TEACHING ROTORCRAFT TECHNOLOGY - FROM ERF 1 TO ERF 40

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Abstract

In the time period spanned by the ERF from 1975 to 2014, technology has undergone colossal development and transition. These changes have affected the entire science and engineering disciplines. This paper focusses on the author's experience in researching and teaching aeronautics and how the developments have helped in the understanding of the aeronautical discipline which has had a major impact on its progression. Most of the discussion will be devoted to rotary wing aspects.

1 INTRODUCTION

In 1975, two major things happened. I finished my Masters course under the mentoring of Ian Cheeseman and also presented part of my work at the first ERF in Southampton. It is now 40 years on and my career is, in many ways over, regarding the coal face of research and development. However, during this period I worked in the helicopter industry at Westland Helicopters and then at my alma mater: the University of Southampton. So I was in a position to see where the undergraduates and postgraduates need to direct their intellect in order to be of most use to the rotorcraft world. I am now helping as a volunteer at a school in Winchester and can now see a similar situation only earlier in the person's educational life. Effectively I have moved backwards from the final area of research and development in industry via the intermediate stage of academia through to the emerging talents of the school child. This has helped me to assemble a mechanism of teaching to provide the stimulation and general curiosity of a potential member of the aeromechanics world.

Having taken my first degree in mathematics, I have attempted to defuse the perceptions of mathematics being difficult and, at its highest level, of limited use. It is vital to educate the mathematical underpinning of all science and engineering and to show how and why it is so important. Over the last 40 years, the manner in which I have been able to pursue these goals has been transformed by the use of technology, both in hardware and software terms. It is often asked how and what – what I have tried to achieve is why and what's the point!

2 CONVENTIONAL MAINFRAME COMPUTING

When I embarked on my career in helicopters, I had come from an establishment who made use of the mainframe computer. The University used the conventional 80 column punched card for input and the standard size page layout for the printed output. In time, plotting was added to the facilities and graphical output could be achieved, albeit with a ballpoint type of pen. Monochrome was the thing and any use of this in published work required the use of scissors and an adhesive such as Grip Fix or Cow Gum. The use often depended on what type of odour you were prepared to endure - almonds or astringent respectively! The input was presented to the system, usually in the building housing the main-frame and the subsequent output was collected from an enormous pile of printouts requiring you to put very wacky codenames on the header to enable you to locate this quicker (not necessarily quick). It was often the case that it was raining which made life potentially hazardous in the case of punched cards – particularly if you lost your footing! This could be made significantly more frustrating if the final output was about 2 inches thick and consisted of a stream of alphanumeric characters which made no sense. You were staring at a core dump and had just written off a few trees all for the sake of a misplaced comma! You also had lost time and the delay could actually interfere with the thinking processes and progress would be slowed. Most of what I have to say in this paper is rooted in this consideration. It not just time, but intellectual momentum that is lost.

As I entered the industry, that situation was still the case. The walk in the rain was now replaced by that well established communication system of the Lister truck! However the advent of the remote terminal was at hand. This was now an important development, not merely for keeping your cards dry, but also the dangers of wear and tear on the cards and the ability to read the input. It also gave much quicker feedback and the momentum could be maintained. This was of major importance when conducting feasibility studies and adjustments to the design details would be under refinement in order to satisfy a given requirement of the specification. A particular example was an early version of what was to become the EH101 where a presentation was imminent and the final mission time had to be achieved. Without rapid feedback this was not possible. The preparatory calculations were conducted on a HP9100B desktop calculator which had a HP9125A plotter connected. The main calculations were performed using its successor. Computing in the office of the 1970's era was of limited power – but still a vital development. The memory had to be tweaked in order to store enough data. At maximum stretch, you could hold 32 numbers. It seems very small beer now but then it permitted very useful work to be done.

Figure 1 – Navy Lynx (Courtesy US Navy)

Figure 2 – HP 9810A Desktop Calculator

Figure 3 – HP 9862 Plotter

The sale of the new Lynx design, Figure 1, to another country for Anti-Submarine Warfare purposes, required a relatively sophisticated demonstration to be given and the successor to the 9100B, the 9810A (Model 10) – Figures 2 & 3 - with the new plotter, was programmed to perform a simulated submarine search and attack mission.

The initial reconnaissance leading to the passive sonobuoy seeding, to the eventual active sonar positioning and subsequent attack by torpedo, all had to occur on the platen of the plotter. The machine used magnetic cards to store and hold programs or data and these were stacked so the memory was being constantly refreshed as the mission developed. Thankfully, the company got the order.

3 THE ADVENT OF THE PERSONAL COMPUTER

In 1981 the IBM personal computer appeared, and although it was not the first to be developed it provided a revolutionary platform on which much could be achieved without having to leave one's desk. It also allowed an enormous flexibility in application software from which a great number of techniques could be generated.

In 1986, the Amstrad Company introduced the 1512PCX closely followed by the 1640. The latter had a 640Kb memory and was equipped with one or two floppy disk drives or a hard drive of 10Mb or 20Mb. In modern terms this is minute but at the time these products made desktop computing more accessible to the general public and gave them considerable computing powers. At the beginning, I was steeped in the notion that computers are for number crunching and was buried in FORTRAN compilers. Editing was problematic as DOS 3.1 was the operating system and we had to wrestle with EDLIN, a line based editing tool. Soon, full screen editors began to appear which made code entry and modification so much easier and more accurate. In time, it became very apparent that the PC was more flexible and could supply many other benefits and tools for use in other matters. Looking back to the early machines makes the modern PC a considerable beast. It is worthwhile to reflect on the speed of processors, the ganging together for parallel processing and the development of storage devices that can just eat up files and seemingly never fill up. That, of course, is a delusion and the infinite hard disk is not yet on the market. However, they are of incredible size and the data transfer rates are comparatively mind-boggling. This speed and capability allows the development of more and more capable software.

