# Kinematics

**By John Gal**

The story of kinematics and its teaching in the Department of Mechanical Engineering is really the story of the people who loved and championed this area of engineering knowledge and discovery. The two people most responsible for the flowering of Kinematics as a separate and distinct area of teaching and research were Jack Phillips and Arthur Sherwood. The person who promoted the need to employ academics with a commitment to this particular discipline was Professor Tom Fink, Head of Department in the 1960s.

Kinematics is the study of the geometrical arrangements of links and joints and their relative movement. Before the arrival of Jack Phillips and Arthur Sherwood, kinematics was just one component of existing subjects such as Engineering Mechanics and Dynamics of Machines. In these subjects, kinematics was considered as a necessary, but only preliminary, part of the mathematical analysis of the velocities, accelerations and forces needed in the design of real machines. As far as is known, in the study of the mechanics of machines there was no particular separation between the kinematics - the study of movement in mechanisms and machines without taking into account mass or inertia - and the kinetics, where the forces as well as mass and inertia need to be considered in the analysis and in the synthesis or design of mechanisms and machines.

## The Phillips-Sherwood Era

Together, Jack Phillips and Arthur Sherwood, completely different personalities, formed a strong friendship. They became the motivating force in establishing and developing kinematics as a distinct engineering discipline and one that attracted, due to no small extent to the special personalities of both, a number of undergraduate thesis and postgraduate students.

Arthur Sherwood was initially employed as Senior Lecturer and had a background in real-world engineering in England, where he had worked in industry and gained a degree in mechanical engineering from the Woolwich Polytechnic Institute. Although he never obtained a PhD, Arthur Sherwood was equipped with an intellectual and scientific capability well beyond the ordinary PhD graduate (as well as beyond quite a few academics). He had, however, quite an eccentric personality, including an almost complete disinterest in his own advancement and no desire to promote his abilities.

In 1963, Dr Jack Phillips came from the University of Western Australia to take up the position of Associate Professor in the Theory of Machines. The inclusion of this specific area in his title was of great significance to Jack. Throughout his period at the Department he made a point of reminding colleagues and others about this fact. This was especially the case when arguing with respect to teaching allocation, equipment funding or philosophical issues of engineering in general and when challenged to justify the continued existence of such a discipline and area of research.

It was also Jack Phillips’s special ability to relate to people of all backgrounds and personalities. This skill allowed him to form collaborations as well as life-long friendships with academics around the world, including the US, China and Eastern Europe, when it was still under communist rule. When visits to communists countries were regarded with suspicion, and could have materially damaged employment prospects at University, Jack pursued these contacts regardless and in no small measure was instrumental in the formation of the IFToMM group (International Federation of the Theory of Machines and Mechanisms) as a founding Member. In Europe and specifically in the Eastern Bloc, Jack's proficiency in the German language was especially important, as that was the language in which he could communicate with academics in such disparate countries as Poland, Romania, Yugoslavia, East Germany and Hungary.

It can be argued that without his involvement as someone from the West, and with his particular personal skills in developing these contacts, IFToMM may not have been established as an organisation that encompassed both the East and the West. Throughout his working life and to the end of his life in 2009, Jack maintained all the contacts he had established with an understanding of what tremendous value such a world-wide professional source of knowledge represented. His unique international contribution was recognised in 2005 with the award of a medal by the IFToMM executive.

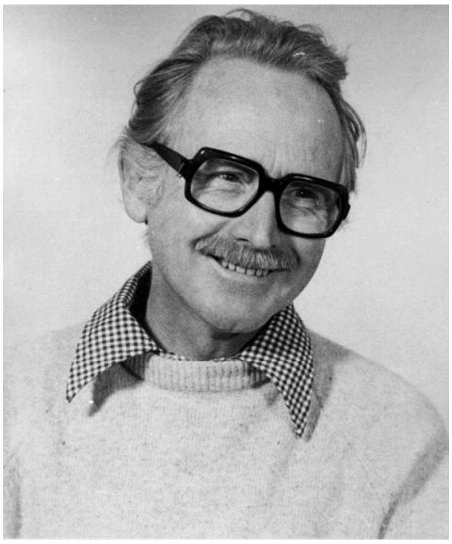


**Figure 1** Jack Phillips, photographed around 1980.

**Figure 2** At the 2004 IFToMM World Congress in Tianjin, China. Left to Right: Jack Phillips; Karl Wolhart, (Austrian Kinematician); Elayne Russell (Jack's partner.)

The era of the 1960's and early 1970's was one in which both students and academics had tremendous freedoms in terms of speaking out, protesting against University decisions and supporting political causes, as well as in pursuing areas of studies of whatever interest. This contrasts sharply with more modern times, when there is no-holds-barred competition not only for funding, but for publications and for acquiring teams of research students and staff, as well as concern about prospects for employment. In the 1960s students tended to attend classes, no matter how boring, for several reasons. Firstly, lecture note handouts were very rare and copying notes taken by other students was highly unreliable, except notes taken by the very best students. So, on the whole, students attended lectures and tutorials even if they gained very little from them.

Secondly, the content of lectures tended to reflect the personal interests, research oriented or otherwise, of the lecturer. This was in many ways regarded as a good thing since, in the main, each lecturer delivered something about which they had a deep knowledge and interest. Students picked up on whether the lecturer was genuine in his enthusiasm or not. However, this approach led sometimes to wild and often fruitless searches in the library for books that could shed further light - or any light sometimes - on the subject of the lectures. So, lectures often consisted of handwritten notes being written in chalk on the blackboard and students furiously trying to copy it all down with not much chance to absorb the material, nor time to understand the underlying theory in any depth.

There were exceptions to this stereotype and certainly one of those was Jack Phillips's lectures in kinematics. Armed with a box full of coloured chalk as well as the occasional working model of a linkage, Jack proceeded to draw diagrams of linkages showing velocities in pink, (for example), components of velocities in green, and the actual displaced new configuration of the linkage in yellow over the top of the existing diagram. Over a period of fifteen to twenty minutes the diagrams took on the appearance of a bird's nest, with lines and vectors going in all directions. Of course there was no point in trying to reproduce these diagrams in any notes taken during the lecture, but Jack Phillips never intended it to be so. His aim was to convey understanding of the concepts, not to provide notes as such. If one really listened and watched, quite often the light-bulb of sudden enlightenment lit up.

Almost always, the notes that Jack brought to lectures consisted of at most one sheet of paper. The reason for the paucity of lecture notes was based on Jack's considered pedagogical philosophy that the most important way to transmit knowledge is to concentrate on understanding the fundamental idea behind a topic. Thus there was no need for equations or even vector algebra in analysing (for example) the velocity characteristics of a machine or linkage, no matter how complex. A vector, representing the velocity of a point in a link, drawn perpendicular to that link rotating about a centre, speaks volumes about the behaviour of that link. The task of determining the precise value by means of trigonometry, vector cross products etc. becomes a trivial task that should be left to the student to do. The main issue is: how do you determine where that centre of rotation is at the instant, and what general principle applies to mechanisms whether these are two-dimensional (as most machines are) or three-dimensional? It was this approach that led to the coloured diagrams and the relative dearth of written notes.

