History of Mechanical Design and Machine Drawing in the School of AMME

By Andrei Lozzi

Pre 1950

Little information survives about teaching staff or methods in Machine Design and Machine Drawing prior to 1950, but we still have evidence of what were probably some of the teaching aids that were used in those days. Figure 1 below is one of many ink drawings made on heavy duty drawing paper, some were even on paper backed by fabric. These drawings were obviously meant to last, and to be seen from a distance as they are all larger than today's A0 format. The drawing on Figure 1 is the only one that is dated and signed, by J. L. Willan, in wartime 1917.

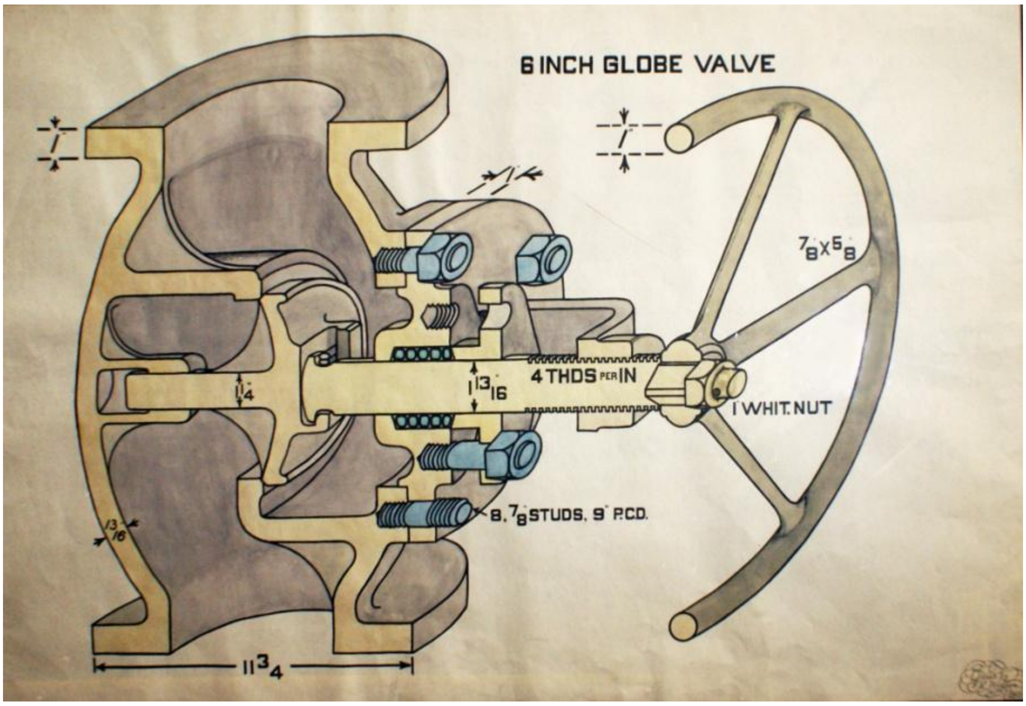


Figure 1 A sectioned valve by J L Willan, 1917. The projection used is probably one of the oblique variations. Oblique is possibly the easiest method by which to achieve a pictorial presentation, but the mind fights with what it sees. Today we are spoiled with instant photo quality perspectives, made possible with solid modellers.

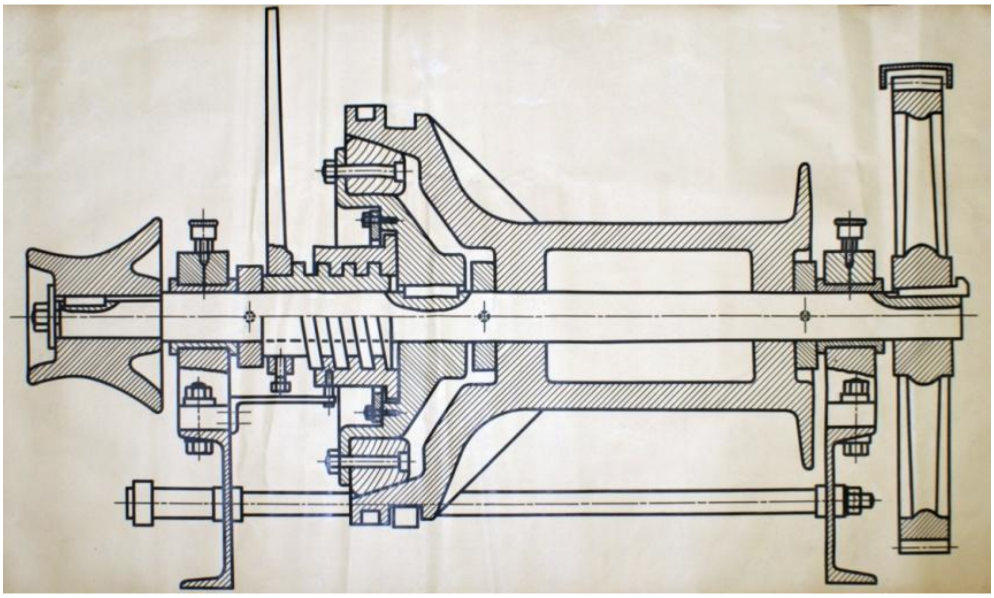


Figure 2 A gear driven rope winch. Left of centre there is a conical clutch, operated by a screw, connecting the rope drum to the geared shaft. The shaft is also coupled at far left to a rope capstan.

Note the oil drip feed to bushes, no rolling element bearings at that time and the spacers located on the shaft by three dowel pins, drilled through the shaft. No light weldments are used here, just heavy cast iron.

