Vision 2030: A Time for Engineering Leadership

[1]R.O. Warrington, [2]F.A. Kulacki, [3]A.C. Warrington
Michigan Technological University, Houghton, MI, US, row@mtu.edu[1],
University of Minnesota, Minneapolis, MN, US, kulacki@me.umn.edu[2],
Michigan Technological University, Houghton, MI, US, acwarrin@mtu.edu[3].

Abstract

Change normally occurs when there is a compelling need, and this is particularly true with engineering education. There have been many studies over the years focusing on engineering education and the need for change, but most have had little or no impact on the educational process unless they were associated with a major societal need. Today there should be no confusion as to the societal need: the growing need for alternative clean energy sources, food and fresh water shortages that are prevalent in many regions of the world, global political and social unrest due to many factors not the least of which is poverty, and growing concerns for the environment. How are the roles of engineering and engineering defined in this broader context, and how should engineering education respond? Alternative responses are explored, and we suggest strategies drawn mainly from the mechanical engineering community that we feel are relevant for engineering education generally. With extensive survey data from academia, industry, and early career engineers, we make the case for substantial change in engineering education, and we present possible scenarios.

1. Introduction

Change normally occurs when there is a compelling need, and this is particularly true with engineering education. There have been many studies over the years focusing on engineering education and the need for change, but most of them have had little or no impact unless they were associated with a major societal need. The arms race and the shift from engineering practice to engineering science after World War II, the emphasis on science and space during the 1960's, and the unfortunate short lived emphasis on sustainability and energy in the late 1970's and early 1980's all resulted in change. More recently, the realization that the purpose of engineering is design [1] has led to a reemphasis of design education and project-based education.

Today there should be no confusion as to the societal need. The Grand Challenges articulated by the US National Academies [2] clearly express societal needs. But what is fundamentally different now than even five years ago or thirty years ago during the first energy crisis? The differences are great with a growing need for alternative clean energy sources, food and fresh water shortages that are prevalent in many regions of the world, global political and social unrest due to many factors not the least of which is poverty, and growing concerns for the environment. Couple all of this with the financial collapse of many institutions and the financial chaos that many governments are experiencing and we have the need for pervasive and comprehensive change. What is engineering's role? Certainly the technical aspects of energy, clean water, food scarcity, and the environment concern the engineer. But is there a need for much greater and broader participation of the engineer?

Engineering's history of invention of both products and processes has served this country well for over two hundred years, but the recent confluence of events is suggests, as Simon Ramo said,

> *Either the engineering profession will broaden greatly or the society will suffer because the matching (between society and technology) will be too haphazard..., a greater engineering needs to evolve...it will come to embrace much more the issues at the technology-society interface.*

Hallmarks of these changes will hopefully be not only increased invention but also the implementation of invention, or innovation. Innovation will require leadership, and that leadership should be from engineers who have the technical insight and ethical courage to solve the grand challenges facing this planet for the benefit of all its inhabitants. We can no longer leave our fate entirely in the hands of often ill informed politicians, lawyers, and business executives. Engineers must take leadership roles not only on technical projects but in society generally. Engineers must lead in their communities, in local, state and federal governments, and engineering must lead us to a sustainable world. There are probably no second chances, now is the time for action, and we have to get it right. Now is the time for engineering leadership, our country needs it and our planet needs it.

What does this mean for what and the way we teach our students? Our students will need to lead not only technically but also socially, politically and ethically. Future engineers will need outstanding communication and people skills, business sense, a global perspective, and an unparalleled understanding of our natural environment. This implies a compassion and passion for our planet, ethics beyond the bottom line, not unlimited growth but sustainable growth, an understanding of the importance of economic growth, and more importantly an appreciation for the equitable distribution of that growth.

This paper presents new data on the status and long-term outlook for engineering education from industry leaders, department heads, faculty, and practicing engineers. While the data is primarily from the work of the American Society of Mechanical Engineers (ASME) Vision 2030 Task Force from 2008 to the present [3], we feel that it is applicable to all engineering disciplines. We make the case for the need for substantial change in the educational process, and we present possible scenarios for change.

2. Methodology

The work of Vision 2030 Task Force has three primary goals. The first goal is to broadly define the knowledge, skills and abilities that mechanical engineering and mechanical engineering technology graduates should have to be globally successful in the future. The second goal is to provide recommendations on features of mechanical engineering education that will help provide graduates with the necessary expertise for successful professional practice. The third goal and perhaps the most important one is to provide recommendations for the development of professional skills in the engineering graduate that will motivate the leadership required for implementing the technology and policy to solve the challenges facing their companies, regions, and the planet.

Our recommendations are based on a rich set of inputs drawn from all of the stakeholders of the mechanical engineering and mechanical engineering technology educational process: faculty, academic administrators, industry employers and leaders, and practicing engineers. These constituent groups guided the task force in framing the key questions to be addressed and the over arching issues to be addressed in our recommendations.

Several methodological tools were used to develop a contemporary viewpoint on the goals of our work including,

An assessment of the literature of the past 30 years that has addressed the form and content of engineering and engineering technology education [3].

Surveys of the stakeholder groups addressing issues related to education and practice (2008-2011) including a special focal study of graduates of the undergraduate program at the Massachusetts Institute of Technology (2010) [4].

Workshops and focal sessions at the International Mechanical Engineering Conference and Exposition (2009, 2010), the University of Houston on engineering technology education (2010), Annual Meeting of the American Society for Engineering Education (2010), 5XME workshop sponsored by the US National Science Foundation (2009).

Our surveys were administered by the ASME and reached over 600 US-based companies, and several thousand practicing engineers, including a goodly number of young engineers who were within ten years of graduation. All mechanical engineering and mechanical engineering technology departments were contacted as well. Response rates were sufficient across all surveys so that statistical analysis could be conducted. Additionally a large amount of anecdotal input was received in the course of several focal workshops with department heads in the mechanical engineering and mechanical engineering technology communities.

3. Survey Results – Early Career Engineers

In this section, we focus on an analysis of an extensive survey of early career mechanical engineers (ECEs) that was completed in spring 2011. The ASME member data base was used to administer the Internet-based survey, and the sample size used for analysis was 635 for engineers with less than 10 years of experience. Approximately 96% of respondents were degreed mechanical engineers with the remainder holding engineering technology degrees. Where possible comparisons with industry responses (more than 1,000) were run to determine differences in perception and measured of performance. The figures below illustrate the range of questions we have generally asked in all of our surveys since 2009. A more detailed presentation and discussion of survey results is given in [3].

Early career engineers were first asked to identify what they thought are the strengths and weaknesses of their undergraduate education. Figures 1 and 2 summarize the responses. Technical fundamentals and problem solving and critical thinking rate highly as might be expected. Surprisingly, interpersonal and teamwork skills were rated highly. More lowly rated were information processing, communications and laboratory procedures. Weaknesses relate to what can be called practical, business process oriented skills that probably can only be obtained via experience in a particular organization and job function. Notably, the lack of knowledge of codes and standards rose to the top of identified weaknesses, which is not surprising given that most US baccalaureate mechanical engineering programs do not devote time to this topic.

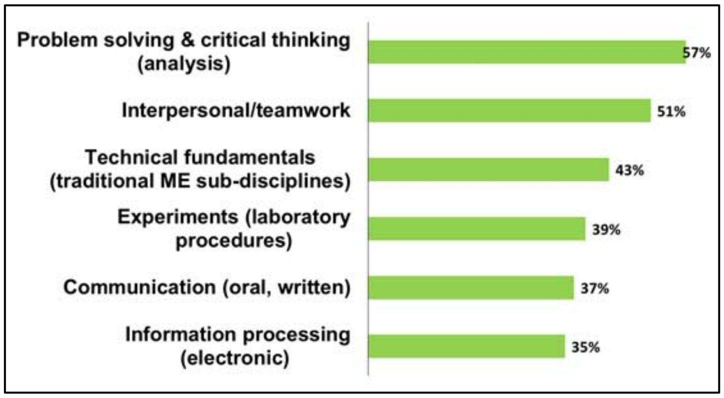

Figure 1. Early career engineers reporting strongest preparation for work. (ASME, Vision 2030 Survey, n = 635, 2011)

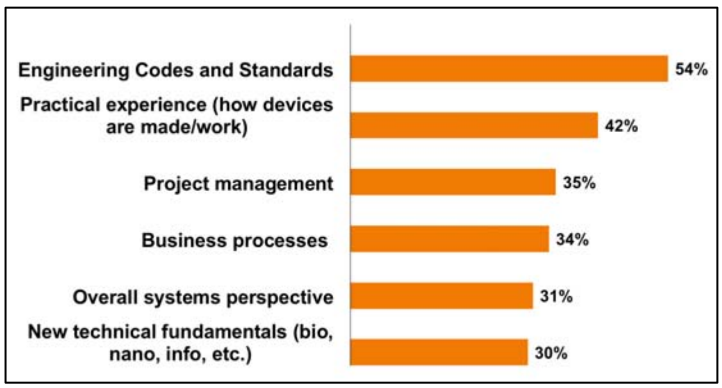

Figure 2. Early career engineers reporting weakest preparation. (ASME, Vision 2030 Survey, n = 635, 2011)

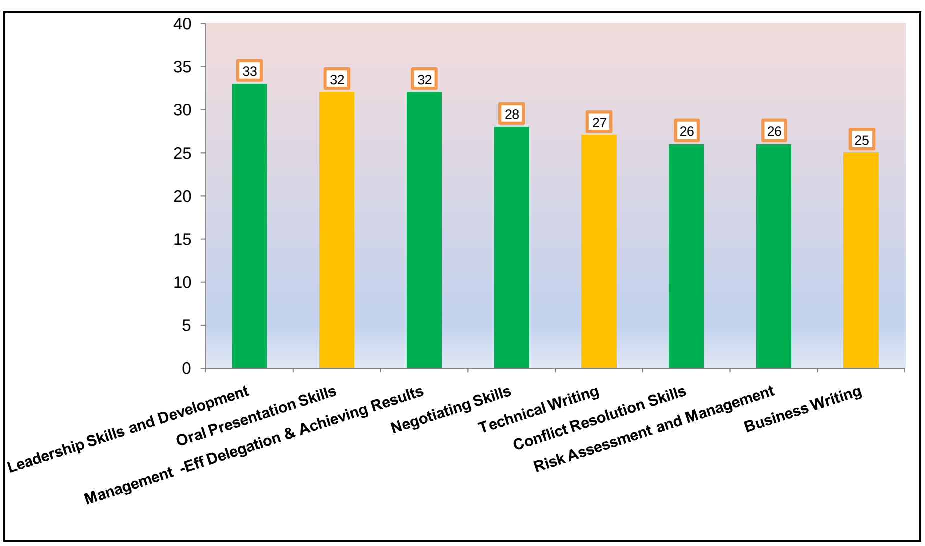

Figure 3. Areas of greatest professional development and need seen by early career engineers. Rated 8-10 on a scale of 1-10 (ASME Vision 2030 Survey, n = 635, 2011)

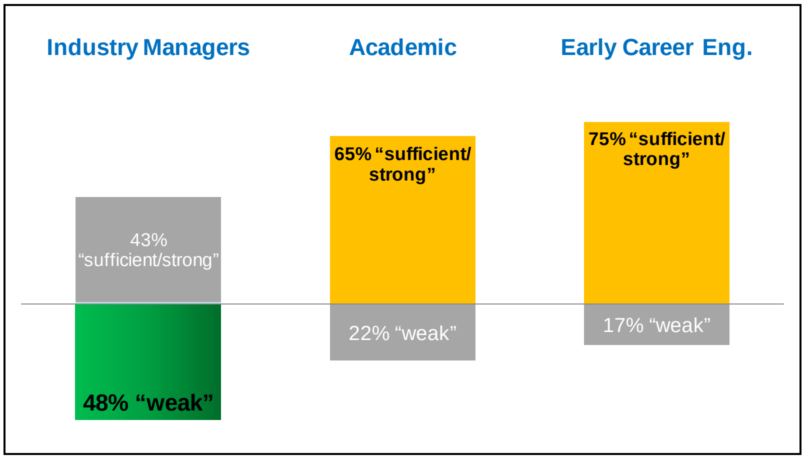

Figure 4. Difference between industry, academics and early career engineers on communication skills. (ASME, Vision 2030 Surveys, 2010-2011)

When asked to identify where they feel the greatest need lies for career and skill development, the early career engineers point largely to soft skills related to administraiton, management and communication (written and verbal presumably in the business setting) . Figure 3 shows the top interests of this group which are all of very much equal weight.

We next asked industry managers, academician and the early engineer cohort to rate preparation and skill level in communications (generally defined). Figure 4 reveals the first of mismatches we find. Industry managers are nearly equally divided on this question, which identifies possibly the adjustment the ECEs need to make in the business setting and most likely some deficiency in their preparation for practice. Academicians and ECEs themselves, on the other hand, strongly feel "sufficient to strong" in this skill set. Whether this comparison reveals either an inherent weakness in the undergraduate degree program or a predisposition held within industry on new college graduates remains a question for future discussion and research.

In concert with communication skills, knowledge of how devices are made and work (generally included under the rubric of practical experience) differences in the viewpoints again surfaced. Figure 5 illustrates a general weakness here, and the ECEs themselves parallel this assessment. Without a context, this result should be viewed only in the most general light, but it is indicative of the strong theoretical focus of most current mechanical engineering undergraduate programs. Early career engineers were a bit less negative on this question even though 34% considered their practical experience a weakness.

In parallel with this question, we asked whether ECEs possessed the necessary systems perspective in their engineering work, and we find surprisingly good agreement across stakeholder groups. Industry leaders answered positively at a rate of 44% and academics at a rate of 46%. The ECE's were less positive, answering at a rate of 31%. Note that all positive response rates ware less than half of the sample. Thus there appears to be a compelling need to address this skill area via pervasive curricular reform

What our recent surveys and those of the past two years have shown is that ECEs and academics view their strengths to generally include problem solving, technical fundamentals, and teamwork. All of these areas consistently registered more than a 40% positive response. Greatest weaknesses identified by ECEs are knowledge of codes and standards and practical experience. Both of these areas registered more than a 40% response rate. Closely following were weaknesses

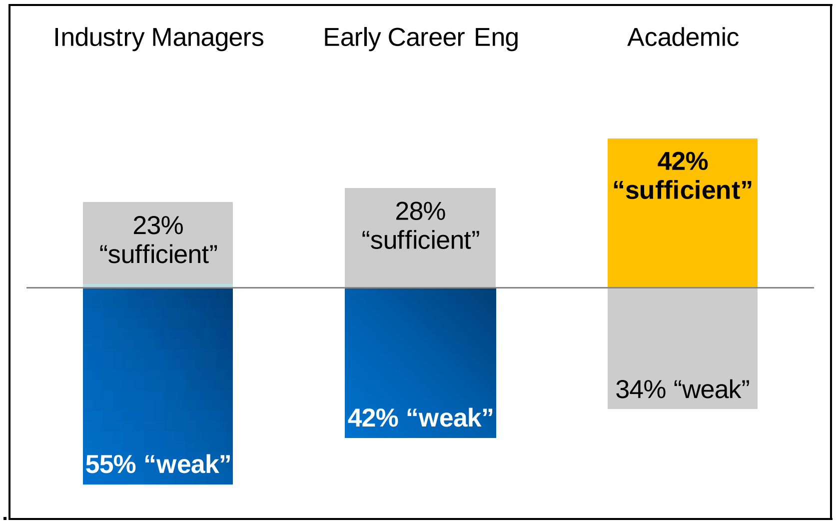

Figure 5. Differences in viewpoint on ECE’s practical experience between industry managers, early career engineers and academics. (ASME Vision 2030 Surveys, 2010-2011)

identified with project management, business processes and an overall systems perspective. We view these latter categories of knowledge as those that are inherently involve maturation and experience in engineering practice and business processes. They are decidedly within the realm of the professional aspects of ECE skill set. It is problematic whether undergraduate engineering programs can provide the necessary training to reduce currently identified knowledge deficits, and to this point, our survey of industry suggests that engineering education should include a practical component [3].

4. Strategies for Change

The guiding principles that form the basis for our recommendations are that industry must generate sustainable growth for economic vitality, the United Nation’s Millennium Goals [5] must be achieved, and the NAE Grand Challenges [2] must be met and solved. Now is the time for engineering education and its leadership to begin targeted educational reform to produce graduates who are both technically and professionally prepared to address the broad and varied challenges and opportunities of the future.

The task force has decided that its recommendations would be neither be prescriptive nor too detailed and would be aimed at encouraging innovation to create an educational paradigm that will succeed in producing world class mechanical engineering practitioners and leaders.

While there are many options and possibilities, components essential for mechanical engineering and mechanical engineering technology curricula are flexibility (e.g., multiple degree paths); strong professional skills (i.e., developing the leader within); more active, discovery-based learning (let the students create) and less factual content in favor of problem definition and solution within larger contexts. A continued strong emphasis on the fundamentals and outstanding problem formulation and solving is mandatory but forgo significant additional technical content beyond the fundamentals in the curriculum. There should be ample opportunities for students to gain experience dealing with big-picture, systems-level problems and constraints. These concepts should be integrated throughout the four-year undergraduate program, and greater reliance for deeper technical knowledge placed on students getting a professional Master’s Degree (those interested in practice) or a Master of Science and/or Ph.D. (those interested in research).

As an example of one institution’s effort to address the over arching challenges we have identified in our work, the Enterprise Program at Michigan Technological University is an example of active, discovery based learning spread throughout the curriculum. This program integrates design, professional skills, and practice based learning in highly multidisciplinary environments that operate much like those a real company. A typical enterprise team is made up of approximately 25 students from multiple majors and is coached/mentored by a faculty member. Engineering, science and business students make up the majority of the team members, and they typically start with an enterprise project after their freshman year. There are currently 28 enterprise teams on campus with almost 800 students (~60% in engineering) participating. Increased retention, high graduation rates, and anecdotally increased job satisfaction and success are outcomes from the program. Also at Michigan Tech, the International Business Ventures Enterprise (Biomedical Solutions for Global Markets) is coached and mentored by two of the authors. It is composed of nominally 25 students (business and biomedical, mechanical, electrical, materials, and technology majors) and has five project teams working on an infant heart enunciator, pandemic ventilator, pressure sore alleviation, and business plan development. Integration of the business and technical students and the requirement for and availability of professional skills course modules are key components of the program. Further details of the program are available on the Enterprise and IBV websites which can be found on the Michigan Tech home page (http://www.enterprise.mtu.edu/).

These recommendations are different than those of past curricular reform efforts, where the debate centered on the mix of mathematics and physical science, engineering topics, and hands-on experience and/or design. What is critical now and in the future is that we maximize creativity, problem formulation/solution and leadership abilities of all our students. This skill mix will be essential for engineers to be successful in engineering practice and to support societies’ drive for a sustainable future. Further we must enable engineering as a profession and engineers as individuals to take a higher level of responsibility and leadership in the affairs of society.

For the mechanical engineering as a whole, the question is, what is the path forward, and can it happen in this decade or even by 2030? Change has always been difficult in higher education, but now it is imperative. We cannot wait for a presidential call for engineering leadership similar to President Kennedy’s call to put a man on the moon and win the space race, “We choose to go to the Moon in this decade and do other things, not because they are easy – but because they are hard!”

The current need is far greater than it was in 1962. This document is intended to get the mechanical engineering and mechanical engineering technology communities thinking and acting on curricular reform. There are currently a few faculty, department heads, and deans initiating substantial change within their programs, and hopefully there will be many more. As one faculty member put it during our work over the past two years, “This is too important, and we have to get it right!”

5. Conclusion

We envision future graduates who have skills and abilities to coordinate, manage and lead global projects; graduates who can enable sustainable growth; graduates who can create their own jobs and jobs for others; graduates who are always thinking about the world’s grand challenges; graduates who are involved in policy decisions at many levels of society; and graduates who become leaders in society so as to enable sustainable solutions for the good of all. These considerations are over arching for mechanical engineering and mechanical engineering technology education despite differences in institutional mission, the breadth of the discipline, and the changing nature of engineering practice.

We believe that future technical solutions alone are not enough to meet business and societal needs. The mechanical engineering profession must ensure that its solutions are implemented in viable economic, social, and environmental terms. This responsibility implies a richer professional framework in their education than presently exists. It implies that engineering and engineers must assume leadership roles not only in the workplace but in other aspects of society as well.

If we are correct in our thinking, the changes we think are necessary will usher in a new era of education every bit a revolutionary as those brought about by the Grinter [6] and Wickenden [7] studies of the mid-20th Century. Our suggested reshaping of engineering education around a revised framework will not be easy, but we think well worth the effort for national economies and the globe.

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Telling Tales: Enhancing the Perception of Engineering

Cliodhna McCormac*, Pagona Papakonstantinou and James Davis

School of Engineering, University of Ulster, Jordanstown, Co. Antrim, BT37 0QB, UK
*T: +44 (0) 28 903 68018, E: c.mccormac1@ulster.ac.uk

Abstract

The progress of an EPSRC project designed to engage school pupils in designing art works to accompany a series of modern day fables that emphasize the significance of Engineering to everyday life and to provide a glimpse of what may emerge in the future is described. Central to this is the creation of a multi level story line which has value beyond the mere curiosity and thus the resulting narrative and embedded contextual material would be designed to be capable of integration within components of the Science, Technology, Engineering and Mathematics (STEM) curricula. The project's remit is to distribute the tales in the form of a series of booklets to schools within Northern Ireland to evaluate the pre and post intervention response in relation to raising the profile of Engineering.

