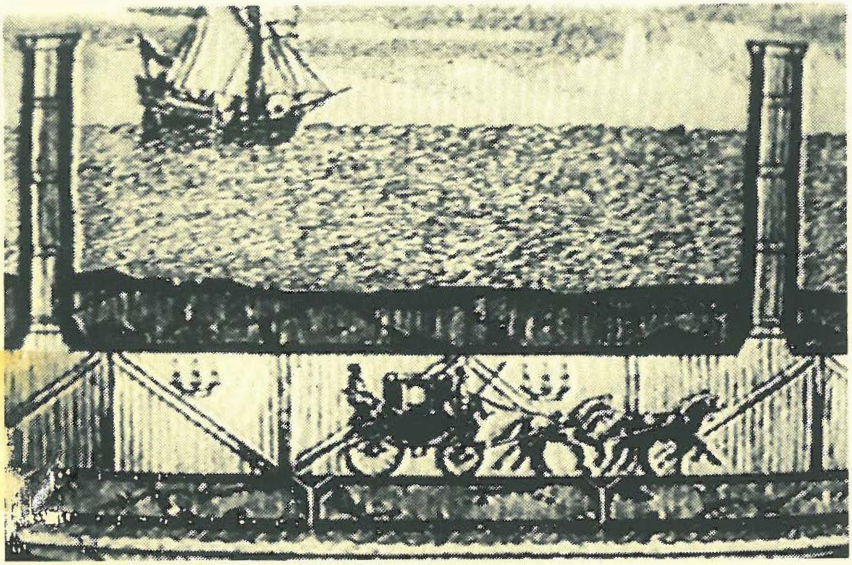
A CONTRIBUTION
TO
TRAVEL



INAUGURAL LECTURE

Delivered at the
University of Wales, Swansea
on 14th March, 1988

by

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A CONTRIBUTION TO TRAVEL

INTRODUCTION

Civilisation or the improvement of society, is, as defined by Aristotle, the search for 'a good life for man'. Most would agree that this is a commendable objective. However, to effect an improvement on extant conditions certain basic 'ingredients' are required. The most important is time to pursue such improvements and this will become available by satisfying man's basic materialistic requirements. This is only feasible if favourable environmental conditions exist. The manner in which communities utilised such time has been governed by many factors ranging from social status and prevailing attitudes to defence. Without external forces being brought to bear, some would regard the status quo to be acceptable and not seek change. Others would, for various reasons, under the same conditions, seek betterment and spatial expansion. A prerequisite to any achievement, however, is some mastery of the environment. Indeed, an engineer can be loosely defined as a person who, through specialisation, can shape nature's materialistic gifts and forces to meet his needs and desires. If such requirements, whether social or economical, are satisfied, then, irrespective of technical merit, the end product is acceptable. However, in order to satiate the seemingly unending quest for economic and social acceptability, significant advances in technological awareness,in both design and use of the environment, are required.

Approximately five thousand years have passed since engineers were first recognised as prominent highly respected members of the community. Engineering, as apparent in ancient Egypt, figure 1 , can therefore be classified as one of the oldest professions!!

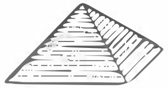
It is not surprising, given an extremely favourable fertile environment, that the areas adjacent to the Tigris and Nile experienced rapid advancements in both socio-economical

FIGURE 1 DEVELOPMENT OF CIVILISATION

BARBARISM

4000 B.C.

3000 B.C.



CIVILISATION

200 B.C. ROADS BRIDGES AQUEDUCTS

142 B.C.

200 A.D.

SUEZ 'CANAL'

ENGINEER

⇧

STAGNATION

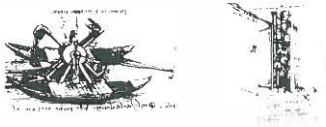
1300 A.D.

⇩

REVIVAL OF ANCIENT ARTS AND TECHNICAL SKILLS (GUNPOWDER INVENTED)

