Professor William Henry Wittrick (1922 – 1986)

See:
http://www.eoas.info/biogs/P000909b.htm
http://www.jstor.org/discover/10.2307/769968?uid=3739560&uid=2129&uid=2&uid=70&uid=4&uid=3739256&sid=47699028759677

From:
http://www.science.org.au/fellows/memoirs/wittrick.html

William Henry Wittrick spent the whole of his childhood in Huddersfield. His parents were by no means well off and had something of a struggle bringing up four children, but his childhood was nevertheless a happy one. His mother was a proficient pianist, had a fine contralto voice and had sung in the well known Huddersfield Choral Society. A source of great pleasure for William was the many enjoyable musical evenings spent around the piano with family and friends, his mother playing the piano and leading the singing.

It was not until the latter part of his secondary education (1933-1940) at Huddersfield College that Wittrick began to show his full scholarly potential. Having passed the School Certificate examination and matriculated, he proceeded to study mathematics, physics and chemistry and came to realise that his strongest subject, and the one that he found most absorbing and enjoyable, was mathematics. He was, too, very fortunate in having a quite outstanding mathematics teacher, Mr. Leslie Horsfall, himself a Cambridge Wrangler. As a result of Wittrick's performance in the Higher School Certificate examination, Mr. Horsfall and the Headmaster persuaded his parents to let him stay on in the Sixth Form for another year and to try for a Cambridge scholarship.

At this stage it was essential that he should have somewhere quiet to study. With two younger sisters and brother, this was not easy at home, and he spent much time studying at his grandmother's house about a mile away. She would purposely refrain from conversation and would sit quietly reading whilst he was working. He owed much to her encouragement during this critical stage; not only did it result in his going to Cambridge, but it was during this time that he really learned how to study.

In preparing for the Cambridge scholarship examinations, Wittrick had decided to drop chemistry and to take applied mathematics instead. The latter he taught himself largely from books under the direction of Mr. Horsfall who also spent many hours of his own time preparing him for the scholarship examinations of St Catherine's College.

He was eminently successful in these examinations and was awarded an Open Exhibition in mathematics at St Catherine's at Easter 1940. In the summer of the same year he re-sat the Higher School Certificate examinations, on the result of which he was awarded both a State scholarship and the Jubilee Exhibition of the Huddersfield Education Committee. He was therefore able to go up to Cambridge in October 1940 without requiring any financial assistance from his parents.

Undergraduate Years

Because of the war, Wittrick had decided to read for the Mechanical Sciences Tripos at Cambridge rather than mathematics and was allowed two years to complete the course. He therefore entered immediately to the second year of the course, and sat for the Tripos in May 1942. During the final year he elected to take four optional B Schedule papers in the subjects of Aeronautics, Applied Mechanics, Theory of Structures (Civil), and Theory of Structures (Mechanical); in addition he also attended lectures in a fifth B subject, namely Heat Engines. His supervisor during these two years was Mr. (later Professor) T.R.C. Fox of King's College, but in his final year he also had special supervision from Mr. H.A. Webb of Trinity College, a scholar who was also a gifted teacher. Like many before him, Wittrick found this contact with Webb a particularly stimulating experience.

On the result of the Tripos in May 1942, Wittrick was awarded the B.A. degree with First Class Honours and Distinctions in Theory of Structures (Civil) and Theory of Structures (Mechanical), and was also awarded the Archibald Denny Prize for Theory of Structures. His college had awarded him a prize in 1941, after his first year, and again in 1942. They also granted him the title of Scholar. Although he had sat for the Tripos in 1942, he was not formally admitted to the degree until 22 June 1943, three academic years after matriculating in the University. In February 1947 he proceeded to the M.A. degree upon payment of the requisite fee.

Early work and research

After taking the Mechanical Sciences Tripos in 1942, Wittrick spent four months with the Hawker Aircraft Company, working at Esher on the stress analysis of the centre fuselage on the Centaurus-engined version of the Tempest fighter aircraft.

The Centaurus was a radial engine manufactured by the Bristol Aeroplane Co., whilst the existing version of the aircraft had a Napier 'Sabre' in-line engine. This necessitated a re-design of the engine mounting and centre fuselage which was essentially a statically indeterminate and rather complicated three-dimensional framework made from aluminium tubes, but with the shear bracing in several of the rectangular panels consisting of two diagonal taut wires. Under load, the likelihood was that the shear of the panel would cause one or other of the two wires to go slack, and before calculation could commence, a decision had to be made about which of the two wires should be omitted in each panel. This was a matter of inspired guess work, and if at the end of the calculation it transpired that the wire that had been retained was carrying compression, it meant that the initial guess had been wrong; the other wire in the panel had then to be included instead and the calculation repeated! The method of analysis was based on Sir Richard Southwell's tension coefficient method and was set out in tabular forrn, whilst the arithmetic was done on a Fuller calculator, a slide rule with a scale 500 in. long in the form of a helix on a cylinder about 3 in. in diameter. The process was therefore laborious and Wittrick spent most his time at Esher going through the many flight and landing cases that the Air Ministry publication AP970 decreed should be considered. Today the entire calculation would be carried out on a digital computer, using a standard program, in a matter of a few minutes.