**John Woolley Building**

There was always something special, perhaps even rebellious, about Jack Phillips and therefore about the subject of kinematics as well. In the 1960's and until 1974-5, when Mechanical and Aeronautical engineering moved to the new building in the Darlington precinct, Jack's office was at the front of the John Woolley building. It had large windows looking out towards the entrance and a relatively spacious interior, or so it seemed to students of the time. Most outstanding was the couch and the en-suite toilet facility of this office.

The need for the en-suite was fairly clear, especially when student consultation in Jack's office was scheduled after extended lunches and drinks in the staff cafeteria, but the precise purpose of the couch was open to speculation and there was a lot of that among students. If Jack Phillips's office layout was not enough to provide interest, then certainly his dress sense was. In Engineering he was unique in the wearing of the famous safari suit, which almost without exception was accompanied by a safari-type shirt that had to have two pockets. Jack's whole appearance and demeanour starkly differed from the rest of the suit or tie-and-tweed-jacket wearing staff, reflecting the differences in social outlook as well as political philosophy. On the one hand you had Professor Phillips, considered a radical (or even, heaven forbid, a socialist) as far as politics is concerned, always challenging people about their beliefs as well as about their concepts of kinematics. On the other hand there was the quite conservative student cohort, at least in engineering, and a significant number of conservative academic staff. Of course there were both students and staff members who did share Jack's philosophy, but they seemed to represent a minority.

The period of the Sixties was also when the Vietnam War and conscription was an all-embracing political issue which permeated every aspect of University life. Generally, engineering students viewed the world from the conservative end and regarded Arts students in particular as being not only radical but also as having no useful employment prospects. Engineering students felt that Arts students would be unable to make a contribution to society, unlike themselves, who would after graduation contribute something tangible and praise-worthy to society, such as a bridge or a power station. In some ways, differences in politics and philosophical approaches reflected differences in personalities as well. These manifested themselves at various times in the way Kinematics was viewed.

Later, in the Eighties and Nineties, when computers became ubiquitous in all aspects of engineering, some viewed Kinematics as no longer relevant, since the geometry and the vector algebra could all be done automatically by computers. This view and the personality differences (according to some observers) created conflict between Jack Phillips and others and resulted in Kinematics being out of favour as an area of research. This period was in the latter stages of the Jack Phillips and Arthur Sherwood era and coincided with the approaching retirement of both in the early and mid-Nineties. Afterwards Kinematics began to be absorbed into other subjects in the undergraduate program.

Apart from Jack Phillip's office there was of course the atmosphere of the John Woolley Building itself, centrally located close to Manning House and to the Quadrangle, offering plenty of opportunities for mischief. Right opposite Jack Phillips's office near the entrance to the building was the main Lecture Theatre, consisting of a ground floor entry door but also including an upstairs dress-circle section of about a dozen seats. Mr. Gordon Vonwiller was the Mechanical Design lecturer in that lecture theatre and it was well-known amongst students that his lectures were not the most engrossing. Students in the dress circle or peanut gallery tried to lighten up the proceedings, using the somewhat unimaginative action of launching paper aeroplanes from this ideal location whenever Mr. Vonwiller turned his back to the class.

A much more entertaining caper was devised by one Tom Fink who just happened to be the son of Professor Tom Fink, Head of Department. Tom Fink (Jr) came in late by a few minutes one day and, having nodded to Mr. Vonwiller, sat down at the back of the lecture theatre downstairs. Some minutes later, Tom again entered by the front door, whereby Mr. Vonwiller (appearing not to have recognised Tom) carried on without stopping. When Tom Fink came through the front door for the third time the expression on Mr. Vonwiller's face was not one of amusement. It is unclear what, if any, disciplinary punishment Tom Fink suffered for this outrageous behaviour, but students of the time well remember the event. They talked about the way Tom climbed out the back window of the lecture theatre, which faced towards the front of the building, before making each new entrance into class.

**Mechanical Engineering**

After a first year of science-only subjects, the second year engineering course consisted of one subject called Engineering (or something similar) while the other three subjects included Physics, Mathematics and one other (depending on the discipline and on other options). The one Engineering subject was, however, actually broken up into at least six distinct subjects such as Mechanics, Materials, Electrical Circuits, Structures, Fluid Mechanics, Machine Drawing and Workshop Technology. In the 1960's unlike in the 1990s, Machine Drawing (and Descriptive Geometry) was programmed into a two-week period before the start of the teaching year. It involved an intense six-to-eight hours every day upstairs in the John Woolley building. Topics included how to sharpen a lead pencil in order to be able to draw a line of the correct thickness, third-angle projections and the engineering standards and symbols used in producing a working drawing from which the product or component could be manufactured. This is a long way from current practices, where 3D models can be produced in a CAD system from which the 2D drawings can be automatically generated, without worrying about such details as hidden lines or thicknesses of lines.

The Workshop Technology subject was also (sort of) outside normal working hours. It was given at the Sydney Technical College (later to become the Institute of Technology and then UTS) on Friday afternoons and evenings, a total of eight hours from 1pm to 9pm. Although the course included lectures on the theory of such topics as machining, welding, forging and casting, at least half of the time was spent in actual practical work such as using a lathe, arc welding and hand tools, activities far from the minds of present-day engineering students. These activities may appear outdated today, but students of the sixties and seventies found this immensely useful and it also provided tremendous opportunities for bonding with fellow students while working together for extended periods of time and having to focus on one specific area.

Kinematics was taught in third year by both Jack Phillips and Arthur Sherwood. The breakdown between them tended to be along the lines that Jack taught the analysis part, the freedom and constraint in mechanisms, the determination of velocities and accelerations of known mechanisms. Arthur concentrated on the synthesis aspects of kinematics, namely the methods of designing a new linkage or mechanism that satisfies certain specified design criteria, such as a coupler point of a 4-bar mechanism having to follow a trajectory that passes through a number of specified points.

The teaching of kinematics continued throughout the Seventies, Eighties and Nineties in the same way, always including the use of actual physical models of linkages and mechanism and with an emphasis on geometrical approaches to analysis and synthesis. The kinematics laboratories in both the old John Woolley building and in the new Darlington campus building had a large number of models of working mechanisms and also models that represented a theoretical principle or geometry. A number of undergraduate thesis students as well as postgraduate students designed and constructed pieces of machinery or mechanisms that formed part of their research projects. These became part of the models on display in the laboratory. By the time Arthur Sherwood and Jack Phillips retired there were a number of glass cupboards filled with unique models and the lab itself was recognised and listed as a genuine museum. A small part of this museum has survived as a display case in the School.