Introduction

The perception of Engineering as a profession has suffered greatly in recent years in relation to recruits to university courses but the loss of esteem within the public arena is, by far, the more worrisome as this typically feeds the career aspirations of the former. While it was once traditionally associated with large scale structures, the increasingly harsh economic climate has seen the sustained erosion of the industrial base and it would appear that there are few, home grown, engineering feats of sufficient iconic status with which to capture the imagination. This is certainly a false assumption given the tremendous advances that have occurred across the Engineering sector but it is one whose effects are exacerbated by historical comparison and highlights a desperate need to increase the visibility of "Modern Engineering". It can be argued that tangibility is a key piece of the puzzle that has been lost as Engineering has moved, at least in Northern Ireland, quite literally from the Titanic to ever smaller scales and, while vital to the emerging needs of high technology manufacturing, can be highly obtuse even to those with a scientific background.

There is, however, a second issue. Even if the miracles of Nano-engineering, a highly topical example, were rendered in a form that provides a final picture readily comprehensible to the average person – would they be willing to look and to expend the time needed to comprehend the significance of the information? There is an implicit danger that, in an age characterised by information overload, the effectiveness of conventional, passive dissemination processes will be severely debilitated/diminished and the message subsequently lost to all but those already within the ranks of the converted. This clearly defeats the purpose of true public engagement. It is therefore the aim of the proposed project, to assess a more covert approach to capturing the attention of those to whom Engineering is regarded, at best, with considerable apathy.

The aim of the present presentation is to outline the strategies being taken with the School of Engineering at Ulster to create a more integrated approach that aims to generate a much more sustainable profile for Engineering across local, regional and national audiences. The secondary objective is to highlight how such processes could be transferred and hopefully adopted across different faculties such that a more coherent international perspective could be fostered that together raises – essentially recaptures - the profile of Engineering as a high value profession.

Booklet Rationale

The heart of the strategy relies on engaging school pupils. Rather than passively supply them with yet more literature – the innovative step is to directly involve the pupils (our prospective audience and future recruitment pool), through outreach, in the preparation of the literature. The approach was to enable them to design art works that would be incorporated into a booklet. However, in contrast to the conventional literature, we set out to rediscover the art of story telling in which the human dimension of Engineering is explored and the concepts and indeed the significance of the design and construction process is put in true context. The intention is to create a series of modern day fables that emphasize the significance of Engineering to everyday life and to provide a glimpse of what may emerge in the future. Central to this is the creation of a multi level story line which has value beyond the mere curiosity and thus the resulting narrative. Embedded within the story would be material capable of integration within components of the Science, Technology, Engineering and Mathematics (STEM) curricula. Thus the booklet could serve as a curricula revision tool for the students in their forthcoming studies and could be readily adopted by school teachers. The booklet would therefore have a life far beyond that of conventional brochure literature.

Methodology and Pedagogical Basis

The core remit relies on the applicants adapting the Jonathan Swift tales of Gulliver's voyage to Lilliput and Brobdingnag as the fictional foundation upon which to present the research being conducted within the School of Engineering. The reason for embedding the Engineering within a fictional background has multiple advantages. We can all remember the fairytales we were told in our youth. Many are constantly reinforced in the media whether through plays, movies or television. They are familiar and our intention is to adapt some of these such that when they are recalled in subsequent life – there would be a possibility of retrieving aspects of the Engineering that they learned through reading the booklet. It is hoped that through emotional engagement with the human elements of the story, there would be a more holistic retention of the ethos of Engineering which would engender positive memories for future recall.

Storytelling was an important, if not vital, stage in our development, representing the logical progression from the cave painting and was the springboard through which societal norms were introduced to the young [1,2]. This oral tradition arguably represented the very introduction to the real world where tales would be told to inform and aid the survival of the community and these methods are still practiced in present day aboriginal societies where the legacy is passed from one generation to the next. There are still faint resonances of this approach in modern societies where fairytales and fables are recounted in bedtime stories. While their present day form is almost invariably used to entertain, this is a largely superficial deployment of a pedagogical vehicle whose historical purpose was predominantly to inform and influence. Engagement with the central narrative was exploited as an emotional hook through which to embed the central message within the mind of the child and thus enhance retention [1]. It is easy to recall the stories of our youth – while the exact details may have been lost to an aging memory - the nuances and core message contained within them are liable to be as clear as when they were first heard [2,3]. In a preliminary survey of 153 undergraduate engineers to assess their literary background – over 90% nominated at least 5 fairy tales/ rhymes as within the top ten story lines that they could recall – the most popular being Humpty Dumpty. Emotional engagement is a key hook and the tragedy of the poor egg certainly has age old resonances. Therein lies the crux of our argument for the use of storytelling as a means of enhancing present day appreciation of Engineering as a positive occupation and potential career.

A substantial knowledge base on the use of emotional engagement has arisen in recent years and the key psychological fundamentals that mediate such processes have long been recognised. A central theme in the fable approach is the empathic melding of the reader with the experience of the central character such that the trials and tribulations are shared. It can be a form of personal, mental, role play in which experiential learning is achieved indirectly and is critical to the present argument as it represents deep learning of a message [2]. Engineering is, in contrast to the academic disciplines, the storyteller's ideal realm in that it contains all of the key ingredients (principally the presence of large challenges, danger and overcoming the seemingly impossible) necessary for the construction of stories that can capture the interest of the reader [2,4,5]. The variety of storyline is dependent only on the imagination of the teller and it is capable of being moulded in an inexhaustible number of ways that can serve to emphasize specifics or generalities and can be tailored to any context. Rather than presenting isolated data or facts – it offers a means of delivering the theme in a holistic and reflective approach that is more amenable to being embedded within deep memory [6,7]. There is an additional advantage in that it can tap into the imagination in a way that conventional lecture material often fails to achieve and facilitates learning of the bigger picture (or in our case the ethos/process) rather than imparting isolated facts about Engineering [2,4,5]. Some of the main merits highlighted in Figure 1.

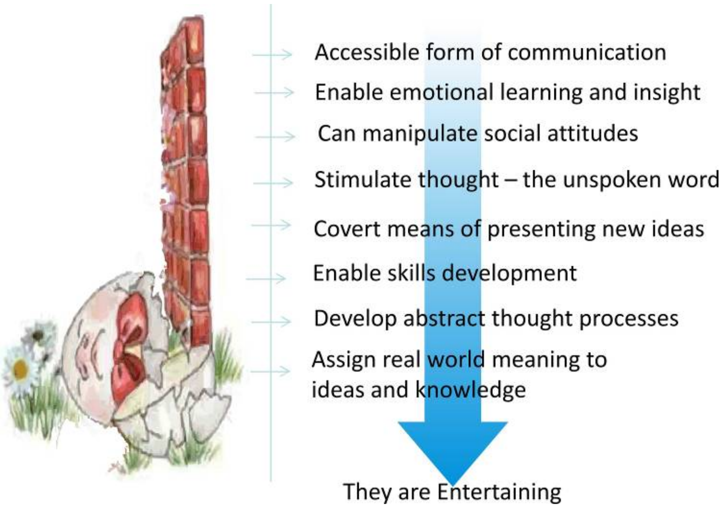

Figure 1. Merits of Narrative

There is little doubt as to the flexibility of the story approach but the crucial question is how to deliver it effectively. Can it be readily adopted across different faculty and what degree of expertise is needed for its implementation? The components of storytelling rest upon the empirically tested foundations of educational psychology [2] but, ultimately, their collation, integration and expression is more art than science and it is clear that the best stories require the addition of what can seem to be an intangible creative element. This could at first glance appear to relegate the strategy to those with a literary background who have nurtured a talent for writing but, while the possession of the latter is certainly advantageous, its absence is not a reason for exclusion. There is an almost innate human perception of what a story is and what it should contain (beginning, middle and end; a challenge and, ideally, a resolution) and while the performance may be variable – everyone is capable of delivering it [2,3]. Providing there is sufficient feedback – the story can be optimised to the appropriate reader level.

It is important to note that the process of storytelling need not be restricted to the lecturer. Storytelling has long been a critical component of medical practice – employed by students and staff irrespective of educational or creative background to share experiences and develop professional competencies [8]. The discussion and review of case histories, consultations and consideration of clinical scenarios are a matter of routine professional development and each embodies a degree of storytelling. It is easy to envisage how a similar format could, in principle, be applied equally well to broad based engineering practice where postgraduates can be involved in an effort to improve their communication skills – as indeed is the intent in the proposed project.

Implementation and Outcomes

It is proposed that the fables would take aspects of the Engineering research being undertaken and weave them into a coherent plot capable of engaging, on a first level, a young audience – typically 11-13 year old. This sets the baseline for accessibility and transferability across all demographics. Surreptitiously embedded within the text or accompanying figures will be a modicum of more complex Engineering and Technology concepts though still residing within the bounds of lay terminology. The latter provides an avenue through which the tale can be adopted within the secondary school science curricula. The main remit however is to convey the challenge and benefits that can accrue from Engineering and thereby strengthen the profile of the profession. As such, the fable approach provides a single vehicle through which to reach many different cohorts. The research base at Ulster provides a large number of “modern” Engineering opportunities which can be incorporated within the narrative. Some of the topics that would be exploited are highlighted in Figure 2.

Figure 2. Engineering Topics

As indicated previously, the main limitation lies not in the story itself, nor the supporting artwork, but rather in its uptake by the public. A multi-threaded strategy is therefore proposed to aid both the compilation of the material (Figure 3) but also its transmission to the home or visitor centre and therein access a much more public arena. The participation of the pupils in the preparation of the artwork supplementing the story is crucial as this fosters greater engagement in the subject being illustrated but also serves to stimulate interest in the final published fable collection. The artwork would be used as a homework based assessment tool within the existing school curricula and, as such, ensures participation but also encourages higher quality submissions. Each participating school would be given a “commission” with the process seeking to effectively mimic the contractual work undertaken by commercial artists. The commission itself serves to illustrate a particular component of the narrative. The reward for completion in this case is not monetary but academic in terms of credits relating to their assessment but with an added incentive that those of sufficient quality would be used in the final fable collection print run.

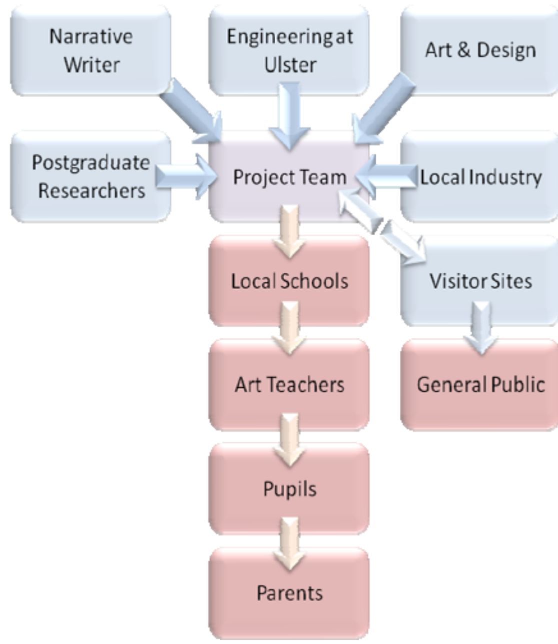

Figure 3. Project programme

Among the advantages of this approach, there is a competitive edge to the preparation of the illustration and, more importantly, the homework based assignment serves as a conduit for the dissemination of key Engineering achievements out with the classroom, thereby potentially raising the visibility of the subject and profession and stimulating discussion within the home. A secondary bonus is also apparent in that the successful completion of the commission will require an appreciation, at least to some extent, of the underlying concepts referred to in the narrative. It should also be noted that in targeting an artistic contribution, the project has the potential to reach an audience that may hitherto have had little regard for the traditional STEM subjects, thus reaching the disaffected rather than the converted.

Project Partners and Target Audience

Preliminary discussions were held with a number of Northern Ireland schools (primary and secondary) and with industry (regional and national) within Northern Ireland to consider the mechanics of the project in terms of integrating the artwork assignment into the existing curricula and the criteria necessary to ensure that the resulting booklet would be of value for pupils – both at primary and secondary level - and the necessary literary style and typical science content. These would act as the advisory panel when constructing the actual narrative. It was anticipated that the pilot project would engage 20 schools (10 primary, 10 secondary) as partners in the first instance. This would give a total participation audience of approximately 2,600 pupils (600 primary and 2000 secondary). The project would release 6000 booklets which, assuming a total return to the home, would generate a readership audience of approx 18,000 (based on 2 parent / 1 child). The latter, however, could clearly be far larger depending on the movement of the booklet through the extended family network and an assessment of such transferability will be a core objective of the project.

An important point to note and a key feature of the project is that a booklet would be produced that will be attractive, have direct and identifiable local interest and will have an accessibility (through the resonance with Swift's work) that appeals across a spectrum of age ranges – all of which have the potential to stimulate curiosity [2,4,5]. It is easy to envisage that the booklet will have a lifespan far greater than a leaflet, an event or other activity and the residence time within the home and transfer between family members within the home could be priceless. As such, the audience figures postulated above, in many respects, represent the minimum but there is clear potential for a far greater and sustained influence.

Conclusions

Storytelling was historically the principal method of disseminating messages about the wider world and how it works and is embodied in the subtext of tales by Aesop and the Grimm brothers and recounted through countless generations. It is important to realise the story is pivotal to making the facts that we wish to convey much more accessible and thereby improve their later recall. This is due primarily to the fact that the underlying story is responsible for capturing the imagination of the listener or reader. In recent times, the narrative that once held our attention has been significantly eroded and replaced with a distillate of hard facts, calculation and process for solving problems – the human dimension is often dismissed as being superfluous to the exam/assessment process as students search through the ever expanding shelves of crib notes. These do little to aid long term memory. As such, the significance of Engineering can be eroded – indeed sacrificed in many respects and the enthusiasm for the subject tragically lost. The status of the profession will suffer as a consequence as the student searches for an alternative career. The strategies outlined above demonstrate a versatile method through which to counter the apathy at a grass roots level. The intention is to foster a more proactive attitude which can pervade the student response to the subject in later years and hopefully the underlying human dimension and societal challenges that Engineering is attempting to meet are reinforced. The case study presented highlights how it can be delivered in a holistic manner that is complementary to existing promotional methods. Most importantly, it provides an inherently transferable method for engagement and reinforcement of the message that contrasts the traditional delivery of such material and thus should enable a greater retention of the key tenets and enable transfer to a wide audience. It is hoped that at the very least the booklets stimulate discussion and therein enhance the esteem in which Engineering should be held – ultimately leading to the revitalization of interest and recruitment.

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Developing tools to improve generic competences assessment: the e-Competentis project

[1]M. Edwards-Schachter, [2]M. J. García-García, [3]L. F. Mazadiego
Institute of Innovation and knowledge Management (INGENIO, CSIC-UPV).
Universidad Politécnica de Valencia, Valencia, Spain, moed@ingenio.upv.es[1];
Dep. de Proyectos y Planificación Rural. Universidad Politécnica de Madrid, Madrid, Spain, mariajesus.garcia.garcia@upm.es[2]
Dep. de Explotación de Recursos Minerales y Obras Subterráneas. Universidad Politécnica de Madrid, Madrid, Spain, luisfelipe.mazadiego@upm.es[3]

Abstract

This paper reports a research project carried out in order to support competency-based assessment practices which includes the creation of a public collaborative space (website http://www.ecompetentis.es). It has been conceived to be a framework for teacher's activities with assessment tools, innovation resources, research projects and a collection of good practices and experiences for generic competences assessment. We particularly describe the Spanish validation of two psychometric tools available in this education portal for assessing "teamwork" and "problem solving" as generic competences. These instruments were applied in pilot experiences to 426 engineering students in four Spanish universities.

Keywords: assessment, generic competences, education web, higher education, engineering education

1. Introduction

In the current climate in European higher education, assuring and enhancing the quality of teaching and learning is a key issue. While the accountability function of assessment and evaluation processes has acquired more importance, the priority in the majority of countries is now to ensure that professionals have the competences, instruments and feedback they need to improve their practice [1]-[2]. However, underlying the current debate about preparation of graduates for the workplace, there are several pitfalls and problems associated to the assessment and accreditation of generic or transferable competences. Assessment and evaluation build on teacher professionalism, but there are relevant constraints related to which assessment methodologies and tools would be selected to determine if students are mastering generic competences.

Despite the quickly diffusion of the competence-based learning in Europe, there is confusion and increasing criticism concerning the concept of competence (in major measure on generic or transferable competences) and its assessment [3]-[4].

From the curricular perspective, specific articulations of competences inform and guide the bases of subsequent assessments. In this sense, competences provide directions to design learning experiences and assignments that will help students gaining practice in using and applying these competences in different contexts [5]. In other words, which appropriate modes of teaching, which learning activities might best foster competences in terms of knowledge, understanding and skills; and how do we assess these competences. Biggs (2003) describes

this as the problem of the “alignment” of teaching, learning activities, and assessment with the intended learning outcomes of a course of study [6].
In this sense and in contrast with a long experiences and background in other countries, competence-based initiatives in Spain are at the early stages of development. Relatively few assessment resources/tools are available in the field and the identification of teaching existing good practices and materials is scarce. While a lot of assessment methods and quality assurance work happen locally and informally, these practices are frequently not documented and there is little evidence as to whether good practice is spread and shared across the education system. In addition, information on generic competences assessment in the Web is confusing and hardly accessible for specific use in the practice teaching. Except for some universities, there are few systematic resources and tools easily available in relation to the assessment of generic competences.
This paper sets out to describe the development of a research project financed by the Ministry of Education and Science (MEC, Ref. EA2009 – 0040) oriented to support teacher assessment activities in higher education, particularly in engineering education [7]. The project team consider that competences assessment should be based on the access to multiple and diversified sources of information with the target of determining if the students have achieved the expected outcomes level. With this purpose this project has developed a collaborative space throughout a website (http://www.ecompetentis.es) which has been conceived to be a support framework for Spanish teachers with assessment tools, innovation resources, research projects and a collection of good practices and experiences, among others. In addition, the paper describes the validation for the Spanish context of two psychometric tools for assessing generic competences. The selected competences were “teamwork”, using the Self-efficacy for teamwork and teamwork behavior questionnaire items [8] and “problem solving”, using the PSI Problem Solving Inventory [9]. Both instruments were applied to 426 engineering students in pilot experiences in four Spanish universities. The rest of the paper is organized as follows. Section 2 presents an overview of generic competences assessment and the project theoretical background, Section 3 exposes the project objectives, followed by a briefly explanation about the validation process of two selected assessment tools and, finally, the last Section comments and conclusions.

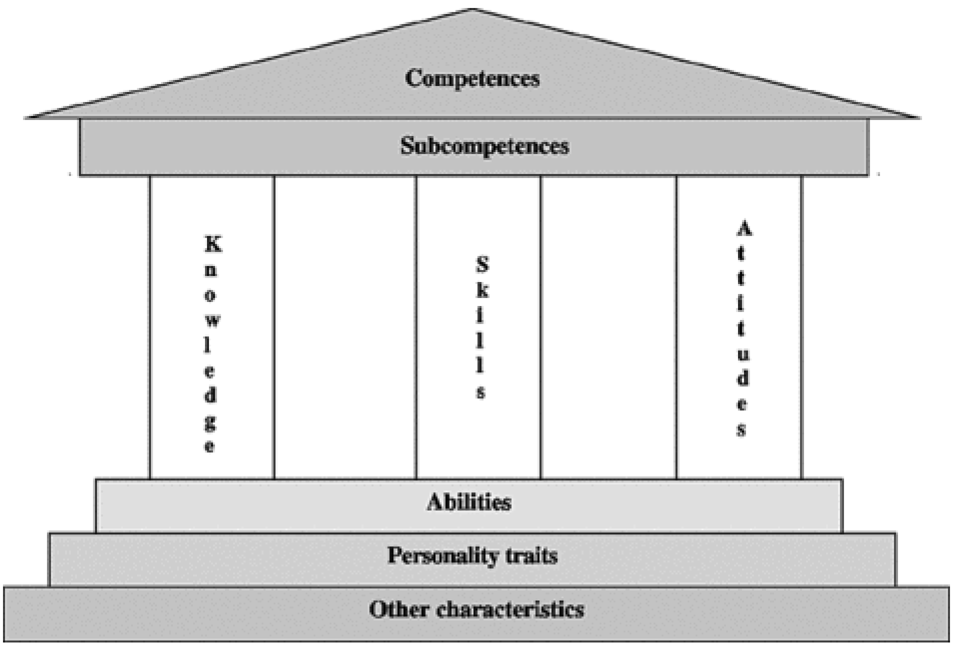
2. Theoretical approach to generic competences assessment

2.1 What means assessing generic competences?

Competence oriented education emphasizes the integrated nature of what students must learn to fulfill future demands from jobs and life. Both emphasis in input-output and the learning process is reflected in the assessment of student performance, moving from knowledge as the dominant (even the single) reference to include a variety of approaches to assessment (portfolio, tutorial work, course work; peer, co and self-assessment, etc.). Current competence based education integrates self-regulated learning, project learning, Project Based Learning (PBL), coaching learning, etc. [4]-[10]. Learning, according to the latest constructivist learning theories, is essentially: (1) constructive, (2) cumulative, (3) self- regulated, (4) goal- oriented, (5) situated, (6) collaborative, and (7) individually different [11]. The learner is an active partner in the process of learning, teaching and assessment. Student perceives, selects, interprets, and integrates new information to form a coherent and meaningful whole with her/his prior knowledge and experiences. These changes in learning theory go together with innovations in instruction and evaluation: new instructional methods are introduced in educational practice, the latest technologies and media are used, and alternative modes of assessment should be implemented [12]. Assessing competences is related to find out what the students know (knowledge), what the students can do, and how well they can do it (skill; performance), how students go about the task of doing their work (process) and also how students feel about their work (motivation, effort and perceptions). In this sense, Mansfield contrasts three different

usages of competence: outcomes (for example, vocational standards describing what people need to be able to do in employment); tasks that people do (describing what currently happens); and personal traits or characteristics (describing what people are like) [13]. These statements are applicable to both specific and generic competences.
The concept of generic or transferable competence is strongly associated with the ability to master complex situations and for this reason it is assumed that “competence” transcends the levels of knowledge and skills to explain how knowledge and skills are applied in an effective way [14]. Generic competence includes high-order abilities related with being able to learn, adapt, anticipate and create in a diversity of knowledge areas, rather than with being able to demonstrate that one has the ability to do.
In the majority of European countries competence is considered a holistic combination of knowledge, skills, abilities and attitudes appropriate to a particular situation. It is a complex “knowledge in action”, resulting from integration, mobilization and fitting of many capacities and skills (which may be of cognitive, emotional, psychomotor or social nature) and of knowledge (declaratory knowledge) effectively used, in different contexts [15]. In the project “Tuning Educational Structures in Europe” (p. 280), competence is defined as “a dynamic combination of attributes - with respect to the knowledge and its application, to the attitudes and responsibilities that describe the results of learning a determined program, or how the students will be able to develop at the end of the educative process” [16]. This concept embraces integration between specific and generic competence.
From these conceptual perspectives the e-Competentis project was designed and developed using the Roe’s “architectural competence model” [17] as a guide for combining assessment methods that we consider appropriated for generic competence assessment (see Fig. 1). Three complementary approaches to competences assessment was proposed considering this model, focusing on the individual (considering personality traits), on the activities development (during all the learning process, including knowledge, skills and attitudes) and the final results/final outcomes (for example, the “products” of a project).