In September 1942, Wittrick was called for interview by C.P. Snow - the archetypal talent spotter of the day - and sent back to Cambridge, primarily to teach Royal Engineer Officer Cadets doing six-month short courses. He was there for two years as a Junior Demonstrator, and during the second of these years he worked on the Liberty-ship problem under the guidance of Richard Weck. Liberty ships were being built in large numbers, using prefabrication techniques, in Henry Kaiser's shipyards in the U.S.A. The problem was that some were failing catastrophically by developing extremely large cracks, due to brittle fracture of the steel. Wittrick assisted Weck in laboratory experiments to measure the residual stresses in butt-welded steel plates when the shrinkage across the weld was constrained elastically.

In October 1944 Wittrick was again interviewed by C.P. Snow and this time sent as a Scientific Officer to the Royal Aircraft Establishment, Farnborough, where he worked in the Structural and Mechanical Engineering Department. The head of the department at that time was Dr. A.G. Pugsley (later Professor Sir Alfred Pugsley, FRS) and among his colleagues who were later to become FRS's were A.R. Collar, E.G. Broadbent and E.H. Mansfield. He worked on two main problems. The first was an airworthiness problem arising from the excess stick forces being experienced by Spitfire pilots due to aileron and elevator distortion in high speed manoeuvres. The second was a theoretical investigation into the possible efficiency of the then new form of structure known as sandwich construction. This became the subject of his first published paper.

University of Sydney (1945-1964)

At the end of World War II the chair of aeronautical engineering at the University of Sydney was occupied by A.V. Stephens, a Cambridge man whose research interest lay in the field of aerodynamics. The department was a small one and, as it was the only one in Australia, Stephens was anxious to attract someone able to develop a strong teaching and research effort in aircraft structures. He therefore sought the advice of Professor J.F. Baker (later Lord Baker of Windrush), originally an aeronautical engineer, who in 1943 had become head of the Engineering Department at Cambridge and had gathered around him a most enthusiastic group to work on steel structures. Wittrick had spent a short period teaching and assisting in research in that department and with his excellent academic record and some experience at the Royal Aircraft Establishment, Farnborough, was highly recommended by Baker. At the age of twenty-three, he became one of the youngest senior lecturers ever appointed to the University of Sydney.

Getting to Sydney in those days with not without its difficulties. Wittrick had married in June 1945, and while he was granted a passage quickly, his wife Joyce had to wait until a later date. The irony of the situation was that the ship in which Bill sailed had some empty berths. Joyce joined her husband some months later after a long tedious journey around the Cape. Both being endowed with Yorkshire determination, they did not allow such frustrations to interfere with the task of making a good life in Australia.

The small department at Sydney had its compensations for Wittrick. The teaching load was not particularly onerous and since his interest in aircraft structures was mainly theoretical, he was able to engage in research very soon after his arrival. At that time, considerable attention was being given to swept-back wings for high-speed aeroplanes and particularly to the delta wing, for which the leading edge is highly swept but the trailing one is more or less unswept so that the taper and 'average' sweep are large. This was a complex problem on which a great deal of work was being done though few papers had been published. For swept and tapered wings with ribs parallel to the root, Wittrick produced solutions for their behaviour under load. He demonstrated the coupling between flexure and twist, and the effect of root restraint which could be significant for large angles of sweep. A detailed account of this work is to be found in his thesis entitled 'Torsion and Bending of Swept and Tapered Wings with Ribs Parallel to the Root', submitted for the degree of Ph.D. The appendix contains detailed numerical applications of the theory to a highly tapered unswept four-boom tube of rectangular section, with a completely restrained root section, under varying bending moment and torque. No mean task when the only aid then available was the mechanical hand-operated calculating machine!

It is interesting to note that when Wittrick was awarded the Ph.D. degree in 1950, he became the first recipient in the University of Sydney. The thesis is now lodged under restricted access in the Rare Books section of the University Library. Associated with it are a number of publications, the first of which was said to be the first paper on this topic published anywhere in the world.