Over the years Jack Phillips also designed and built a Universal Display Machine, better known as “The Thing”, the purpose of which was to provide a platform for demonstrating the movement and function of different types of mechanisms and such practical mechanical devices as belts, constant velocity joints, bearings and gears. It was powered by a single electrical motor and all the moving devices were driven through belts, chains and gears by this single motor. The display machine showed the working mechanism of a sewing machine, the movement of a paint-mixer linkage, a number of different constant velocity joints, (including ones from front-wheel driven cars), as well as demonstrating kinematic theory such as the movement between two polodes (locus of the instant centre-of-rotation between two links of the mechanism) of a quick-return mechanism. This display machine is singularly attractive not only to students but to all visitors to the School, as it shows many things moving in an organised manner and yet it has the appearance of a Heath-Robinson machine.

## Hashim Durrani and Hasso Nibbe

In the John Woolley building, the Kinematics Laboratory was located right next to Jack Phillips's office and it also had an internal office crammed with two postgraduates. When Jack first arrived a technical officer was assigned to him in order to assist with the construction of the models, with the running of some experiments and with manufacturing equipment required for postgraduate projects. Hashim Durrani started in this role sometime in the mid-Sixties and moved on sometime in the early Seventies, replaced by Hasso Nibbe from New Zealand. Hasso had not only fitter-and-turner training but also technical drawing experience. Later when Jack was writing his two-volume treatise on screw theory, Hasso had a significant role in producing the final versions of hundreds of diagrams that Jack designed and drew from scratch. Many pieces of experimental equipment that filled the Kinematics lab were Hasso's handiwork.

These included the Universal Display Machine which Hasso built from its beginnings (to Jack's design specifications of course), starting with strange looking steel box structures joined together in an apparently random manner. The rationale behind this apparently random structure, however, can be seen in the 'completed' display machine today. In fact, it was never intended that this machine be 'completed' since its design specifically allowed for new models and devices to be added as required. This machine is virtually the School's only remaining visible legacy to Jack's hands-on approach to teaching kinematics and to his skills in practical machine design.

Hasso Nibbe was an interesting character with a very outgoing personality: he got along well with most students as well as with staff. It is true that during end-of-semester or Christmas parties his outgoing personality often rose to such great heights, (and one hopes that he won't mind this being mentioned), that he felt comfortable in making unusual comments and heckles during speeches by others. These interruptions were almost always accepted in good humour even when they were somewhat inappropriate and they provided hilarity in what otherwise may have been quite a sleep-inducing dissertation by the Head of Department (for example). The relationship between Hasso and Jack Phillips developed into a close friendship over the years, as did most of the relationships that Jack had with his postgraduate students and like-minded staff. They lasted well past Jack's retirement.

## Screw Theory & Jack Phillips

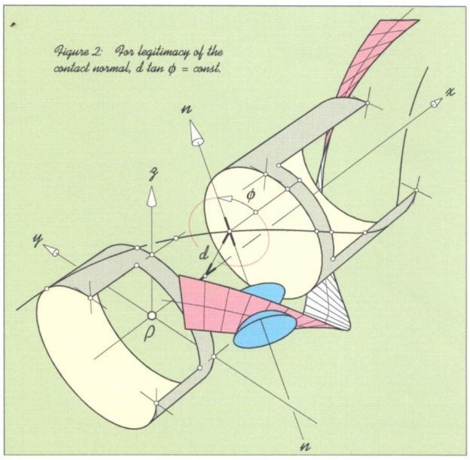
In almost all textbooks on kinematics for university undergraduate or even for postgraduate students, the mention of screw axes is completely absent. The reason for this is most likely to be that screw axes, or more simply screws, (the two-dimensional version of which are instantaneous axes of rotation) are used to represent the relative movement between pairs of links in a *three*-dimensional mechanism. In the most general case, when two members of a mechanism move relative to each other, they do so in a way where at every instant during that movement there exists a unique axis about which one link rotates but along which it also translates, relative to the other link. In other words, one link performs a screwing motion about the other. Such screw axes are 3D equivalents of the well-known and well-studied 2D instantaneous axes of rotation for planar mechanisms.

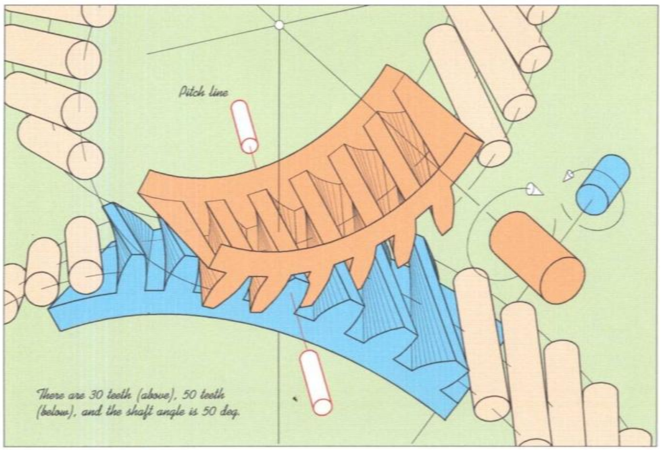
From his early days in Western Australia when he was designing and testing agricultural machines, Jack Phillips had been studying mechanisms in terms of the screws and the pattern of screws that exist in three-dimensional movement. In the kinematic community world-wide and in certain branches of mathematics this area is known as "Screw Theory". At first mention of this topic, students tend to snigger a bit and show some interest, thinking that it may lead to an area of their familiarity, but they soon discover that there is more to it than meets the eye. Jack always included some aspects of screw theory, the very basic aspects, in his teachings of kinematics. In a third year Mechanical Engineering course it represented the leading edge of theory of machines research.

The extension of the 2D version of the 'three-centres-in-line' theorem used in the velocity analysis of planar linkages to the third dimension in 1964 was one of the first research achievements of Jack Phillips in this area. He published a paper on it together with Professor Ken Hunt from Monash University, also one of the few prominent kinematicians in Australia [4]. This theorem showed that when three bodies are in relative motion and two of the instantaneous screw axes are known, then the third screw axis must be a member of a cylindroid defined by the two known screws. A cylindriod is a geometrical surface which consists of a central axis and straight lines intersecting it at right-angles all along the fixed length of the central axis, in such a way that they intersect a cylinder, based on the central axis, in a sinusoidal curve. Suffice to say that the pattern of straight lines represent all the possible locations of the third screw axis of the motion between the three moving bodies. In fact the cylindroid is a simple 'screw system'.