During the mid 1980s this author attempted to paste a large number of these drawings on the concrete ceiling of the Mechanical Engineering Drawing Office, (room S319 building J07). The aspiration was of course to follow in the footsteps of Michelangelo Buanarroti and his work on the ceiling of the Sistine Chapel. Our old drawings looked great up there, but good intentions sometimes come undone: the glue did not hold for more than a few months and the whole idea was seen as some sort of fire risk. Michelangelo tried a lot harder for his art that I did.

Mr Gordon B. Vonwiller 1950 - 1977

Students in the drawing and design courses in the Engineering Departments spent a great deal of time doing pencil drawings. Simple yet practical stress calculations were done by long hand with a slide rule and log tables. Students of mechanical and civil engineering probably did more than others, but drawing and design courses were available from the first to the last year. In order to become fairly proficient design draughtsmen, students spent several afternoons each week in large drawing offices using pencils of many grades of hardness, drawing at timber drawing boards with manual instruments. A few extant drawings show that possibly all of the calculations supporting the design were done in the margin of the drawing. External consulting engineering firms provided much of the tutorial expertise that was required to run such large classes.

Today, it is a little difficult to appreciate the mental and manual skill necessary to make precise, clean, neat, well organised drawings, which are also rational designs. It used to take between three and five years in a drawing office to train a draughtsman coming directly from school to produce good quality drawings**,** without the analysis. The courses given at that time in our department prepared the student to apply established good design practices supported by basic stress calculations to the making of professional level engineering designs and drawings.

Engineering Drawing and Descriptive Drawing

Drawing practices have taken thousands of years to gel into the present form. Gaspar Monge is credited with refining drawing techniques in 1780, so that the correct size and shape of any item could be represented in a drawing. Hitherto drawings were seen more as art applied to the work of artisans. The earliest example of a ‘drawing’ that objectively represents an engineering product to scale in two dimensions was a plan of a fort scraped on a clay tablet circa 4000 BC, as shown below in Figure 3.

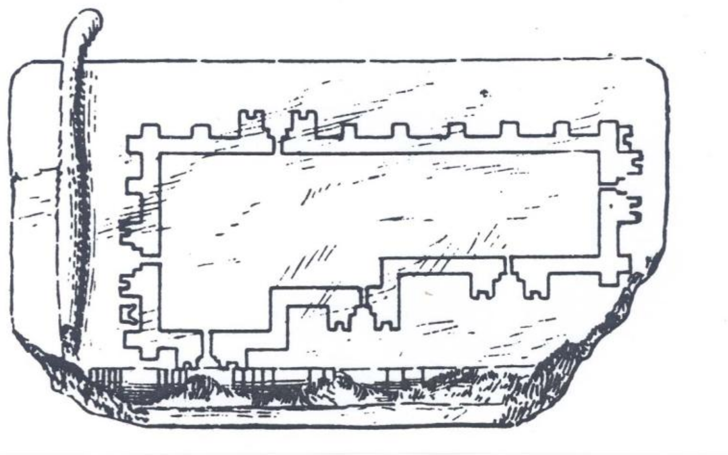


Fig. 3 Plan of a fortress (part of a statue now in the Louvre) from the earliest period of Chaldean art, 4000BC. Transactions ASCE May 1891.

Mr Monge assembled and clarified the geometric means which can be used to deduce the true length and angle of any graphic element, of any part, drawn by the rules of orthogonal projection. That is, by using one or more two-dimensional drawings, all three-dimensional specification of an item can be extracted. The accuracy of the information so obtained is limited by the accuracy of the line work and the stability of the material on which the work is done. At the time, Gaspar Monge’s work was seen to be of such significance that it was kept a secret from the British. Knowing the actual shape of any component is of course absolutely necessary for its manufacture.

Some of the information encoded in earlier drawings had to be deduced from symbols presented in the artwork, not just what could be measured on the drawing. An example of this was demonstrated by Mr Peter Morgan, Senior Lecturer, sometime in the 1980s. He calculated that an Egyptian funerary artwork which showed a large monument being dragged along (Figure 4) could in fact be taken to be a precise engineering description of how such a load could be, and probably was, moved. Peter Morgan compared the force required to move the sled on the wetted, packed earth, to the pulling force possible by the men on the ropes ahead of it. He concluded that what we are looking at is not a fanciful and almost abstract flat painting, but as close to our current concept of an engineering design drawing as the ancient Egyptians were able to produce.

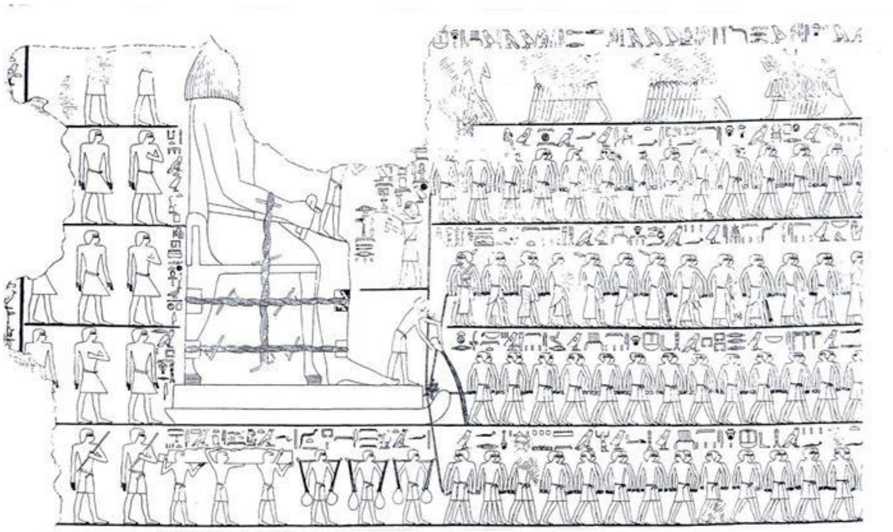


Figure 4 Egyptian Tomb Drawing. The Archaeological Survey of Egypt, El Bersheh, 1893.