1400 A.D. – 1500 A.D. FIGURE 1 DEVELOPMENT OF CIVILISATION (cont'd)

CIVILISATION



IDEAS FOR MECHANICAL DEVICES (LEONARDO DA VINCI)
ARCH BRIDGES – LARGER SPAN

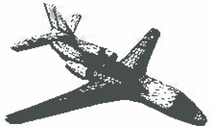
RAPID PROGRESS

INNOVATIVE MACHINES TO MATCH IDEAS

1800 A.D. – 1900 A.D.

LONG TUNNELS, SUSPENSION BRIDGES

1900 A.D.



AIRCRAFT, SPACE FLIGHTS

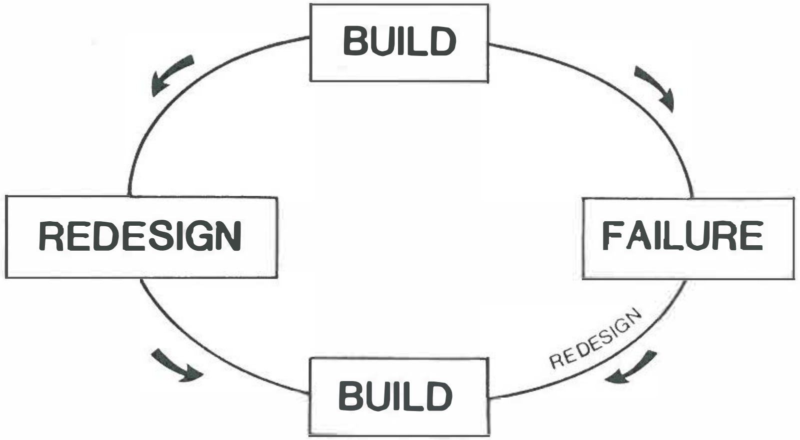


FIGURE 2 SIMPLIFIED CYCLE OF EVENTS

and engineering developments. Indeed, it was in these areas, in the 30th century B.C., that civilisation as we know it today began to evolve. With very limited mechanical and almost no scientific or technical knowledge, the great Pyramid Age, 3000-2500 B.C., is indicative of a rapid development of the practical arts. A period of technical stagnation ensued, partly due to isolation and since a glorifying necessity had been satisfied without, however, any significant contribution to previously known technical skills. However, one notable contribution was the development of planning and organisational techniques in the effective construction of major engineering works. Communication and the transportation of materials did not prove a problem is such a community, although isolated,with long reaches of navigable rivers at its disposal. The Egyptians under these conditions became master builders but their empirical qualitative approach was a contributory factor in their ultimate decline. Their approach did, however, form the basis for the more questioning approach of the Greeks. Here we have the first technical innovators who advanced scientific knowledge to such an extent that technical procedures developed at that time are still in use to this day. Archimedes, 281-212 B.C., acclaimed for both theoretical insight and mechanical development, epitomises the contribution of that age. A period of potential explosive development was prevented by an inexplicable prevailing opinion that the practical utilisation of such advocated techniques was contemptuous. Their practical implementation, incidentally by an architektron, was, therefore, never encouraged. Indeed Plato, the father of modern geometry, discouraged the practical use of his principles and regarded these as a mental exercise not to be debased by use in practice. Such attitudes did not prevent the Greeks from developing a sea based communication system across the Mediterranean, supported by well designed and constructed vessels and harbour installations.

The Romans served as an emissary for the Greek scientific advancements in that they put theory into practice by building roads, bridges, aqueducts and townships all over western Europe. In this era, engineering became a powerful mechanism by which the Romans expanded and maintained a vast empire. Once more the engineer, Architectus, was elevated to a position of power. However, his contribution to basic concepts in engineering was minimal. This does not imply that the 'practical art' of building did not progress as evidenced by the increasing elegance of bridges and aqueducts. As an indicator of their contribution such products rival, both practically and aesthetically, similar projects undertaken within the last two hundred years. With the fall of the Roman empire, there followed a period of stagnation in both the theory and practice of engineering, this extended over a subsequent period of nearly 1000 years until its revival in the Middle Ages. In the earlier period discussed above, Tertullian, in about 200 A.D. coined the word 'engenium' when recording an attack by Roman forces on the Carthagenians in referring to a new 'ingenium' - an ingeneous device. The originators of such devices were called ingeniators, the origin of the modern word engineer. The name given to the modern day engineer has, therefore, an unfortunate origin.

Thes Middle Ages, dominated by a fuedal system, saw little if no advancement in communication. Indeed, the lack of these fostered and maintained such a system and not until the advent of gunpowder, in the 14th century, were the insular fortifications of the period to become an ineffective defence against the cannon. The concurrent advent of the associated metallurgical 'art' produced an engineering revolution hitherto unsurpassed. Ancient arts were revived and the 15th century experienced rapid technological and scientific advancements. Indeed, this rate of progress has, particularly in the last century, been accelerated by both military and commercial necessity.

The intention of the writer is to chronicle certain events, some associated with the early stages of civilisation and others with the present, which have captured the imagination or objectives demanded the attention of governments, engineers and the public at large. In some, the contribution to the design as developed at Swansea of the end product will be mentioned.

TO ENGINEER IS HUMAN

Engineering triumphs and failures are closely interwoven. Necessity, whether imposed by failure, economic or social factors, is the 'mother' of changes in engineering design and construction. A simplistic representation of the continuous cycle associated with engineering development is shown in Figure 2. The process of construction build/re-design/build is continuous whichever direction is taken. For instance, starting from the upper, successfully built and tested project, and proceeding in an anticlockwise direction, the inevitable tendency is to either modify the design or suggest a radical change resulting in a completely new design. As long ago as the Pyramid Age in ancient Egypt, small changes in design, such as changing the steepness of the sides of the pyramid, resulted in failure. Fortunately, each re-design and build does not result in failure and many minor modifications are usually made, resulting in a successful structure before a failure occurs. With each successful project the circle becomes inverted. With the advent of a failure then the clockwise path is taken and the lessons learnt from such an occurrence incorporated into the design procedure for the next project.