In 1984, Jack's first volume of a two-volume treatise on screw systems as applied to the theory of machines was published, after many years of work. It was entitled *Freedom in Machinery – Volume 1: Introducing Screw Theory*. The completed two volumes represented a life's work for Jack. Amongst those around the world who have a connection to this area it has been recognised as a work of exceptional depth and quality, unique in its written style (immediately recognisable as belonging to Jack) as well as in terms of its amazing hand-drawn illustrations.

After the second volume *Screw Theory Exemplified* was published in 1990, Jack set about applying his extensive familiarity with screw theory to developing a unifying theory for the families of spatial gears, including all involute-toothed gears. Examples of such gears in practice include the so-called hypoid gears one finds in rear-wheel driven cars and trucks. After his retirement in 1987, Jack worked on this project on his own and even taught himself how to use a CAD system, with which he produced many extremely complex and intricate three-dimensional diagrams of gears in mesh (and the related screw geometry) to illustrate his thesis. He presented his unifying gear theory at a number of conferences and meetings with gear experts. In 2003 a book on this was published under the title *General Spatial Involute Gearing* [5] and the work has found many admirers [1, 2]. Some of the large number of coloured drawings that formed the basis of the final publication are so spectacular that a sample is included here. Unfortunately the diagrams in the book are black and white.




**Figures 3.1, 3.2** Computer drawings by Jack Phillips of the geometry of general spatial involute gears.

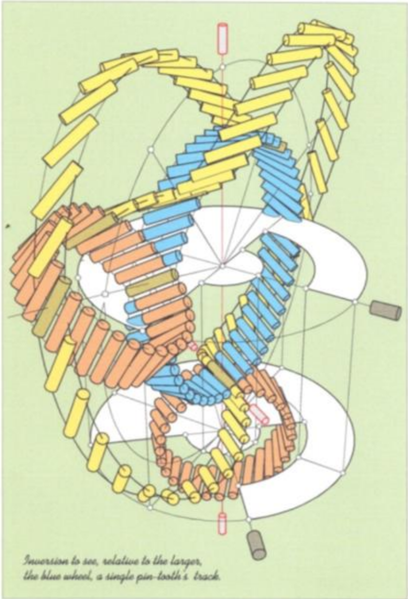



**Figure 3.3** Computer drawing by Jack Phillips of the geometry of general spatial involute gears.

Throughout the Seventies and Eighties Jack continued to teach kinematics to third year Mechanical Engineering students, while being more and more pre-occupied with the work on his two-volume opus on freedom and constraint in machinery and screw theory. In the process, he engaged a wide range of colleagues, postgraduate students and overseas experts in conversation and discussion about many aspects of the work that he was undertaking. Often postgraduates would be given part of a chapter to read and comment upon even as they were struggling with their own thesis writing. Jack always considered the feedback comments seriously, however, and the postgraduates had an opportunity to compare writing styles, points of grammar and presentation as well as ways to express concepts in an unambiguous manner.

During this period Jack was allocated the teaching of first year Statics, a level at which he had not taught since he arrived at Sydney University. The reasons for allocating this teaching to Jack are a little murky, but he was determined at the beginning of these students' engineering careers not only to make a good job of teaching, but also to instil the ideas of freedom and constraint, the fundamental relationships between forces/moments and linear/angular velocities, and even the basics of screw theory. This approach was spectacularly different from anything these students had experienced up to that point and may have been a little beyond the capabilities of a fair proportion of the class. Jonathan Vincent, a tutor at the time, remembers a tutorial assignment involving a dentist's chair. It required the identification of the screw axes and determination of some of the velocities. It was only in later years that students from this class finally understood the mechanics and realised the significance of what was taught to them in first year. Perhaps fortunately, Jack was not asked to teach first year Statics again, and he returned to teaching third year Kinematics.

Students 'sussed out' lecturers pretty easily and knew their weak points as well as their strengths. They often tried to take advantage of this knowledge when seeking extra marks or when complaining about exam results. In Industrial Organisation & Management, for example, the lecturer Roy Peterson took his subject very seriously, so when students made comments that most of what he was teaching was really "just common sense" he got quite annoyed. He regarded it as disparaging of his professional competence and of course that was precisely why students repeatedly made these comments.

Students noticed Jack Phillips's regular lateness to lectures, but he took it in good humour when students wrote a piece about this in the 1986 yearbook (reproduced here). Jack was perceived by students to be fair but eccentric (see 'Ode to Jack') and maintained very good relations with students even when they found themselves on the wrong side of a pass mark in an exam. On one particular occasion, Jack failed a student in a kinematics exam as he could not make head or tail of what was written in the paper. The student came to inquire why he had failed, and Jack, having no specific explanation for giving a fail mark, gave the paper to the student, saying "I could not make out what you are on about at all. Here, you tell me what this is all about." The student took a quick look at the paper and after a few seconds said: "F---ed if I know!"

**The Arthur Sherwood Story**

Looking back, the two academics involved in the teaching of kinematics could not have been more different in either background or character. Jack Phillips came from Melbourne with a private school upbringing, made possible only after winning a scholarship. In his professional life he gathered a very diverse and large group of acquaintances and contacts around the world, including many from East European countries. On the other hand, Arthur Sherwood came from a quite different public school background in England, and had a personality much less interested in building a large network of friends. Nevertheless, at some fundamental level the two personalities not only got on well, but built a close relationship with each other.

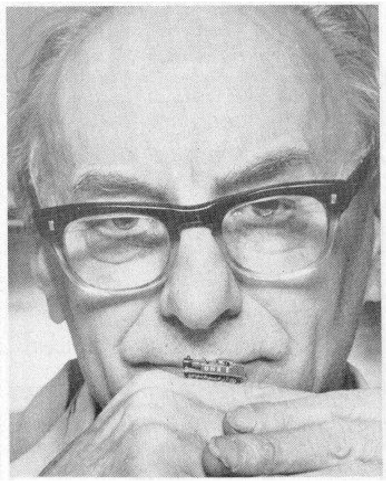
Their teaching methods were also quite different. Arthur Sherwood loved the mathematical approach and was often astounded that students did not follow the process as easily as he did. In fact Arthur was a genius and had many of the characteristics of what is the stereotype of a genius – a little absent-minded, incredibly innovative (as evidenced by his miniature trains and new biomedical devices), but also a little quirky in the way he interpreted everyday events and relationships. His quirky thinking is illustrated by his almost yearly contribution to the student yearbook of somewhat ribald ditties and poems. A few of the more restrained ones are included here (Figure 9).