3.1 Early Office Software

Having been used to generating results by a conventional programming method, the emergence of software to support writing, data presentation and without the need to generate load modules, the transfer of results to documentation, of any type, proved a vital move forwards. The entire process of performing calculations, collating experimental results and producing the final publications became the norm and data transfer between the various pieces of software became a simple copy and paste.

Word processing formed the first vanguard of this new world. Word Perfect started as a DOS based word processor. The layout was not WYSIWYG but with a little practice highly presentable documents were then at hand – see Figure 4.

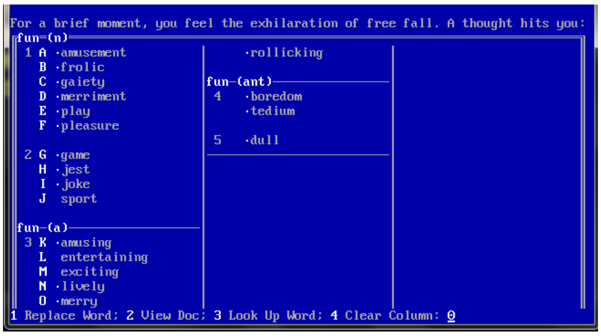

Figure 4 - Word Perfect Thesaurus

Soon after, the software package DrawPerfect appeared and at once, results from calculations and experiments could be inserted into the package and processed as required. It also permitted graphical presentations to be obtained and the whole system allowed "conversation" between it and a word processor. These were not the only pieces of software available but you can only master some and starting with the WordPerfect family was purely to adopt the in-house system at the time.

Microsoft Word was its competitor and would form one of the core elements of the Office environment. Word processors were then WYSIWYG and editing, as happening now, was made considerably easier. Ultimately, the move to this supplier was triggered by my employer adopting a different set up.

The spreadsheet was being developed and, at first, it proved a useful method of data handling and general processing. However, once it is understood that there is a programming language in the background, the spreadsheet can move on to more extensive, involved and dedicated computation. After working on smaller projects, it became possible to have a full performance analysis conducted for a proposed helicopter design – Figure 5.

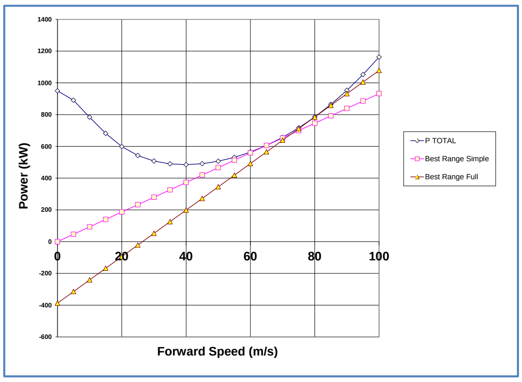

Figure 5 - Spreadsheet on Helicopter Performance

The aerodynamic models that could be sensibly used were limited, but simpler methods could be readily incorporated. Actuator disc modelling is the most straightforward and has limitations on operating a helicopter near to a flight envelope boundary. Therefore the use of this type of calculation must not stray close to where stall is a possibility. That said, in the initial concept of a helicopter design, this method allows considerable flexibility in the viewing of an emerging aircraft profile and by using the goal seek and solver components of the spreadsheet, optimisation of specific elements of the design can be accomplished. This has become a major contributor to teaching aircraft behaviour with changing details and how to take a specification to generate and verify a workable design from a blank sheet of paper. You will never produce graduates who are *"oven-ready"* but you can indeed give them the tools to become useful employees almost from immediately joining a company or research institution.

The use of presentation packages needs, in the author's opinion, great care. The flexibility in the features available and the plethora of colours, clipart and layouts can, sometimes cause a presentation to look like an explosion in a paint factory. However, with care, attention and reining in the artistic aspirations, high quality work can be effectively presented. This has had a major impact on teaching provision. It also allows a gateway to open learning in producing web based material.

The emergence of the World Wide Web and the effect of Tim Berners-Lee's devising HTML and its driving force, the introduction of the internet has been nothing short of seismic. It has changed all our lives and opens up many doors to research, teaching and the use of software. Downloading of files is so commonplace nowadays that it is difficult to remember the days of wrestling with 15 floppy discs to install software!

Documentation, including images, is a considerable consumer of disk space so when Adobe produced Acrobat in 1993 for, initially Mac based computers and then for Windows 3.1, things could change. PDF is not the only format for compressing files for transmission but it probably is the most common. With the web, important and historic documents are now commonly available which has supported research and teaching for a number of years. Long gone are the office shelves creaking under the weight of all this reference material. The danger of hanging on to original books and reports runs very strong, but moving to electronic documentation allows many time-saving features to be adopted. In retirement, I have become a Cathedral guide, and trying to compress 1500 years of history into notes requires a large library. The books are not available because of their age and value but electronic versions are available to all.