The engineer cannot be completely innovative and must, to a large extent, use the scientific knowledge and technical tools available at the time. It seems, therefore, remarkable that some of the more spectacular innovative engineering projects of the past were, since they were based largely on intuition, successful. Such intuitive designs have been and continue to be the proving ground for most current and future design procedures. Due to necessity, engineers have been obliged to design and construct without a full appreciation of the response of the end product to the rigours of use. The tendency has been for 'gowned gentlemen' to prove, after the event, why a project has been a success or otherwise.

Well known examples of failure which lead to re-assessment, re-design and successful implementation include the Suez Canal, Tacoma Narrows Bridge, the channel tunnel, aviation and space travel. These span prehistory to modern times and each is associated with a different type of initial failure(s).

The earliest form of transport utilised navigable waters. Advantages to be gained by the construction of a waterway connecting the Mediterranean and the Red Sea are numerous, not least of which, in the days of sail, was the reduction in loss of life whilst rounding Cape Horn. The first navigable waterway was used in the time of the Pharoahs but, owing to the demise of Egyptian isolation and domination, the channel silted up and reverted to desert. The Greeks and Romans, in succession, opened up routes from the Nile Delta to the Bitter Lakes. Napolean's desire to re-build a waterway was thwarted by human error in that a survey undertaken on his behalf in 1769 indicated, erroneously, that there was a 29 ft. difference in the water levels between the two seas. The completion of the canal, in 1869, by Ferdinand de Lessops was acclaimed as one of the outstanding achievements of the time, Figure 3. This despite remarks by no less a personage than Robert Stephenson 'A canal is impossible - the thing would only be a ditch'.Unfortunately de Lessops' subsequent attempt at constructing the Panama Canal, 1880-1889, was thwarted, not by technical incompetence but by a lack of knowledge regarding tropical diseases. Due to the malarial carrying tetse fly some thousands of lives were lost and the project was abandoned. When such knowledge became available the canal was completed and is still in use, in more or less the same form, today.

The lessons learnt from failures are not always retained and used in subsequent designs. A prime example of such an instance is response of the Telford designed Menai Suspension Bridge, Figure 4. This bold 'new' design was completed in 1826 and collapsed during gale force winds in 1839. The same basic failure mode was repeated when the Tacoma Narrows Bridge, 'galloping Gertie' collapsed spectacularly on November 7th, 1940, when the wind speed was only 42 m.p.h. The aerodynamic response of the bridge, as Telford's earlier version, had not been fully appreciated. A simple modification, such as the aerodynamic section of the Severn Bridge would have eliminated that type of response. The importance of testing scale models, or even the finished structure, had become standard practice as early as the mid 19th century. A strong advocate of pre-construction tests was Robert Stephenson who applied rigorous tests during the construction of the Britannia Railway Bridge over the Menai Straits. The revolutionary box type construction with its 100 ft. span and one central support, was considered by other prominent engineers of the day to be under-designed. Indeed, as a precautionary measure, towers

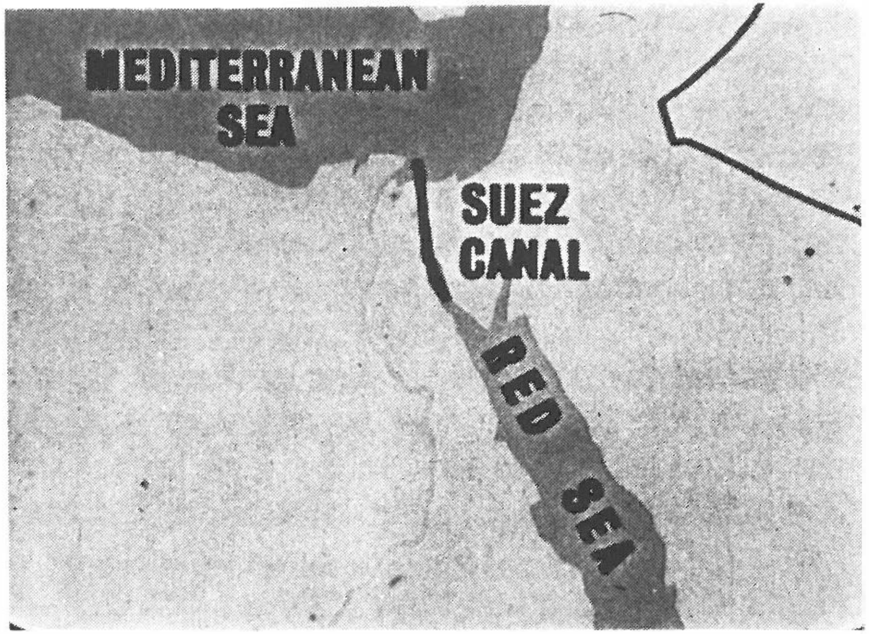


FIGURE 3 THE SUEZ CANAL

FIGURE 4 THE 'TELFORD' MENAI SUSPENSION BRIDGE

which could have accommodated suspension chains were incorporated into the bridge design and actually constructed. Although these subsequently proved to be unnecessary, the bridge 'failed' in 1970 when it was set alight by two youths hunting for bats in the timber roof of the bridge. Should Stephenson have anticipated such an event?