Finally with the understanding developed during the Renaissance of how depth can be represented on a 2D sheet, precise drawings could be generated, such as the complex 3D constructions shown in Figure 5 below.

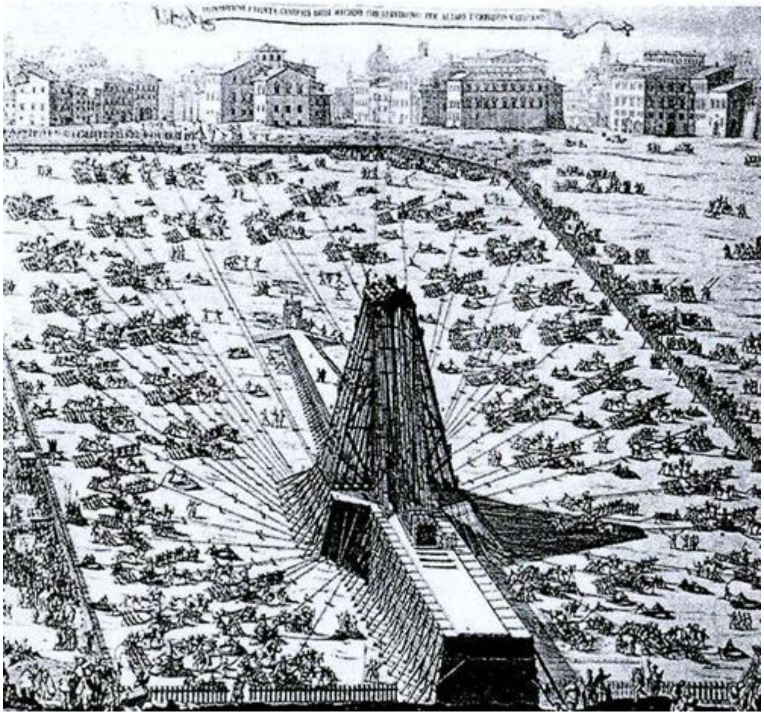


Figure 5 The erection of the Obelisk of Augustus, Saint Peter Piazza, the Vatican. The number and disposition of nine hundred men, seventy-five horses, ropes and pulleys are supposedly portrayed precisely, although the rules of perspective seem to have been somewhat bent in the representation of the buildings in the background.

Being able to objectively draw any component and assembly on sheets of paper leaves the draft persons with the problem of how to carry out their work practically and economically. Economy is a vital consideration because industry cannot cope with machine components being represented faithfully with all their visible features. Figure 5 must be taken as a work of art, to be hung and admired, it does not present the details which would be included in a modern production drawing. Most fine details are omitted and many complex ones are simplified or replaced by symbols. Methods have had to be developed to unerringly differentiate between visible and hidden outlines, the representation of curved surfaces, features that are necessary but excessively detailed such as threads, hundreds of rivets, surface finish from machining, outlines before and after welding, etc.

To provide the very necessary universally recognised practical solutions, drafting standards were instituted and progressively developed. Gordon Vonwiller worked on the development of the Australian Standard Association AS1100. Mr. F. K. (Keith) Fraser was employed to assist as draughtsman and along with his apprentices he established much of that standard that relates to mechanical drawings.

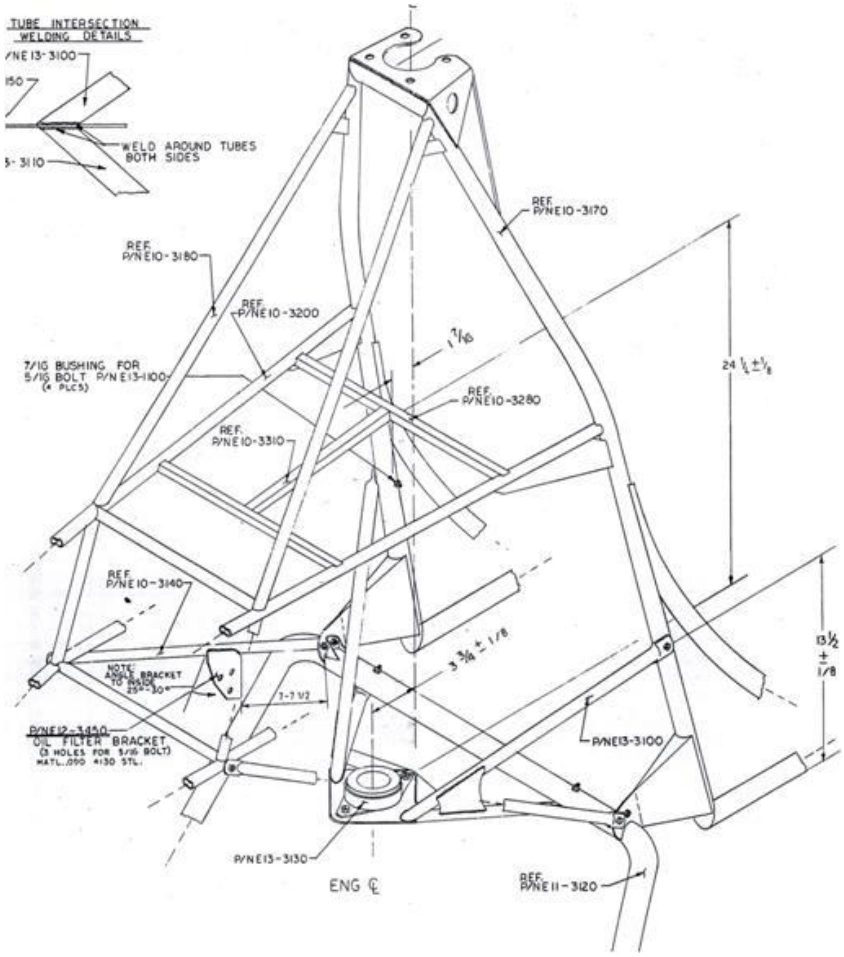


Figure 6 An example of a 3D drawing of the frame of a gyrocopter by Mr John Blackler. The drawing has been constructed by the rules of isometric projection. It approximates a perspective drawing, but it is easier to extract dimensions from and is much easier to draw. Mr John Blackler was a part time lecturer in aeronautical engineering and consultant for the mechanical department between 1965 and 1997.