4 TESTING TECHNIQUES

In testing, wind tunnels in particular, two main difficulties present are the effects of scaling and interference. Scaling is mainly involved with the matching of Reynolds and Mach numbers. Improvements to wind tunnels using pressurisation and cryogenic environments have shown ways forward in achieving this. Magnetic suspension has itself shown that load measurement can be achieved without mounting the model externally. Flow speed measurement has suffered from two distinct problems, firstly the effect of interference of using probes to actually perform the measurements and the ability to investigate internal flows. Two techniques have evolved, using light, to enable such measurements to be undertaken without using probes, these being Laser Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV). Both require the flow surrounding the model to be seeded with minute particles such as a water-based fluid mist. Laser light is then used to track these particles and thereby measure the flow velocity remotely. With the avoidance of a probe, LDA is used to investigate flow data, to a high degree of precision at specific points, whilst PIV gives an overall flow pattern of streamlines and vorticity distribution over an area at the same time. This can be repeated a number of times per second permitting the flow to be analysed dynamically.

One use of the PIV technique has been the observation of flow fields surrounding a thrusting rotor. This has taken several forms, ground effect and more extensively the flow over a ship' flight deck and how a helicopter rotor downwash interact together. Conventional air or water flow tunnels are used at the beginning to get the student/researcher to use simple tufts or air bubble release to observe the overall flow patterns and dynamic character before embarking on a PIV flow survey. All testing is subject to erroneous measurements and it is important that the experimenter develops a sense of when a particular result, or set of results, are suspect. Retesting can then be achieved before the tunnel set up is dismantled. Figures 6 & 7 show the installation of a rotor/ship model set up in a Southampton wind tunnel which produced a set of flow patterns as the helicopter approached the ship and the changing flow interactions that occurred. Typical results are shown in Figure 8 (no rotor) and Figure 9 (rotor present).