Similar parallels can be found in all branches of engineering and the remainder of the current text is directed at two such projects with a chequered history but which have lead to successful designs and, indeed, implementation in practice. In each the role played by the writer and colleagues at Swansea in such designs will be outlined. The first relates to structures such as the channel tunnel and the second, seemingly far removed, is the design of turbine blades used in modern turbine propulsion systems.

TUNNEL DESIGN

Of the seventy or so proposals for tunnelling under the English Channel most have been conceived from similar basic concepts. The first, in 1802, Figure 5, was considerably in advance of technological knowledge at the time and was, therefore, destined to fail. As early as the mid 19th century the concept of trenches dug into the ocean bed and tunnels placed into these excavations or bridges spanning the channel had already been mooted as viable alternative proposals. These concepts have not changed to the present time although technical advances and 'political harmony' have, finally, resulted in the initiation of a project which should be completed by 1993. Political, usually prompted by military reasons, interaction have frequently resulted in a cessation of operations. This occurred in 1880, when 2 km. had been completed, and in 1973, with workings of 1 km. in length. Indeed, it is surprising, since the withdrawal by the British Government at that time on economic grounds, that the project is now being actively pursued. The sequence outlined above again follows the simple cycle of design/failure/redesign. For the present example, however, the usual reasoning associated with the lack of technical knowledge was, in a significant number of cases, not the governing factor and 'failure' stemmed from political or military arguments.

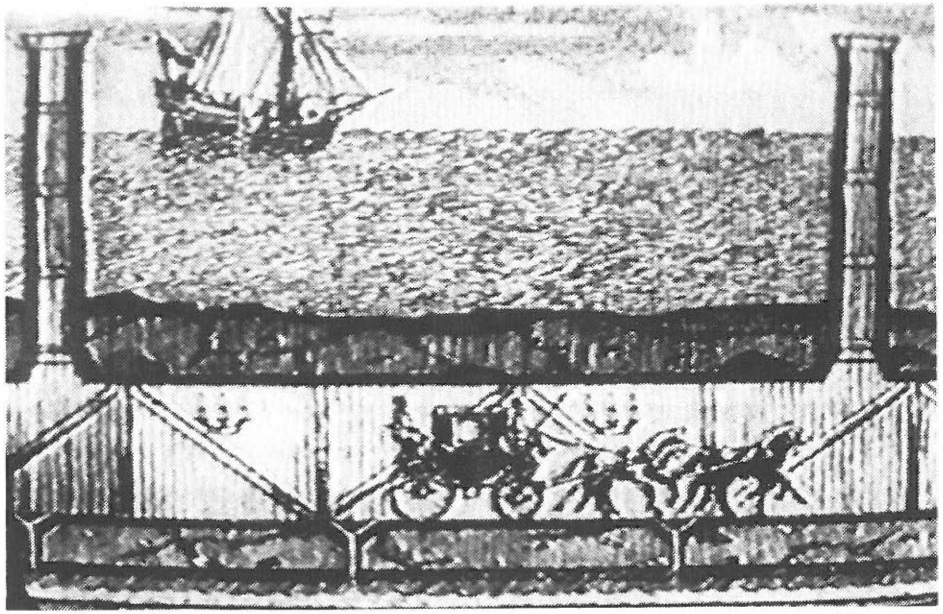
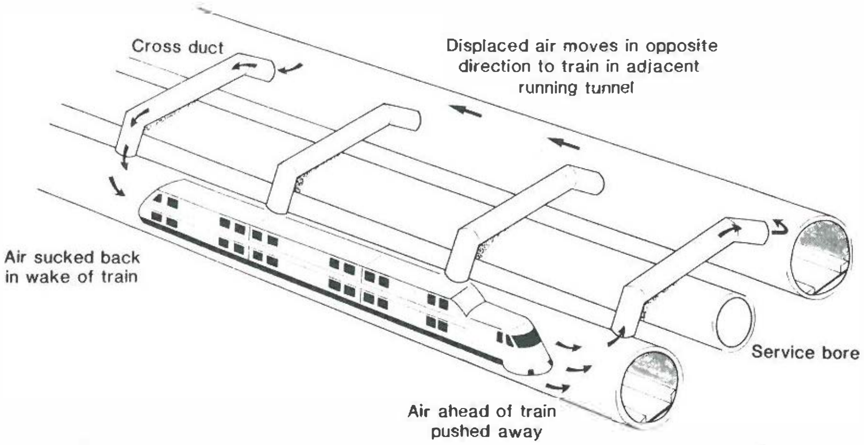


FIGURE 5 AN EARLY PROPOSAL FOR THE CHANNEL TUNNEL

Of the advocated recent proposals the Eurotunnel has been chosen as the most acceptable design. The Eurobridge, consisting of a seven span suspension bridge, and Euroroute, combined bridge and tunnel, were destined for rejection due to the obvious hazards associated with the volume of shipping in the channel and the disastrous examples of the consequences of such a structure, as illustrated by the bridge over Chesapeake Bay. The channel expressway, comprising a twin road and tunnel complex, proved to be rather costly. Finally, the Eurotunnel, Figures 6 and 7, a twin rail construction, was agreed upon by Mrs. Thatcher and Monsieur Mitterand in 1987. A key factor, not technical, was that neither Government was required to financially underwrite the project. A consequence is that a significant proportion of the shares issued have been acquired by countries outside Europe!!