Up until the 1980s two related drawing courses were attended by most engineering students: they were Engineering Drawing and Descriptive Geometry. The first taught, in part, the manual skills required to handle pencils, compasses, rules and other aids necessary to generate a clean and precise drawing. It also in part introduced the students to the application of the Drawing Standards. The course of Descriptive Geometry put the students through exercises designed to reveal how three dimensional information could be extracted from two dimensional drawings. (Notably, Gaspar Monge has been seen as the father of Descriptive Geometry). Each of these courses used to occupy students for about the equivalent of two weeks of full time study.

The Descriptive Geometry course was the first to be replaced upon the introduction of computer graphics in the 1980s. Computer graphics could now provide spatial information to a much greater accuracy than possible hitherto by hand and pencil. The Engineering Drawing course, however, could not be replaced until Computer Aided Drafting software and hardware became available.

Peter Morgan, Senior Lecturer 1967 - 1976

Peter applied curiosity and intense interest to the search for inventive and ever more effective solutions to engineering problems. He gave extraordinarily motivating lectures, which seemed to stir even the most lethargic of students. His demonstrated belief that better solutions could be revealed to those that sought them was contagious. Peter seemed to reflect a British desire to excel in creativity, but unfortunately focused less on the plodding detail work that has to follow in order to produce high performance and reliable products. Peter's attention could centre on almost any topic, from better coordinated traffic lights to screw threads that would be resistant to damage by crossing. I believe that he demonstrated that if one applied a fresh attitude, today described as 'lateral thinking', surprising advances could be made, on what had otherwise been considered intractable problems. Peter opened his student's eyes and gave them the desire and confidence to try.

In 1978, sometime after his death, the P.G. Morgan Memorial Prize in Mechanical Design was established, to commemorate his gifted and enthusiastic contributions to teaching. It is awarded annually to any sufficiently meritorious undergraduate or postgraduate work in design.

Dr Arnoscht Brichta 1973 - 1986

Arnoscht endeavoured to introduce European design manuals (Czechoslovakian & German) to design. As opposed to the methods presented in the British text used at that time, his approach displayed an almost obsessive attention to detail calculations. The expectations were and still are, that some of those mainly German methods may give more accurate estimates of stress and strain within machine components. What created considerable difficulties was that some of Arnoscht's material seemed to apply theories and practices that were developed in relative isolation from those that were currently accepted. Arnoscht's lecturing approach seemed to be almost devoid of the 'search for creative solutions' idea that was the core of Peter Morgan's teaching. Unfortunately Arnoscht's ambitions to arrive at a coherent set of guidelines were stymied by the mountains of uncoordinated details that surfaced from his collection of European references.

Andrei Lozzi 1980 - 2012

The author, having spent some time working in several government and industrial enterprises, began teaching with the ambition that our graduates should be capable of being useful from the first day they were employed in a design office. He could not see why in the space of four years we should not produce practical and resourceful graduates with sound theoretical knowledge.

Fatigue Analysis Applied to the Design of All Mechanical Components

The method for estimating the fatigue strength of material located in different areas of a component was adopted from that developed by the American Society of Manufacturing Engineers. This method was applied by Joseph Shigley (1909 – 1994) in the seven editions of his design text and applied more recently by R L Norton to almost all machine components. Both these authors produced texts that are almost encyclopaedic in their application and are unusually comprehensible to undergraduates. Shigley provided a very reasonable view that one approach of fatigue analysis could be in principle applied to all machine components. He ultimately had to revert to long established industry practices where inertia or momentum was too large to redirect. Surprisingly the methods used to estimate fatigue strengths appear not to be extensively supported by tests available in the public domain, but experience has shown that they are sufficiently conservative as not to raise real fears. It appears that components designed to these methods may be somewhat heavier than if a more exact method were available.

Arrival of Computer Aided Drafting (CAD)

In 1980 the first CAD system was installed in the Departments of Mechanical and Electrical Engineering. A Computervision system was purchased, with two terminals in the Mechanical Department (really just two) and one terminal in the Electrical department. This system cost a great deal, at the time it was in the order of $110 000. It was, I believe, the first in any Australian university and was quite a feather in our cap. It must have taken quite some work by professors Bob Bilger and Roger Tanner to arrange the funds to acquire the system. It is worth providing some details of the system, because although not that unusual at the time, it was very different from today’s installations. The principal calculation unit took the form of distributed components on one large circuit board. Memory was located on other equally large boards. The system had in fact three or more calculation units, one did the floating point calculations, another just drew the figures on the screen, and a lower precision unit moved software and data on and off the pack of ten double sided 300 mm diameter disks of total capacity of 150 MB. Each terminal had 137 KB of memory available. This memory was used and reused for most operations. Drawing a straight line tangent to a circle, for example, required more than forty-seven reloads of that memory. Much of the early CAD software could only work with dedicated hardware, which could not be used for other applications. Consequently were extraordinarily expensive.

For about ten years we offered part time introductory CAD courses extending over one term for draft-persons and engineers. Initially we had very good response from engineers employed in industry. As other universities and TAFE colleges began to acquire their own systems, the declining quality of the people enrolling began to make it difficult to give a satisfactory course.