With hindsight, we can see that Wittrick's adoption of the well-established assumption of rigid line-of-flight ribs was not appropriate for swept wings, because it markedly exaggerated the coupling between torsion and flexure. However, this served a useful purpose, because it highlighted a novel structural phenomenon and acted as both a trigger and a spur to those who then recognised the need for a more exact analysis.

In the early 1950s Wittrick returned to his interest in buckling, prompted by problems arising in the design of swept wings concerning the elastic stability of irregularly shaped panels (such as parallelograms and triangles) subjected to edge loads. He also produced an elegant solution for the buckling of orthotropic and isotropic rectangular plates under various biaxial loading and boundary conditions. A number of other papers on similar topics were also published. Indeed, in 1954 his papers formed a substantial part of the literature on these problems.

During this period Wittrick found time to examine a number of intriguing problems in the wider field of engineering. One example was his work on the stability of a heated bimetallic disc, which constituted one of the few exact solutions of the stability of a non-linear elastic system to be published up to that time. The behaviour of the disc also relates to the thermo-elastic stability of skin panels of supersonic aircraft and missiles. Another example was his study of the theory of crossed flexural pivots, which had been widely used in scientific instruments, particularly balances, because of their inherent lack of friction. When subjected to load they exhibited certain phenomena associated with their stability that were often undesirable. Wittrick's papers on this topic gave a comprehensive analysis of their behaviour and led to the design of new and improved flexural pivots in which the undesirable features were to a large extent eliminated.

By 1953, having devoted some years to research on swept-back wings in an environment somewhat remote from other centres of aeronautical research, Wittrick decided that it was time to acquaint himself more fully with overseas ideas on these problems. He therefore arranged to spend about six months at the California Institute of Technology working with a group interested in the structural behaviour of swept-back wings. He was awarded a Fullbright/Smith-Mundt grant and appointed a Research Fellow at CIT where he was invited to conduct weekly seminars on the results of his own research. Also, in collaboration with Professor Y.C. Fung, he made a study of a (structural) boundary-layer phenomenon that occurs, for example, at the free edges of thin cantilever plates in the large-deflexion regime. This edge effect involves localised out-of-plane displacements that result in middle-surface forces which, because of the curvature of the plate, have components acting normal to the plate. Over a narrow region, typically of order (plate thickness/plate curvature)1/2, these forces cause the moment per unit length in a direction normal to the boundary to increase from zero to a value that effectively enables the interior regions of the plate to deform linearly into a developable surface. When this research was undertaken, Fung and Wittrick were unaware of the inextensional theory of plates(1) that gave a general technique for determining the generators of such developable surfaces. These separate researches were, however, complementary because the one provided details of the localised mechanisms required for the other. Interest in these researches stemmed from their application to very thin solid wings and fins on missiles.

On his return to Sydney, Wittrick was promoted to Reader. One of the referees was a senior member of CIT who made the comment: 'Dr. Wittrick is the type of scholar and research worker that we would have liked to keep at CIT as a member of our permanent staff. This is not only the feeling of those in the Aeronautics Department, but also of the staff members in our Applied Mathematics, Mechanical Engineering and Applied Mathematics groups'.

In 1956, Wittrick succeeded Stephens as Lawrence Hargrave Professor of Aeronautical Engineering at Sydney, and was inevitably drawn more into the affairs of the Faculty where his clear thinking and grasp of essentials were greatly appreciated. Over the years, he had built up a reputation among staff and students not only as a scholar and research worker brimming over with ideas, but also as someone who had developed an excellent relationship with his small band of students both as a teacher and a friend. He had little time for academic politics and even less for ponderous administrative procedures and interminable committees. Nevertheless, he was prepared to give time to devising a scheme for processing examination results that, for students with good aggregates, allowed certain compensations for shortcomings in a few subjects. This did much to quicken the progress of these students without in any way reducing standards. He also found time to take part in sport. As one of his colleagues of that time, G.A.O. Davies (now head of the Department of Aeronautics at Imperial College of Science and Technology) has remarked, 'Bill Wittrick had this [respect] in full measure in all fields, including the sporting one. Postgraduates found that guile is a powerful weapon on the squash court and a pretty potent one in the hands of a slow spinner on a turning wicket too'. It was therefore particularly appropriate that for some years Wittrick served as Senate representative on the Sports Union Committee.