A particular aspect of the countless design concepts, associated with structures of this type, that are accommodated in a 'final' product has been the subject of research at Swansea. This is based on the simulation of the physical as constructed structure by a computer based 'model'. Of the number of such models created only one will be given as a typical example. It is common knowledge to all that any moving vehicle will, due to its source of power and function with the surrounding air, will generate heat. For vehicles travelling over the land surface the dissipation of such heat is not problematic. However, during the passage of trains through long tunnels, every twelve minutes in the case of the channel tunnel, a steady build-up of heat, and therefore temperature, could occur. This could lead to temperatures higher than those which are deemed tolerable. Knowing the heat generated by each train during its passage through a tunnel the computer based model can poredict both the spatial and timewise magnitude of the local temperature.

A typical example, Figure 8, where a two tube tunnel is investigated using a numerical finite element based model, the resulting steady state temperatures are as shown, Figure 9. Bearing in mind the geological complexity of the surrounding strata and the conditions are transient, this real problem, intractible until quite recently, can now be simulated with



DRAUGHT CONTROL BY CROSS DUCTS

FIGURE 6 ADVOCATED TUNNEL LAYOUT

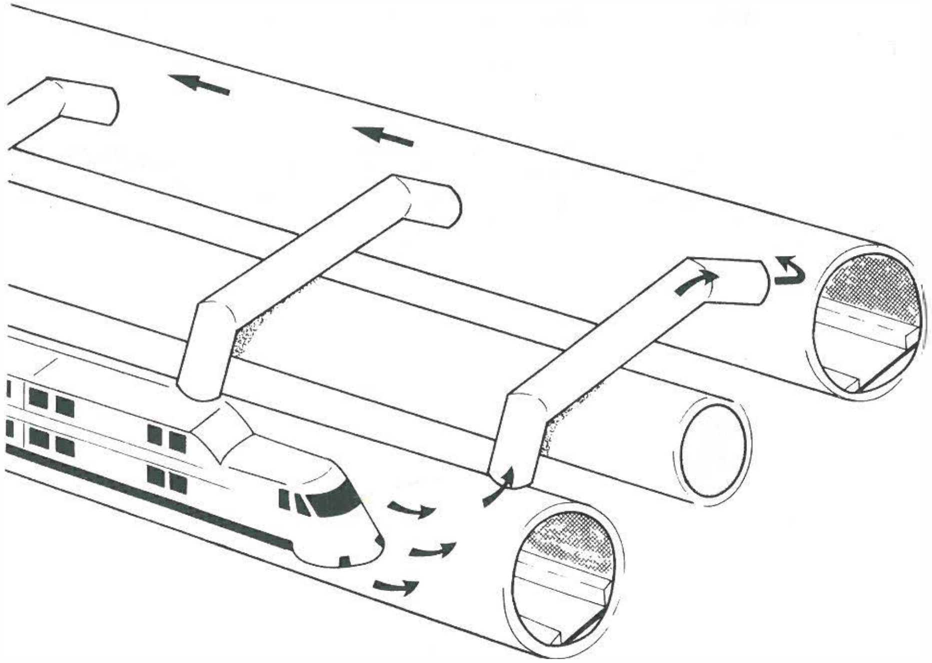
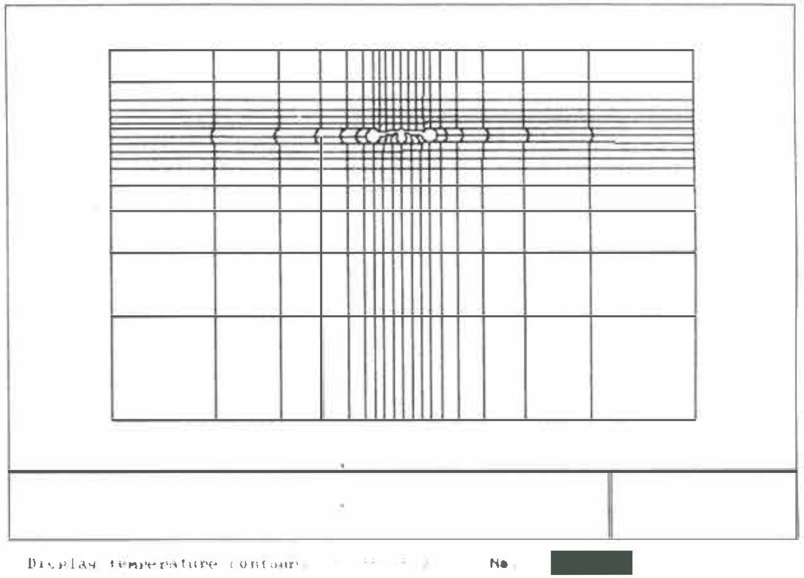
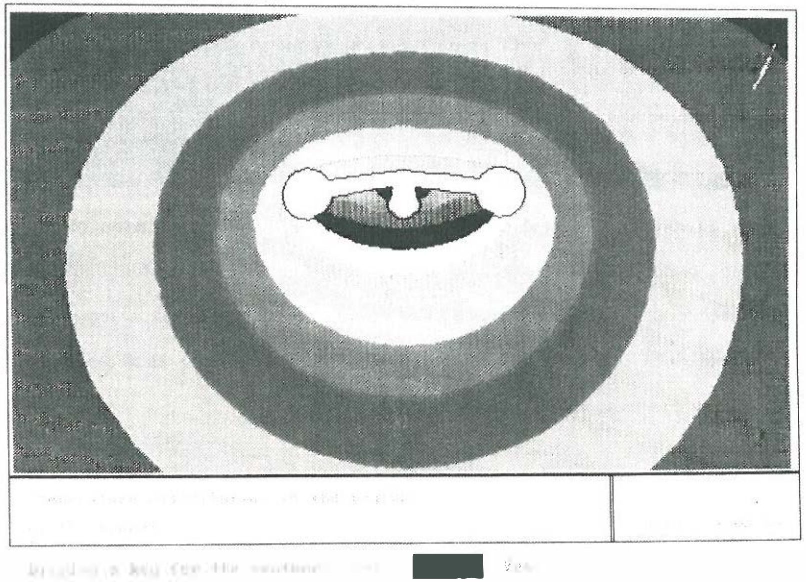