Figure 1.Adapted from Roe’s architectural model of competences



Generic competences are interrelated with specific ones and both rest on the pillars of knowledge, skills, and attitudes. This whole structure is built upon the individual person's dispositions, i.e., abilities, personality traits, interests, values, among other characteristics.

2.2 Pitfalls and constraints in generic competences assessment

In the teaching practice generic competences are generally interpreted in the light of the disciplinary area. Even in cases in which the graduates will almost certainly be expected to work in areas not directly related to the subject where they will receive a degree, the academics' perception of the generic competences remains quite tightly tied to the subject area disciplines themselves. For this reason, for each generic competence a distinction must be made between disciplinary areas in which the competence is considered important or even fundamental, a priority for the discipline, and those in which its connection with the subject area is less clear. Another important aspect is the curricular treatment of generic competences. Across Europe, there are two main ways of teaching or embedding generic competences:

a) These competences can be considered as part of a degree program, of separate course units/modules to enable students to master at least part of the generic competences. In this respect one could think of, for example, communication competences (writing and oral skills) and ICT competences.
b) Generic competences also can be developed as part of or integrated into subject programmes and modules.

It is striking to see how differently some generic competences have been understood in the context of the various subject area groups. Sometimes strong differences can be noted between different national traditions within a single subject area. However it is more common to observe strong differences in perception and methods between different subject areas [17]. And maybe even the most important difficulty for competences assessing is that competences cannot be directly observed in all its complexity, they can be inferred from behavior and performance and require planning actions that will gather evidence, in quantity and quality sufficient to make reasonable judgments about them. Students are the protagonists in the assessment processes. In words of Knight (1995) "students often don't know why the system is as it is, or how they are meant to do something. Basic questions remain unanswered, for example, 'What skills am I being assessed on?', 'Why do we have exams? Students have numerous doubts regarding the *reliability*, *validity* and *effectiveness* of assessment, as well as the degree to which it contributes to the learning process" [18].

2.3 Generic competences assessment: from summative to formative assessment

A literature review shows the following multiple purposes of assessment:

- **Summative assessment**: which aim is to monitor educational progress or improvement. Educators, policymakers, parents and the public want to know how much students are learning compared to the standards of performance or to their peers.
- **Formative assessment (or assessment for learning)**: which aim is to provide teachers and students with feedback. Teachers can use the feedback to revise their classroom practices, and students can use the feedback to monitor, reflect and improve their own learning.

- **Accountability assessment**: this third purpose of assessment is to drive changes in practice and policy by holding people accountable for achieving the desired reforms.

For Scriven, who introduced the concept of “formative assessment”, this kind of evaluation aims at providing data that permit successive adaptations of a new program during the phases of its development and its implementation [20]. According to Nicola and Macfarlane-Dickb (2006) formative assessment refers to assessment that is specifically intended to generate feedback on performance to improve and accelerate learning. A central argument is that, in higher education, formative assessment and feedback should be used to empower students as self-regulated learners [19]. The construct of self-regulation refers to the degree to which students can regulate aspects of their thinking, motivation and behaviour during learning [21]-[22].
Formative assessment recognizes that each learner has to construct an understanding for her- or himself, using both incoming stimuli and existing knowledge, and not merely absorbing transmitted knowledge [23]. These views of learning acknowledge that both students’ existing knowledge and thinking processes influence the learning outcomes achieved and, therefore, both need to be taken into account in teaching and assessment. Both formative and summative assessment influence learning. In other words, to improve learning outcomes, we need to consider not only the teaching and learning activities, but also the assessment tasks [24]

Although the extent to which formative assessment improves learning outcomes is now wide being recognized and there has been much written on the importance of formative assessment to improve learning and standards of achievement, there has been little research on the process of formative assessment itself [25]-[26] As Black and Wiliam (1998) has suggested, there is a need to explore views of learning and their interrelationships with assessment practices and tools [26]. This has been the principal aim of the project e-Competentis, which is presented in the following section.

3. The e-Competentis project

3.1 Objectives

More specifically, the general objectives of this project have been:

- The design, research and development of assessment tools for assessing generic competences in higher education,

- The elaboration of a web portal for supporting teaching activities related to generic competences assessment

As far as generic competences are concerned, this website offers: assessing tools, innovation and investigation projects and successful experiences, etc. However, eCompetentis constitutes a collaboration space and would soon provide some other instruments, projects and experiences of colleagues who are interested in participating. The portal has the following structure:

1. **Home page**, with general information and welcome.
2. **e-Competentis Project**: description of the research project.
3. Projects: contains research or educational innovation projects related to the development and assessment of transferable competences (or skills). All registered participants may post both a summary of the project and other documents or materials they wish to share with others.

4. **Instruments**: lists the available assessment methodologies, instruments and tools. These instruments can be in different formats, from a text file or pdf format to online self-assessment questionnaires immediate use of students. In the same way as in the case of projects, any registered user can enter your assessment tools.
5. **Success stories**: lists various experiences/good practices applied in the classroom that can be considered a reference or have useful input for general application. Unlike projects, experience is essential to the existence of active processes applied in the classroom. In the same way as in previous cases registered users can post their experiences.
6. **Links**: list of other web sites related to the competency assessment.

The portal is in the first stage of its development. At the present there are two psychometric instruments available for the assessment of the generic competences “teamwork” and “problem solving”, which have been translated and validated for the Spanish context.

3.2 Can psychometric tests contribute to generic competences assessment?

The answer to this question is “yes, of course”. Psychometrics concerned with the theory and technique of educational and psychological measurement, which includes the measurement of knowledge, abilities, attitudes, and personality traits. The field is primarily concerned with the construction and validation of measurement instruments, such as questionnaires, tests, and personality assessments. Stout (2002) has analyzed 15 years of psychometrics in educational practices, suggesting that the summative assessment testing paradigm that has driven test measurement research for over half a century is giving way to a new paradigm that in addition embraces skills level formative assessment, opening up a plethora of challenging, exciting, and important research problems for psychometricians [27]. This author affirms that “the summative assessment paradigm for testing is being supplanted by a new blended summative assessment and formative assessment paradigm” (p. 515), with sometimes the same test being used for both purposes and sometimes new tests being developed for formative assessment purposes alone.

An ample scope of generic competence assessment should include a diversity of instruments, such as personality tests, tests of knowledge or skill, oral presentations, multiple choice questions, laboratory reports, portfolios, fieldwork reports, written essays or reports, practical demonstrations, etc. When discussing assessment issues across different cultures, it is important to probe the different ideas about what should be taken into account in assessment vary. For example some systems prize hard work, others high achievement, others high potential. This underlying value system is easily forgotten in a straightforward description of what modes of assessment are used, but in a ‘mobile Europe’ is one which should be better understood [16]. In our project we have selected two generic competences

3.3 Validation and research Can psychometric tests contribute to generic competences assessment?

At present we are able to offer two measurement tests to assess generic skills "Teamwork" [8] and "problem solving" [9]-[30]. For this purpose, we have translated tests and validated scheduled the trial of these meters in a pilot project. After an ample literature review we have selected the Problem-Solving Inventory (PSI) [9]-[30]-[32] and the Self-efficacy for teamwork and teamwork behavior questionnaire items [9]. To translate the tests into Spanish, diverse methods were used to ensure that content, semantic, and technical equivalence was ascertained. For cross-cultural research, content equivalence is established by determining whether the content of each item of the instrument is relevant to the target culture. The essence of semantic equivalence is that the meaning of each item remains the same after translation into the target language. [31]

Conceptual perspective of problem-solving competence in the e-Competentis project

Rational problem solving is a *constructive problem-solving style* that is defined as the rational, deliberate, and systematic application of effective problem-solving skills. As noted earlier, this model identifies four major problem-solving aspects (or *sub-competences*): (a) problem definition and formulation, (b) generation of alternative solutions, (c) decision making, and (d) solution implementation and verification. In problem definition and formulation, the problem solver tries to clarify and understand the problem by gathering as many specific and concrete facts about the problem as possible, identifying demands and obstacles, and setting realistic problem-solving goals. Reeff (1999, p. 48) considers that "problem-solving is (goal directed) thinking and action in situations for which no routine solution procedure is available. The problem solver has a more or less well-defined goal, but does not immediately know how to reach it. The incongruence of goals and admissible operators constitutes a problem. The understanding of the problem situation and its step-by-step transformation, based on planning and reasoning, constitute the process of problem solving" [28]
The Problem-Solving Inventory (PSI) is a 32-item Likert-type inventory that is described by the authors as a measure of "problem-solving appraisal," or an individual's perceptions of his or her problem-solving behavior and attitudes [9]-[30]. The model is based on the conceptualization of problem solving as an important personality variable involving cognitive, behavioral, and affective domains.

Conceptual perspective of team-work competence in the e-Competentis project

Rooted in social cognitive theory, team efficacy is an extension of Bandura's (1986) work on self-efficacy, which refers to an individual's belief in his or her ability to accomplish a task [34]-[35].
Despite extensive attention has been paid to team efficacy, the extant research takes two different perspectives in the conceptualization of the construct, with focus on a) the team efficacy at the individual level, articulating that team efficacy is rooted in self-efficacy and thus can be reflected as the aggregation of individual perceptions of confidence on a group's capability and b) the team efficacy as a group-level construct, representing group members' shared belief on a group's capabilities, resources, and constraints [36].
In this project we have considered the questionnaire proposed by Tasa, Taggar & Seijts (2007) for studying both the effects of individual-level and team-level factors on observed behaviors and the subsequent development of collective efficacy for mastering a complex team task. In their work self-efficacy for teamwork, task-relevant knowledge, and collective efficacy predicted individual teamwork behaviors (rated by peers). Table 1 summarizes some aspects of the validation process related to these instruments. Table 2 shows the comparison between the results obtained in the e-Competentis project with other studies realized in other countries [37].
(For more details information see the link
http://82.223.210.121/mec/ayudas/CasaVer.asp?P=29~~397).

Table 1. Comparison between results of Chan study and e-Competentis

Description	Problem Solving Inventory (PSI)	Self-efficacy for teamwork and teamwork behaviour questionnaire
Author	D'Zurilla & Goldfried (1971), Heppner & Peterson (1982); Heppner (1988), Heppner, Witty & Dixon (2004)	Tasa, Taggar & Seijts (2007)
Cross-cultural application	More than 120 studies in USA, Mexico, China, Canada, etc.	Multiple adaptations in several countries
Concept	*Problem solving* is defined as the self-directed cognitive-behavioral process by which an individual, couple, or group attempts to identify or discover effective solutions for specific problem in everyday living. More specifically, this cognitive-behavioral process (a) makes available a variety of potentially effective solutions for a particular problem and (b) increases the probability of selecting the most effective solution from among the various alternatives.	*Teamwork* is defined in this project as the capacity for working as a member of an interdisciplinary team, with the aim of contribute to its development with pragmatism, accountability, efficiency and effectiveness, taking into account the available resources.
Sample	Male: 63 Female: 46 Missing data: 3 Total: 112 students	Male: 304 Female: 122 Missing data: 0 Total: 426 students
	Universidad Politécnica de Cataluña, Universidad de Girona, Universidad Politécnica de Valladolid and Universidad Politécnica de Madrid	
Date	March to May 2010	

Table 2. Comparison between results of Chan study and e-Competentis research

eCompetis	PSC	AAS	PC	H-PSI	PSSE	PSS	M-PSI	PSE	RC	DC	C-PSI
Mean	30.44	54.76	18.62	103.81	20.28	28.21	48.49	12.39	11.99	17.83	42.21
SD	7.76	99.52	10.60	2.95	13.15	12.10	6.81	5.88	7.84	11.59	4.93
AM	2.77	3.42	3.72	3.24	2.90	3.13	3.03	2.48	2.40	3.57	2.81
ASD	0.76	0.86	0.47	0.84	0.82	3.13	0.89	0.26	0.35	0.52	0.66
Alpha	0.74	0.45	0.61	0.70	0.52	0.43	0.67	0.84	0.79	0.62	0.72
Item	11	16	5	32	7	9	16	5	5	5	15

Chan	PSC	AAS	PC	H-PSI	PSSE	PSS	M-PSI	PSE	RC	DC	C-PSI
Mean	29.89	45.54	17.47	92.90	19.39	23.54	42.93	13.40	12.40	17.49	43.29
SD	5.93	8.72	3.35	14.79	4.28	5.62	8.56	3.33	3.39	3.39	7.54
AM	2.72	2.85	3.49	2.90	2.77	2.62	2.68	2.68	2.48	3.50	2.93
ASD	0.54	0.55	0.67	0.46	0.61	0.62	0.54	0.66	0.68	0.68	0.48
Alpha	0.76	0.81	0.62	0.87	0.70	0.77	0.82	0.74	0.72	0.62	0.78
Item	11	16	5	32	7	9	16	5	5	5	15

Where: PSC=Problem Solving Confidence ; AAS=Approach Avoidance Style; PC=Personal Control; HPSI=Heppner Problem Solving Inventory (complet); PPSE=Problem Solving Self-Efficacy; PSS=Problem Solving Skills; M-PSI=Maydeu-Olivares/D'Zurilla Problem Solving Inventory (other study); PSE=Problem Solving Efficacy; RC=Rational Coping; DC=Dysfunctional

Coping; C-PSI=Chan (Problem Solving Inventory Chan case); AM= mean and ASD (mean and standard deviation adjusted for each scale item, respectively) and Alpha is the Cronbach coefficient.

4. Conclusion

Overall, the project has contributed to understanding and improving the generic competences assessment. We have considered the generic competences assessment with both the constructivist perspective and the renewed treatment in the light of contemporary theories of cognitive psychology. Psychometric test such as Problem-Solving Inventory (PSI) and the Self-efficacy for teamwork and teamwork behaviour questionnaire are considered as relevant tools for assessing generic competences. In particular, our results confirm that the two psychometric tools have been translated and adapted correctly for the Spanish language and that it fulfil the psychometric properties required for these instruments.

On other hand, the creation of the e-Competentis web can help to share best practices, innovative and effective assessment methods and resources in Hispanic countries, where these initiatives are practically non-existent. At the present, the portal offers contents related to the problem-solving, team-work and creativity competences, but no doubt others will be added in the future.

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Undergraduate Educational Research Activities in Aeronautical Engineering at the United States Air Force Academy

[1]D.N. Barlow. [2]T. E. McLaughlin, [3]C. F. Wisniewski
US Air Force Academy, USAF Academy, CO, USA, Neal.Barlow @usafa.edu[1];
US Air Force Academy, USAF Academy, CO, USA, Tom.Mclaughlin @usafa.edu[2];
US Air Force Academy, USAF Academy, CO, USA, Charles.Wisniewski@usafa.edu[3]

Abstract

During the past decade, the Aeronautical Engineering Department has purposefully transformed its curriculum and facilities to require both experimental and computational research as an integral part of its undergraduate educational program. Recognizing that experiment and computational knowledge and skills are critical and complementary to an undergraduate education, the curriculum has evolved to include both traditional and computational fluids course work and laboratory experiences. In addition, each student (cadet) is required to participate in a real-world research project in addition to the traditional year-long design experience. The traditional laboratory experience is accompanied by a requirement to conduct either an experimental or computational project that responds to a "real" customer's needs. USAFA is fortunate to have an outstanding experimental and computational infrastructure to support its undergraduate educational research activities.

1. Introduction

The Department of Aeronautics (DFAN), in existence since the organization of the United States Air Force Academy (USAFA) in 1955, has offered an accredited Aeronautical Engineering degree since 1967. DFAN has remained dedicated first and foremost to USAFA's unique and primary mission statement: *To educate, train, and inspire men and women to become officers of character, motivated to lead the United States Air Force in service to our nation*.[1] In the course of fulfilling this mission, cadets and faculty serving in DFAN have consistently achieved exemplary results in their military service, academic scholarship, and research during and after their USAFA attendance.

"Capable of flying at tremendous speeds (200mph) and executing astonishingly agile maneuvers, the Peregrine Falcon is a true ruler of the air, fully worthy of its fame as a raptor of unequaled predator abilities."[2]

A better mascot couldn't have been chosen for the men and women attending and serving at the United States Air Force Academy. With a sharp vision for integrity, service, and excellence, USAFA faculty and graduates have produced high achievements in all facets of U.S. Air Force operations and its research and development complex. Cadets (officer candidates) are challenged and stretched in their knowledge and intellect with an ABET accredited curriculum, an intense leadership laboratory environment, a comprehensive peer-driven character development program, and strenuous physical training.[3] Cadets are exposed to all facets of a world-class military air and space force. Many taste the freedom and discipline of flight in various training programs for the first time during their cadet career. Graduates leave USAFA with a Bachelors of Science degree and a commission as a Second Lieutenant. They join a "long blue line" of officers dedicated to leading airmen. They continue their education and service as weapons system operators, technical experts, specialists or in graduate student. As past graduates have reached the upper levels of leadership in USAF military service or civilian workforce, they've demonstrated the value of the unique USAFA educational experience.

While, a premium is placed on the development of officers via a well-integrated military training program including leadership development, physical fitness, athletic competition, and flight training, at the heart of a cadet's development is a robust core curriculum consisting of 102 academic hours divided between humanities (25 hours), social sciences (27 hours), basic sciences (27 hours), engineering (18 hours), and physical education (5 hours). The foundation of the experience is found in the values of the institution, expressed daily by a faculty of over 700 dedicated professors and staff, composed of civilian professors and military officers, supported by an exceptional enlisted, civil service and contract staff. The men and women of the USAFA faculty serve as role models and mentors for the cadets, sharing the warfighter spirit as well as their technical and leadership expertise. In addition to the required core, the Academy offers 32 academic majors as well as a foreign language minor. Thanks to the mission of the USAF, aeronautics and related fields contribute heavily to the Academy curriculum. The Aeronautical Engineering Department has 25 full time faculty members supported by approximately 30 laboratory and administrative staff members, including almost 20 researchers supported by a variety of research and grant funding. The major requires an additional 45 semester hours of engineering courses past the core curriculum, totalling 147 semester hours required for graduation.[1]

During the past decade, the Aeronautical Engineering Department has purposefully transformed its curriculum and facilities to require both experimental and computational research as an integral part of its undergraduate educational program. Recognizing that experiment and computational knowledge and skills are critical and complementary to an undergraduate education, the curriculum has evolved to include both traditional and computational fluids course work and laboratory experiences. In addition, each student (cadet) is required to participate in a real-world research project in addition to the traditional year-long design experience. The traditional laboratory experience is accompanied by a requirement to conduct either an experimental or computational project that responds to a "real" customer's needs. Customers are typically United States Department of Defense (DoD) research and development or acquisition offices. Other customers include DoD contractors and NASA entities. Students also have the opportunity for follow on summer research activities at DoD and contractor facilities as well as senior level independent study research opportunities which meet elective requirements and the opportunity to compete in the American Institute of Aeronautics and Astronautics' Regional Paper Competition. Cadets are provided with unprecedented opportunities for 'hands-on' experiences and for making contributions to 'real world' programs. Including the Class of 2011, DFAN has produced over 2,000 aeronautics engineers for service in the USAF.

Since 1955, over 300 faculty members have served within DFAN, supervised by 14 Department Heads. Historically, a majority of the faculty members have been active-duty military members, serving several years at the Academy before moving on to operational military assignments, advanced educational opportunities, or civilian life. With a Master of Science or Doctoral degree in Engineering, these military faculty members range in academic rank from instructors to full professors. Above and beyond the technical knowledge shared in the classroom, they serve as critical military role models for cadets. Their "war stories", involving character, integrity, and leadership issues as well as technical "been there, done that" wisdom, help the cadets internalize the Air Force's core values: *Integrity First, Service Before Self,* and *Excellence in All We Do*.