After the Comet aircraft disaster in 1953, Wittrick turned his attention to problems of minimising stress concentrations around the windows in aircraft fuselages. 'Neutral hole' theory(2) showed that it was theoretically possible to design a reinforced hole such that there were no stress concentrations in the surrounding plate. For the 2:1 stress field in a pressurised fuselage, the neutral hole is a square-root of 2:1 'vertical' ellipse - a not unreasonable shape - but the total weight of the required edge reinforcement is about 2.5 times the weight of the 'removed' plate. There is therefore a design trade-off between weight and stress concentration. The neutral reinforcement also exhibits a localised peak near the ends of the major axis, whereas the designer would prefer a uniform reinforcement. There was therefore a need to determine the stress concentrations due to elliptical and other holes with various degrees of uniform edge reinforcement. To tackle this formidable range of problems, Wittrick turned to analytical methods put forward by the Russian school of elasticians that had become known through translations by J.R.M. Radok of two of Muskhelishvili's books. In this way he was able to predict the stress concentrations around reinforced holes of 'rounded square' and 'rounded triangular' shape, in addition to the important 'neutral' elliptical shape that has been used in various civil aircraft windows. For part of this work Wittrick was awarded the Orville Wright Prize of the Royal Aeronautical Society.

An event that was of great interest to Wittrick was the establishment of a computer facility at the University of Sydney in 1956. This was probably the first viable digital computer in the Southern Hemisphere and was appropriately called Silliac since it was a development of the Illiac pioneered by the University of Illinois. Wittrick's early work on swept-wing structures and on stress concentrations around holes in shells, and his first excursions into plate bending, were more than enough to convince him of the research advantages of this new tool. Again his colleague Davies has given a graphic account of Bill's enthusiasm: 'The machine was as large as a double decker bus and its thousands of valves rapidly overtaxed the air-conditioning system, so that it was rarely 100% reliable. Bill could be seen, with the few academics willing to embrace such a monster, loading, compiling, bootstrapping and diagnosing faults on the machine itself - including corrective measures such as hitting the valves with a rubber hammer'. But for all its shortcomings, Silliac was not decommissioned until 1968.

On appointment to the chair, Wittrick began to take a more active part in the national research programme in aeronautics. He became a member of the Australian Aeronautical Research Committee, charged with the task of advising the Minister for Supply who had under his control the aircraft factories and Aeronautical Research Laboratories in Melbourne. In 1961 Wittrick was invited by the Minister to become chairman of this committee. It was therefore entirely appropriate that in 1962 he should be appointed one of the three Australian representatives on the Commonwealth Aeronautical Advisory Council responsible for co-ordinating aeronautical research throughout the Commonwealth.

Wittrick again went on sabbatical leave in 1960. Part of the time was spent as a visiting professor at the College of Aeronautics at Cranfield, and the rest making visits to universities and industrial organisations, first in the USA under the sponsorship of the Carnegie Corporation, then in Canada and certain European countries. He returned from this experience convinced that there were still many problems of plate buckling in need of examination. This is reflected in his subsequent papers such as those dealing with the effect of tapering thickness, elastic restraints and some further non-linear shell-boundary-layer effects.

In 1964 Bill Wittrick was still a comparatively young man of forty-two. He had been nearly twenty years in the same department and was obviously ready for some new challenge. To his colleagues he frankly expressed the view that it would be a good thing for himself and the vitality of his department if he were to move on. He had made outstanding contributions to the fund of Australian research that had been recognised by special awards and notably by his election to Fellowship of the Australian Academy of Science in 1958. He had played a full and active part in all aspects of university life and was currently Dean of the Faculty of Engineering. His acceptance of the chair of structural engineering at the University of Birmingham was a matter of great regret. Yet Bill, Joyce, Jane and Ann - as the family were affectionately known - left Australia with the sincere good wishes of friends, colleagues and students alike.

Birmingham University (1964-1982)

After going to Birmingham University in October 1964, the main thrust of Wittrick's research was to provide aerospace designers with the means of calculating, accurately and efficiently, the buckling loads or natural frequencies of vibration, together with the associated modes, of thin prismatic structures, the individual walls of which are subjected to uniform biaxial compression and shear and may have either isotropic (metal) or anisotropic (composite) elastic properties.

The work started in a fairly small way from an idea Wittrick had in 1965 for extending the Engineering Sciences Data Unit - Structures Data Sheets on the local (i.e. short wavelength) buckling of stiffened isotropic panels to cope with loading cases in which the individual flats carry shear in addition to longitudinal compression. The wavelength was supposed to be sufficiently small compared with the panel length for end effects to be ignored, so that the panel could be considered to be effectively of infinite length. It was assumed that the longitudinal line junctions between adjoining flats remained straight during buckling, but that rotations occurred about them. The fact that the nodal lines in the flats are curved in the presence of shear loading, resulting in (spatial) phase differences between the sinusoidally varying rotations about the various junctions, was allowed for by introducing complex vectors of rotations and the concept of complex 'stability functions'. The stiffness matrices turned out to be complex Hermitian. This work was done in conjunction with a Ph.D. student, P.L.V. Curzon, and resulted in four joint papers published in 1968 and 1969.