I refer to this system and many that followed as Computer Aided Drafting systems, because few associated engineering calculations could be done. The press at the time reported with great enthusiasm that such systems were capable of 'designing the harbour bridge at the press of the button'. Another catch phrase often used by vendors was that their package's capability was 'only limited by one's imagination'. Once one became familiar with the number of low level functions required for simple operations, however, one also became convinced that their capability was limited by one's own lifetime. The fact was that for a long time CAD systems could only just draw lines, initially in 2D, later in 3D. Later still they could begin to specify and represent surfaces. One could practice spatial design not analytic design. On the positive side, if one made an error in the location of a few lines it could much more easily be corrected on a CAD system than on an ink drawing. Also, these systems allowed the consideration of variations on the shape and size of things with relative ease, before a choice was made.

Some of the earliest systems generated files that could only drive pen plotters. The resulting drawings were ten or more times more accurate than manual drawings. That is, the number of bits available for the geometric calculations and for the mechanism driving the pens simply gave a more accurate drawing than could humans.

It was hoped that once we had become familiar with our CAD system we could also attract industrial collaborations. That had been the experience of Universities in the USA and UK, but was not the case for us. Engineering establishments in the Sydney area took to CAD with gusto. Many paid large sums for systems that were used to make sheet drawings perhaps no more than twenty percent faster than what could be done manually. Fortunately there were an increasing number of applications where these systems could provide significant and (at times) dramatic improvement in productivity. These included where they could be used to drive numerically controlled machines tools and in the preparation of steel structural elements for civil constructions. At last, they could be cut, drilled and welded on a factory floor with the confidence that the parts would all fit where required within close tolerances, when assembled at the construction site.

3D CAD 'wire frame' systems were (and still are) the ultimate descriptive drawing machine. They could provide dimensions and angles to a precision of 1 in 10^6 or better, many orders more precise than had previously been possible. One particular application where the precision of the line work became absolutely critical was in the development of large scale integrated circuits. Up to this time, the work of Vonwiller in the application of Engineering Drafting Standards continued to be absolutely necessary.

Numeric Solvers

A range of numerical optimising software is built into Microsoft Excel and other packages. These use linear and non linear methods that allow a designer to answer such questions as: ‘what is the combination of dimensions that would produce the lightest or cheapest part or assembly, for a particular type of design?’ The use of a ‘solver’ does not relieve the designer of the need to choose or invent the design, it just provides the dimensions that meet a correctly posed objective question. Thus far these solvers find the nearest ‘optimal’ solution to the starting point and do not carry out guided or exhaustive searches. Some of the advantages that come with the use of the solver built into Excel are firstly that it is almost universally installed in all PCs and secondly that answers are obtained in split seconds. An incorrect or incomplete set of boundary conditions or inappropriate objective function result in nonsense answers, also in split seconds. Thus the student has the opportunity to learn from rapid feedback. It is interesting to note that in my design classes, from among mature age students of diverse backgrounds, only those that came from financial institutions, had heard of the use of these solvers. That perhaps indicates that money matters more and engineers may be a little slow.

Solid Modellers and the Continuing Evolution of CAD

CAD (Computer Aided Designing) has for a long time given the impression that it may be the most rapidly evolving software used by engineers, possibly because drawing, modelling or using graphic symbols is central to almost all engineering activities. Every few years such large advances are made that many of us would initially consider discontinuing what we are using and adopting the newer CAD. Fortunately or otherwise, one of the greatest investments in a design office lies in the acquisition of the expertise of draft-people and designers in the use of their CAD system. We note that drawing office staff often develop the sort of attachment to their CAD system akin to some sort of religion, faithfully defending it against all sorts of appropriate criticisms. Because of the loss of productivity experienced over the months that it takes to become effective with new systems, companies change their CAD systems with great care.

Computervision, CadKey, CADDSman and SolidWorks CAD Systems Used in the School

After our experience with Computervision we became weary of expensive turn-key CAD systems that could provide only a few seats and could not be used for any other purpose. In 1987 a university grant of about $90 000 allowed the Department to furnish the first undergraduate computer lab and the purchase of ten microcomputers. Unfortunately these ‘µcomputers’ proved to be quite unreliable. They were locally assembled IBM PC clones. Within a few years they were replaced with twenty very reliable NEC Japanese machines, which were also clones. Initially the many different µcomputers on the market all required dedicated software and parts; but eventually practical, fully compatible and affordable PCs became available. This lab developed into a general purpose undergraduate lab, not just limited to CAD use.

In the PC lab we initially installed an advanced new package that had won a large number of orders from the American military: CadKey. Within a few years, due to its ever increasing maintenance cost, it was replaced with CADDSman. This last system had been written by a group of programmers and engineers that had worked for the local vendor of Computervison. CADDSman proved to be very effective, it was developed steadily and was inexpensive. For the first time, students could develop substantial programs that interacted with drawing files, extract data and make changes to drawings.

With the advent of Microsoft Windows NT (New Technology), PCs suddenly had a thirty-two bit operating system and the RAM memory limit of 640 KB was blown out to a 4000 MB limit. PCs became giant killers instead of being slightly better than toys. At least twelve new solid modellers became available to be ported to NT machines. We set out to compare solid modellers: we were able to borrow two systems and Professor Assad Masri allowed us to buy two more. It quickly became clear to us that SolidWorks was the better system for our use.

Solid Modelling, FEA, CFD, Kinematic & Dynamic Analysis

SolidWorks (SW) has been progressively and very effectively improved and expanded since the Department started using it in 1997. SolidWorks was eventually bought by Dassault Industries and is marketed next to their high-end Cattia CAD system. It has been reported that these two systems together account for the single largest fraction of all Solid Modeller installations. SolidWorks currently comes bundled with FEA, CFD and Motion (kinematic & dynamic) packages. The FEA system began with just high order P solid elements, but today it includes plates, struts, beams, weldments, vibration, fatigue, optimisation, impact and heat conduction. One of the major attractions of SolidWorks is that it also comes with a comprehensive and excellent set of standalone tutorials, covering all of its fields. SolidWorks is programmed to generate detailed drawings and assembly drawings directly from solid models.