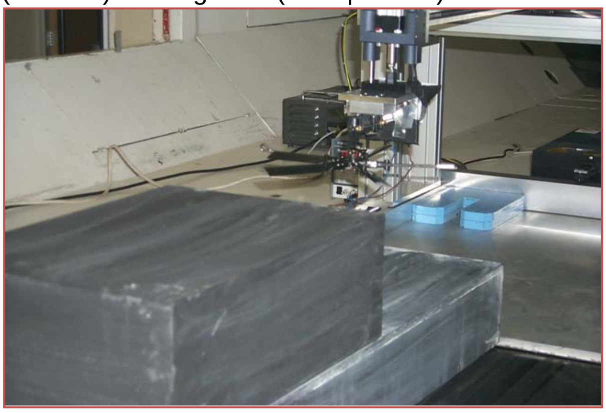

Figure 6 – Rotor Ship Model in Wind Tunnel

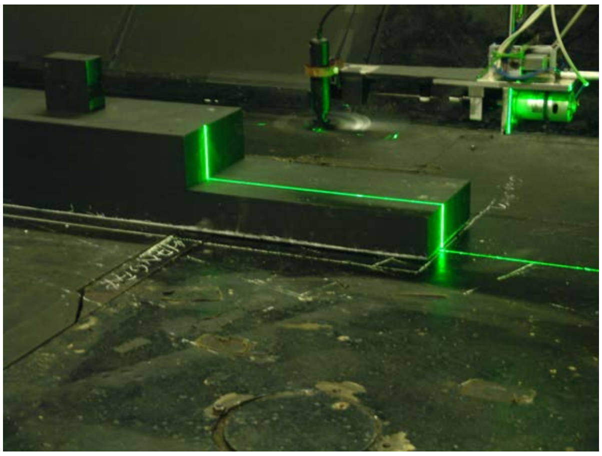

Figure 7 – PIV Laser Sheets over Model Flight Deck

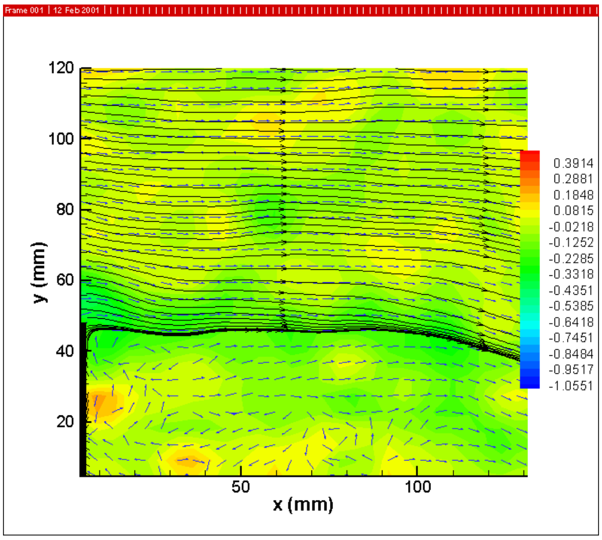

Figure 8 – PIV Image of Ship Only Deck Flow

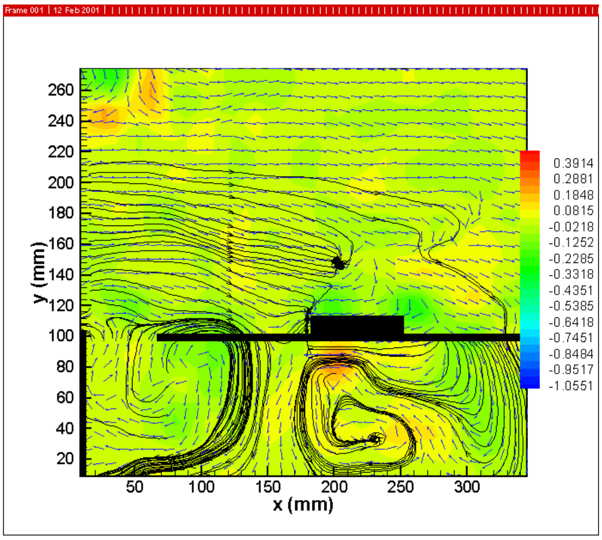

Figure 9 – PIV Image of Ship & Rotor Deck Flow

A fixed wing project, which involved a rotational element, was part of a Doctoral research programme but also enabled a final year undergraduate to use PIV for his project. The tumbling motion of a particular type of microlight aircraft was known but the exact nature of the aerodynamic forces driving it was not. It seemed paradoxical in that a high nose up attitude of the wing relative to the fuselage produced a nose down rotation. The effect of a nose down pitch rate combined with an aircraft configuration where the main mass of the aircraft lay to the rear of the wing could be seen to generate a negative lift – sustaining the nose down rotation. The trailing edge of the wing tips is normally kept in position being braced by so called “tip sticks”. Video evidence was showing that these could break and a reflex camber could be formed at the trailing edge giving rise to a localised lift force at the tip trailing edge. However, the use of PIV enabled the developing flow over the wing to be observed as it rotated – as shown in Figures 10 to 15. These show that as the wing passes over the upward vertical it takes a “bite” out of the upcoming flow and a vortex is generated at the leading edge. As the wing continues to rotate, the vortex increases in intensity and also moves along the wing chord towards the trailing edge whilst remaining close to it. This produces a suction force which works in the same direction to sustain a nose down rotation. This result has been instrumental in generating revisions to safety requirements which have been adopted into the microlight aircraft arena. Without PIV this could not have been achieved.