Wittrick quickly realised that the approach could be generalised to include all possible forms of buckling in a unified way, provided that the prevailing conditions were such that all modes were sinusoidal or nearly so. That is the case if the stresses in the flats are invariant in the longitudinal direction, and either the ratio of half-wavelength to the panel length is small enough for end effects to be unimportant or (in the absence of shear loading) the ends of the panel are 'diaphragm supported'. In general the longitudinal line junctions no longer remain straight during buckling and each one has four (complex) degrees of freedom associated with it, consisting of three translations plus one rotation. In order to cater for the destabilising effect of the membrane loading in the flats on in-plane deformations (which is necessary, for example, in the case of a web of a stiffener in an overall mode, or a flange of a stiffener in a torsional mode), it was necessary to base the equations of equilibrium of the theory of elasticity on the geometry of a deformed element. The analytical basis is provided in 'A unified approach to the initial buckling of stiffened panels in compression', Aeronautical Quarterly, 19 (1968), 265-283, for calculating the buckling loads of panels under uniform longitudinal compression. This was extended in 'General sinusoidal stiffness matrices for buckling and vibration analyses of thin flat-walled structures', Int. J. Mech. Sci., 10 (1958), 949-966, to include more complicated load systems, with each flat subjected to biaxial compression and shear. Moreover, by permitting all forces and displacements to vary sinusoidally with time, the analysis also opened up the possibility of calculating either the critical buckling loads (corresponding to zero frequency) or the natural frequencies and modes of a loaded panel, within a single computer program.

The one big problem remaining, before the by now large body of theory could be incorporated into a general-purpose computer program for use by designers, was how to extract the eigenvalues, i.e. the critical loads or natural frequencies. Because the stiffness matrices are derived from exact solutions of the partial differential equations, the elements of the overall stiffness matrix (the singularity of which provides the criterion for calculating the eigenvalues) are transcendental functions of the eigenvalues and not linear ones as in a conventional (approximate) finite-element solution. The only known method of solution at that time was by trial and error, based upon the value of the determinant. For many reasons this is both unreliable and inefficient. First, it is all too easy to miss eigenvalues in the event of coincident or nearly coincident ones; secondly, it is impossible to know a priori how small to make the load (or frequency) increment in the trial and error process; thirdly, the determinant may change sign via infinity as well as via zero; fourthly, such infinities in exceptional cases coincide with each other and with zeros; and finally such methods are extremely difficult to incorporate into a general-purpose program.

It took several years to overcome this problem but, in the end, F.W. Williams and Wittrick developed an extension of the Sturm sequence procedure. In both buckling and vibration problems it enables the number of eigenvalues lying between zero and any chosen value to be calculated with ease and provides a safe, reliable and efficient algorithm for general-purpose programs. The algorithm was first published in the context of vibration of skeletal frames and then of any linearly elastic structure but was also extended to apply to the buckling problem. It should be noted that in the latter problem, unlike the vibration one, both positive and negative eigenvalues can occur in general. The algorithm also provides a straightforward exact means of assembling the structure from substructures which may themselves be assembled from smaller substructures and so on to any depth, thereby enabling the maximum possible advantage to be taken of any repetition as is usual in stiffened panels (e.g. identical and equally-spaced stiffeners). The algorithm has found many applications and was developed further to cover vibration of spinning bodies.

Finally the whole analysis was further extended to include anisotropy of the individual flats, such as occurs in composite structures. It was assumed that there is no interaction between bending and membrane forces and deformations (i.e. symmetric lay-ups) and that the membrane properties are orthotropic (i.e. equal numbers of plies in the +0 and -0 directions). The bending properties were taken to be fully anisotropic, including interaction between bending and twist.

The later stages of development of all this theory, and its incorporation into the general-purpose computer program called VIPASA (Vibration and Instability of Plate Assemblies with Shear and Anisotropy), was carried out under a research contract supervised by Dr. F.W. Williams (later Professor of Civil Engineering, UWIST, Cardiff). The program was commissioned during 1972 and handed over to the Royal Aircraft Establishment and the aerospace industry.

Following a joint paper about this work that was presented at an IUTAM Symposium at Harvard in 1974, the program was extensively tested by NASA and subsequently made available to all the major aerospace organisations in the USA and Britain. It has been used on numerous design projects and was immediately chosen by NASA for checking the design of the Space Shuttle. In the latter role it correctly predicted a type of buckling failure that had been missed in the design stages and was only found during test.