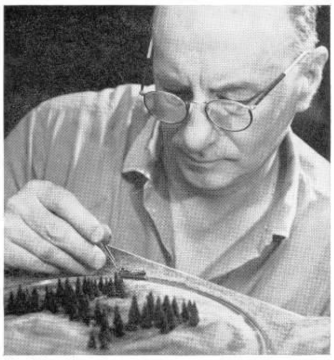
A signature characteristic of Arthur Sherwood, as far as students were concerned, was his habit of wearing plastic sandals and shoes in both summer and winter when such footwear was yet to reach the heights of fashion. Less well known was the fact that this footwear was invariably accompanied by purple socks and (thanks to information obtained much later) it turns out that he bought these purple socks in bulk, possibly a few dozen at a time. This was done in order to save himself from ever having to go shopping again, something which he disliked intensely.

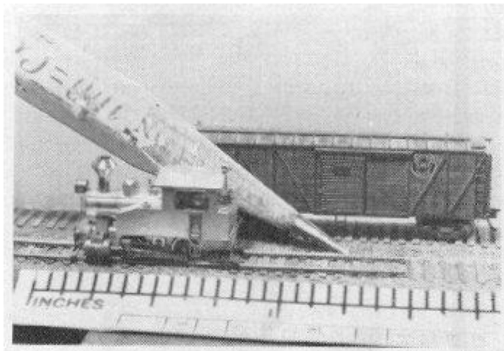
Such important aspects of academics' outward features played a large role in how students tended to categorise their lecturers, even if, deep down, they also understood and often valued the abilities and genuineness of each. At end-of-year barbeques students presented some staff with gifts that reflected their impression of what particular people "needed". In Arthur's case one year, students presented him with a pair of plastic thongs amid great amusement and laughter from all. Somewhat surprisingly, Arthur seemed to be puzzled as to the significance of the plastic thongs and according to some who were there was perhaps even a bit offended, but this is not certain. In any case, the plastic thongs were just one instance of students identifying particular foibles or habits of academics. Another was when, to go with his safari suit, Jack Phillips was presented with a pith helmet, which he proudly kept on display in his office for many years.

Arthur Sherwood taught physiotherapy students not only kinematics but also other subjects including Measurement and Instrumentation, and occasionally Biomechanics. One suspects that he could have taught almost any subject if he put his mind to it, since his practical engineering training and background in England (in addition to his genius) was always evident in the development of his amazing and perhaps not really well-recognised biomedical instruments and aids.

His practical engineering training was also on display in his hobby of constructing miniature steam trains. The miniature steam trains were so small that apparently there was no recognised gauge that fitted such a small size. These models were not only fully working steam engines with tenders and carriages, but the pistons and linkages were a perfect scale representation of the actual steam engines. Arthur created the components on watchmaker's lathes and mini milling machines, which he modified to suit the task, in his garage workshop. He also manufactured other tools and developed new techniques to make these extremely small steam engines.








**Figures 4.1, 4.2, 4.3** Arthur Sherwood with his fully working miniature steam engines, built to scale in his own workshop.

In class, Arthur was irritated by students talking and not paying attention to the "elegant" solutions that he presented to difficult mathematical problems. On a one-to-one basis, however, such as with his thesis students, he got on very well as long as they showed interest and put in some effort. One such student worked on a thesis project involving the manufacture of polygonal shapes using only a lathe. This was one of those ingenious and quite anti-intuitive ideas with which Arthur often came up. The thesis project was successful and Arthur was quite pleased with the student and the end result, except for one particular aspect.

The submission of student theses included the requirement that they be hard-cover bound. In this particular case, in the 1980s when word-processing by computer was just beginning and there was no such thing as a colour printer or digital camera, the student submitted two thick volumes. One of these volumes consisted of fifty or more full-page A4 colour photographs and nothing else. The other volume was the typed text of the thesis, but both volumes were leather bound with gold-leaf lettering. Needless to say, the cost of such an enterprise, the A4 colour photographs and leather binding together, was way beyond the scope of most academics let alone students. The event caused quite a stir, but also amusement, and set a standard for thesis submission that was never allowed to be repeated.

As a postscript to this event, it is interesting to note that John Gal (who tutored the student with the leather-bound thesis in the 1980s) was lecturing in Mechatronic Engineering at UWS in the mid-2000s. As coincidence would have it, he ended up teaching manufacturing to the son of Arthur Sherwood's thesis student (who shall remain unnamed). And no, unlike his father, the son did not submit a leather-bound thesis with gold-leaf lettering!

In the 1970s and 1980s Arthur developed biomedical devices and instruments while he was working with orthopaedic surgeons at Royal North Shore Hospital and the Children's Hospital at Camperdown. They represented unique life-changing, maybe even life-saving, contributions. His halo-pelvic girdle, used to correct curved spines in scoliosis sufferers, was one design that was recognised by the University. Arthur was awarded a prize for his work on it by the Chancellor (see Figure 5). This was one of the very few occasions when Arthur gave in to advice to wear a suit. The halo-pelvic girdle consisted of two stainless-steel rings, externally fitted to the head and around the pelvis by means of screws tapped into the bone of both the skull and the pelvis [6]. Three or four steel rods connected the two rings where turnbuckles were used to gradually change the length of the rods so that the spine was straightened over a period of time. Although the appearance of this device being worn by a scoliosis sufferer was quite horrendous, there was no pain associated with wearing it over an extended period and the end result for the patient represented a new life.

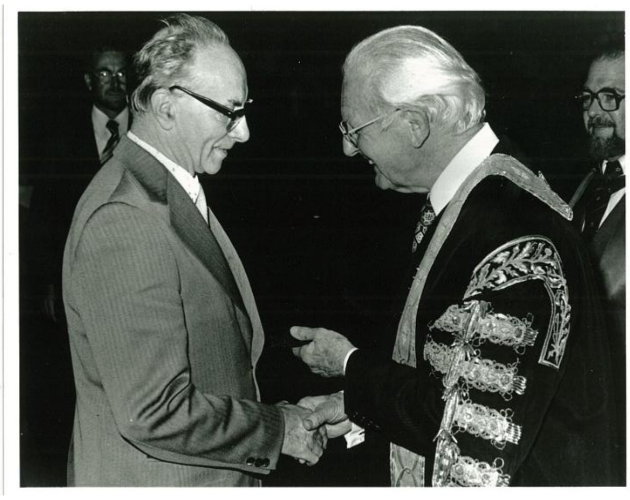


**Figure 5** Associate Professor Arthur Sherwood receiving his award from the Chancellor, Sir Hermann Black.

Other instruments that Arthur Sherwood invented related to hip-joint replacement and the need to drill and correctly align the hole in the thigh bone, into which the stem of the artificial joint has to fit. In all these developments and inventions Arthur made many of the initial prototypes with his own hands, both at home and also using the Department's workshop. As always, although Arthur was extremely proud of his achievements in this area, and he often brought some of his prototypes to the staff tea room, he seemed not to care about promotion or using his considerable achievements to advance his personal position. Perhaps due to his eccentricities and priorities, Arthur was never inclined to promote himself or his spectacular inventions and research developments.