FIGURE 7 ADVOCATED TUNNEL LAYOUT



Display temperature contours No

FIGURE 8 FINITE ELEMENT DISCRETISATION AROUND THE ADVOCATED TUNNEL



Display a key for the contours Yes

FIGURE 9 POSSIBLE STEADY STATE DISTRIBUTION OF TEMPERATURE relative ease on a personal computer. If the resulting ambient temperatures prove to be too high, then remedial action can be easily undertaken.

TURBINES

The evolution of the modern day turbine has, in terms of time span, been extremely rapid. Utilisation of such machines is now widespread, including aircraft, ships and some experimental cars. Most individuals, with the exception of those directly involved in the design, manufacture and maintenance of such power sources, accept these engineering interpretations of basic ideas as an additional, convenient aid to today's civilisation. Although spectacular initial successes such as space travel, receive considerable attention, the gradual evolution and perfection of turbines receives little publicity. However, this does not detract from the effort and expertise invested in such progress. One has only to consider the seemingly unsophisticated, but very effective, Spitfire and Hurricane of a few short years ago and compare these with modern aircraft such as the supersonic passenger aircraft the Concorde or Discovery, Figure 10. The transformation and advancements seem remarkable and this is in no small measure due to the development of turbines producing enormous power, Figure 11. Similar advancements are also apparent in both ocean going vessels and space craft. Indeed, each turbine blade in a jet engine, Figure 12, is subjected to extremely large loads, due to centrifugal action, and develop considerable h.p., to propel the aircraft, and resist very high temperatures for efficiency. In terms of everyday objects each blade would be subject to a load equivalent to two London double-decker buses, would develop more h.p. than a Ford Escort 1.6 and withstand a temperature in excess of five times that of a normal kitchen oven. This for such a small object, a few inches long, is a remarkable achievement.

In order to produce the required power/weight ratios demanded for modern craft, the turbine blades become subjected to higher and higher temperatures. A rule of thumb is that as the temperature in combustion chambers increase then the more efficient an engine becomes. This leads to the obvious request to improve on blade design regarding its