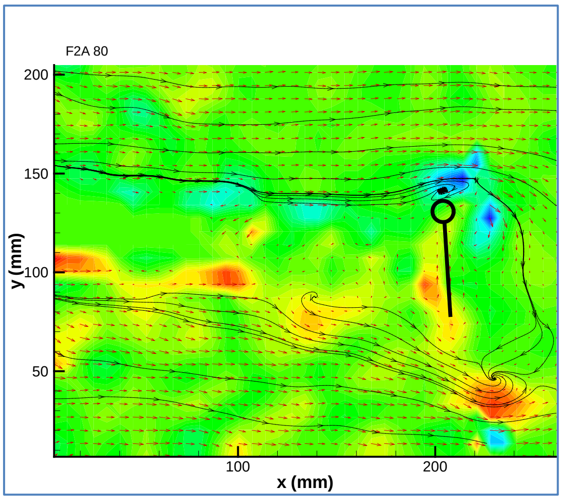

Figure 10 – PIV - Tumble 1

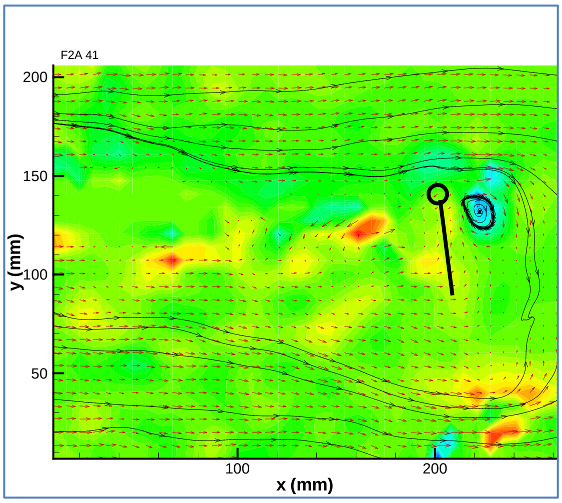

Figure 11– PIV - Tumble 2

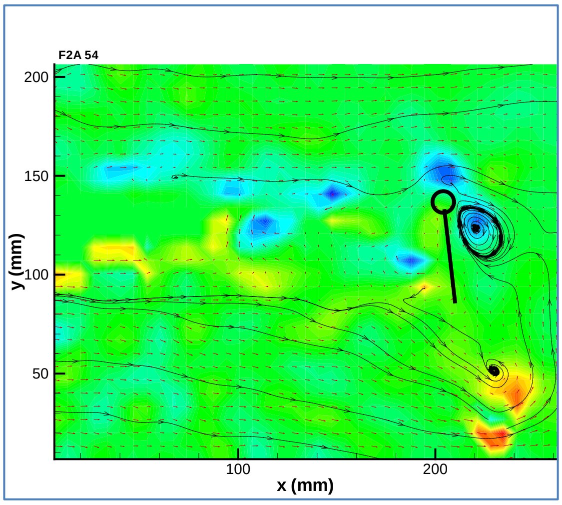

Figure 12– PIV - Tumble 3

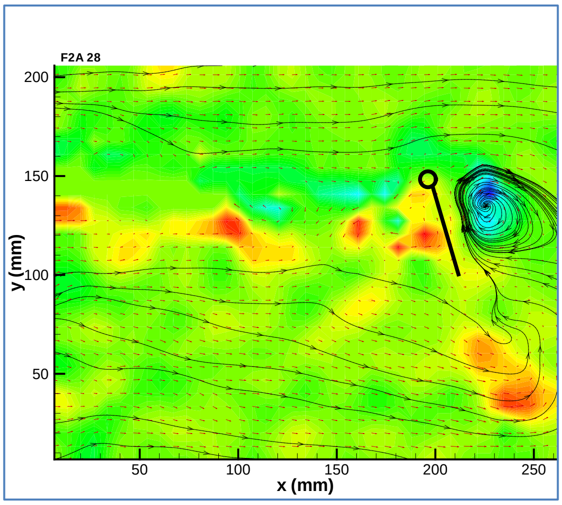

Figure 13– PIV - Tumble 4

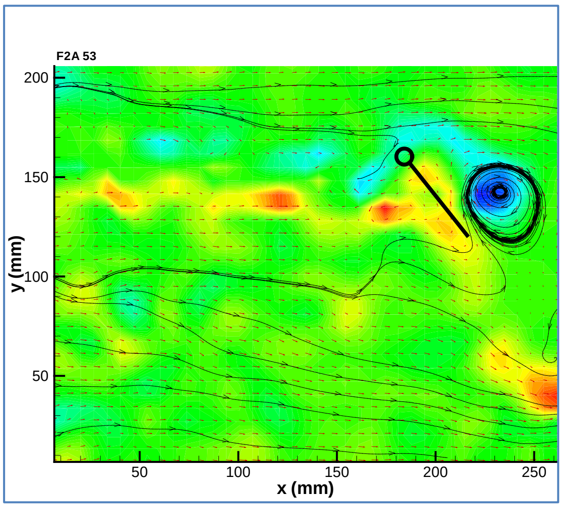

Figure 14– PIV - Tumble 5

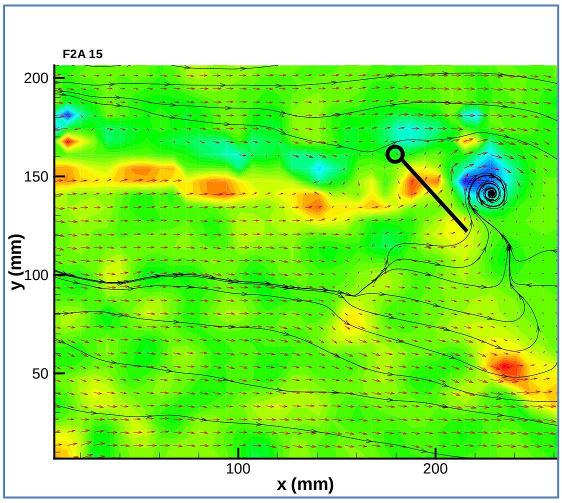

Figure 15 – PIV - Tumble 6

5 TEACHING METHODS

With regard to methods of teaching, the old standard “chalk and talk” became the acetate “reel and spiel” which then became the white board, the laptop and then to the intelligent white board - all being designed and developed over this period.

5.1 Introduction of Software to Teaching

In many ways, we are looking at method of presentation. They cannot immediately affect the technical content although they can allow the production of teaching material for the students. They coordinate the lecture presentations to the material issued to students and this can be achieved by the concurrent developing of a web site which is also produced by these software packages. However, the use of PC computers, particularly laptops, with the sophisticated software now available, allows the students to develop their understanding of design techniques and the ability to produce a vehicle to a given specification. In their career, they will face the blank sheet of paper. This can be very daunting at first and the immediate question of *"where do I start?"* must be resisted and the learner introduced to the design process from need to detailed design and how to use the computer effectively. Not to just present the data, construct a viva presentation and write the subsequent report, but to work hand-in-hand using the speed and power of the computer to answer the many questions that arise during the design evolution and also to steer the vehicle design into the most advantageous configuration. It should also show how a flexible approach can help immensely if the specification should change and the whole process can adapt to the revised requirement.

Matlab (Matrix Laboratory) is the result of many people's efforts. It was intended to enable the move away from programming and compiling main programmes subroutines in languages such as FORTRAN and to supply a set of routines which can be readily used to produce the required set of software. It also allowed the easy generation of graphical output and this can be used to produce video animations. Animations can be converted to a standard video format for distribution or inclusion in the lecture material. They can also be introduced to a web based teaching scheme with no further effort.

Figures 16 & 17 show the positions of blade vortex interactions in 2D and 3D. For the latter, the vertical scale is a measure of the vortex 'age' from its formation to the interaction expressed in rotor azimuth angle.