## The Third Man – John Gal

If there is one claim to fame that John Gal can make in the kinematics area, it is the fact that he spent more than half a life time, a total of thirty years, in various positions in the Engineering Department at Sydney University. This was a period significantly more than either Jack Phillips or Arthur Sherwood. Starting as an undergraduate student in 1966 and finishing as a Lecturer in 1996, John himself went through a transformation from an idealistic innocent to a greying academic, holding the fort of kinematics single-handedly because everybody else had effectively abandoned ship. Of course this is true metaphorically only, but by 1996 with both Jack and Arthur retired, and after many restructures in the School to try and accommodate the new demands of the computer-based commercial world, the subject of Kinematics had to make room for such new areas as CAD/CAM, robotics and mechatronics. Thus Kinematics was no longer a stand-alone subject but was combined into areas such as Dynamics of Machines.

When he first arrived at University from Crow's Nest Boys High School, John had the impression that he had entered into the hallowed halls of an institution where the people were of the highest level of intellectualism and he assumed that they would have an innate tendency towards integrity and honesty. It was a fantastic experience in 1966 to find oneself in an environment of political free-for-all, with the freedom to be involved in discussion on any topic with fellow students, and to get away from the structured and relatively narrow school life.

The delusion about everybody being honest was destroyed very quickly in first year when John was playing tennis with his mates and left his wallet in a pair of trousers in the dressing room. It did not take long to discover upon his return that although the wallet was there, the twenty dollar note that had been in it was missing. The fact that a fellow student must have taken the money was a revelation and spawned a realisation that students had come from many different backgrounds but were not in fact really any different from the rest of the population.

The second revelation came much later, when John became a postgraduate student and had much closer contact with academic staff. There were the morning and afternoon tea sessions when one could interact with everybody from the Head of Department down to the technical staff and discuss anything including politics, sex and religion. The real characters and personalities of people at these sessions were on display and the various issues and tensions became more visible than in undergraduate times. The second delusion about the high level of intellectualism among academics dissipated when issues about funding, equipment, and philosophical outlook brought the child-with-a-tantrum to the fore. John Gal maintains that even after he became an academic he never exhibited such behaviour... but there's no-one available to verify that!

Over the thirty years spent in the School, John tutored/demonstrated and later lectured in many different subjects. These included: experiments in Fluid Mechanics in Bob Halliday's towing tank; diesel engines; gas turbines; thermodynamics; control systems and of course in kinematics. As a postgraduate student it was expected (not least by the upcoming undergraduates) that the tutor or demonstrator would know everything, but of course the reality was quite different. It was only in attempting to teach a subject that John discovered just how little he knew about anything, including kinematics. The experience of having to face up to teaching and respond to questions from smart students was a valuable lesson and a precondition for undertaking research where self-questioning was very valuable.

By 1976, John was giving a six-to-eight week course in Fortran programming to a third year Mechanical Engineering class, amongst the members of which one Nhan Phan Thien was a special student, although this was not obvious till the time came for submission of the final programming project. The task was as simple as determining the factorial of a number supplied via a user input. In the era when punched cards were used as a method of running a program, the expectation for such a task was merely a printout of the program and a brief description of the structure. Nhan Phan Thien submitted a program that had a number of alternative methods, error checks and a twenty-page treatise on aspects of the program that were way beyond the requirements. This turned out to be the same Nhan Phan Thien who a few years later completed his PhD in two years and had to wait one year before he could submit it. It was the same Nhan Phan Thien who in the late 1980's returned to the School and was awarded a Personal Chair.

Unlike Nhan Phan Thien, John Gal took a significantly longer time - close to ten years - to complete his PhD project. While undertaking tutoring and demonstrating in many different subjects, John was also trying to complete a research Masters (and later his PhD.) After Joanne Clarke abandoned her

Masters project in 1971 on the kinematics of jaw motion, John took over the project in the hope that it could be converted into a PhD project in the following year. As it turned out during a search of the literature, the core of the proposed project seemed to be the same as the one studied, and published, by a team of researchers at Case Western Reserve University in the USA. Although there would have been plenty of opportunities to change directions a little and still have a good PhD project, John was deflated by the discovery and decided to do something else for a PhD, and so he decided to write the jaw-motion project up as a Masters thesis. The end result of this decision was that it took about three years to complete the Masters, but the outcome was in many ways better than expected. Post-PhD, the Masters was the basis for the award of an ARC research grant and a career-long involvement with jaw mechanics research.

Until 1981 when John was appointed to a Professional Officer position, he tutored for both Jack Phillips and Arthur Sherwood in Kinematics (a full-year subject) as well as in a number of other subjects. This was undertaken while he was still enrolled full-time in a PhD program on the kinematics of robots. Around June-July 1976 Jack organised an international workshop, held at the Department. Some of the best known academics in the theory of machines area came, including Bernie Roth from Stanford University, Ken Waldron of walking machines fame from Ohio State University, John Uicker from University of Wisconsin and Ken Hunt from Monash. There were quite a number of others as well, including just about all the known kinematicians in Australia (including Eddie Baker from UNSW and Fred Sticher from UTS, who was one of Jack Phillips's ex-postgraduate students.)

Even though Jack had extensive and longstanding contacts with these academics, as well as with academics from Europe (especially from Eastern Europe as one of the founding members of IFToMM), this workshop was probably the first occasion when a kinematics-specific conference/workshop was held in Australia. John Uicker, by that stage a well-known figure with at least one book to his name as well as being the developer of a mechanism design package used by GM and Ford in the USA, was in attendance and invited John Gal to do some post-doctoral research on robotics in Wisconsin. This was a unique opportunity for John and he planned to take up the offer, except that when John Uicker returned to Wisconsin he found that there was no funding. Workshop pictures below (Figure 6):

**Figure 6.1** L to R: John Uicker (Wisconsin, USA); Jack Phillips; Gerry Hirschorn (NSWIT); unknown (USA); J Eddie Baker (UNSW); unknown (USA); Ken Waldron (Ohio, USA)

**Figure 6.2** L to R: Del Tesar (Florida, USA); unknown; Jack Phillips; unknown; John Gal; Gerry Hirschorn (NSWIT); Arthur Sherwood; J Eddie Baker (UNSW); unknown.

**Figure 6.3** L to R: unknown; Peter Swenson (?); Fred Sticher (NSWIT); John Gal; Kim White (hidden); Jack Phillips; J Eddie Baker; Ken Hunt (Monash); John Kent; Arthur Sherwood.