DFAN's civilian faculty members, either permanent or visiting, provide the backbone of continuity to the department's technical expertise and curriculum organization. With Doctoral degrees in Engineering and a wide range of prior military, academic, and industrial experiences, these professors help their cadets develop an understanding of their responsibility to their customers and the discipline, knowledge and skills required of professional engineers. Currently a third of DFAN's 25 faculty members are civilian. National and international current events, including USAFA and USAF policies, plans, and activities world-wide, are discussed regularly in the classroom alongside the aeronautics curriculum, keeping the institution's goal always front and center.

Beyond the classroom, the annual contributions of the DFAN faculty to the overall mission of the Academy via extracurricular activities are outstanding. In a typical year, the DFAN faculty and staff led over 60 cadet research and development projects in aeronautics and related fields, authored or co-authored over 30 professional papers and presentations, spent well over 100 hours in local schools or hosting student visits to the Academy, providing aerospace education to the local community, and served in over 20 different after-hours military leadership/mentorship positions with the cadet wing, providing academic counseling, ethics training, or supervision of the cadet-to-cadet training program.

2. Facilities

A critical component of the aeronautics major's education -- hands-on research and development -- occurs in the DFAN Aeronautics Laboratory. To implement the curriculum requires an extensive suite of facilities. USAFA is fortunate to have had a substantial investment in experimental infrastructure since its inception, and a series of upgrades over the years to keep them relevant. The Laboratory is a 7,500 m^3 facility housing nine major wind tunnels capable of various test velocities from low speeds to Mach 4.5, a water tunnel, three jet engine test cells including operational J-69 and F-109 cycles, a rocket/internal combustion engine test cell, two Genesis 3000 flight simulators, and a variety of smaller experimental equipment. Each major facility has a technician dedicated to its operation, maintenance and upgrade. This ensures they do not fall into disrepair, and establishes continuity in their operational capability.

The most versatile and well-employed facility is the Subsonic Wind Tunnel (Fig 1). The SWT, with a 0.91 x 0.91 x 3 m test section, operates at Mach numbers from 0.05 to 0.6 (clean tunnel). As this covers the range where most flight takes place, it is well-used. Fully a third of all research performed here is based in this facility. A well-developed internal force balance measurement capability allows six force components to be measured simultaneously, facilitating lift, drag, axial force, and pitch/roll/yaw moments to be determined. The tunnel will be upgraded in late Fall 2011 with an external force balance, capable of larger measurement ranges and state-of-the-art accuracy.

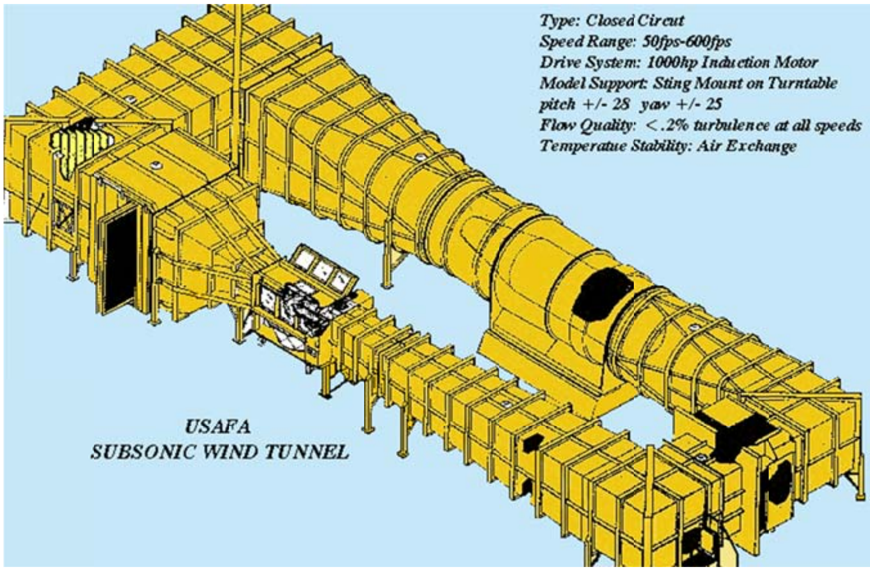

Figure 1 Subsonic Wind Tunnel Schematic

The Trisonic Wind Tunnel (TWT), Fig 2, complements the SWT with a high subsonic, transonic and supersonic capability. With a 0.3 x 0.3 m test section, it is a blowdown facility. Six tanks with 150 m^3 of storage can be pumped to over 3.5 MPa, resulting in test run time of up to three minutes, depending on Mach number. The tunnel has a continuous subsonic capability as low as M = 0.4 through transonic, with a variable porosity cart. Fixed nozzle blocks allow operation at Mach numbers of 1.39, 1.68, 2.02. 2.45, 3.48 and 4.38. A pressure control system allows the system to work at Reynolds numbers between 1 and $13x10^6$ per meter.

Dual low speed wind tunnels as in Fig 3, also with test sections of 0.91 x 0.91 m cross section, complement the SWT. They operate at up to 30 m/s, and their simple, open-return design eases operation, allowing students to run the facility unsupervised. Like the SWT and TWT, they also have a well-developed force and moment measurement capability.

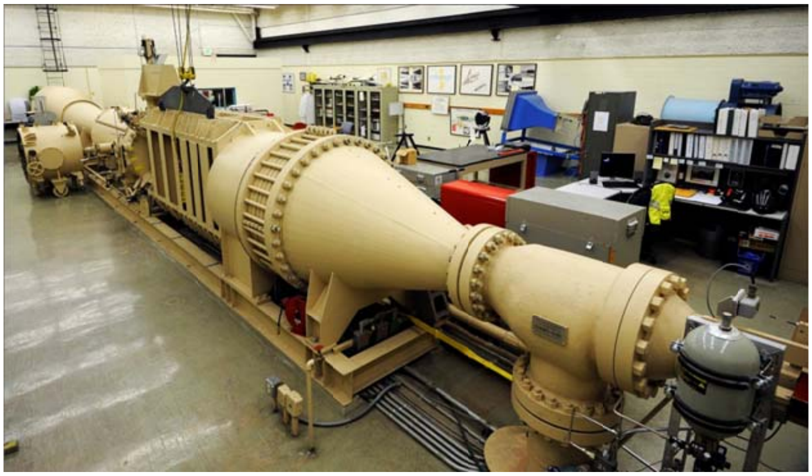

Figure 2 Trisonic Wind Tunnel

Figure 3. Low Speed Wind Tunnels

A water tunnel (Fig 4) provides a flow visualization capability to further illustrate findings from the other facilities. With a 38 x 51 cm test section, the water tunnel is primarily used with dye visualization to mark and track flow particle behavior. A particle image velocimetry system and laser Doppler velocimeter provide highly accurate and dense velocity information.

In addition to the wind tunnels, four hardened engine test cells provide for testing of gas turbine, internal combustion and rocket engines. Water brake and eddy current dynamometers are the main diagnostic tool for internal combustion performance, and heavily instrumented J-69 (Figure 5) and F-109 turbofan engine provide excellent platforms for diagnosing current research areas of interest, including engine swirl and stall.

In support of the computational education and research mission, the Department manages a SGI Altix ICE 8400 parallel processing computer system with 144 core processors, 2GB RAM per core and 6TB common RAID storage. This local capability is in addition to access to the large national HPC sites through the Defense Research Network. The Department has active computational research programs in virtual flight testing and system identification, aero servo optics and closed loop flow control and is the principle investigator of a 7M cpu hour U.S Department of Defense High Performance Computing challenge grant.

Figure 4. Water Tunnel

3. Experimental Education

The department's experimental efforts have evolved over an extended period. Twenty years ago, the extensive facilities were under-utilized and little productive research was performed. The requisite experimental methods class was then geared toward an understanding of all available means of measuring pressure, force, temperature and velocity. A smaller portion of the syllabus was devoted to an experimental effort under a faculty "sponsor", but these investigations were cursory and rarely focused on discovery of new knowledge. As, initially, a few goal-oriented, sponsored research efforts were undertaken for outside customers, it quickly became clear that the higher achieving students assigned these projects took away a great deal from the experience. Their depth of knowledge and appreciation of the discovery process seemed to be bearing great fruit for them, both in their graduate studies and their subsequent careers.

It was clear that students responded well to the challenges of a funded research project, where a sponsoring organization was very interested in, and were willing to pay for, the results of the students' investigation. The quality and volume of students' performance far outstripped that of those with "make work" experimental efforts. It became clear that the knowledge that their work was of importance to entities outside the academic environment produced an entirely different motivation. It was also clear that the students responded and benefited tremendously from the consistent and high level of interaction with their faculty sponsor. Not only did the faculty member provide mentorship through the experimental process, they modeled the behavior of the professional engineer in the solution of problems; students understood from example what the professional did when the experiment didn't work, the data were incorrect, or the outcome wasn't expected.

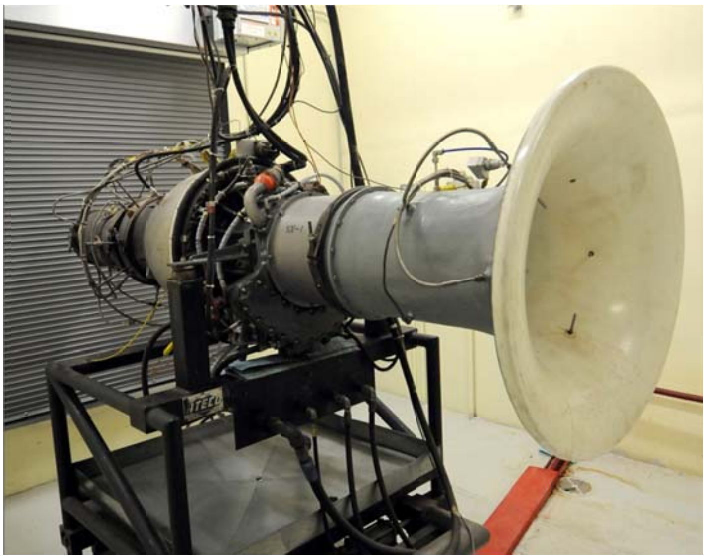

Figure 5. J-69 Turbojet Engine

Two substantial changes were then made to the experimental curriculum. First, a leadership commitment was made to extending to all students the "best practice" of participating in a real, timely and sponsored research effort. Commitment to attracting outside funding resulted in a trickle, then a stream and a river of outside sponsorship, over time. That sponsorship meant that additional full time staff could be hired to complement the strained faculty time available to support projects. At this point, teams of two cadets (never more than three) are paired with a faculty "team leader" in the solution of a current basic or applied, sponsored research program. This is now universal; all students majoring in aeronautical engineering, regardless of skill or grade history, participate in funded experimental investigations. To our knowledge, this is the only program in the world where this occurs at the undergraduate level.

A second, riskier change provided surprising results. Faculty team leaders regularly complained that there was insufficient time in the semester to complete the project. With half the semester taken up with theory and lecture, it became more and more difficult to complete everyone's project, especially since there was a need for more rigorous experimentation to meet sponsor needs. To provide the additional time, the classroom effort was cut in half, to only 10 lessons. This provided just enough time to introduce measurement systems and strain gauge-based transducers; discuss signal conditioning and data recording; and bring in statistical concepts and data uncertainty. Two laboratories to experiment with a cantilever beam force measurement and a hot film anemometer rounded out the effort before students began to concentrate on their projects. While it was feared that the elimination of more traditional surveys of all measurement techniques would weaken their experimental base, just the opposite happened. With the additional project time, students were able to delve more deeply into the measurement technology used in their particular experiment. They became experts in that methodology through repetitive use. Subsequently, with the knowledge that they could learn all that was needed about a particular transducer, they were much more keen and able to learn about different transducers on their own, without introduction in the classroom. In short, the time previously spent on comprehensive treatment of measurement technology wasn't missed.

A current list of projects indicates the eclectic nature of the research undertaken in support of undergraduate education (Table 1). Clearly, given the breadth of efforts, there can be little commonality of experience from one team to another. That appears to be of little consequence, as there are rarely complaints about differences in experience, either from the students or the organizations gaining their services after graduation.

Once students have gained the basic understanding and experience with experimental methods in the Aeronautics Laboratory Course, they may continue their development through optional programs. Cadet summer research affords motivated students the opportunity to spend part of their summer, before senior year, at a government, industry or academic institution, either furthering the efforts initiated in the first class, or expanding to an entirely different area. Approximately 50% of students are able to take advantage of this opportunity. More motivated students, typically those who have validated some USAFA core course requirements, extend their depth even more with independent study courses, wherein for two or even three semesters they can extend their depth and understanding on a research topic.

Table 1. Current Projects

Project	Sponsor
A-10 Aircraft Surface Patch Investigations	USAF Ogden Air Logistics Center
Micro Air Vehicle Stability Analysis	USAF Research Lab/Munitions
Fighter-Sized Target	USAF Research Lab/Air Vehicles
Reusable Booster	USAF Research Lab/Air Vehicles
Rotax 914 Knock Assessment	USAF Research Lab/Air Vehicles
F109 Turbofan Flow Disturbance	Arnold Engineering Development Center
Cycloidal Wave Energy Converter	National Science Foundation
Tangent Ogive Vortex Control	Republic of Korea Agency for Defense Development
Orion Pilot Chute Aerodynamic Characteristics	NASA
Plasma Actuators	USAF Office of Scientific Research
Parachute Suspension Line Drag Analysis	US Army Natick Soldier Center

4. Computational Education

Similarly, the department has substantially revised its computational fluid dynamic curriculum to provide graduates with the skills necessary to perform such simulations. The Department has found that the cadets come to the Academy with relatively high levels of computer skills but very much lacking in the computer programming abilities necessary for success as the modern engineer. Unfortunately, the curriculum at the Academy is very much constrained by the overarching core that a programming course could not be added. The Department instead took the approach of adding computer projects into individual aeronautical engineering courses thereby weaving a computational thread throughout nearly the entire curriculum. Development of computer skills begins in the sophomore level thermodynamics course with basic Matlab programming in which the cadets learn basic operation, syntax and how to write simple "for" loops. In the junior level flight mechanics and aerodynamics courses, the cadets learn to write subroutines, import and export data, perform numerical integration and nested "for" loops as they work on projects like analyzing velocity data from the wake behind a cylinder to calculate drag, unsteady response to an impulsively accelerated wall in Poiseuille/Couette flow, and potential flow theory solution to flow over an airfoil.

The centerpiece of computational skills development is a spring semester junior level aerodynamics course which is designed to make the cadets "intelligent users" of advanced computational fluid dynamics codes. The cadets begin this course by utilizing a vortex panel method code to compare aircraft lift characteristics to wind tunnel and flight test data. They are then introduced to finite differencing and write their own code in Maltab to solve the heat and wave equations. The second half of the course is dedicated to teaching the cadets the four steps in the computational fluid dynamic solution process: geometry generation, grid generation, flow solution and post processing. The cadets utilize commercial software packages and a local parallel process computer system in the application of this four step process to solve for the flow around a 3-D inviscid wing and a 2-D viscous airfoil. This computational fluid dynamics course represents one of only a handful in the nation at the undergraduate level that is *required* by all aeronautical engineering majors in a program. The computational tread continues into the senior year where cadets apply these computational tools to analyze the aerodynamics of their aircraft designs in the capstone courses. Advanced CFD elective and independent research courses are also offered, giving cadets the opportunity to engage in sponsored computational research projects with a faculty mentor similar to experimental projects outlined above.

5. Additional Program Elements

Also of special note is DFAN's Flight Test Techniques course, a special semester-long immersion in the academic and operational aspects of aircraft performance testing. In this highly-competitive elective course, students practice flight test data collection and analysis methods. At the end of the semester, they visit the actual TPS facilities in California to validate their skills during USAF T-38 Talon supersonic trainer flights. Many aeronautics majors have gone on from this unique experience to graduate from an Air Force, Navy, or international TPS programs.[7]

6. Recognition and Awards

The Academy's overall engineering program is recognized consistently as one of the nation's top five undergraduate programs.[8] The aerospace curriculum in particular was recently rated as the second-best undergraduate program in the nation.[8] Furthermore, USAFA won the National Aeronautics Association 2001 Cliff Henderson Award for "significant and lasting contributions to the promotion and advancement of aviation and space activity in our United States and around the world."[5] The department has averaged 12 students enrolled in AE 499 with an average of 6 AIAA papers published per year. In the last three years alone cadets from the Department have been awarded first place twice, second place twice and third place three times at the AIAA Region V Student Paper Conference in addition to receiving top honors at the AIAA international student paper competition. This level of success can only be achieved through a concerted long term effort focused on building the necessary skills as well as instilling the proper mind set to perform independent research.

Despite having a reputation as one of the most difficult majors at the Air Force Academy, the Aeronautics Department continues to attract high numbers of talented students with between 60-80 majors per year. Even through this number of students represents only 6-8% of a typical Academy graduating class, they can hold as many as 20 of the top 100 slots based on overall order of merit. This high class ranking results in average of 15 graduate scholarships award per year including nationally competitively appointments to MIT, University of Washington and Rice. The cadets' active duty career fields are pre-selected prior to graduation based on class ranking and personnel desire. 50% of a typical graduating class of Aero majors will go on to pilot training with approximately 15% going into engineering or aircraft maintenance and the remainder into other specialized career fields. Surveys of the supervisors of recent graduates indicate that the in-depth and applied curriculum prepares the students well for whichever career field they end up serving.

7. Conclusion

The United States Air Force Academy has made, and will continue to make, significant and lasting contributions to the promotion and advancement of aviation and space activity in our United States and around the world. USAFA's Department of Aeronautics is an integral part of the institution, providing critical components of the academic curriculum while supporting the professional military officer training program in numerous ways. USAFA graduates have proven the worth of their education in numerous ways in the military and civilian spheres of influence. DFAN is proud of its contributions to aerospace power in these last four decades of a century of manned flight.

The combination of faculty, facilities and curriculum at the United States Air Force Academy offer a superb environment for collaborative aeronautical engineering educational research activities. In addition, numerous research activities sponsored by Department of Defense and NASA customers offer both sabbatical and postdoctoral education and research opportunities. As a result of the unique educational research opportunities associated with the Academy's aeronautical engineering, the Air Force Academy is well positioned to graduate and commission officers with the knowledge and skills to develop new technical solutions and prepared to serve and lead the United States' highly technical air and space forces.

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The Center for Ecohydraulics Research Mountain StreamLab – a facility for collaborative research and education

[1]Ralph Budwig and [2]Peter Goodwin
Center for Ecohydraulics Research, University of Idaho Boise Campus, Boise, Idaho, USA, rbudwig@uidaho.edu [1] ;pgoodwin@uidaho.edu [2]

Abstract

The University of Idaho (UI), Center for Ecohydraulics Research (CER), Mountain StreamLab (MSL) features a large-scale sediment flume to allow fundamental and applied research of processes in mountain streams with a *unique combination of scale, instrumentation, and computer-control.* The goal of the MSL is to create a multi-user facility to allow a broad community of researchers and students to benefit from this unique, complex, and expensive laboratory. This paper describes the capabilities of the facility and accompanying instrumentation; as well as efforts to provide enhanced distance access through a suite of web based functions. The MSL hosted ten projects in 2010. Two of these projects are highlighted as examples in this paper – this first is a basic study that relates to sediment transport in mountain streams and the second examines how probe disturbances may lead to scour of a channel bottom.

1. Introduction

The University of Idaho (UI), Center for Ecohydraulics Research (CER), Mountain StreamLab (MSL) features a large-scale sediment flume to allow fundamental and applied research of processes in mountain streams with a *unique combination of scale, instrumentation, and computer-control.* The MSL, built in 2004, was carefully designed to fill a current void in laboratory facilities to study the interaction of sediment and turbulence and to overcome many of the problems associated with laboratory scaling. A combination of operational features makes this facility unique. The flume is 20m long, 2m wide, and 1.2m deep and includes a slope variable up to 10%. Flow rates may be set manually or by a computer interface, with the low flow system providing metered volume flow rates between 0.6 and 60 liters/second (0.021 to 2.1 CFS) and the high flow rate system providing metered volume flow rates between 60 and 850 liters/second (2.1 to 30 CFS). The flume is equipped with a custom designed, computer controlled instrumentation platform and can simultaneously measure multiple processes, such as bedform response to varying hydrographs. In addition, tri-modal sediment size distributions can be fed into the flume at high transport rates. After passing through the flume, the sediment is collected into a sediment weighing drum at the downstream end of the flume. This provides a continuous

Figure 1. The CER high gradient sediment flume.

reading of the overall bedload transport rate. More technical detail on the MSL is provided in Section 2.

The goal of the MSL is to create a multi-user facility to allow a broad community of researchers and students to benefit from this unique, complex, and expensive laboratory. They are able to observe experiments in real-time though a recently implemented web based lab-cam system. Additional web based applications to facilitate collaboration are in the planning stages and are described in Section 2.

Broad and collaborative access to this unique facility will contribute to advances in geomorphology research, particularly in emerging themes such as ecohydraulics that span several disciplines of science and engineering. Examples of recent MSL project topics include: sediment transport in mountain streams, physical modeling of a salmon redd, sediment flux through a pool-riffle stream configurations, modeling of building stability when subjected to glacial lake outburst flooding, and physical modeling of sediment transport though a river diversion. More details on selected studies are provided in Section 3.