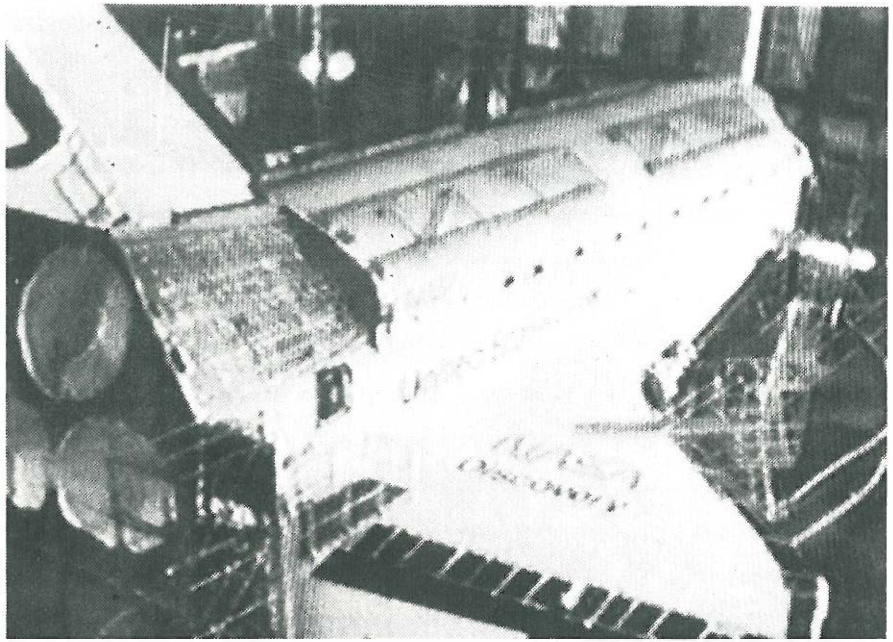


FIGURE 10 VOYAGER

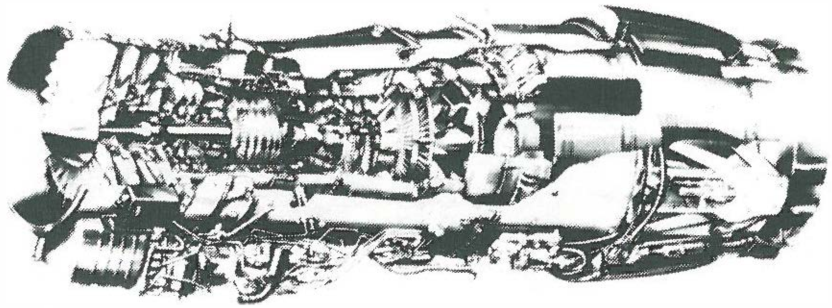


FIGURE 11 TYPICAL TURBINE

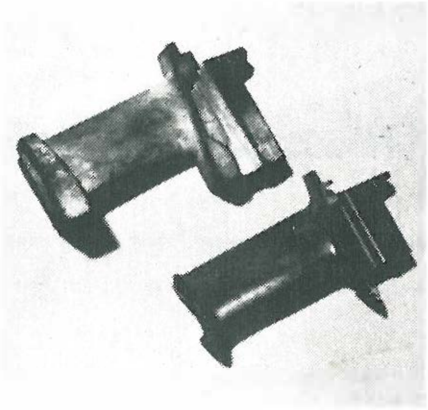


FIGURE 12 TYPICAL TURBINE BLADES

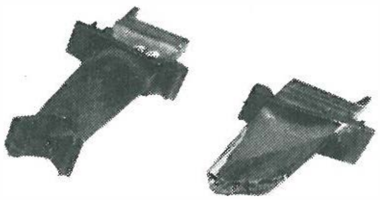


FIGURE 13 TURBINE BLADES SHOWING COOLING DUCTS AND FAILED BLADE

performance. All metals for which such blades are manufactured have limited metallurgical properties regarding their tolerance to high temperatures. It soon became apparent to engine designers, that with the limited improvements that could be made in thermal properties of metals, a method of cooling such blades had to be devised.

This lack of such a facility and the resulting failure is demonstrated in Figure 13. The first diagram shows a blade in pristine condition and the second the disintegration resulting from overheating. Fortunately, such events as shown were confined to the laboratory. However, the result only defines a new problem for the designer which, if progress is to be made, must be solved. Current research embraces both the above and the provision of a heat resistance coating to the surface of a blade thus inhibiting the transfer of heat, and resulting increase in temperature, to the load bearing, metal core of the resulting composite.

Cooling, in most blades, is now achieved by circulating cold air through ducts within the blade, Figure 14. Again, the development of computer techniques, based on the turbulent form of the Navier-Stokes equations, to simulate such a phenomenon constitutes a further design tool for the practising engineer. A computer drawn 'picture' of a typical section of a cooling duct and the resulting temperature distribution is shown on Figure 15. This technology related to cooling is now an accepted integral part of the aeroengine designers' tool kit. However, as mentioned earlier, no matter how sophisticated a design may become the cycle of design/build/failure is again applicable. In this instance, failures have, fortunately, been largely confined to the laboratory resulting in a well placed worldwide public confidence in the designers of British turbines.

CONCLUDING REMARKS

The main message which the writer has attempted to convey is that in the field of modern transportation the age old evolutionary processes still apply. With the advent of sophisticated computational power an additional tool for the designer procedures based on