By 1980 John was at the "writing up" stage of his PhD and therefore considered himself available for some real employment. In 1981 he was employed as a Professional Officer in the School. At that time the School obtained the first CAD system and John developed a CAD course as part of the third year Mechanical Design subject and he later included a CAM/NC machining component as part of a Manufacturing unit. This occupied a significant part of John's teaching duties, but during this time he also gave a course in Machine Drawing to a second year class and taught Statics for a semester. In the meantime he was meant to be finishing his PhD, but being a dedicated procrastinator, time was slipping away without significant progress. Jack Phillips, John's supervisor, decided to give a subtle nudge by taking John to a play by David Williamson called 'The Perfectionist'. Whether this provided the necessary impetus or not, John finally completed his PhD in 1983. Ironically, John Uicker was one of the examiners.

Between 1983 and 1994, John undertook many different teaching tasks, continuing with his own research activities, as well as establishing a robotic assembly line. These were all activities that he regarded as equivalent to the duties of an academic, and (as others would readily testify) he complained unsuccessfully to anyone who would listen that he should be recognised as an academic. Some people questioned the advisability of wanting to be an academic saying that "you need to have half your brain removed to be an academic." Seemingly taking this requirement to heart, John had an unfortunate encounter with a brain surgeon in 1991, and subsequently was finally appointed as a Lecturer in 1994.

**Postgraduate Students in Kinematics**

Joanne Clarke was one of the first, if not the first, female postgraduate student in Mechanical Engineering in the early 1970s. She chose to undertake a Masters by Research degree in the kinematics of human jaw movement under Jack Phillips's supervision. This involved attempting to simulate the six degrees-of-freedom motion of the human mandible using a six-legged spatial mechanism called the deformable octahedron or Stewart Platform. It was also known as a flight simulator mechanism since structurally they were identical.

Joanne carried out a significant amount of literature review and by 1972 involved another Masters student, Kees (aka Chris) Hoogesteger, who wanted to calibrate the deformable octahedron using a separately constructed spatial 4-bar mechanism. The motion of the spatial 4-bar, a single degree-of-freedom (DOF) device, could be determined algebraically and thus used to impart a known motion to the 6 DOF Stewart Platform when the two mechanisms were clamped together.

John Gal, another postgraduate Masters student starting in 1971, was working on the algebraic solution of the spatial 4-bar and so three different projects came together for the one final outcome of developing a jaw-motion simulator. Joanne Clarke left in late 1971 and by the end of 1972, Chris Hoogesteger decided that he would not convert his project into a PhD program nor into a research based MEng.Sc. He was keen to go out into industry and start earning a real income.

In the period between 1969 and 1974, two exceptional PhD students, Bruce Hockey and Fred Sticher, were undertaking projects in kinematics related areas. Bruce was working on the dynamic balancing of reciprocating mechanisms such as the quite common crank-rocker linkage used in many different types of machines. This was in the time when computer programs were submitted by means of punched cards to main frame computers and the mathematics of such a problem was all done manually. In the course of his PhD project, Bruce published a number of journal papers and received a University award in addition to his PhD degree. A working model of his balanced crank-rocker mechanism is part of the Jack Phillips Display Machine.

After graduation Bruce went on to work for the Water Board and rose to a high level in engineering management. Meanwhile, Fred Sticher was working on a more theoretical project for his PhD. He had a penchant for algebraic solutions to problems in mechanisms and by 1971 had published at least two journal papers, one thirty-six pages long on methods of synthesis of spatial mechanisms. Later on, he was one of the first in the world to determine that the most general, spatial seven-link mechanism has exactly thirty-two different assembly configurations.

Fred maintained his interest in kinematics well past his PhD. He was one of a very few who had a deep enough understanding of screw theory not only to argue with Jack Phillips about various aspects of screw geometry, but also to challenge and sometimes correct ideas or concepts with which Jack often consulted him. Fred moved to UTS as a Lecturer before it became a university and continued to publish work in dynamics, kinematics and screw theory.

For a few years when both Bruce Hockey and Fred Sticher were writing their PhD theses, they shared a very small room in the Kinematics Laboratory in the John Woolley building. The closeness was good for discussing problems but sometimes it was too close for comfort. John Gal and Bruce Hockey shared that room as well for a year or so and they also did some activities together that relied on their kinematic and geometrical knowledge, in order to supplement their meagre incomes. One of the Sydney tabloid newspapers, the Daily Mirror, ran a reader competition called 'Spot the Ball' that required participants to send in a cut-out picture of the weekend rugby league game marking with an ‘x’ the location of the ball, which had been removed from the picture. John and Bruce were the judges. Armed with set squares, compasses, protractors and rulers, as well as with a method based on triangulation and scaling calculations, John and Bruce ploughed through the closest one hundred entries, out of thousands, to try and identify the winner. The monetary rewards were probably not spectacular, but, as John Gal relates, the power of ruling over who the winner would be was intoxicating... well, not really!?

Kim White was another brilliant postgraduate student under Jack Phillips’s supervision. Kim was not only consulted and asked to read Jack’s book chapters during their writing, as was just about everyone who came into contact with Jack, but he also contributed in significant ways to the content of some parts of the book. On backlash in mechanism joints and on some algebraic solutions, Kim spent considerable time in verifying mathematically what Jack deduced geometrically. Apart from tutoring in a number of subjects, Kim also got involved in Bryan Roberts’s flying wind-generator project and in the design of a kit aeroplane together with John Blackler (from Aeronautical Engineering).

These two projects were not related to Kim’s PhD thesis topic but occupied a lot of his time, most probably because it also became his main interest. Another skill that Kim kept fairly quiet, possibly because it came under the heading of ‘foreign order’, was the engine overhaul of his Datsun sports car. Kim led the way in this type of work. Others, such as John Gal, attempted the same job on their own car, with much less success, having learnt a little from Kim’s experience. Kim was eventually employed full-time by the private sponsor, on the design and construction of the kit aircraft.

In the early eighties Yu Hon-Cheung, became a postgraduate candidate with a specific interest in screw theory. He came from a mathematics background. During his time in the School he built a number of models out of straight bits of thin metal rods, representing some theoretical concept related to screw systems. At the time these models appeared to the uninitiated, (and perhaps even to everyone except the most deeply initiated), to be a completely random arrangement of rods closely resembling birds’ nests. There is no doubt that Hon knew exactly what these models represented and in fact they brought into reality aspects of the very complex and difficult geometrical idea of a screw system. A screw system, depending on the degree-of-freedom of the mechanism in question, is the locations or geometric arrangement of all the possible combinations of instantaneous screw axes when a parameter of each joint is varied.

During his period at the School, Hon became a follower of the philosophies of Karl Jung and many discussions on these took place with fellow students and others. Hon did not complete his PhD thesis and returned to Hong Kong to join his family there. Yet for many years afterwards, Hon continued his study of screw theory and published some papers on the topic. He kept in contact with Jack Phillips and Jack also visited Hong Kong occasionally.