The application of FEA within Solid Works is particularly productive. An operator can move from component definition to its stress/ deflection analysis and back to redefinition with ease. With our current PCs, hundreds of thousands of elements can be dealt with within minutes. The students are given a range of parts to analyse and develop in their third year, from simple to complex and complete whole assemblies in their fourth year.

What is a surprise even to many experienced observers is that while CAD development often just inches along, at times it can take quite amazing leaps, as seems to be taking place right now among some developers. These phenomena require us to keep constantly in contact with the vendors and industry. **Formula SAE**

The American Society of Automotive Engineers initiated this student-based competition in order to enhance US engineering students' awareness of their automotive industry. The competition has become international, and there are currently about four hundred teams worldwide. Each team is expected to produce a new car each year, but this is seldom done because of the work and expense involved. Australia has produced three world beaters over the last ten years from Wollongong, RMIT and Western Australian University. This pre-eminence may not continue for long since German and central European universities have begun to show extraordinary commitment.

The underlying concept of the competition is for students to be involved in every aspect of creating a hypothetical company which has been commissioned to design and market a profitable formula style car. The competition is designed to challenge and enhance the knowledge and creativity of the students. The team must develop trust in their workmates and work closely together to successfully make a car of which they will be proud. The competition begins in December of one year and ends the following December.

To function well the team requires managers, marketers, designers, analysts, machinists, mechanics, mechatronics students, IT and computer scientists, all of whom are hard working and enthusiastic. As the academic advisor I set the guidelines, approve the selection of team leaders and thesis topics, while the team leaders (largely) pick the team. Although there is several times more work required for these theses than normal, the competition to join the team is surprisingly high.

Paul McHugh initiated our FSAE involvement in 2001, while I assisted for three years. I took over management from 2004, because I had more time available being semi-retired and I had the desire to push machine design education further. Both Paul and I held the expectation that as a project it would reach a zenith in popularity and then it would decline. Thus far the zenith has climber higher and higher.

FSAE - A Means to Extend our Design and Manufacturing Education

An example of the work done in this project is displayed below. We have so far accumulated about one hundred and fifty theses in this field. The depth and breadth of the work done is extraordinary. I think a few pictures representing the students’ products will probably give the best impression.

We currently are using a 550 cc twin cylinder Aprilia motocross engine, because it has good torque and is compact and light. At times we have had two students simulating, analysing and manufacturing improved air intake systems. The software that has proved most effective comes from Ricardo of the UK. To establish the inlet and outlet conditions to the intake manifold, the whole engine is simulated as a one dimensional system while the inlet manifold itself is simulated as a 3D CFD space. The computer runs needed to cover a reasonable rpm range have taken up to a week on quick PCs.

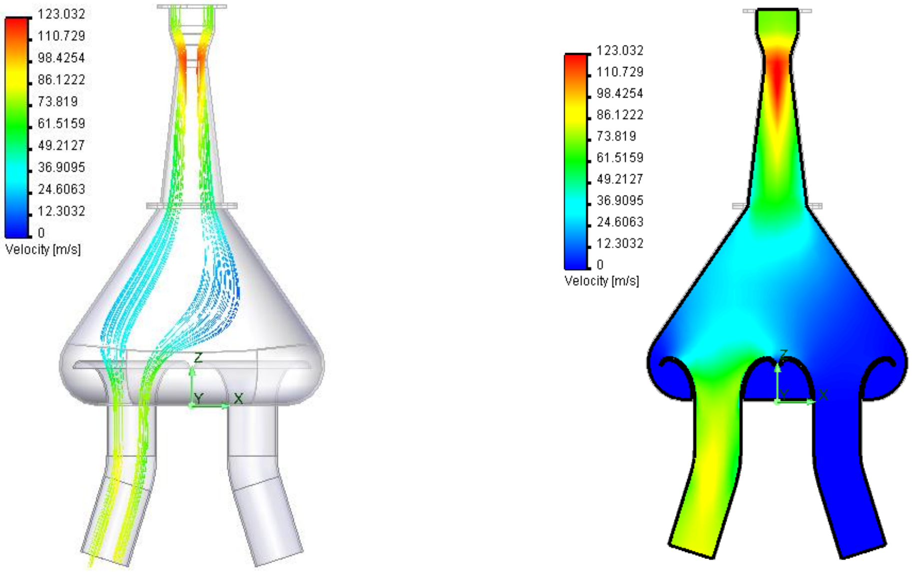


Figure 7 Above is shown the streamlines and velocity contours within the inlet manifold. A 20 mm diameter throat is required, at which location sonic condition is reached at higher rpm.

The CFD simulations are able to reproduce the unstable flow downstream of the supersonic patch that creates considerable turbulence. In part this has lead to a better choice of angle for the divergence duct.

Figure 8 A partially assembled car. The students invent, design, analyse, manufacture and test nearly all parts of the car except for the engine and gearbox.

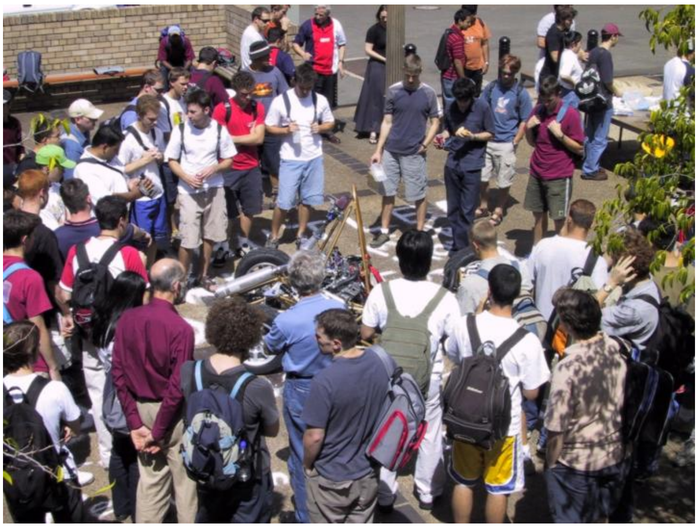


Figure 9 Marketing and public relations. We display our cars at Engineering Week in the City, motor shows at Darling Harbor, historical race car meetings and Open Days on the University Grounds. In this way we enhance our profile for the University and our sponsors.