Wittrick's plate and eigenvalue work led more or less directly to many other papers. However, his interests were much broader than this and led to significant contributions in other areas.

Wittrick's work on the stability of plates opened up the possibility of a better understanding and the solution of a number of structural problems in civil engineering. These have been examined by research workers in various countries. In Australia, use has been made of Wittrick's analyses by N.W. Murray (professor of civil engineering at Monash University) to obtain theoretical results for comparison with some careful experimental studies of the influence of initial imperfections on the buckling loads of steel plates. The treatment described by Wittrick is an exact solution and was later followed up by an alternative semi-analytical finite-strip method. The latter has been extended by G.J. Hancock (associate professor of civil engineering at the University of Sydney) to interpret the behaviour of steel I-beams fabricated from steel plate when subject to local, distortional and lateral buckling.

Retirement

For a number of years Wittrick suffered increasingly from breathlessness. This became much worse in 1979, when it was diagnosed as the restrictive airways disease emphysema. Thereafter he regularly used inhalers to alleviate - but not cure - the condition, but his activities were severely restricted as a result. In addition he felt increasingly out of place as head of a fairly large department of civil engineering because his research interests, as well as most of his close professional contacts, were predominantly in the aeronautical field. Further, in view of the increasing pressure upon university engineering departments to develop closer ties with industry and to turn out graduates supposedly more useful to industry, Wittrick felt more and more that he should make the way clear for the University to replace him with someone more strongly in sympathy with these views and more committed to civil engineering. The University agreed to his request in February 1980 that he be allowed to stand down from the headship of the department (to which he had been appointed as a permanent position) whilst still retaining his chair. Wittrick then applied for, and was granted, three months' sabbatical leave later in the year in order that he should not appear to be 'breathing down the neck' of his successor, friend and colleague Michael Hamlin when he assumed office in September.

When in 1980 Wittrick retired from his position as Beale Professor in the Department of Civil Engineering at Birmingham, his colleagues working in his own particular area of technical interest wished to mark the occasion by providing some form of permanent record in his honour. This took the form of a book comprising contributions from some of his many friends and colleagues in the field of structural mechanics. Appropriately, the volume was published by the Oxford University Press with which Wittrick had had a long association, not least as one of the editors of the Oxford Engineering Science series.

Early in 1982, Wittrick decided to retire at the age of 60, partly because his illness was making it increasingly burdensome for him to carry out his professional duties, partly because of the financial squeeze that was by then causing all British universities to encourage early retirement. He was elected Emeritus Professor and was given the use of a small office in the Department of Civil Engineering which he valued greatly, going to Birmingham for one day in most weeks. This enabled him to continue to do some research, and to have the stimulus of talking to colleagues with interests similar to his own. The standard of his contributions did not decline after retirement nor did their quantity reduce very much. His mind was as alert as ever and the pleasure of his company was only qualified by sadness at the trying physical restrictions caused by emphysema that he bore with great patience but which were too obvious for him to hide, even though by nature he would have wished to do so. He died on 2 July 1986.

Australian friends and colleagues will remember Bill Wittrick as a man of cheerful disposition and a great sense of fun that he sometimes allowed to disguise his considerable intellectual qualities. Even so he was by nature a quiet man with the ability to derive great satisfaction from the simpler things of life. He and his charming wife and their two daughters were an ideal family; Bill and Joyce never allowed their own activities to detract from the care and concern they had for the well-being and education of their children. They made many friends and their friendship had about it a constant and enduring quality; and when they returned to England those friends when travelling overseas would always be sure of a warm welcome at the Wittrick home.

To Bill, research was a very important part of his life; he gained immense satisfaction from developing mathematics to reveal the complex modes of behaviour of metal structures. He had a great respect for the power of mathematical analysis and an equal regard for clear definition of the mechanics of the problems he chose to study. He had the gift of exceptionally clear exposition, evident in all his writing, teaching and supervision of research.

He was especially interested in the part that skill and craftsmanship play in producing the beautiful things with which we like to surround ourselves. He had himself acquired considerable skill in the use of woodworking tools and he took much pleasure in making many fine pieces of furniture, some entirely to his own design. In later years he turned his attention to bookbinding and there exist some particularly elegant examples of his work.

The image of the man comes more clearly into focus in the following personal reflections of a few of those who had the privilege of working closely with him.

Professor G.A.O. Davies writes:

In 1959, as a young engineer in the Advanced Projects Office at British Aerospace Filton, I knew of Bill Wittrick as a very useful reference for certain plate buckling problems and when I was offered the opportunity to join him at the University of Sydney I looked forward to meeting a scientist and a scholar. I was not disappointed.