Sometime around 1985-7, a Visiting Fellow from northern China arrived to work with Jack Phillips. This was well before the Tiananmen Square protests and very few Chinese students or scholars had permission to travel overseas at that time. In the case of Dr Zhang Wen-Xiang, his journey to Sydney marked the first time he had travelled outside China and the first time he had ever flown in a plane. As it turned out when Hasso Nibbe drove to meet him at the airport, it was also the first time he had ever travelled in a private car. That car trip, maybe because of the way Hasso drove, made a very strong impression on Zhang. After a short period he started to feel nauseous and then threw up. As it turned out, and not surprisingly, Zhang was suffering from cultural shock.

Zhang was an extremely quick learner and was soon able to engage in everyday conversations about differences between life in China and in Australia and, with considerable restraint, about political differences as well. After that initial car trip Zhang was quite keen to see as much as he could of Sydney. This included his visit to the beach, another first in his life, as he had never seen an ocean either. Zhang worked on various topics of Jack's book and they also published a number of papers together. The contact between them continued well past Zhang's return to China, where his overseas experience was a crucial element in Zhang's rapid promotion at his home university, eventually to a level equivalent to Vice Chancellor.

Footnote:
The author of this chapter apologises sincerely for any omissions, errors or misinterpretations, as all of the content is based on the author's significantly flawed memory.

**Figure 7** 'Ode to Jack'

ODE TO JACK

Oh my favourite Lecturer Jack,
You overwhelm me with the intelligence I lack
I clamber for seats in the lectures you pack
But can't get enough and must keep coming back.

To hear those mindboggling lectures you fill
In seventh year I'm attending your lectures, still
As you boggle my mind with your mindboggling skill
Give us all such a mindboggling thrill.

To the vastness of your mind there is no measure
You know that your presence we really treasure
Your personal force gives me momemnts of pleasure
And a couple of times you have given me siezures.

I really don't have harf your wit
If only I understood your wisdom just a bit
I would be good enough for your lectures and fit
To escape grovelling in this intellecktual cesspit.

We appreciate your mindboggling factual generosity
The way your lectures progress with such rapid velocity.
Yet some villains fall asleep, but to this blatant atrocity
You magnificantly refrain from any animosity.

**Figure 8** **Chronology of a Jack Lecture**

# Chronology of a Jack Lecture

## A play in two parts by Eddy Viscosity

Scene: Tutorial room 2, Mechanical Engineering Building, University of Sydney. This room is filled with nice, regular rows of tables (although the front two rows of tables remain unoccupied). Occasionally aircraft are heard flying overhead and loud sawing noises are emitted from the workshop below.

Time: Friday morning, 10:00am – 12:15pm

Part 1

10:00am. The room is deserted save for a couple of rats (which Joanne has not yet trodden on).

10:10am. Students (starting with those at the spanker end of the spectrum) begin entering the classroom.

10:20am. Jack enters the room in a great rush and apologises for being late. He brings with him the usual pile of unique gadgets and volume 2 of his new book.

10:30am Most students have by now arrived and Jack is telling the class enthusiastically about some of the more interesting aspects of his recent trip to China.

10:40am The subject matter of the lecture logically progresses onward towards the topics particularly dear to Jack's heart and Jack now complains bitterly about designs and designers who force us to live in a second-rate, over-constrained world.

10:50am Jack complains very bitterly about upcoming generation of computer-head engineers and the lack of student ability to view objects in three dimensions.

11:00am Jack goes to morning tea. Students follow suit and head off to the Purcell Room.

Part 2

11:30am Students (again starting with those at the spanker end of the spectrum) begin arriving back in the classroom.

11:45am Jack arrives back in the tutorial room and switches straight into high-speed lecture mode.

11:55am Jack's lecture rate begins to rise exponentially in an attempt to try and compensate for the march of time.

12:00pm Jack's lecture rate is still rising and Howie is having to concentrate to keep pace. Bob Halliday has arrived and is waiting at the door, ready to give his lecture.

12:05pm Realising the end is nigh, Jack refuses to go down without fighting and recommends a number of textbooks "for those who are interested."

{A typical Jack reference: Kovslosky; written about 1956 (possibly 1958)

- Either a red or blue cover
- Has a very good section on screw triangles in chapter 7 or 9

∗ Written in Hungarian, Jack has a copy if we have difficulty finding it }

12:10pm The lecture ends abruptly and Jack apologises profusely to Bob Halliday for taking up five minutes of his lecture time.

12:12pm Jack's lecture has interested a number of students who follow him outside for interrogation. Jack however is in a desperate hurry to get somewhere and all questions are answered as succinctly as possible. A handful of students are invited to come to Jack's office and borrow some of his unique references.

12:15pm Jack manages to break free and walks offstage.

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CURTAIN

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**Figure 9** A. A. Sherwood Ditties

**UNCIVIL ENGINEERS**

*I've often wondered if in ages past some rude engineer*
*Was responsiple for the names given to bits of mechanical gear,*
*For whoever classified the two main components with thread*
*Must have been thinking of screws in bed*
*Which often lead (after some while)*
*To something synonymous to a coarse term for a file.*
*A jet discharging liquid is referred to as a nipple*
*A word not usually mentioned by respectable pipple;*
*If a tap's behind it, it's often called a cock*
*A word which, out of context, could land one in the dock.*
*With so many items having sexual terms to denote 'em*
*Why isn't the cage in a ball race called a scrotum.*

*SHERWOOD.*

**LOVE NEST**

*He grabbed me by my slender neck,*
*I could not call or scream.*
*He dragged me to his dingy room*
*Where we could not be seen.*

*He took away my flimsy wrap,*
*And gazed upon my form.*
*I was so cold, so scared, so damp,*
*And he so delightfully warm.*

*His fevered lips he pressed to mine,*
*I gave him every drop.*
*He took away my very soul*
*I could not make him stop.*

*He made me what I am today,*
*That's why you find me here*
*A broken bottle thrown away*
*That once was full of beer.*

*SHERWOOD.*

**FAIRY TALES OF THE IVORY TOWER**
**(with apologies to Lewis Carrol)**

*"The time has come" the tutor said*
*"To talk of many things*
*Of pulleys without friction*
*And on them weightless strings*
*And concentrated masses*
*Suspended on light springs*
*And why the simple pendulum*
*Has isochronous swings."*
*Then up spoke one rude student*
*"Are these not just playthings;*
*What happens in reality*
*When shaft to pulley clings,*
*And airflow round our model planes*
*Is much disturbed by strings.*
*How then can we really know*
*What goes on round the wings?"*
*Then replied the tutor*
*"Such things you should not ask*
*They are not in the syllabus*
*And not part of my task.*
*The beauty of my theories*
*I must preserve intact*
*You'll find them far more elegant*
*Than horrid ugly fact."*

*A. A. SHERWOOD.*

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