2. Laboratory Description

2.1 Description of the MSL

The MSL is located at the Boise branch campus of the University of Idaho, on the first floor of the Idaho Water Center, where water-related agencies and graduate education programs are collocated. The MSL features a large scale, tilting-sediment flume and has a 186 square meter (2000 square foot) model basin area adjacent to the flume (Figure 2). The flume is 20 meters long, with a width of 2m and a depth of 1.2m. The maximum slope of the flume is 10%. Water is pumped from a 242,000 liter catch basin to the flume or to the modeling basing area directly for high flow rate applications or through a head tank for low flow rate applications. Magnetic flow meters are used to measure volume flow rate. The low flow system provides metered volume flow rates between 0.6 and 60 liters/second (0.021 to 2.1 CFS) and the high flow rate system provides metered volume flow rates between 60 and 850 liters/second (2.1 to 30 CFS). Flow

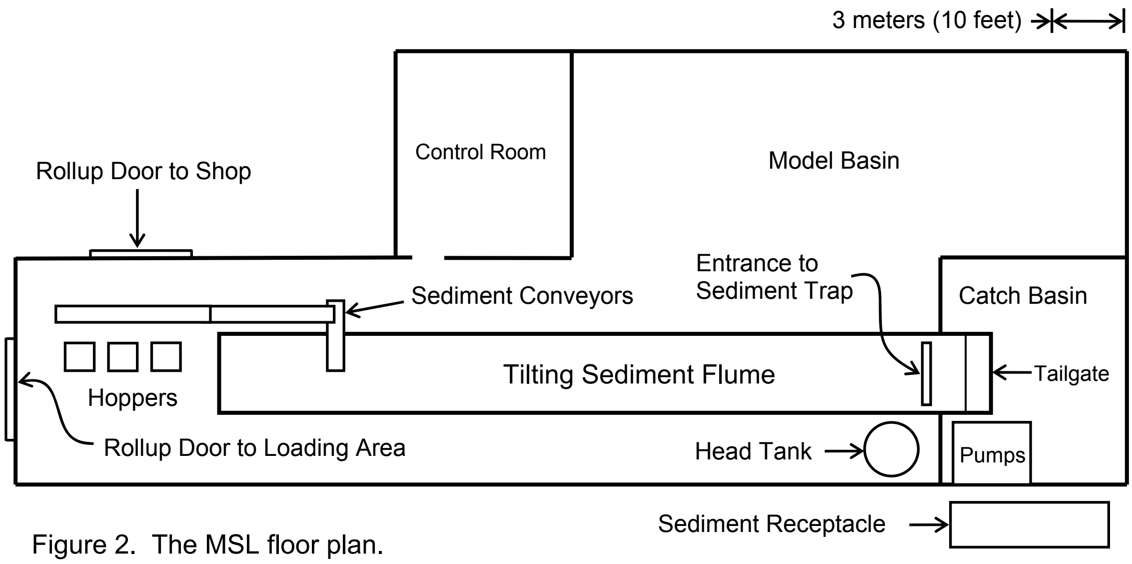

Figure 2. The MSL floor plan.

rates may be set manually or by a computer interface. The flume sediment system is designed to feed sand and river rock in an open circuit (non-recirculating) mode. Sediment is stored in three sediment hoppers, so that up to three sizes of sediment can be delivered simultaneously, each at calibrated mass flow rates. The sediment feeding system can handle grain sizes from 0.5 mm to 40 mm. Larger cobbles may be manually loaded into the flume. An overhead crane that follows the length of the flume and the model basin area is used to move bulk bags of sediment for loading the hoppers as well as for manual placement into the flume. After passing through the flume, the sediment is collected into a sediment weighing drum at the downstream end of the flume. This provides a continuous reading of the overall bedload transport rate. The weighing drum, when full, dumps sediment into a holding tank. The sediment is augured from the holding tank into a slurry pump intake tube and then pumped to a receptacle in the alley that is adjacent to the MSL. A water return pump then draws water from the top of the receptacle and returns it to the flume catch basin. The sediment that collects in the receptacle is periodically transported to a local gravel yard, where it is reprocessed and sold for commercial applications.

The model basin area adjacent to the flume provides ample space for a variety of hydraulic and ecohydraulic physical models. Water can be supplied to this part of the laboratory from either the head tank or the variable speed pumps and is discharged into the catch basin after exiting the model.

The flume is equipped with a custom-designed, computer-controlled instrumentation platform that can move a measuring probe to any prescribed x, y, and z location or sequence of locations along the length, width, and depth of the flume. The platform has an on-board computer to host measuring instruments and custom software to record measured data along with the location at which it was measured. Major instrumentation in the MSL includes:

- A stereoscopic particle image velocimetry (PIV) system with megapixel resolution and 15 Hz frame rate. High end visualization software processes and displays PIV results.
- A high-speed (up to 50 kHz sampling rate), high accuracy (better than 0.1 mm) charge-coupled device (CCD), laser displacement sensor is mounted on the instrumentation platform and can be used to scan water surface profiles and sediment bed profiles.
- A custom eight channel ultrasonic sediment bed profiling system provides real-time bed profiling through a water column.
- An acoustic Doppler velocimeter (ADV) system that provides down-looking and side–looking capabilities.
- A Dual-frequency Identification Sonar (DIDSON) acoustic digital movie camera acquires planar images of underwater objects and boundary features. The DIDSON can function even with a water column that is loaded with suspended sediment and is optically opaque. The flume in the MSL has floor and side ports to mount the DIDSON.
- A high speed camera system to capture sediment motion

The MSL is adjacent to a design and fabrication facility. The fabrication equipment is available for model fabrication and for fabrication of custom instrumentation for the MSL.

2.2 Technology to facilitate collaboration

A web-based lab-cam system was installed in 2010 and is now operational. The system allows for real-time viewing of experiments by streaming video with off-site control of pan, tilt, and zoom of the lab-cams. Collaborators have full access to the lab-cams through a standard Internet browser. Two additional web based applications to facilitate collaboration are in the planning stages. The first will collect MSL data streams and to display them on a web-based interface. Local and distance users will have web access to real-time snapshots of data streams as well as ability to download complete data sets for post-processing. The second will be a large data management facility where experimental data may be stored and retrieved via the web-based interface. This will be especially useful for large data sets such as those associated with PIV or the water column or laser scan bed topography.

3. Examples of Recent Projects

The MSL has been used by research by faculty from regional and national universities as well as by northwest divisions of agencies including the U.S. Forest Service, U.S. Geological Survey, and the U.S. Bureau of Reclamation (Table 1). In addition, we have significant collaboration with other universities and research communities, including a MOU that articulates the MSL a part of the NSF National Center for Earth Surface Dynamics (NCED) and a part of the St Anthony Falls Laboratory (SAFL). CER has a global network of collaborators located in Europe, Asia, and South America. We partner with the Center for Patagonia Ecosystem Research (Chile) and are advisors to the European Union-Latin America Center for the Environment (Chile). Table 1 presents a list of projects that were conducted in 2010.

Table 1. MSL Projects in 2010

Name and Affiliation	**Research Topic, Sponsor, and Status**
Elowyn Yager, Ph.D. (CER)	CER Keystone class project, February, 2010
Ms. Heidi Schott (CER) Elowyn Yager, Ph.D. Joel Johnson, Ph.D. U. Texas at Austin	Sediment transport in mountain streams, funded by NSF Career Award #***0847799***. March & April, 2010, with additional work planned for 2011
Ralph Budwig, Ph.D.	Transformation of the stream laboratory into a distance-use facility for collaborative research and education, Idaho EPSCoR equipment grant, May to August, 2010
Ms. Holly Bentz, USFS Wolfgang Kampke, Karlsruher Institut für Technologie (KIT) Ralph Budwig, Ph.D.	Physical modeling of modified culvert flow to aid fish passage, U.S.Forest Service, June, 2010
Mr. Joe Wagenbrenner (WSU) U.S. Forest Service	Physical modeling of hill slope erosion and in-channel treatments, USFS, July, 2010
Ms. Natalie Spencer University of London	Physical modeling of ram-dirt building stability when subjected to glacial lake outburst flooding, July, 2010
Mr. Sagar Neupane (CER) Ms. Lauren Perrault (CER) Ms. Heidi Schott (CER)	Follow-up to CER Keystone class project on sediment erosion in a gravel stream bed with alternating rows of large cobbles, October, 2010
Mr. Todd Buxton (UI) Alex Fremier, Ph.D. (UI) Elowyn Yager, Ph.D.	Proof of concept experiments for physical modeling of a salmon redd, October, 2010
Ms. Sharon Parkinson, USBR Mr. Neal Bradshaw (CER) Peter Goodwin, Ph.D. Diego Caamano, Ph.D., Universidad de Concepción Ralph Budwig, Ph.D.	Sediment flux through pools, U.S. Bureau of Reclamation, November and December of 2010
Harindra Fernando, Ph.D., U. Notre Dame Peter Goodwin, Ph.D. Ralph Budwig, Ph.D. Mr. Neal Bradshaw	Preliminary physical modeling of river diversions, December 2010

More detailed summaries of two current and MSL projects are below.

3.1 Sediment transport in mountain streams (Yager and Schott, UI; Johnson, UT-Austin)

In mountainous drainage basins, steep channels (gradients of 3-20%) occupy the majority of the total channel length. The volume and grain sizes of sediment supplied from steep channels and hillslopes influence the success of downstream river restoration projects. The aquatic habitat and water quality in restored sites are partially controlled by the magnitude and grain-size distribution of the sediment supply. Accurate predictions of sediment flux in steep streams are needed before the potential success of many restoration sites can be determined. In addition, we cannot answer fundamental geomorphologic questions without knowledge of sediment transport in steep headwater streams.

Most sediment transport equations are based on empirical fits to data measured at the reach-scale and therefore do not include the mechanics of grain motion. Furthermore, traditional bedload transport equations derived for low-gradient channels typically over-predict sediment flux in steep, rough streams by several orders of magnitude (e.g. Bathurst et al., 1987; Rickenmann, 1997; D'Agostino and Lenzi, 1999). Most streams, particularly steep channels, have relatively wide grain-size distributions that are divided into distinct spatial patches with narrower grain-size distributions. Relatively little field work has been conducted on sediment patches (e.g. Paola and Seal, 1995; Lisle, 1995; Dietrich et al., 2005), and no theory currently exists to explain the location, grain size distributions, sediment transport rates and stability of sediment patches. Use of a reach-averaged grain size and shear stress in streams with patches can cause sediment flux predictions to be incorrect by orders of magnitude. Furthermore, the use of time-averaged flow measurements in unsteady or nonuniform environments, which are typical of steep streams, to predict sediment motion have been unsuccessful (e.g. Nelson et al., 1995; Sumer et al., 2003). The turbulent parameters (velocity intensities, pressure variations, etc.) directly responsible for sediment transport are also relatively uncertain (e.g. Kalinske, 1943; Nelson et al., 1995; Papanicolaou et al., 2001; Schmeeckle et al., 2007) and very few measurements have been made for the range of flow conditions found in steep streams (Papanicolaou et al., 2002). Yager therefore hypothesized that bedload transport equations for steep, rough streams need to include 1) the range of turbulence and grain properties that control the initiation of grain motion 2) the spatial variability in stresses and bedload transport rates on patches, and 3) the effects of temporal and spatial variations in sediment supply.

Figure 3. The test grain.

Flume experiments in the MSL are being used to further the understanding of the complex interactions between sediment transport, bed grain sizes, flow turbulence and channel roughness on initiation of grain motion. To measure local conditions, a mobile test grain was constructed that measured pressures at specific points around the grain. The 50 mm diameter test grain is shown in Figure 3. The test grain has seven surface pressure ports each connected to a pressure transducer inside the test grain. These pressure transducers were sampled at frequency of 1000 hz.

The test grain was placed on a fixed bed, so the pocket geometry was constant throughout all experiments. The contact points of the test grain on the bed were three force sensors that measured force fluctuations of the test grain. The sampling rate for these sensors was also 1000 hz.

Particle Imaging Velocimetry (PIV) was used to measure the 3D velocity field in a streamwise slice of the water column over the diametral plane of the test grain. Pressure, force, and PIV measurements were *simultaneously* collected during the initiation of motion of the test grain.

For brevity – we show only force transducer signals in this paper. Figure 4 shows the outputs of the three force sensors the mobile grain was placed upon. The time immediately before the signals flat-line are the point when the particle moved. The white signal is the upstream force sensor, and the pink and blue signals are the downstream left and right respectively. The most notable observation of these outputs is the range of force fluctuations is greater at the lower slope than at the higher slope. This suggests that the particle can endure greater force at the lower slopes before it rotates out of its pocket. This does make sense in that less of the particle's weight is in the downstream direction at lower slopes.

3.2 Probe disturbances and potential scour (Budwig; Chris Hocut, Notre Dame U.)

Measurement probes that penetrate the free surface of a river or an open channel are often used to measure flow conditions, water quality or bed topography. These probes interact with the flow causing disturbances, which alter the flow and may also locally scour the sediment bed, whereby velocity fluctuations and vorticity cause the sediment particles close to the tip of the probe to erode and be transported downstream. Example probes include underwater cameras, ultrasonic depth probes, acoustic Doppler current profilers (ADCP), acoustic Doppler velocimeters (ADV), and water quality probes.

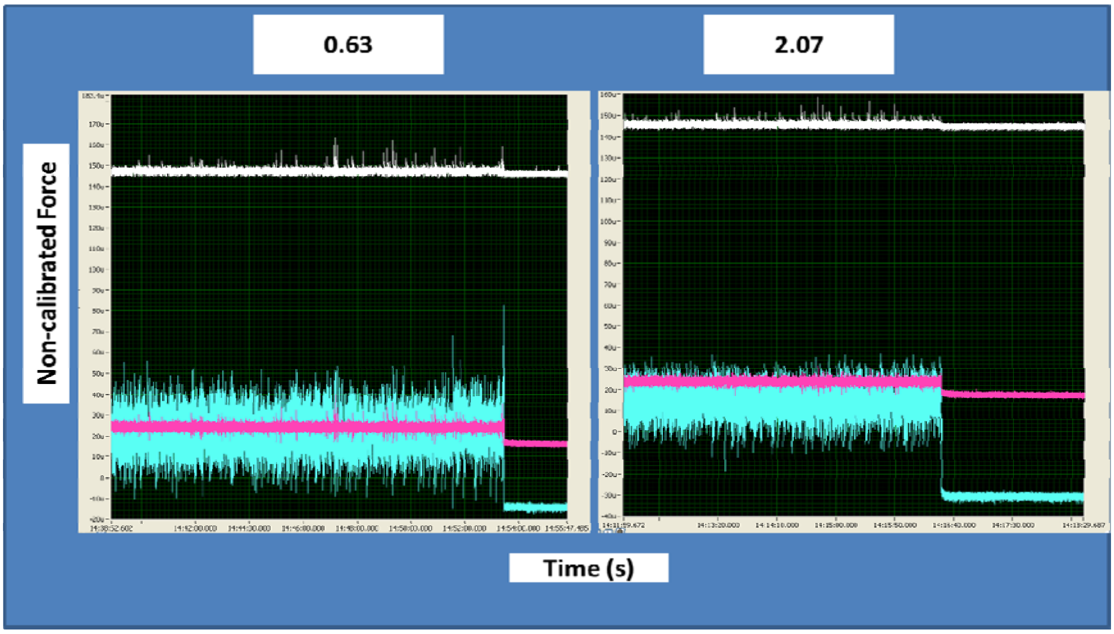

Figure 4. Force sensor outputs for slopes of 0.63% and 2.07%

The authors are aware of four previous studies of the flow around bluff bodies that were not in contact with wall of an open channel. Krampa-Morlu and Balachandar (2001) measured the wake velocity of a flat plate in an open channel suspended above the channel bottom. A “wall jet” like flow interacted with the wake flow behind the plate. The velocity profiles in the immediate wake were distorted and in the form of an S shape showing a significant deviation from the approaching freestream velocity profile. Snyder and Castro (1999) found a downward flow disturbance induced by an ADV transducer probe in a tow tank. The vertical velocity was always negative and had a value of approximately 2% of the horizontal speed. Rusello et al. (2006) compared the flow disturbance of a Sontek MicroADV and a Nortek Vectrino ADV in a flume. The MicroADV showed substantial deflection of the flow near the central transducer. Muste et al. (2010) investigated the flow disturbance of an ADCP in a flume. The flow velocity decreased and directed downwards as it approached the upstream side of the ADCP. The velocity then increased as the flow passed under the ADCP and decreased downstream in the wake. The flow disturbance extended up to half of the depth of the flow.

The present study experimentally investigated open channel flow disturbance due to a suspended circular cylinder that penetrated the free surface. A circular cylinder was selected (rather than a particular probe configuration) as a paradigm problem to yield fundamental physical understanding of the disturbance flow field. The cylinder penetration depth that caused interaction with the channel bottom was also investigated. This present study is an extension of the study of disturbances caused by probes that penetrated the free surface of an open channel when the cylinder was 7D (17.8cm) above the channel bottom performed by Sanders et al. (2009).

The experimental configuration is shown in Figure 5. The distance between the tip of the cylinder and the channel bottom was varied. The cylinder diameter was fixed at 2.54 cm. In this paper, for brevity, we will only shown a limited set of results for when the cylinder tip was D/2 (1.3cm) above the channel bottom.

Figure 6 shows the PIV generated vector field for the open channel flow with the cylinder D/2 (1.3cm) above the bottom. The turbulent wake was present directly downstream of the cylinder.

The wake started below the cylinder and propagated upwards to the top of the FOV as it moved downstream. It can also be seen that that the disturbance from the cylinder extends to the channel bottom just downstream of the tip of the cylinder.

Figure 7 shows an image of the scour hole and dune created by the presence of the cylinder D/2 (1.3cm) above a sand bed. This cylinder location was the farthest tested distance above the sand bed which caused scour. Figure 8 shows the surface plot and contour plot of the sand bed after thirty minutes of flow as measured by the CCD laser sensor. The maximum height of the dune was 0.39cm above the sand surface and the maximum depth of the scour hole was 0.09cm below the sand surface. The x-distance between the maximum height of the dune and the maximum depth of the scour hole was 3.69cm. The width of the scour hole was 5.5cm and the width of the dune was 8cm. The distance from the cylinder center line to the maximum scour hole depth and maximum dune height was -0.96cm and 2.7cm, respectively.

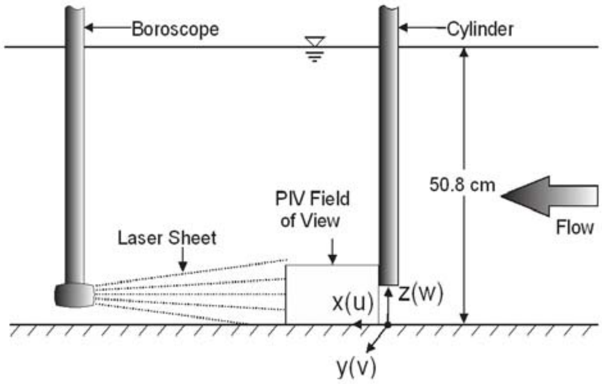

Figure 5. Location of PIV field of view.

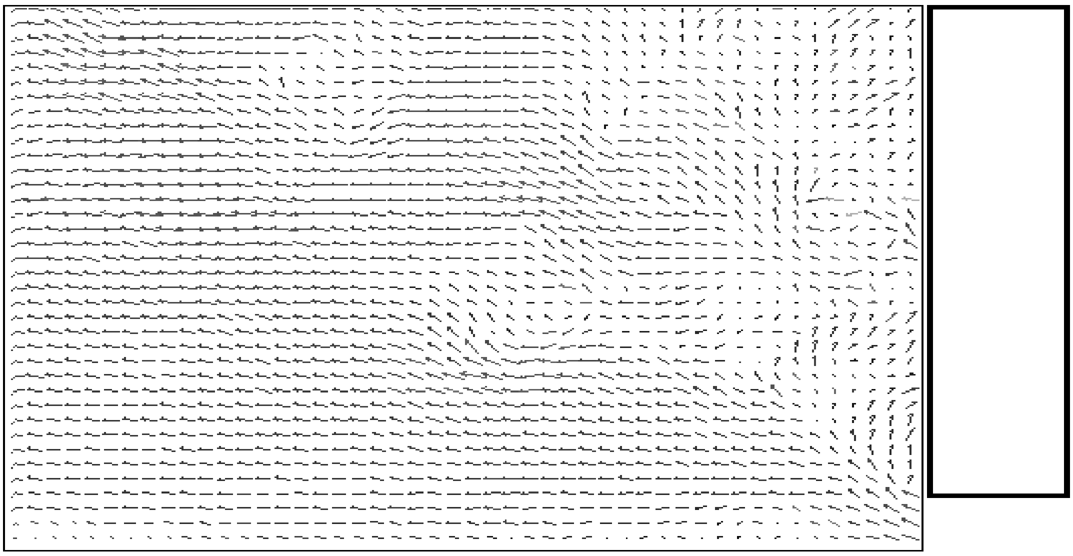

Figure 6. Vector field with tip of cylinder D/2 above channel bottom. Flow is from right to left.

Figure 7. Image of score dune and hole. Cylinder is D/2 above the channel bottom.