The Department of Aeronautics in Sydney was small even though it was the only such Department of Aeronautics in Australia. Some thirty third- and fourth-year undergraduates, with a handful of postgraduates, meant that the teaching and research load could be adequately managed by the Head of the Department (Professor Wittrick), the Reader - P.T. Fink (later Chief Scientist, Department of Defence, Australia), a Senior Lecturer - J.J. Mahony (later Professor of Applied Mathematics at the University of Western Australia) and myself. Such a small department meant that the staff knew all students intimately and vice-versa, so the opportunity to foster young research talent and watch it mature was an experience few enjoy today. Bill Wittrick clearly enjoyed this role and commanded always the affection and loyalty of all undergraduates and research students.

In the early sixties his work on swept-wing structures, on stress concentrations around holes in shells, and his early excursions into plate bending led him naturally to the infant digital computer. His enthusiasm was not blinkered, however, and he was still producing elegant analytical solutions. When he returned to England after nearly twenty years at Sydney University he left behind hundreds of graduates and postgraduates who remember an enthusiast with the ability to communicate, a researcher full of ideas and eager to share and a scholar whose papers were a model of lucidity. His many academic colleagues and students counted him as a friend. He was always direct and never oblique. Above all he was a gentleman in both senses. In the past 26 years that I have known him I never once heard an unkind word spoken of him, he enjoyed a unique mixture of respect and affection. His many papers are a fitting memorial to his scholarship, but his enthusiasm, industry, loyalty and sense of fun remain embedded in the memories of his colleagues, co-workers, and students in the United Kingdom and in Australia.

Professor F.W. Williams has said:

Shortly after my move to Birmingham in 1967 Bill invited me to work with him to develop computer programs which were the fore-runners of the later VIPASA. Then I quickly experienced a sense of privilege, respect and even awe, which I think was probably typical of all Bill's junior co-workers. His courtesy and consideration was unfailing. An abiding memory is the way he would identify and remove one's areas of ignorance. He would ascertain that a particular point, or a whole area of work, was outside one's experience in a way which was direct but never crushing. Then he would pick up his fountain pen (never a biro!) and write rapidly, in bold and clear script, an explanation the lucidity of which is rarely matched even in lectures which have taken hours to prepare. I soon formed a strong image of our relationship as that of a craftsman and his apprentice, and Bill, like the best of master craftsmen, passed on by example and training the very highest standards of scholarly integrity, enthusiasm and thoroughness.

Associate Professor G.J. Hancock writes:

In 1978 I published a paper on the local, distortional and lateral buckling of I-beams using the semi-analytical finite strip method of Plank and Wittrick. When I arrived in Birmingham in October 1978 to spend six months sabbatical leave working with Professor Wittrick, the first question he asked me was why I had chosen the semi-analytical method in preference to his earlier published exact method. It became clear from our subsequent discussions that although he had been a major contributor to the former method his heart lay with the latter.

The main purpose of my work at Birmingham was to develop a non-linear analysis of plates in the post-buckling range, using the semi-analytical finite strip method, a task in which I received from Professor Wittrick maximum support both financial and intellectual. We met at regular intervals when he would listen to a summary of what I had been doing and then give me a set of references from which he thought I might clarify some of my difficulties and misunderstandings. I look back on those sessions as one of the most stimulating periods of my career.

The semi-analytical method continues to be developed by other research workers including Professor Murray at Monash University, Professor Sridharan at Washington University and at Sydney University to include material plasticity and to demonstrate the advantages of incorporating the spline finite strip method. Professor Wittrick took a keen interest in all this work and communicated with me regularly right up to the time of his death.

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Notes
(1) Mansfield, E.H., 'A large-deflexion theory for thin plates', RAE Rep. Struct., 153 (1953); see also Quart. J. Mech. & Appl. Math., 8 (1955), 338-352.
(2) Mansfield, E.H., 'Neutral holes in plane sheet - reinforced holes which are elastically equivalent to the uncut sheet', RAE Rep. Struct., 90 (1950); also Aero. Res. Council, Rep. & Memo., No. 2815.

Selected Publications:

W.H. Wittrick, “Correlation between some stabililty problems for orthotropic and isotropic plates under biaxial and uni-axial direct stress, Aero. Quart., Vol. 4, pp. 83-92, 1952

Wittrick, W. H., Myers, D. M., and Blunden, W. R., 1953. “Stability of a bimetallic disk”. Quarterly Journal of Mechanics and Applied Mathematics, 6(1), p. 15.