Figure 10 The space frame has to be designed and analysed, tubes have to be ordered, cut and welded. There are strength, rigidity and safety requirements to be met. Technicians from our workshop help with the more demanding operations.

We are carrying out experiments into the use of aluminium honeycomb for a lighter, stiffer but more fragile chassis.

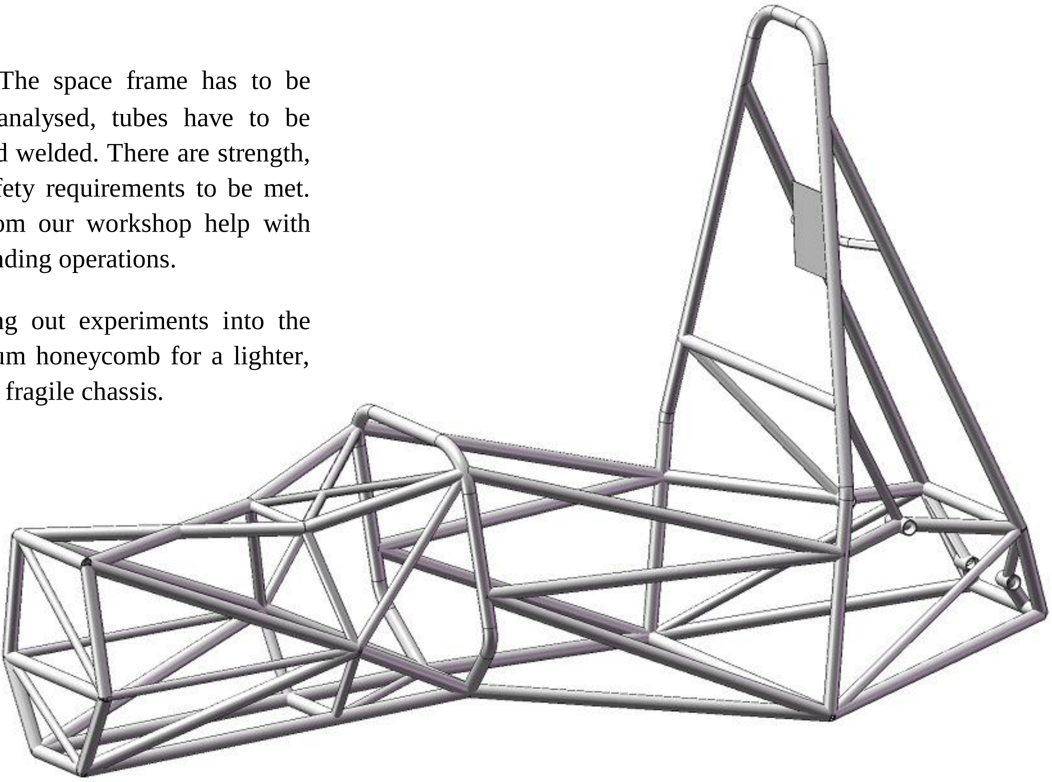


Figure 11 In this competition one sees variations in design methods not seen elsewhere. Students truly do lateral thinking. Thanks to the light loads, in order to save weight hollow aluminium shafts have been developed with steel lined pockets (below) for tripod CV joints built into the wheel shafts.

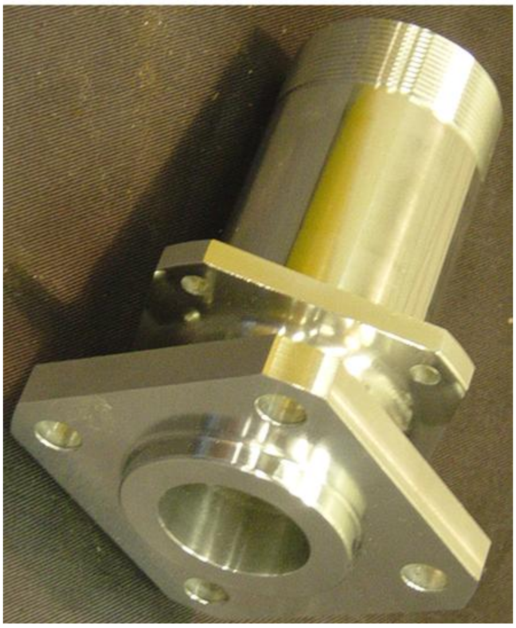


Figure 12 (At Left) The vertical upright that provides location for the wheel bearings and connection to the suspension A arms is subjected to relatively large bending moments while cornering.

Here one is constructed into a box section using 1.2 mm sheet steel. We have also made them from Al alloy sheet, but these required excessive manufacturing time.

Currently we are making these from two milled aluminium sections, glued together along a mid vertical plane.

We have also developed a brake dynamometer in order to arrive at tailor made brakes that better meet torque and heat loads.

Figure 13 Effective differentials for this competition are hard to source. Below, the innards of a differential intended for a heavier car is contained in a housing milled from a large diameter A1alloy bar. We found that aluminium chain wheels are quite effective and that the differential housing could be used to mount the single rear brake. A sizeable oversight shown here is that the brake calliper is placed at a low point. This position may be good for lowering the Centre of Gravity, but terrible when bleeding the calliper.