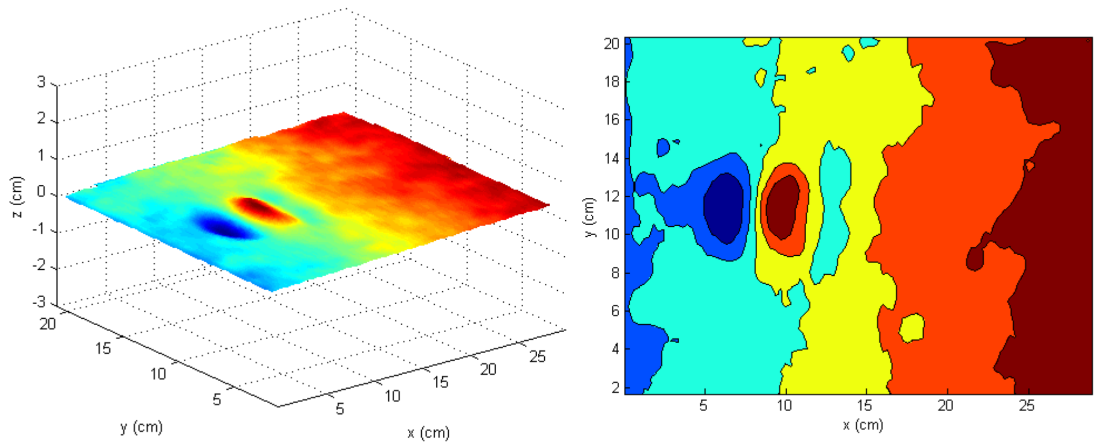

Figure 8. Surface and contour plots with the cylinder D/2 above sand. The Δz between each color in contour plot represents 0.8mm of depth. Flow is from left to right.

4. Concluding Remarks

The ten projects hosted in 2010 have demonstrated capability and accessibility for collaborative projects in the MSL. Broad and collaborative access to this unique facility will contribute to advances in geomorphology research, particularly in emerging themes such as ecohydraulics that span several disciplines of science and engineering. Additional instrumentation as well as web based applications are in the planning stages, with the goal to further facilitate collaborative research and education.

5. Acknowledgements

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Unique Remote Experiments in Engineering: USA, Armenia, Canada, Colombia, Germany, Mexico, Romania & Spain

[1]Jim Henry, [2]Oleg Gasparyan, [3]Benito Serrano-Rosales, [4]Ioan Ruja, [5]Javier Garcia-Zubia, [6]Hamadou Saliah-Hassane & [7]Juan C. Montoya

University of Tennessee at Chattanooga, Chattanooga, USA, jim-henry@utc.edu[1];
State Engineering University of Armenia, Yerevan, Armenia, ogasparyan@gmail.com[2];
Automonous University of Zacatecas, Zacatecas, Mexico, beniser@prodigy.net.mx[3];
University Eftimie Murgu, Reşiţa, Romania, i.ruja@uem.ro[4];
University of Deusto, Bilbao, Spain, zubia@deusto.es[5];
Télé-université du Université du Québec à Montréal, Montreal, Canada, saliah-hassane.hamadou@teluq.uqam.ca[6];
Escuela de Administración y Finanzas e Instituto Tecnológico, Medellin, Colombia, jcmontoy@eafit.edu.co[7]

Abstract

This paper presents the results of past collaborations and potential for future collaborations between and among multiple schools in multiple countries. Universities in USA, Spain and Canada have real laboratory systems on-line that other countries' schools have used remotely for education and research. These on-line laboratory systems are used (remotely) for experiments variously in system identification and controller design and in transient and steady-state testing as well as other purposes. These collaborations have led to and will lead to more cases where schools on both ends of the Internet are developing the hardware, software and infrastructure to establish real on-line experiments to be shared beneficially with others in the group and beyond.

1. Introduction

Remote Laboratories are a tool to support students in performing experiments as laboratories do in hands-on labs, but through the Internet. Remote Labs are becoming a significant learning tool in engineering education. Remote Laboratories offer a number of advantages to students:

- by in large, students can work from anywhere at anytime as long as they have Internet or smart-phone capabilities;
- students can work with teams including students at other locations;
- students can do experimentation on equipment that is unique, larger, smaller, more expensive, more available or other potential learning systems.

Remote Laboratories also offer a number of advantages to universities and colleges:

- for schools that have more students than laboratory facilities, they can provide alternative methods of learning
- they can be used as a adjunct to the established local laboratories at any institution
- remotely run experiments can be demonstrated during regular classes or in any other situation with students
- for schools with budgetary shortages, the remote lab experiments may present outstanding monetary savings

Properly designed Remote Laboratories can be designed to be available to nearly any Internet-connected device: computers and smart phones and anything in between, and particularly without regard to operating system.

1.1 Some attributes of Remote Experimentation

Remotely operated laboratories can be shared among multiple universities. Shared laboratories have several financial and pedagogical advantages: avoiding the duplication of equipment, and hence, enabling the more efficient use of resources; increasing the exposure of students to the multidisciplinary nature of engineering activities; encouraging interaction of faculty and students across disciplines and locations. Among the main advantages of such laboratories are: differing experiments--access to experiments located at different universities; flexible time-schedules--some experiments can be accessed 24 hours a day; saving travel time and cost--student's presence at the experiment location is not necessary (the case that is particularly important for disabled students); not endangering a remote user--any equipment malfunction will not be a danger; saving equipment costs--expensive experiments are shared among universities.

A collaborative project between USA and Armenia is being carried out now with the main objectives being: creation of a shared control laboratory and networking infrastructure for implementation of the WEB-based remote laboratory experiments at Armenia's Cybernetics, Mechanical Engineering, and Chemical Engineering Departments based on the innovative solutions developed in the USA; creating the necessary premises for further replicating similar networking infrastructures at the regional Armenian towns of Gyumri, Vanadzor, Hapan; familiarizing the educators and experts from Armenia with new trends, approaches, and technologies in the field of WEB-based laboratory experimentation. More details are available in the paper by Henry and Gasparyan, 2009. Many other universities are exploring such kinds of collaboration.

1.2 Characteristics of the Communication between the Student and the Laboratory Equipment

The characteristics of the platform determine its usability from different points of view: students, teachers, laboratories, IT-services, etc. The main characteristics are: universality, security, interoperability, deployability, scalability and scheduling. An open-source system has been developed in Spain that has demonstrated attention to these characteristics and is robust from the laboratory hardware and IT-services point of view. This system is described with more detail in a paper by Zubia, 2011.

2. Student Response and Student Learning

One important aspect of remote experiments is the response of the student and the quality and quantity of learning that the student experiences. Several surveys among the authors have shown that students generally think the remote labs are useful (Zubia, 2011; Henry, 2010). The sense of "presence" in the laboratory appears to be quite significant. One of us (Henry) took a survey in his class this year, asking, "What are the benefits and advantages of doing experiments with equipment and taking data?" A majority of the students included "doing hands-on" experiments in their responses, even though the experiments were done remotely. It may be true that for the generation of students we have now, "hands on" has different meaning than that to which many of us are accustomed.

Surveys of students using remote laboratories in Spain have shown correlations between items related to "usefulness" and the students' "sense of immersion". It has been observed in Spain and in the USA that "as much immersive experience in a remote experiment the much better it will be for the user" (Zubia, 2011; Corter, 2007; DiBiasio, 2010; Ma and Nickerson, 2006). There is, of course, to be expected the same phenomena to be demonstrated across various countries.

3. Examples of Collaboration

Remote connection was used to do remote experiments by a student in Mexico working on a thesis, using the laboratories in the USA, specifically a system of two non interacting tanks. An example of the experimental results is shown in Figure 1, showing a dynamic response to a step input change (Henry, 2010). The student conducted the experiments remotely, completed the modeling and completed a thesis describing his work (Guerrero, et al, 2010).

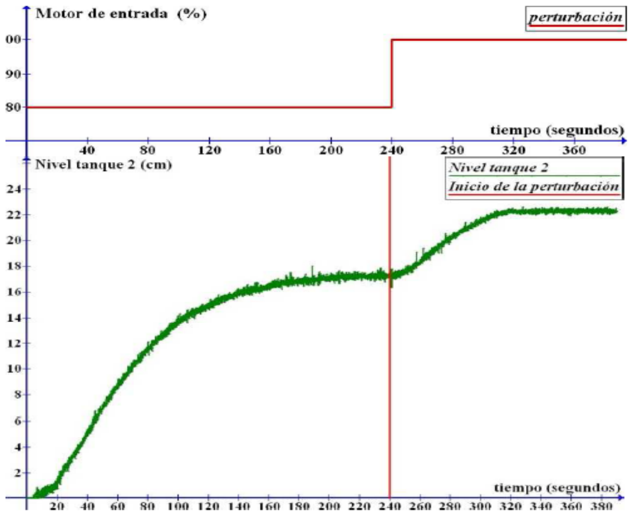

Figure 1: Response of the level of tank 2 to a step perturbation.

Students in Romania have used local and remote experimentation in the experimental identification of the induction motor; the determination of the technical performances of the dynamic and stationary regime of automatic control systems with controllers of the proportional, "P," and proportional-integral, "PI," type; and the optimal adjustment of the P and PI type controllers. There is an increased interest of the students who participate in these works as compared to other students (Ruja, 2011). Also, the students' trust increases towards the subjects under study, especially when they find out that in the USA, for example, they study the same technical problems and they use similar equipment and instruments. The unique behavior regarding the practical remote control experiments is shared among students, including other specializations, and there are discussions among the students referring to the performance of computers, programming languages, connecting protocols to the Internet, the rapidity of data transmission, the way of registering the data, the reliability of the fact experienced, measuring units, etc. All of these latter items are good indicators that student learning is occurring.

Canadian workers are helping the Francophone countries of Africa to engage in remote experimentation. They have clearly described the infrastructure in setting up remote experiments (Saliah-Hassan, 2005). They are working to develop tools and methods to develop course materials suited to mobile phones, smart-phones and Personal Digital Assistants. Some regions in Africa have highly developed cellular phone communication networks.

4. Future Work

Further analysis of student learning and attitudes must be continued. This analysis is, of course, the *raison d'être* of all of our teaching activities. Further progress is being made to make remote laboratory experimentation available that meet the criteria mentioned in Section 1, above.

5. Acknowledgements

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Advanced Test Reactor National Scientific User Facility

[1]F. M. Marshall, [2]T. R. Allen, [3]J. B. Benson, [4]M. C. Thelen

[1]Idaho National Laboratory, Idaho Falls, ID, USA, Frances.Marshall@inl.gov
[2]University of Wisconsin, Madison, WI, USA, allen@engr.wisc.edu
[3]Idaho National Laboratory, Idaho Falls, ID, USA, Jeff.Benson@inl.gov
[4]Idaho National Laboratory, Idaho Falls, ID, USA, Mary.Thelen@inl.gov

Abstract

The Advanced Test Reactor (ATR), at the Idaho National Laboratory (INL), is a large test reactor for providing the capability for studying the effects of intense neutron and gamma radiation on reactor materials and fuels. The ATR is a pressurized, light-water, high flux test reactor with a maximum operating power of 250 MW_{th}. The INL also has several hot cells and other laboratories in which irradiated material can be examined to study material irradiation effects. In 2007 the US Department of Energy (DOE) designated the ATR as a National Scientific User Facility (NSUF) to facilitate greater access to the ATR and the associated INL laboratories for material testing research by a broader user community. This paper highlights the ATR NSUF research program and the associated educational initiatives.

1.0 Introduction

In 2007, the Advanced Test Reactor (ATR), located at Idaho National Laboratory (INL), was designated by the U. S. Department of Energy (DOE) as a National Scientific User Facility (NSUF). This designation made test space within the ATR and post-irradiation examination (PIE) equipment at INL available for use by approved researchers via a proposal and peer review process. The goal of the ATR NSUF is to provide those researchers with the best ideas access to the most advanced test capability, regardless of the proposer's physical location.

Goals of the ATR NSUF are to define the cutting edge of nuclear technology research in high temperature and radiation environments, contribute to improved industry performance of current and future light water reactors, and stimulate cooperative research between user groups conducting basic and applied research. As part of meeting each of these three goals, the ATR NSUF has developed a broad educational program aimed at increasing the number of researchers knowledgeable about reactor experimentation, post irradiation examination techniques, and material radiation effect fundamentals. The educational program also includes a wide variety of internship opportunities, faculty/student research team projects, partnerships with other DOE laboratory and university experimental facilities, annual User Week, which includes several seminars on ATR and partner facility research, collaborative experiment projects, graduate research fellowships, and opportunities for postdoctoral researchers and visiting scientists.

Since 2007, the ATR NSUF has expanded its reactor test space, obtained access to additional PIE equipment, taken steps to ensure the most advanced post-irradiation analysis possible, and initiated an educational program and digital learning library to help potential users better understand the critical issues in reactor technology and how a test reactor facility could be used to address this critical research. This article describes these expanded capabilities and services so that researchers can take full advantage of this national resource.

Recognizing that INL may not have all the desired PIE equipment, or that some equipment may become oversubscribed, the ATR NSUF established a Partnership Program. This program invited universities to nominate their capability to become part of a broader user facility. Several universities and one national laboratory have been added to the ATR NSUF with capability that includes reactor-testing space, PIE equipment, and ion beam irradiation facilities.

2.0 Facility Capability Summary

Several facilities are available for the ATR NSUF user community. Some of these are at the INL and many more are available through the ATR NSUF partnership program.

2.1 Advanced Test Reactor

The ATR was designed to optimize fuel and material testing for the Navy's nuclear propulsion program. It began operation in 1967, and has operated continuously since then, averaging about 250 operating days per year. Irradiation of material and fuel in the ATR can simulate many years of prototypical operation in a few months or years of testing. This capability is valuable for testing materials and fuels in support of light water reactors (LWRs) and more advanced reactor designs. Unlike U.S. commercial LWRs, the ATR has no established lifetime or shutdown date. All core internal components are removed and replaced every eight to ten years during a core internals changeout outage, which typically takes about six months.

The ATR is a pressurized, light-water moderated and cooled, beryllium-reflected, enriched uranium fueled reactor with a maximum operating power of 250 MW_{th}. The ATR core cross section, shown in Figure 1, consists of 40 curved aluminum plate fuel elements configured in a serpentine arrangement around a three-by-three array of large irradiation locations in the core or flux traps, where the peak thermal flux can reach 1.0×10^{15} n/cm^2-sec, and peak fast flux (E>1.0 MeV) 5×10^{14} n/cm^2-sec. This core configuration creates five main reactor power lobes (regions) that can be operated at different powers during the same operating cycle. Along with the nine flux traps, there are 68 irradiation test positions ranging in diameter from 1.27 to 12.7 cm and all 122 cm long, and the irradiation tanks outside the core reflector tank have 34 low-flux irradiation positions.

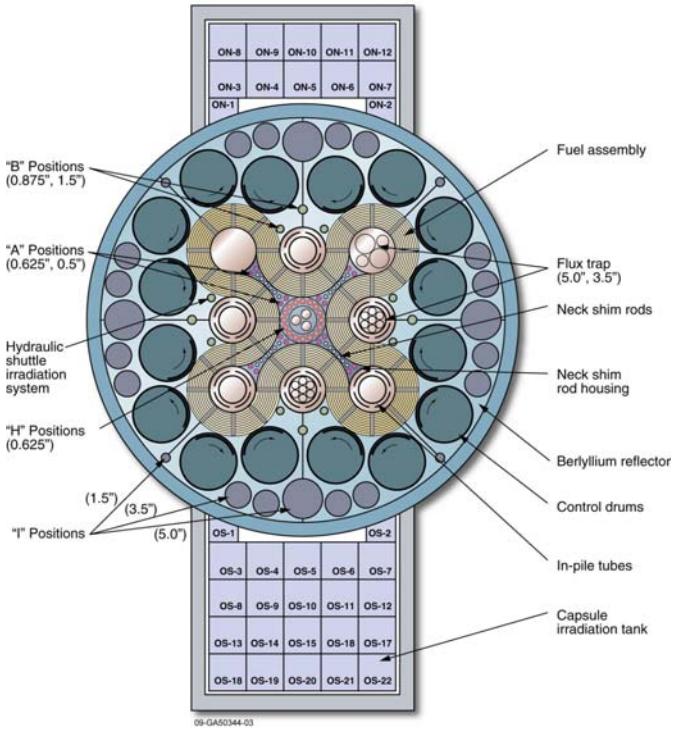

Figure 1. ATR core cross section.

General design information and operating characteristics for the ATR are presented in Table 1. The ATR can be operated with large power variations among its nine flux traps using a combination of control cylinders (drums) and neck shim rods. The beryllium control cylinders contain hafnium plates that can be rotated toward and away from the core, allowing for a symmetrical axial flux and eliminating axial variability among experiment specimens. This minimizes axial flux variations for experimenters.

Table 1. ATR design and operating data.

Reactor	
Thermal Power (Maximum Design Power)	250 MW_{th}
Power Density	1.0 MW/L
Maximum Thermal Neutron Flux	1.0 $x10^{15}$ n/cm^2-sec
Maximum Fast Flux	5.0 $x10^{14}$ n/cm^2-sec
Primary Coolant System	
Design Pressure	390 psig (2.7 MPa)
Design Temperature	240°F (115°C)
Maximum Coolant Flow Rate	49,000 gpm (3.09 m^3/sec)
Coolant Temperature (Operating)	<125°F (52°C) inlet <160°F (71°C) outlet

There are three primary experiment configurations in the ATR - static capsule, instrumented lead, and pressurized water loop. Experiments must remain in the ATR for the entire duration of the operating cycle (average length of 49 days), except for experiments performed in the Hydraulic Shuttle Irradiation System (HSIS). The HSIS enables small volume, short duration, irradiations to be performed in the ATR, and can include up to 14 small shuttle capsules in a single shuttle operation.

The ATR building also houses the ATR Critical (ATRC) facility, which a full-size replica of the ATR, but operates at low power (5 kW maximum). It is used to evaluate an experiment's potential impact on the ATR core, by measuring experiment control rod worths, reactivities, thermal and fast neutron distributions, gamma heat generation rates, and void/temperature reactivity coefficients before inserting an experiment into the ATR.

2.1.1 Static Capsule Experiments

Static capsule experiments consist of tubing filled with material to be irradiated that is placed in the ATR. A test may consist of a single long capsule or a series of shorter capsules stacked on top of each other. Experiment materials that can come in contact with ATR primary coolant system (PCS) can be configured so the capsule is exposed to and cooled by the ATR primary coolant system. An example of this configuration is fuel plate testing in which the material contacting with the PCS is the same material as ATR fuel element cladding.

Static capsules have no instrumentation, but can include flux-monitor wires and temperature melt wires for examination following irradiation. Limited temperature controls can be designed into the capsule using an insulating gas gap between the test specimen and the outside capsule wall. The size of the gap is determined by analyzing the experiment temperature requirements. An appropriate insulating or conducting gas is then sealed into the capsule.

2.1.2 Instrumented Lead Experiments

Some experiments need specialized environments, such as an oxidized cover gas, or temperature control. A fueled experiment, for example, may need to be tested for fission gases, which could indicate a failure of the experiment specimen. The instrumented lead experiment establishes and monitors precise environmental conditions, thereby ensuring that the experiment's data objectives are met. Temperatures can be controlled between 250-1200°C, within +/- 5°C. Instrumented lead experiments allow the experiment parameters to be displayed in real time on an operator control panel. Instruments can also be configured to alert operators and experimenters, if the experiment parameters exceed test limits. Instrumented lead experiments also have the capability of recording and archiving data for any monitored experiment parameter; data is typically saved for six months.

2.1.3 Pressurized Water Loop Experiments

Pressurized water loop experiments can be placed in ATR flux traps that have in-pile tubes. These in-pile tubes provide a barrier between the ATR PCS and a secondary pressurized water loop coolant system so that pressurized water loop experiments are isolated from the ATR PCS. The secondary cooling system uses pumps, coolers, ion exchangers, and heaters to control experiment temperature, pressure, chemistry, and flow. All of the secondary loop parameters are continuously monitored, and controlled to ensure precise testing conditions.

Loop tests can precisely represent conditions in a commercial pressurized water reactor. Operator control display stations for each loop continuously display information, which can be monitored by the ATR staff. Test sponsors receive preliminary irradiation data before the irradiations are completed, so there are opportunities to modify testing conditions if needed. The data from the experiment instruments are collected and archived similar to the data in the instrumented lead experiments.

2.2 Post-Irradiation Examination Capabilities

Post-irradiation examination (PIE) capabilities are available to ATR NSUF users at numerous facilities at the INL, including the Hot Fuel Examination Facility (HFEF), Analytical Laboratory (AL), Electron Microscopy Laboratory (EML), and Fuels and Applied Science Building (FASB). These facilities house equipment and processes used for nondestructive examination, sample preparation, chemical, isotope, and radiological analysis, mechanical and thermal property examination, and microstructure property analysis. Figure 2 is a photograph of the interior of the HFEF.

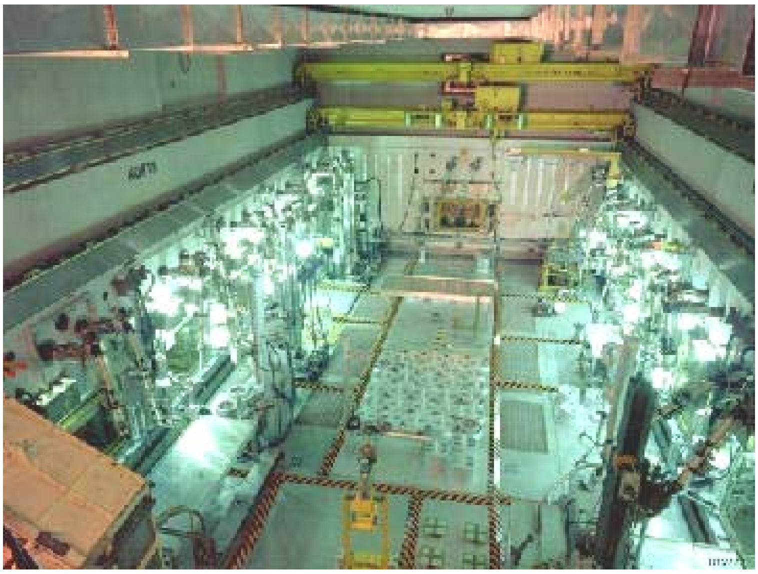

Figure 2. Hot Fuel Examination Facility.