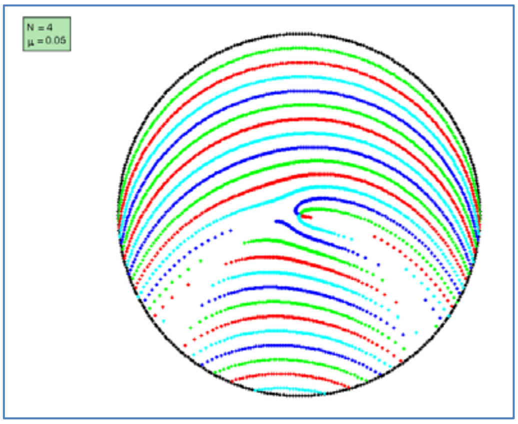

Figure 16 – Blade Vortex Interaction Plot 2D

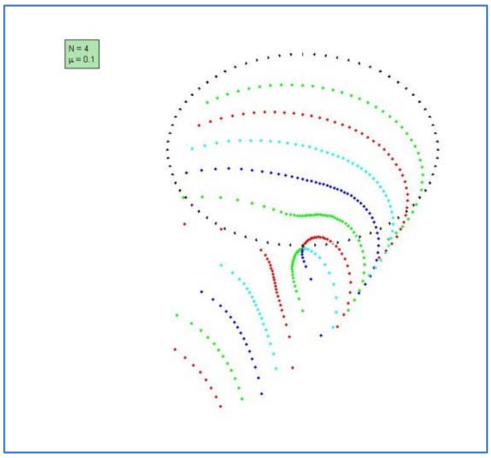

Figure 17 – Blade Vortex Interaction Plot 3D

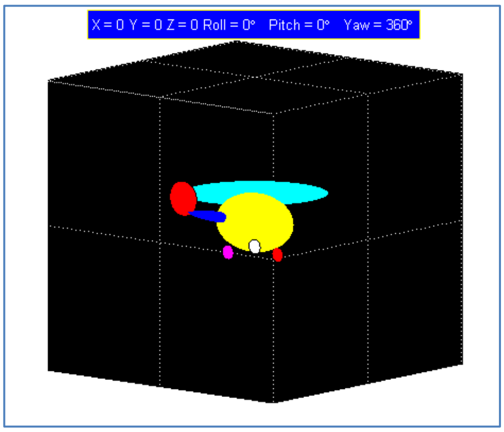

Figure 18 – Matlab Modelling of Generic Heliocpter

In many ways, the author's experience of Matlab has been in three distinct directions. Firstly to perform calculations in a manner where the writing of the software is relatively straightforward and where the detailed analysis techniques are ready *"on tap".* Secondly is to use the results, often in animation form, in order to understand aeroelastic phenomena. Thirdly is the ability to produce demonstrations for use in the lecture room and to allow students to have software available for their design work. (A helicopter fuselage and rotors can be assembled using simple Matlab features as shown in Figure 18.) This, of course, carries the danger of spoon-feeding! It has also been used in assessing the technical aspects (supporting a legal process) to determine the possible motion of a helicopter during its final moments before impact with a building. It permitted an assessment of the motion of the blades and fuselage being consistent with the claimed damage to a building and surrounding area.

Matlab has gone forwards to a position of considerable influence and has applications in many subject areas.

5.1.1 Examples

One use in teaching rotorcraft dynamics has been the understanding of the forces that produce ground resonance. As it is a very complicated calculation, the teaching of it often uses a simplified situation, such as rigid blades and a single degree of freedom for the rotor head. The solution of the resulting polynomial equation can be quickly achieved using a supplied routine. The number of fuselage freedoms can be increased and the resulting eigenvalue problem is also handled by supplied routines. The complex roots are sorted with respect to the frequency and the damping of each root can be calculated and plotted.

The position of the rotor head and blades combined centre of gravity can be easily calculated but the resulting motion does not immediately indicate the driving forces for the resonant condition – Figures 19 & 20. An animation can be generated, with only a small modification to the code, and this can be used to show the progressive and regressive modes and their effect on the dynamics.

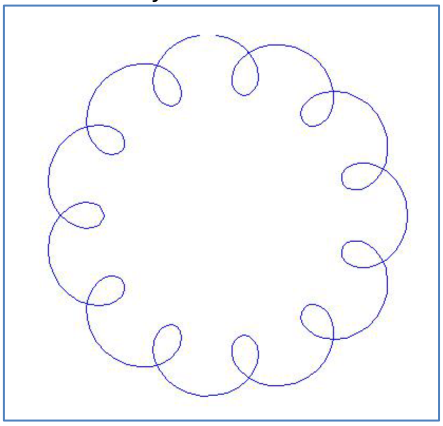

Figure 19 – Simple Ground Resonance CG Path

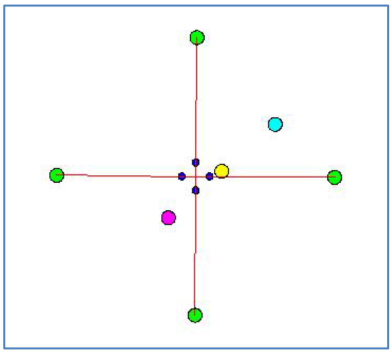

Figure 20 – Simple Ground Resonance Progressive and Regressive Interpretation

A second example concerns the positions of blade vortex interaction (already introduced in Figures 16 & 17) over the rotor disc, whilst examining forward flight, and the variation with advance ratio. The locus of these positions seem to form three distinct types and the interaction between them seems, at first, puzzling. However, using Matlab to produce a set of vortex interaction plots and to animate them with increasing advance ratio shows how these types are all related and how at certain advance ratios, they can transform from one to another.

6 PHOTOGRAPHIC TECHNOLOGY

In the last 20 years photography has undergone an almost complete transformation from a film based science to one that is based on digital sensors. Resolution of detail is key and this has improved with a large change in capability. Early digital cameras could produce images of 3Mp for a 35mm aspect ratio. As examples, the Nikon Corporation produced the D100 in February 2002. It has a sensor of reduced size to 35mm (36mm x 24mm) and produced 6Mp resolution. The D200 released in November 2005 produced about 10Mp. The D700 of mid 2008 used a full frame sensor of 12Mp and the D800 of early 2012 increased the resolution to files of 36Mp.

The ability to process images is a very useful capability. From a photographic point of view it permits the cleaning up and enhancing of the images to provide a pleasing result. It also allows flow imagery to be enhanced, and thereby improve the efficacy of the data and its interpretation. In February 1990, Adobe released Photoshop 1.0. It was the brainchild of Thomas Knoll and his brother John. In terms of influence it cannot be overstated as it has become such a powerful tool. The use of imagery, for research, or for presentation is of considerable importance and software like Photoshop gives enormous flexibility to the user.

As an example, Figure 21 shows a stroboscopic photograph of smoke being used to indicate the wake under a hovering model rotor. Figure 22 shows this image after using the Smart Sharpen filter with Figure 23 showing the photographic inverse. The features can be heightened using this advanced software.