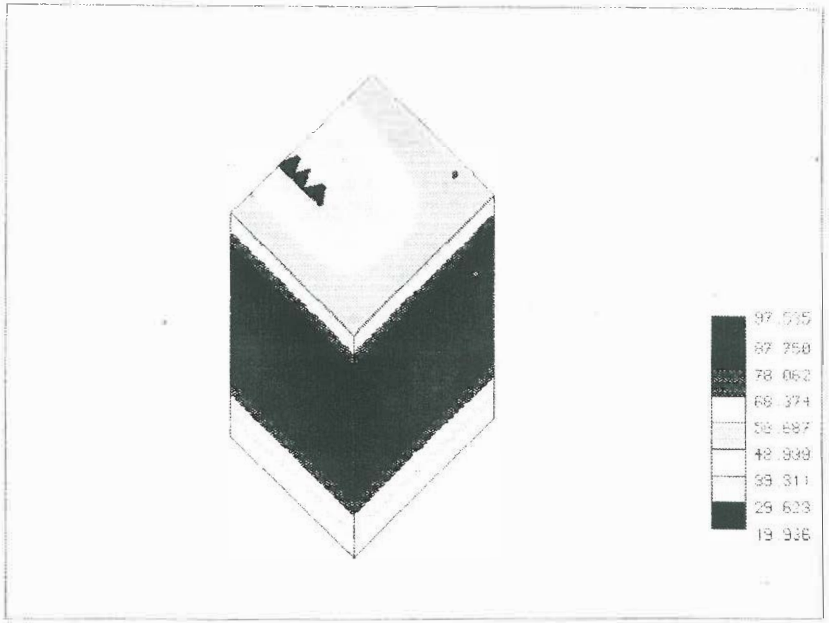


FIGURE 14 VIEW OF COOLING DUCT - FINITE ELEMENT DISCRETISATION

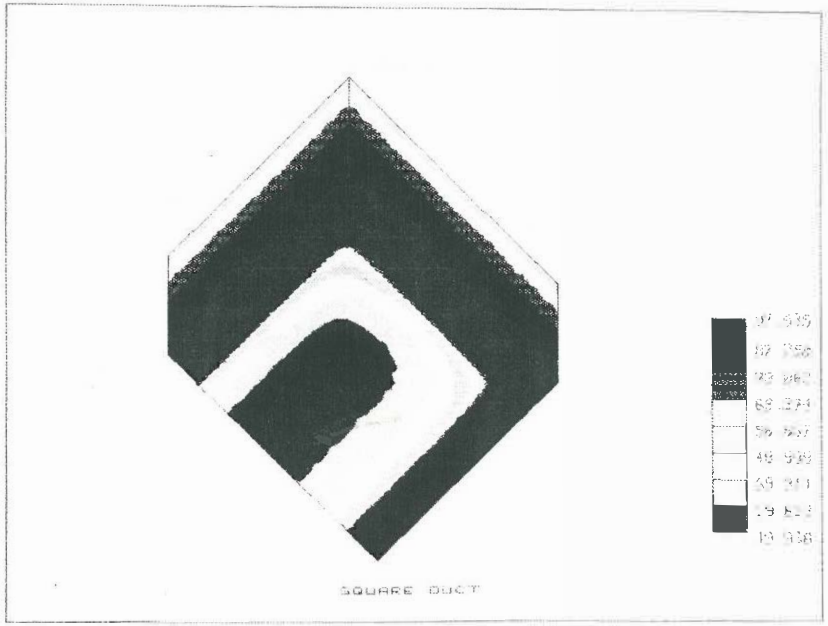


FIGURE 15 TEMPERATURE DISTRIBUTION IN THE COOLING DUCT

past events and current theory become increasingly easier to incorporate into a new design. This stems from the recognised fact that recall from a data bank within a computer's straightforward and associated previous events can be recorded, again with immediate recall. A cautionary remark however, is that although the computer has immediate recall of facts and procedures, these can, and already have, been used increasingly by the designer. The old fashioned simple checks and intuition should always be applied and each mode of failure investigated. If, due to lack of experience, a designer recalls only those procedures that he deems to be applicable then the result could be a 'computer based' design failure. This is not conjuecture but a proven fact.

ACKNOWLEDGEMENTS

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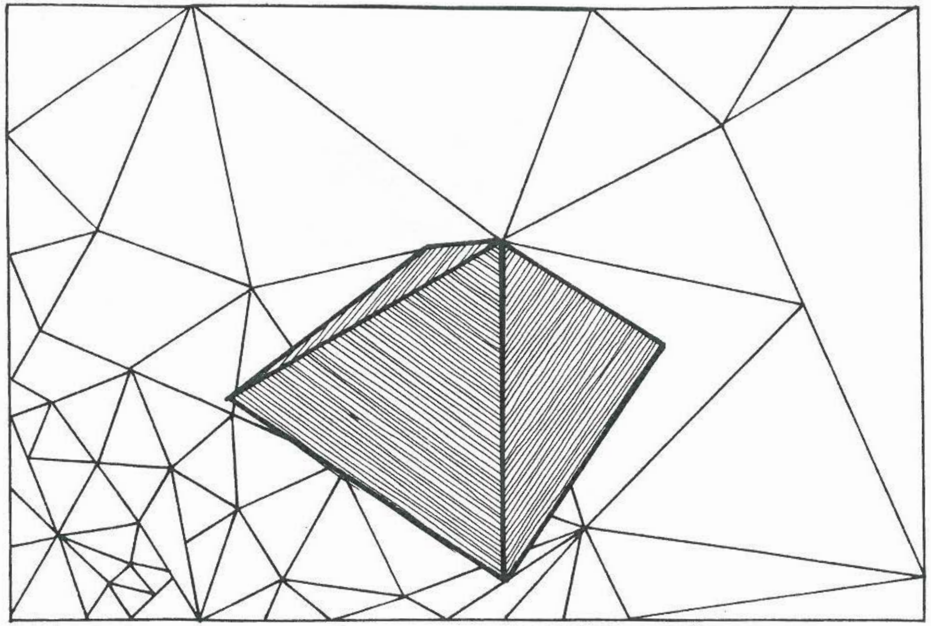

ARE WE BACK
WHERE WE STARTED ?