2.2.1 Nondestructive Examinations

Nondestructive examination activities are available at the HFEF. Capabilities include neutron radiography using 250 kW TRIGA reactor, with two beam tubes and two separate radiography stations, precision gamma, dimensional inspections using a continuous contact profilometer, element/capsule bow and length examinations to measure distortion (bow) and length of fuel elements, visual exams, eddy current examinations to measures material defects, and high precision specific gravity measurements using pycnometer and immersion scales.

2.2.2 Sample Preparation

Samples preparation capabilities include solid metallography, which consists of sectioning and cutting, mounting into metallographic bases, and grinding and polishing processes and equipment, and gas sampling using laser puncture and gas collection processes.

2.2.3 Chemical, Isotopic, and Radiological Analysis

Chemical, isotopic, and radiological analysis of irradiated fuel and material meeting National Institute of Standards and Technology traceability standards capabilities include inductively coupled plasma mass spectrometry with dynamic reaction cell, inductively coupled plasma atomic emission spectroscopy, atomic absorption analysis, thermal ionization mass spectrometry, gas mass analysis, isotope mass separator, gross and isotopic radiological analysis, gross alpha/beta analysis, alpha, beta, and gamma spectroscopy analysis.

2.2.4 Mechanical Property Examination

Mechanical property examination activities are available for high radiation samples in the EML, HFEF Main Cell, and the lower-dose, contact-handled FASB. Capabilities include metallography, microhardness testing, tensile testing, and shear punch testing.

2.2.5 Thermal Property Examinations

Thermal property examination instruments and processes are available at the INL Materials and Fuels Complex. Capabilities include: thermal diffusivity (laser flash method and scanning diffusivity analysis), differential scanning calorimitry, and high temperature furnace for accident testing of high temperature gas-cooled reactor fuel.

2.2.6 Microstructure Property Analysis

State-of-the-art microstructure property analysis instruments capable of micro and nanoscale characterization are available at INL. Capabilities include scanning transmission electron microscope (STEM) with energy dispersive x-ray spectrometer, scanning electron microscope (SEM) with energy dispersive and wavelength dispersive x-ray spectrometers and electron back scatter diffraction detector, field emission gun (FEG) SEM, dual beam focused ion beam (FIB) that enables site specific sectioning of materials for 3D analysis or high resolution, TEM characterization, shielded electron microprobe to analyze elements from Be through Cm with full matrix correction, including fission gases on samples, and x-ray diffractometer to perform microscale phase identification, small-sample powder diffraction, and texture determination.

2.2.7 Instruments in the Center for Advanced Energy Studies (CAES)

The CAES facility located in Idaho Falls, supports the partnerships between INL and universities. It houses a newly installed nanoindenter, atomic force microscope, FIB, FEG-STEM, and local electron atom probe for characterization of low-level radioactive materials.

2.3 University Partner Capabilities

In addition to the capabilities of the INL facilities, the ATR NSUF has facilitated access to the facilities described below for the ATR NSUF user community.

2.3.1 Massachusetts Institute of Technology (MIT) Reactor

The MIT reactor is a 5 MW_{th} tank-type research reactor. It has three positions available for in-core fuel and materials experiments for water loops at pressurized water reactor/boiling water reactor conditions, high-temperature gas reactor environments at temperatures up to 1400°C and fuel tests at LWR temperatures have been operated and custom conditions can also be provided. Fast and thermal neutron fluxes are up to 1×10^{14} and 5×10^{14} n/cm^2–s, respectively.

2.3.2 North Carolina State University (NCSU) PULSTAR Reactor

The PULSTAR reactor is a 1 MW_{th} research reactor, fueled by uranium dioxide pellets in zircaloy cladding. The fuel provides response characteristics that are similar to commercial LWRs, which allows teaching experiments to measure moderator temperature, power reactivity coefficients, and doppler feedback. In 2007, the PULSTAR reactor produced the most intense low-energy positron beam with the highest positron rate of any comparable facility worldwide.

2.3.3 Nuclear Services Laboratories.

Nuclear Services laboratories at North Carolina State University (NC-State) offer neutron activation analysis, radiography, imaging, and positron spectrometry capabilities.

2.3.4 Irradiated Materials Complex (IMC) at University of Michigan (UM)

The UM IMC Complex houses laboratories and hot cells for conducting high-temperature mechanical property, corrosion and stress corrosion cracking experiments on neutron irradiated materials in an aqueous environment and for characterizing fracture surfaces after failure.

2.3.5 Harry Reid Center Radiochemistry Laboratories.

The Radiochemistry Laboratories at University of Nevada, Las Vegas (UNLV) offer metallographic microscopy, x-ray powder diffraction, Rietveld analysis, SEM and STEM, electron probe microanalysis, and x-ray fluorescence spectrometry.

2.3.6 Characterization Laboratory for Irradiated Materials.

The Characterization Laboratory for Irradiated Materials at the University of Wisconsin–Madison (UW-M) SEM and STEM on neutron-irradiated materials.

2.3.7 Michigan Ion Beam Laboratory.

The 1.7 MV Tandetron accelerator in the Michigan Ion Beam Laboratory at the University of Michigan (U-M) offers controlled temperature proton irradiation capabilities with energies up to 3.4 MeV as well as heavy ion irradiation.

2.3.8 Tandem Accelerator Ion Beam

A 1.7 MV terminal voltage tandem ion accelerator at UW-M features dual ion sources for producing negative ions with a sputtering source or using a radio frequency plasma source. The analysis beamline is capable of elastic recoil detection and nuclear reaction analysis.

2.3.9 Illinois Institute of Technology (IIT) Beamline

The MRCAT beamline at Argonne National Laboratory's Advanced Photon Source (APS) offers synchrotron radiation experiment capabilities, including x-ray diffraction, x-ray absorption, x-ray fluorescence and 5 μm spot size fluorescence microscopy.

2.3.10 University of California at Berkeley (UCB)

At the UCB Nuclear Engineering laboratory, nanoindenter capabilities are available for testing on low radioactive samples.

2.3.11 High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL)

The HFIR provides a high flux (up to $5x10^{15}$ n/cm^2-s thermal) material irradiation test capabilities are similar to those available at the ATR.

3. Proposal Options

Researchers can gain access to the ATR NSUF facilities described above through several proposal options. These have evolved over time to meet researcher requests and provide the maximum possible flexibility. All proposal submittals are completed through the web site at http://atrnsuf.inl.gov/. All proposals received against open calls and RTEs are subject to a peer-review process before selection. An accredited U.S. university or college must lead research proposals for irradiation/post-irradiation experiments. Collaborations with other national laboratories, federal agencies, non-U.S. universities, and industry are encouraged. Any U.S.-based entities, including universities, national laboratories, and industry can propose research that would use the MRCAT beamline at the APS or would be conducted as an RTE.

3.1 Open Calls

The annual open call for reactor irradiation or major PIE proposals is a continuously open rolling call with project selections twice a year, in the fall and in the spring. This gives researchers the flexibility of writing proposals at their leisure and allows ATR NSUF to make two sets of awards each year. Proposals for these calls focus on irradiation/post irradiation examination of materials and fuels and on post irradiation examination of previously irradiated materials or fuels from the ATR NSUF Sample Library. These calls also offer researchers the option to submit proposals for synchrotron radiation experiments through the ATR NSUF partnership with IIT.

3.2 Rapid-Turnaround Experiments (RTEs)

An experiment is considered an RTE if it can be completed in two months or less, such as PIE of previously irradiated fuels or materials, ion beam irradiation, and neutron scattering experiments. The call for RTEs is always open, allowing proposals to be submitted at any time. RTE proposals are reviewed within a month of submittal and awarded throughout the year based on ranking and the availability of funds.

3.3 New-User Experiment

In response to requests from university faculty members, ATR NSUF developed a New-User Experiment to provide an opportunity for university researchers to experience the intricacies of designing and conducting an in-reactor test. The ATR NSUF Director selects the materials to be irradiated and each university researcher involved in the project can work with INL staff to design an experiment that meets the data objectives. To participate, researchers submit a letter of interest through the web site.

4.0 Education Programs

The objective of the ATR NSUF education programs is to establish a cadre of nuclear energy researchers, facilitating the advancement of nuclear science and technology through reactor-based testing. It optimizes the value of these programs by developing strategic partnerships with universities and helps inform the academic user community of nuclear energy issues and tools available to address research questions. ATR NSUF uses focused internships, fellowships, and faculty/student exchanges to encourage faculty and student access to cutting-edge and one-of-a-kind tools for conducting reactor-based research in nuclear science and technology, fuels, and materials. Researchers gain access to key mentors, world-class facilities, and equipment. From these collaborations, a new text book on irradiation test planning and execution is in development. A major emphasis of all education programs is to allow for maximum interaction and access to the critical components of the nation's experimental nuclear research infrastructure.

4.1 Internships

Internships are the direct mechanism by which undergraduate and graduate students can be introduced to mentors. Each year, approximately 23 interns are exposed to ATR NSUF research and gain experience with tools in reactor-based nuclear science and technology. Interns typically spend 10 to 12 weeks at the INL in the summer. Graduate students may use their intern experience to conduct thesis or dissertation research, in a more focused experience than the undergraduate internship, that can last for up to one year. Internships are also used to support the increased impact of the ATR NSUF on facility operations.

4.2 Fellowships

Post-doctoral fellowships give recent doctoral graduates an opportunity for a short (up to three years) duration appointment in areas that align with current or future ATR NSUF research.

4.3 Visiting Scientists

The ATR NSUF education program has two programs for visiting scientists and students. The Faculty and Student Research Team (FSRT) program awards faculty-led team contracts to partner with an INL mentor and work on building capability needed in the user facility. In addition, teams gain an understanding of INL, build technical knowledge, and establish relationships with INL researchers. The ATR NSUF also uses an INL program called the Faculty and Staff Exchange program, in which participants are sent to universities or other research facilities and university faculty can visit INL. Researchers are encouraged to spend time at a university/INL to teach, perform research, collaborate, and be involved in campus/laboratory life.

4.4 User Week.

Annually, the ATR NSUF hosts a User Week to provide a venue to inform the nuclear science and technology community of current issues and the tools and facilities available through the use of the ATR NSUF to address these issues. User Week is comprised of a research forum that discusses current nuclear technology research being conducted in the NSUF. Sessions are held to familiarize participants with the ATR NSUF research facilities and capabilities. Discussions are held to facilitate potential industry-laboratory-university collaborations. User Week offers extended courses on fuels and materials and how to plan and execute irradiation experiments. Up to 50 travel scholarships are available to faculty and student participants.

4.5 Short Courses/Workshops

Portions of courses from User Week have been available as short courses at universities, technical society meetings, or technical meetings. As examples, short courses are adapted from the Experimenters' Course or the Fuels and Materials course.

5.0 Acknowledgements

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A unique full scale water research facility for applied and fundamental research, technology development, education and public outreach

Eoghan Clifford[1,*] **Edmond O'Reilly**[1] **Michael Rodgers**[2]

[1] Civil Engineering NUI GALWAYeoghan.clifford@nuigalway.ie (* corresponding author); edmond.oreilly@nuigalway.ie

[2] Rodgers Morgan Environmental Ltd, Galway michaelrodgers64@gmail.com

Abstract

At present in Europe, there is a need, driven mainly by EU environmental legislation, for sustainable, robust and economic water, wastewater and sludge treatment technologies. Furthermore these technologies are required to be increasingly energy efficient, employ new monitoring and control techniques and have reduced maintenance. This will present many opportunities for the water and wastewater industries, cognate companies and research organisations. Local authorities, universities and other stakeholders will also be required to educate and train students and staff in the use and operation of new technologies.

To meet these challenges NUI Galway, with funding from the EPA, and support from Galway County Council, have developed the NUI Galway/EPA Water Research Facility (WRF). The WRF is a full-scale test bed for innovative wastewater and water treatment technologies and comprises a full-scale wastewater treatment plant (treating up to 50 m^3/day), a tertiary treatment facility (treating up to 2 m^3/hr) capable of supporting a number of technologies such as automatic sand filtration, activated carbon systems, chlorine dosing, UV etc., and remote operating, monitoring and control processes.

Keywords

Water Research Facility, WRF, educational facility, full-scale test bed, technology development, water and wastewater infrastructure

1. Introduction

Water and wastewater technologies are required to comply with the stringent regulations such as the the EU Water Framework Directive and the Drinking Water Directive (2000/60/EC; 98/83/EC) while (i) being energy efficient (ii) have low maintenance and (ii) have low operation requirements (Boller et al, 1997). In developing, and developed countries, pollution, over-exploitation of natural resources, damage to aquatic ecosystems and population changes are driving the demand for new technologies, public awareness and the education of highly skilled water professionals. Worldwide over 1.2 billion people do not have access to safe drinking water and 2.4 billion people lack basic sanitation. The treatment of wastewater from small towns in the population equivalent (PE) range of 200 - 2,000 PE can be a particular problem that generates different problems to those encountered in larger conurbations.

For example decentralised wastewater treatment plants can be advantageous as the local value of water and avoiding the cost of water conveyance offset the economies of scale of larger plants (Norton, 2009). However, failure of mechanical components, high energy requirements and the need for full time on site operators are just some of the problems associated with decentralised water and wastewater treatment plants (Norton, 2009). The scale of many of these decentralised water and wastewater treatment systems cannot justify the presence of a full time operator and this has proven to be a particular challenge.

Public concern relating to environmental pollution has been growing in recent years and there is a now a global demand for low energy, low maintenance and versatile environmental technologies for the treatment of waters and wastewaters. However, further to public health protection it is increasingly recognised that research infrastructure is vital for (i) promoting innovation, technology and policy development, (ii) supporting the conditions for leading-edge research (iii) creating sustainable employment and (iii) educating new generations of researchers and innovators (Research EU, 2011). Such research infrastructure can also play a larger societal role by increasing knowledge among the general population on issues relevant to their daily lives. In the water and wastewater sectors, there are a limited number of large scale infrastructures available for the research and industry communities. Examples include the Wastewater Technology Centre in Ontario, Canada and the Institute for Urban Wwater Management (ISA), Aachen University, Germany that provide full scale test facilities and/or certification for water and wastewater technologies. The Questor Applied Technology Unit, Queens University Belfast, comprises a multi-disciplined team that help industry develop new technologies in this sector.

In 2006 the NUI Galway research team carried out a survey across all industry, policy makers, research institutes, 3rd level institutes and public bodies (including local authorities) in Ireland and found 93 % of respondents stated that the construction of a full sale test facility in Ireland stakeholders for the water and wastewater sectors was required (NUI Galway, 2006).

In this context it was considered necessary to construct a facility capable of examining proprietary and novel water and wastewater treatment technologies. Furthermore the facility could be used to (i) test new sensor and analytical equipment in real-life situations, (ii) develop real-time monitoring and control infrastructure (iii) enable the development of on-site educational programs for students, water professionals and the general public. Such a facility was proposed, designed, constructed, commissioned and operated by researchers in Civil

Engineering, NUI Galway – at Galway County Council's Tuam Wastewater Treatment Plant (TWWTP) – and is known as the NUI Galway/EPA Water Research Facility (WRF).

2. NUI Galway/EPA Water Research Facility

The WRF (Figure 1) is located in Tuam, Co. Galway. This site was selected for a number of reasons including: (i) its excellent accessibility from all major population centres on the national motorway network (Galway to Tuam motorway due to commence); (ii) its proximity to NUI Galway; (iii) available space on-site; and (iv) is ideal for influent wastewater is pumped to the WRF from the near-by TWWTP. The TWWTP was commissioned in 1996 with a design PE of 25,000. In 2006, Tuam had urban and environs populations of 2997 and 3888, respectively and average daily flows to the TWWTP of 5,000 m^3/day (CSO, 2010). The WRF was officially opened in February 2010 by Minister Michael Finneran (then Minister for State with responsibility for Housing and Local Services).

Figure 1 – The NUI Galway/EPA WRF.

Prior to entering the TWWTP, raw municipal wastewater passes through a basic 25 mm bar screen at a pumping station about 1 km upstream of the plant and is pumped to the TWWTP. The wastewater then passes through an automatic 10 mm screen located in the open influent channel. A portion of this inflow is pumped at user defined intervals to the WRF from the influent channel of the TWWTP (prior to the storm over-flow location and primary settlement tanks, see Extraction Point in Figure 2). The WRF can currently process a maximum of about 50 m^3 wastewater/day, though this can be varied depending on the work being carried out at any given time and the level of treatment required.

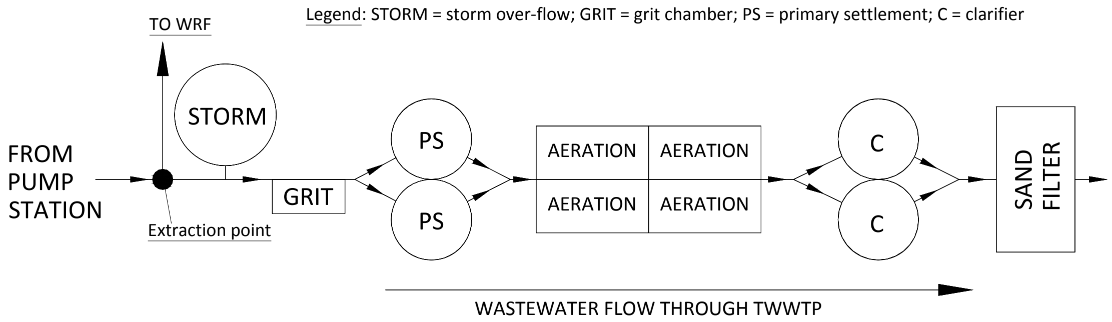


Figure 2 – Location of extraction point for WRF at the TWWTP.

2.1 WRF – plant layout

Wastewater entering the WRF is pumped to the primary settlement tanks of the WRF. From there, it was available for technologies being tested at the WRF that require primary-settled influent wastewater. A general layout of the WRF is shown in Figure 2.

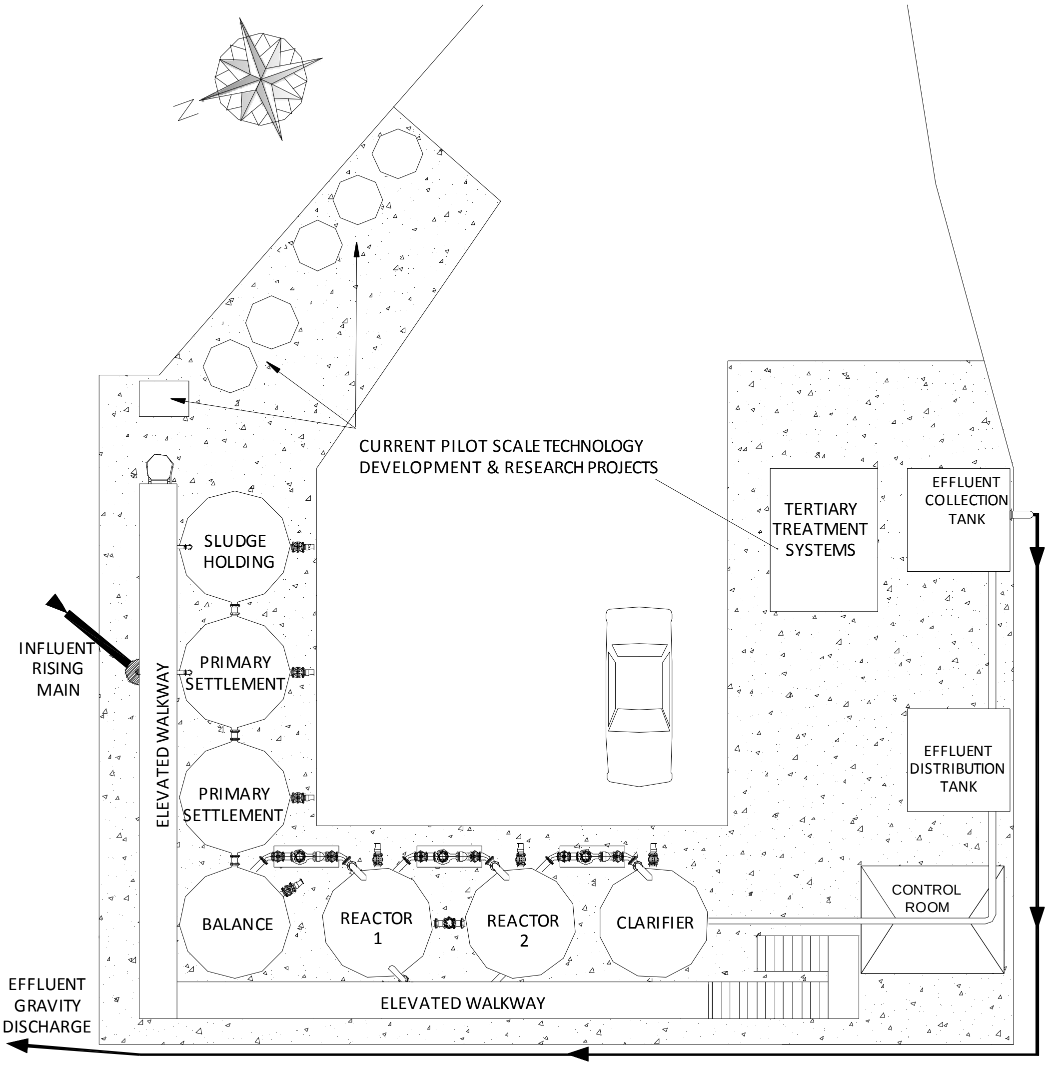


Figure 3 – General layout of the WRF.