Figure 21 – Smoke Original

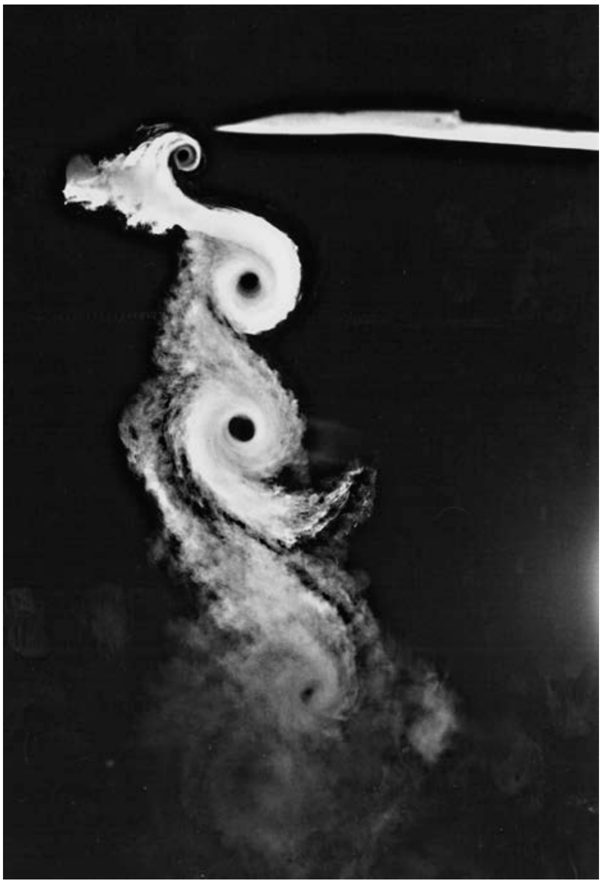

Figure 22 – Smoke + Smart Sharpen

Figure 23 – Smoke + Smart Sharpen + Inverse

7 CAD/CAM – PROJECT DESIGN

As with most software packages of this type, the concept of performing the design and verification within the same environment is common. From a teaching point of view, this will generate, within the student, a sense of examining the design from many different viewpoints, but using them to focus the design to the specification. It will help to form the thought process that will demonstrate how one aspect of a design is totally influential for the remainder of the process. It will give the emerging engineer the ability to test their design in aspects of assembly, strength, susceptibility to vibration and dynamic loads, flow pattern simulation and finally to obtain a photo-realistic set of views of the final product. Photo editing tools can then be used to place it in a given context. To illustrate these ideas a few examples are presented.

7.1 Wykeham Flyer

Teaching at the Winchester school gave the final year students the task of designing a racer type of helicopter for an AHS Design Competition. Timetabling did not permit the resulting design to be entered in the competition but it provided a useful design specification to work towards. Figure 24 shows the design and placed on an aerial view of the school grounds using a photographic image processor.

Figure 24 – Wykeham Flyer over Winchester

7.2 Flow Simulation – (Computational Fluid Dynamics)

The ability to synthesise the fluid flow external to a body or within a cavity has made the effectiveness of a particular design much more readily interpreted. In the realms of industry, or research institutions, the accuracy of the particular modelling algorithms is vital, however, in the teaching environment, the level of detail is not so important. It is still vital to obtain realistic and repeatable solutions but the input to a design decision at learning level is not so strict. The aim here is to encourage the student to question the flow patterns, observe whether the original intentions of the design conform to the results and get a relatively rapid feedback on the effect of design changes. The whole point is to answer these questions and difficulties rapidly and effectively. When the student eventually moves into the real world, they will need to have a working knowledge of modern design practices and how software is becoming an essential tool in the process. Decisions will still require a level of understanding of the disciplines needed but also be able to use the so-called *"gut-feeling"* that often provides a difficult to explain, but very valuable, input to the design evolution. An example is the Shipborne Helicopter.

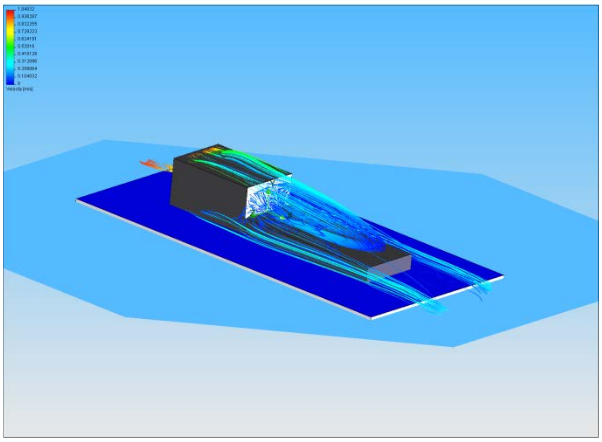

Figure 25 – Flow Simulation of Ship Flow

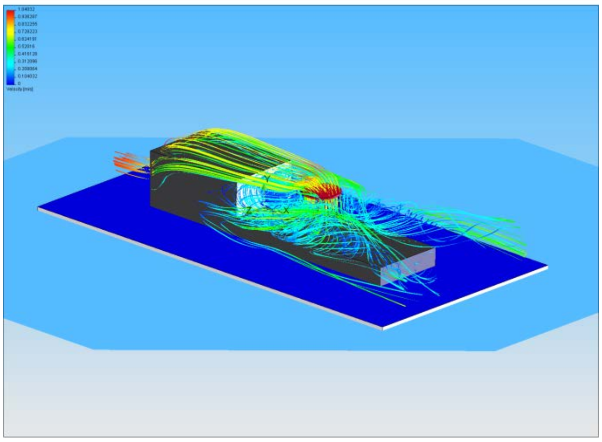

Figure 26 – Flow Simulation of Ship & Rotor Flow

Figures 25 & 26 show how a CAD/CAM flow simulation can be used to illustrate the basic flow interactions. They show the overall differences in flow geometry with the introduction of the rotor downwash to the separated flow over the ship's flight deck.