Y.C. Fung and W.H. Wittrick, “A boundary layer phenomenon in the large deflexion of thin plates”, The Quarterly Journal of Mechanics and Applied Mathematics, 1955, Oxford University Press,
doi: 10.1093/qjmam/8.2.191
ABSTRACT: In the large deflexion of thin plates with free edges, boundary layers develop along those edges under certain conditions. The non-linear effects of membrane stress are confined to the boundary layers and elsewhere the equations are linear. Boundarylayer equations are derived and integrated, and are then applied to some specific problems.

W.H. Wittrick. Rates of change of eigenvalues, with reference to buckling and vibration problems. Journal of the Royal Aeronautical Society, 66:590–591, 1962.

W.H. Wittrick, “General sinusoidal stiffness matrices for buckling and vibration analyses of thin flat-walled structures”, International Journal of Mechanical Sciences, Vol. 10, No. 12, December 1968, pp. 949-966, doi:10.1016/0020-7403(68)90049-0
ABSTRACT: This paper is concerned with the derivation of stiffness matrices for the buckling or vibration analysis of any structure consisting of a series of long, thin, flat plates rigidly connected together at their longitudinal edges. Each plate is assumed to be subjected to a basic state of plane stress which is longitudinally invariant, and it is further assumed that the mode of buckling or vibration varies sinusoidally in the longitudinal

direction. During buckling or vibration, the edges of any individual plate are subjected to additional systems of forces and moments which are sinusoidally distributed along the edges, and these give rise to sinusoidally varying edge displacements and rotations. Spatial phase differences between the forces and displacements are accounted for by defining them in terms of complex quantities. The sinusoidal edge forces and displacements are split into two uncoupled systems, corresponding to out-of-plane and in-plane displacements, and two stiffness matrices are defined. The out-of-plane stiffness matrix is shown to be in general complex, and Hermitian in form, but the inplane stiffness matrix is real and symmetrical. Explicit expressions are derived for the elements of the matrices, in which all the essential destabilizing effects of the basic stresses, as well as dynamic effects, are included. Finally, it is shown that buckling and vibration phenomena for any structure of this type are closely interrelated.

Wittrick, W. H., "A Unified Approach to the Initial Buckling of Stiffened Panels in Compression," The Aeronautical Quarterly, Aug. 1968, pp. 265-283.

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Wittrick, W. H. and Williams, F.W. A general algorithm for computing natural frequencies of elastic structures. Q. J. Mech. Appl. Math., 1971, 24(3), 263-284.

W.H. Wittrick (Department of Civil Engineering, University of Birmingham, Birmingham 15 UK), “On the local buckling of truss-type corrugated-core sandwich panels in compression”, International Journal of Mechanical Sciences, Vol. 14, No. 4, April 1972, pp. 263-264, doi:10.1016/0020-7403(72)90067-7
ABSTRACT: A theoretical analysis of the local buckling of corrugated-core sandwich panels with truss-type (i.e. triangular) corrugations in compression is developed. It has the unusual feature that the nodal lines of the buckling mode are not assumed to be straight and perpendicular to the direction of compression. Such modes are found to correspond to slightly lower buckling stresses than the usual type, for panels with a wide range of geometries. The existence of modes of this type has been observed experimentally.
Wittrick, W. H. and Williams, F. W. An algorithm for computing critical buckling loads of elastic structures. J. Struct. Mech., 1973, 1(4), 497-518.

W. H. Wittrick and F. W. Williams (Department of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, England), “Buckling and vibration of anisotropic or isotropic plate assemblies under combined loadings”, International Journal of Mechanical Sciences, Vol. 16, No. 4, April 1974, pp. 209-239, doi:10.1016/0020-7403(74)90069-1
ABSTRACT: This paper describes the underlying theory, and a general-purpose computer program, VIPASA, for determining the critical buckling stresses or natural frequencies of vibration of thin prismatic structures, consisting of a series of plates rigidly connected together along longitudinal edges. Each plate may be either isotropic or anisotropic and may carry a basic stress system consisting of longitudinal and transverse direct stress combined with shear. The structure is assumed to be subjected to a “dead load” system which does not cause buckling; in addition a “live load” system, defined in magnitude by a single load factor, may be applied and the value of the load factor at buckling is determined. Alternatively the natural frequencies of vibration of the structure when subjected to the dead load system are determined. Any number of critical load factors or natural frequencies can be obtained. The theory is based upon the assumption that all modes are sinusoidal, in the sense that all three components of displacement vary sinusoidally along any longitudinal line, but phase differences are incorporated to allow for the effects of anisotropy and shear. Apart from this assumption no

further approximations are made other than those inherent in thin plate theory.

Plank, R. J. and Wittrick, W. H. Buckling under combined loading of thin, flat-walled structures by a complex finite strip method. Int. J. Numer. Methods Eng., 1974, 8(2),323-339.

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