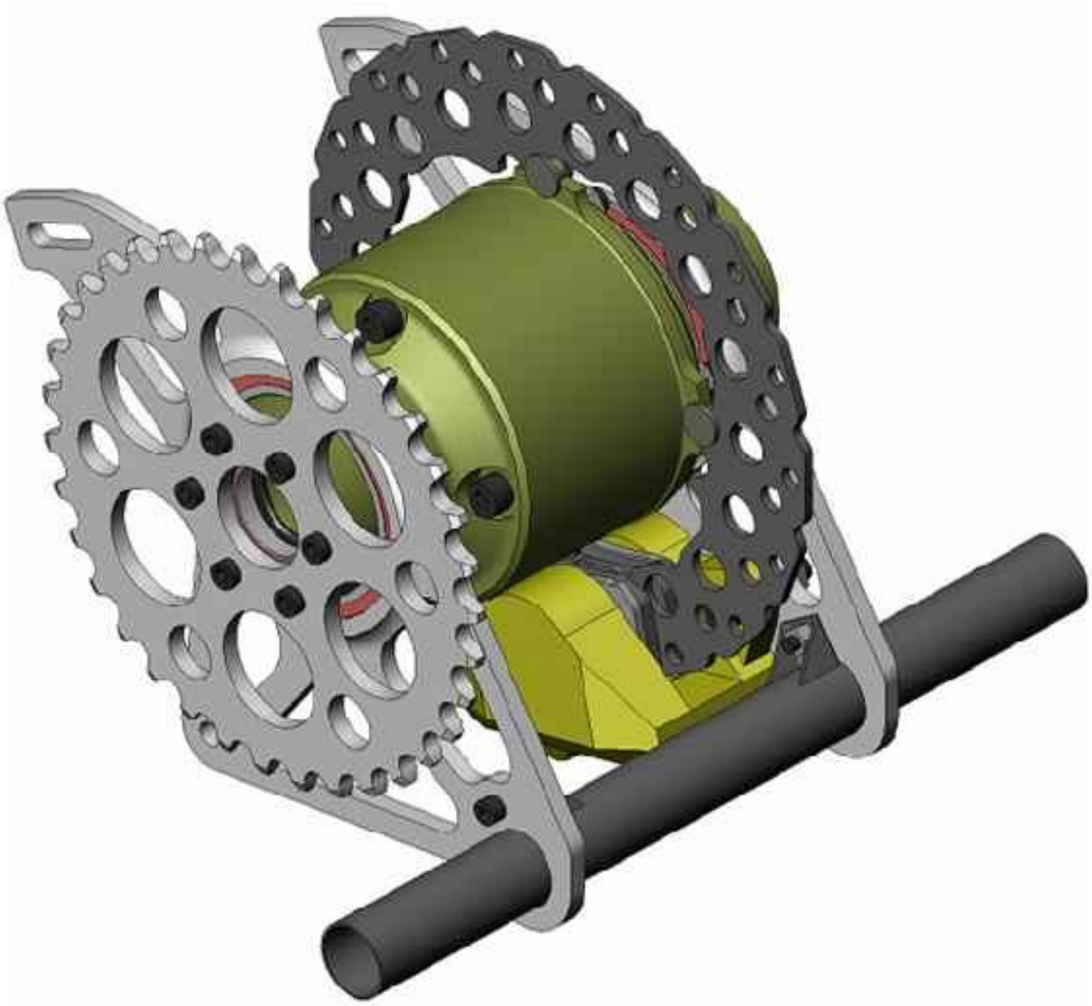
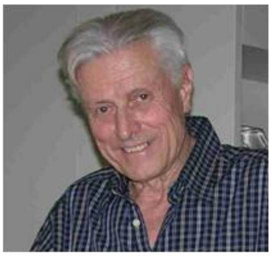


Figure 14 The team and car of 2011. After several years' development, our engines started easily and had good torque and power characteristics. We had for the first time a good quality data-logger. The team and team leaders were experienced and very dedicated and with the good guidance of senior technician Greg Elder all components were well made and reliable. Since 2008, when led by Adam Austin, the teams have progressively built on the first Aprilia powered car. Greg Elder is seen third from right (above) and team leaders Gwylim Johnstone and Edward Jarvie at the car (below). These are just a very few of the many, many students of whom we can be thoroughly proud.

Author's Note: Some of what is written here is based upon imperfect memories and hearsay, but nevertheless reinforced by ongoing discoveries and experiences.

Andrei Lozzi



Andrei Lozzi was born in Rome in 1938 and arrived in Australia in 1950. He attended Richmond Rural School, from there joined Qantas as an apprentice aircraft mechanic and later worked as a draftsman. Like many others who aspired to becoming professional in those years, he attended night school to matriculate and then entered university part-time. He acquired a BSc in Mathematics and Physics from the University of NSW in 1964. After Qantas he was employed as an experimental officer at the Australian Atomic Energy commission.

Having decided that pure science was not quite what he wanted, he joined the Department of Mechanical Engineering, University of Sydney, as a Research Assistant. There he designed and supervised the construction of various supersonic wind tunnels and shock tubes, under the supervision of Dr Roy Henderson. This led to an MEngSc and a PhD in 1975 in the experimental study of shock wave reflections.

He taught mathematics at TAFE for a year before moving to the RTA crash research laboratory as a senior engineer. Andrei remained there for about four years carrying out full-size side-impact simulations between cars and poles and working on other projects. In 1980 he was appointed by Professor Roger Tanner to a lectureship in engineering drawing and machine design. Amongst other work he carried out full size car-to-truck impact simulations, researched non-circular gears and worked on pattern recognition.

He retired in 1998 as a Senior Lecturer when he turned sixty, because it was advantageous to do so. Andrei has since taken up contracts, year by year, with the school of AMME, teaching CAD, drawing and machine design. Since 2004 he has administered the School’s Formula SAE team. The challenge to educate and motivate a new team of students, to make a better car each year, has been more than enough to prevent Andrei from taking up gardening.