7.3 Brown Out

The CAD/CAD software has been used to look at "brown-out" conditions. The model is very straightforward in placing a circular disc above a level plane. A side wind is readily generated and the rotor downwash is taken to be uniform and of a value typical of a helicopter. The flow patterns were generated and turned into a dynamic presentation as shown in Figure 27. This is a typical feature of the post-processing suite of options.

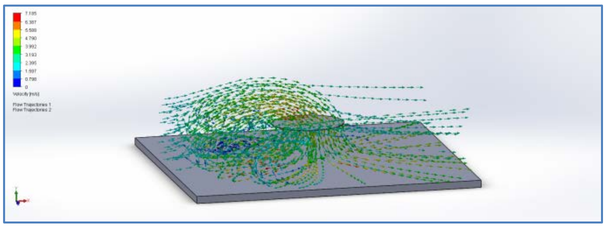

Figure 27 – Flow Simulation of Brown Out

7.4 Motion Study

The dynamic interaction of vehicles in various environments can be studied. Springs, dampers and external forces are input and the motion calculated from a given position. A simple example is the behaviour of an undercarriage when performing a vertical landing. See Figure 28.

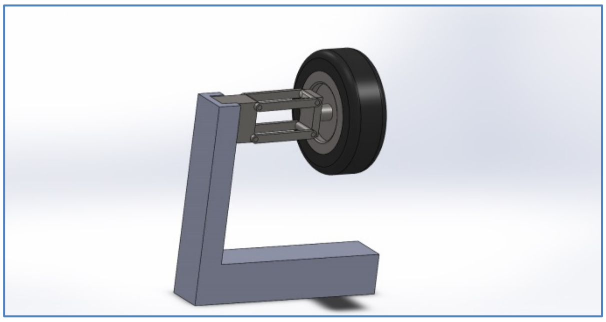

Figure 28 – Simple Drop Test

7.5 Kaman Rotor

The linking of components in an assembly can help in the understanding of the relative motions. One example, shown in Figure 29, is the intermeshing rotor of a Kaman helicopter such as the KMax. At first it seems almost impossible to see how such a configuration can operate without a self-trimming effect on the rotor radius.

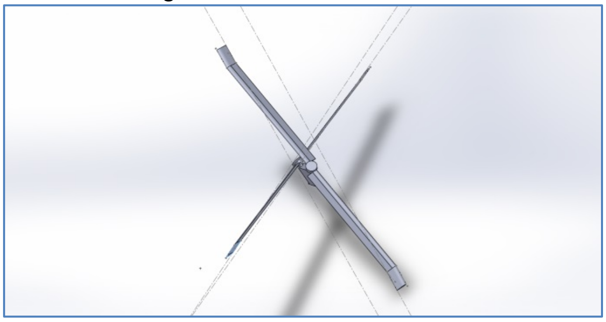

Figure 29 – Intermeshing Rotors

7.6 Blade Modes

The vibration of a structure, or assembly, can be synthesised in this type of software. The effect of loads on the structure or the modal frequencies and shapes can be determined. With the teaching of rotor dynamics, it provides useful information on how a blade vibrates naturally and how the attachment to the rotor head is vitally important in the dynamics of the blades. It gives the student an understanding of the order of modes in increasing frequency. It also helps develop in the student, the manner in which a blade system will react to the variation of aerodynamic loading across the rotor disc. Figure 30 shows the result for a non-rotating blade – second flap mode.

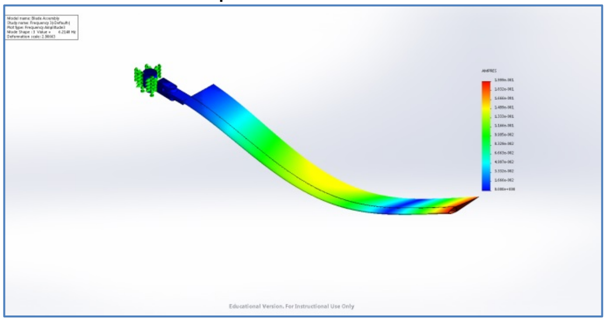

Figure 30 – Solidworks Modelling of Second Flap Mode

8 WHERE NEXT?

Good question! The design phases of an air vehicle can now be seen to emerge from a computer with a full understanding of air flow, dynamic characteristics, dynamic behaviour under loads and a photorealistic view of the final product. With the development of 3D printing and indeed 3D scanning, the outer ends of the design/development/production phases can now be addressed. Industry is using these tools freely nowadays but the classroom has not quite caught up. This will soon happen and the process from the need for a future air vehicle, to starting with as blank sheet of paper, to the various design phases and then to final production can be introduced to the student. So why is this important? As already stated, a student will never be fully "oven-ready" simply because each branch of the industry has its own type of software used and methods of implementation. What the student can be is a person with a good understanding of the overall principles and how they contribute to the research and design process. Adapting that knowledge and experience can now be achieved quickly when they finally enter the outside world and learn to apply their skills in practice.

I need to make a final comment, which is really an apology. When teaching students to write reports and papers properly, I often told them to use third person throughout. I have broken this rule as you have just read. The case for the defence is that this is the record of a personal journey and I hope the reader will forgive my lapses.

9 ACKNOWLEDGEMENTS

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