The main technology employed to treat the bulk of the wastewater at the WRF is the pumped flow biofilm reactor (PFBR) - a novel attached growth wastewater treatment technology, developed and patented in NUI Galway. Extensively tested at laboratory and pilot scale, the PFBR has proven to be an efficient, robust and cost effective technology that is simple to maintain and operate (Rodgers et al., 2004, Zhan et al., 2005; O'Reilly et al., 2011). The design of the WRF allows the reactor tanks to accommodate other process such as activated sludge and sequencing batch reactor systems (Figure 4).

Figure 4 - Photograph of the PFBR at the WRF. Shown from right to left are; 1 No. sludge holding tank, 2 No. primary settlement tanks, 1 No. balance tank, 2 No. reactor tanks, and 1 No. clarifier.

Each tank in Figure 4 measures 4 m high and 3 m in diameter. An additional 2 tanks (2.5 m square and shown in Figure 3) – the effluent distribution and effluent collection tanks – provide additional storage of secondary treated wastewater for further use in various research and development projects.

Treated wastewater from the main PFBR system can be passed through a number of tertiary treatment systems (shown as ‘tertiary treatment systems’ in Figure 3). Currently, an automatic sand filtration system and a UV disinfection system are installed. The facility has been designed in a plug and play manner allowing technologies undergoing trials to be easily plugged into the system such as chlorine contact tanks, activated carbon filters, zeolite adsorption systems etc. Figures 5 and 6a show a schematic and picture, respectively, of the system, which includes: (i) ports for sampling the wastewater before and after each tertiary treatment system; (ii) automatically controlled backwashing of the filter systems; and (iii) in-line pressure measurement that can provide essential information on system performance and clogging; and (iv) a user-friendly interface and control system.

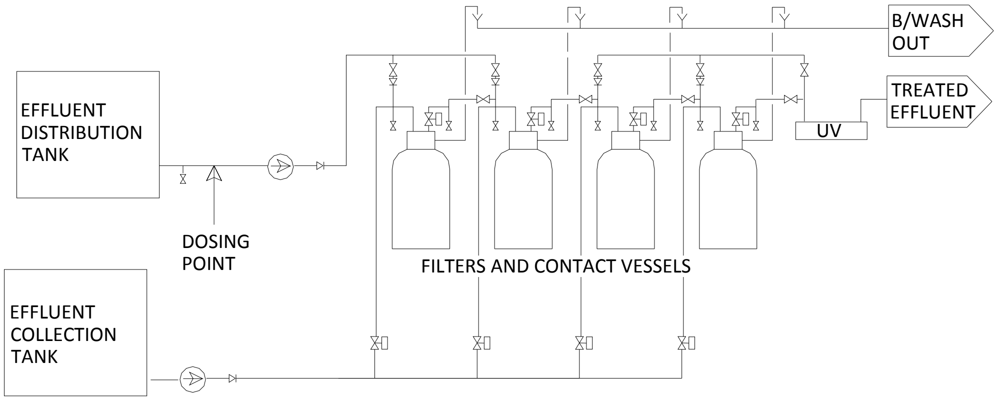
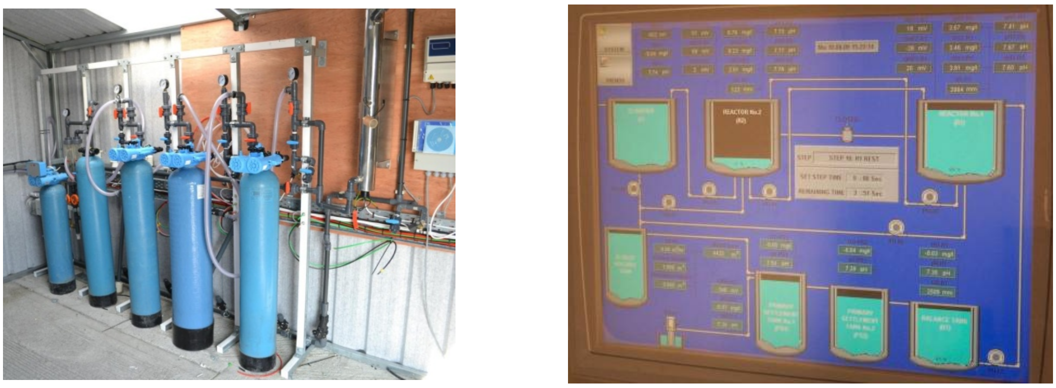


Figure 5 – Layout of tertiary treatment system at the WRF



Figures 6(a) and (b) – The tertiary treatment system installed at the WRF and the HMI installed at the WRF.

2.2 WRF – control and monitoring systems

A bespoke control system was developed for the PFBR at the WRF. A programmable logic controller (PLC) manages the operation of all the mechanical and electrical equipment for the main PFBR wastewater treatment system. A touch screen human machine interface (HMI) allows the operator on-site access to all aspects to the system. All system controls and data are viewable and recorded by the PLC, displayed on a HMI which is linked to PC in the control office (Figure 6b). Using a USB broadband connection and a remote control software package, this PC can be accessed remotely allowing the research team to have full control of the PFBR from any location. For example, the flow rate trough the system, the length of the treatment cycle, the current water levels in the reactor tanks or the operation of all pumps and motorized valves can be viewed in real time and controlled remotely. The tertiary treatment system is controlled by a separate PLC.

Wastewater samples are taken at various points in the treatment system manually or using automatic samplers. Furthermore, real time measurements of dissolved oxygen (DO), pH, oxidation reduction potential (ORP) and flow are combined with operational parameters such as pumps run time and energy usage to optimise the treatment cycle; this can be viewed remotely and in real time. A mobile remote monitoring and control system (MRMC) is available on site and comprises sensors and analysers to measure various water and gas parameters (eg. chemical oxygen demand, ammonium-nitrogen, nitrate-nitrogen, phosphate-phosphorous, carbon dioxide, methane etc). As with the above mentioned sensors, data from the MRMC unit can also be remotely interrogated. It is planned that all operations and process data generated on-site will be centrally linked and available for remote interrogation.

3. Research and development infrastructure utilisation. (Technology development, research, public outreach and education etc?)

3.1 Research and technology development

The WRF is in operation for about 16 months and has significantly enhanced the research and technology development capability at NUI Galway. The pilot-scale PFBR - an example of a technology developed by a universitiy at a laboratory scale before being trialled at pilot and fullscale - featured at a recent WEF/IWA conference (O'Reilly et al., 2010. Academics and industry attending the conference highlighted the lack of such facilities for large scale research infrastructure. Various stakeholders and a number of international academics have visited the WRF

Furthermore the development of the WRF has also allowed for significant collaboration to develop between NUI Galway, industry and other research and third level institutes. To-date the facility has supported two Enterprise Ireland funded technology commercialisation projects (one of which has resulted in the issuing of a commercial license). Currently, a further Enterprise Ireland funded technology development project is located and has been installed on-site at the WRF and undergoing investigation. In collaboration with industry, a novel tertiary wastewater treatment technology will be evaluated funded through the Enterprise Ireland Innovation Voucher scheme,.

A collaborative project with the Marine Institute in Oranmore is currently underway and is utilising the tertiary treatment system. A standardised application system is being developed to allow industry, research groups or other stakeholders apply to carry out research at a pilot scale at the WRF.

3.1 Public outreach and education

The WRF has proven particularly effective as an educational and public outreach tool. Two examples of these include the Engineers Ireland *Engineers Week* at the Galway Museum (February 2011) and the NUI Galway Open Day (April 2011). A model PFBR, fabricated by the research team, was employed at a display in both exhibitions along with a laptop computer showing the WRF in live operation.

For example, visitors and students could view in real-time the wastewater treatment process, watch changing readings from various sensors live and then link these values to the physical process on site, view current and previous energy utilisation rates and, stop and start pumps operating on site. The model, manually operated at the displays, helped visitors visualise the processes they were viewing on the computer screen. In both cases it proved extremely popular with surprising interest being shown by the public. The WRF can help raise public awareness of water and wastewater treatment, reduce public apathy to wastewater and sludge treatment process in particular and aid the public understand their role in helping these systems operate efficiently. The research team are currently developing plans to provide career professional development (CPD) for engineers, scientists and managers based on the technologies at the WRF.

The WRF is also used to show third level engineering and science students a full scale wastewater treatment process. The potential of online sensors and control systems is easily apparent on site visits and the WRF allows wastewater and water treatment theory to be seen in practice. A typical onsite visit, giving an overview of all the on-site systems can be completed in about 1.5 hours.

3.3 Policy development

The operation of the WRF under normal on-site conditions at the WRF can facilitate the formation of formal guidelines for technology usage and policy. An example of this would include the significant variation that can be encountered in daily influent wastewater characteristics both in terms of flow and contaminant concentration. Such information can be vital in helping new and existing wastewater treatment facilities meet new stringent discharge limits and operate more efficiently. However, frequency monitoring of influent may not be in place in most wastewater sites.

The WRF has a large range of sensors and monitoring equipment installed and thus it has been possible to monitor the performance and maintenance requirements of these systems over an extended period of time. It is possible to provide guidelines to other decentralised treatment systems on the types of sensors that may (i) be most robust, (ii) require least maintenance, (iii) be cost effective and, (iv) are reliable. Remote control of the WRF has also shown the potential of developing a standardised control and monitoring system for decentralised wastewater and water treatment systems. These are brief examples of the types of recommendations that have been proposed as a result of the EPA funded large-scale project on small-scale wastewater treatment and are currently in press with the EPA (O'Reilly et al., 2011).

4. Discussion and conclusions

The WRF offers a state-of-the-art world class research facility in Ireland for industry, state bodies, universities, research institutes and other organisations to carry out fundamental and applied research on environmental technologies. The facility can provide an interactive platform where researchers, industry and the public sector can develop synergies that can lead to the protection of health and the environment and to the creation of wealth and jobs in Ireland through the development of new technologies for the home and export markets. New technologies can be trialled in real-life scenarios at a well monitored and managed research facility.

The extensive real-time access to the WRF allows researchers to remotely monitor research activities at the WRF. It is confidentially expected that after an initial start-up period, the WRF can be financially self sustaining. It is envisaged that a number of researchers, engineers and scientists would be employed at the facility and at NUI Galway to carry out and supervise varied research projects and liaise with industry. Thus both fundamental and applied research could be carried out with a unique collaboration between industry, university, state bodies and other organisations.

Open days for the public, students and stakeholders could be a feature of the facility, encouraging interest and enthusiasm for the oft maligned wastewater and water treatment sectors. The WRF has featured on Eco Eye (RTE 1) and it is envisaged a number of animations describing the engineering processes employed at the WRF along with YouTube videos will form part of future open days both on and off site.

The advantages of the WRF include:

- access to wastewater at various stages of treatment allowing for technologies to be trialled for primary, secondary and tertiary treatment. The WRF can process up to 50 m^3/day of wastewater
- a well-equipped site for testing new sensors and analysers for water and gaseous contaminant monitoring at various stages of treatment
- the MRMC can be deployed to technologies on-site or can be used off-site where new technologies are being applied on particular wastewaters e.g., in food processing facilities. The NUI Galway research team have real-time access to data from the MRMC thus allowing instantaneous feedback on process efficiency
- access to wastewater sludge allowing new sludge treatment methods to be tested
- an easily accessible site at Tuam, Co. Galway

- process samples that are regularly taken and monitored and can be tested at the excellently equipped Environmental Engineering Laboratories, NUI Galway
- experienced NUI Galway research staff to operate and maintain the research facility.

A number of upgrades to the WRF are planned and pending funding opportunities these include; (i) an improved broadband connection, (ii) an on-site laboratory, (iii) development of a dedicated website and (iii) a new multi-layered control and monitoring system that links all processes currently on site and allows new projects that are installed on-site to be easily connected to this system. This would allow the relevant stakeholders to access their project details on line and follow progress remotely. It is also envisaged that YouTube videos would be uploaded to provide information on the facilities capabilities.

The NUI Galway/EPA WRF provides a unique research facility with advantages that include: (i) increased opportunities for successful research funding proposals; (ii) world-class fundamental and applied research; (iii) education and training of graduate, postgraduate and post doctoral researchers; (iv) increased collaboration between industries, research and policy-making institutes; (v) public and technical education and training of stakeholders; (vi) high profile dissemination of issues regarding water, wastewater and environmental technologies; (vi) policy planning; (vii) developing and testing novel indigenous environmental technologies and products; and (viii) attracting visiting academics and students from leading international institutions.

Acknowledgements

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Supersonic Research Facilities and Opportunities at the United States Air Force Academy

[1]R.M. Cummings [2]T.E. McLaughlin,, [3]D.N. Barlow
US Air Force Academy, USAF Academy, CO, USA, Russ.Cummings @usafa.edu[1];
US Air Force Academy, USAF Academy, CO, USA, Tom.Mclaughlin @usafa.edu[2];
US Air Force Academy, USAF Academy, CO, USA, Neal.Barlow@usafa.edu[3]

Abstract

The US Air Force Academy (USAFA) has one of the best-equipped academic aeronautics laboratories in the world. Among the many wind tunnels and test facilities housed in the USAFA Aeronautics Laboratory is a high speed blowdown facility called the Trisonic Wind Tunnel. In addition, a new Mach 6 Ludwieg Tube is currently being designed and will be online in May 2012. Substantial research opportunities exist for graduate, post-graduate, sabbatical, and exchange researchers, developing the capabilities of the Ludwieg tube and making use of the Trisonic Tunnel's well-developed force measurement and Schlieren photography capabilities. An example of such collaboration is the current development of the Background Oriented Schlieren capability.

1. Introduction

The Department of Aeronautics (DFAN), in existence since the organization of the United States Air Force Academy (USAFA) in 1955, has offered an accredited Aeronautical Engineering degree since 1967. DFAN has remained dedicated first and foremost to USAFA's unique and primary mission statement: *To educate, train, and inspire men and women to become officers of character, motivated to lead the United States Air Force in service to our nation*.[1] Cadets (officer candidates) are challenged and stretched in their knowledge and intellect with an ABET accredited curriculum, an intense leadership laboratory environment, a comprehensive peer-driven character development program, and strenuous physical training. They are exposed to all facets of a world-class military air and space force. Many taste the freedom and discipline of flight in various training programs for the first time during their cadet career. Graduates leave USAFA with a Bachelors of Science degree and a commission as a Second Lieutenant. They join a "long blue line" of officers dedicated to leading airmen. They continue their education and service as a weapons system operator, technical expert, specialist or graduate student.

While a premium is placed on the development of officers via a well-integrated military training program, including leadership development, physical fitness, athletic competition, and flight training, at the heart of a cadet's development is a robust core curriculum consisting of 102 academic hours divided between humanities (25 hours), social sciences (27 hours), basic sciences (27 hours), engineering (18 hours), and physical education (5 hours). In addition to the required core, the Academy offers 32 academic majors as well as a foreign language minor. Thanks to the mission of the USAF, aeronautics and related fields contribute heavily to the Academy curriculum. The Aeronautical Engineering Department has 25 full time faculty supported by approximately 30 laboratory and administrative staff including almost 20 researchers supported by a variety of research and grant funding. The major requires an additional 45 semester hours of engineering courses past the core curriculum for a total of 147 required graduation hours.[1]

During the past decade, the Aeronautical Engineering Department has purposefully transformed its programs and facilities to require both experimental and computational research as an integral part of its undergraduate educational program. Recognizing that experiment and computational knowledge and skills are critical and complementary to an undergraduate education, the curriculum has evolved to include both traditional and computational fluids course work and laboratory experiences. In addition, each student (cadet) is required to participate in a real-world research project in addition to the traditional year-long design experience. The traditional laboratory experience is accompanied by a requirement to conduct either an experimental or computational project that responds to a “real” customer’s needs. Customers are typically United States Department of Defense (DoD) research and development or acquisition offices. Other customers include DoD contractors and NASA entities. Students also have the opportunity for follow on summer research activities at DoD and contractor facilities as well as senior level independent study research opportunities which meet elective requirements and the opportunity to compete in the American Institute of Aeronautics and Astronautics’ Regional Paper Competition. Cadets are provided with unprecedented opportunities for ‘hands-on’ experiences and for making contributions to ‘real world’ programs. Including the Class of 2011, DFAN has produced over 2,000 aeronautics engineers for service in the USAF.

A critical component of the aeronautics major’s education -- hands-on research and development -- occurs in the DFAN Aeronautics Laboratory. The Laboratory is a 80,000 ft^2 ($7432m^2$) facility housing nine major wind tunnels capable of various test velocities from low speeds to Mach 4.5, a water tunnel, three jet engine test cells including operational J-69 and F-109 cycles, a rocket/internal combustion engine test cell, two Genesis 3000 flight simulators, and a variety of smaller experimental equipment. The laboratory also includes two computer-based design classrooms and a complete machine shop. Research takes place under the guidance and leadership of the Director of the Aeronautics and Research Center. The Director’s efforts ensure that every cadet is involved in a real-world customer research project. These efforts are complemented by a robust computational capability (Modeling and Simulation Center) added in the last decade through the USAFA’s High Performance Computing Initiative. The Center’s Director likewise ensures cadet opportunities through interdisciplinary research in unsteady, turbulent computational fluid dynamics. In the labs, cadets benefit from working alongside experienced faculty members and technicians. Working as a team, the cadets and their instructors make significant contributions to real-world research, development, and operational programs sponsored by the USAF, NASA, and other DoD, civilian, and educational agencies.

Also of special note is DFAN’s Flight Test Techniques course, a special semester-long immersion in the academic and operational aspects of aircraft performance testing. In this highly-competitive elective course, students practice flight test data collection and analysis methods. At the end of the semester, they visit the actual Test Pilot School (TPS) facilities in California to validate their skills during USAF T-38 Talon supersonic trainer flights. Many aeronautics majors have gone on from this unique experience to graduate from an Air Force, Navy, or international TPS programs.[2]

The Academy’s overall engineering program is recognized consistently as one of the nation’s top five undergraduate programs.[3] The aerospace curriculum in particular was recently rated as the second-best undergraduate program in the nation.[4] Furthermore, USAFA won the National Aeronautics Association 2001 Cliff Henderson Award for “significant and lasting contributions to the promotion and advancement of aviation and space activity in our United States and around the world.”[5]

2. USAFA current high speed facility

The current high speed facility at the US Air Force Academy is the Trisonic Wind Tunnel (TWT), which is a blow-down facility capable of a Mach number range for $M = 0.14$ to $M = 4.5$ and a run time of up to 7 minutes, depending on the Mach number (see Figure 1). For supersonic Mach numbers, fixed nozzle blocks for nominal Mach numbers of M = 1.4, 1.7, 2.0, 2.5, 3.0, 3.5, 4.5 are available (the actual Mach numbers computed from stagnation and test section conditions are M = 1.39, 1.68, 2.02, 2.48, 2.98, 3.47, 4.38).

Figure 1: USAFA trisonic wind tunnel.

Supply air is compressed up to 600*psi* by a two stage compressor arrangement and stored in six heated tanks with a total volume of 5000 cubic feet (142m^3). Between the compressors and the storage tanks, the air is dried to eliminate condensation during runs at the highest Mach number. The upper Mach number limit is due to the maximum temperature that can be achieved in the storage facility.

The test section is 1*ft* x 1*ft* x 1*ft* (0.3048*m* x 0.3048*m* x 0.3048*m*) with optical access through 1*ft* diameter windows on both sides of the test section. Models are mounted on a hydraulically controlled sting that allows for an angle of attack variation of $\pm 10°$. For flow diagnostics, a Schlieren system is used with the optical access windows on the sides of the test section. A Background Oriented Schlieren system is also currently being developed for the tunnel. In addition, static pressure ports can be used on models, for which tubing is routed to pressure transducers outside the test section through the sealed sting mechanism.

A safety shut-off valve, as well as a hydraulic feedback controlled valve that regulates the stagnation pressure during a run, are located upstream of the stilling chamber. Downstream of the test section, an adjustable second throat ensures that the start-up shock does not propagate back into the test section. Finally, the air is exhausted into the ambient atmosphere.

The performance envelope of the TWT (Figure 2) establishes the stagnation pressure limits for a given Mach number, as well as the pressure altitude (static pressure), dynamic pressure, and the Reynolds number per inch. The tunnel is currently limited at $M = 4.5$ and unit Reynolds numbers of approximately 1.0 X 10^6/*in* (39.4 X 10^6/*m*).

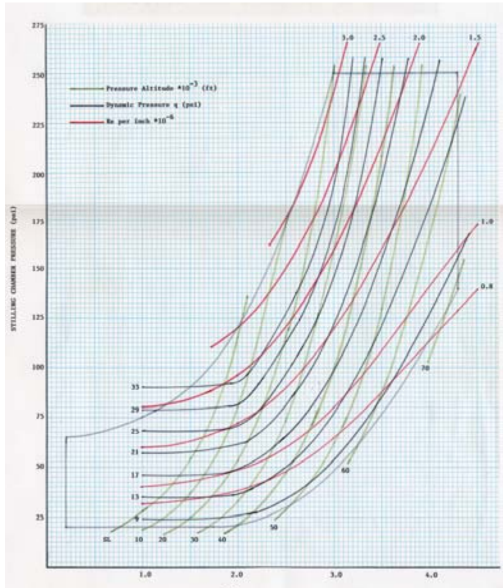

Figure 2: USAFA trisonic wind tunnel performance chart.

The TWT was originally designed as a force and moment tunnel, and it still functions well in that mode. Over the years other test requirements have led to using the TWT for a variety of tests, including: transverse jet blowing, surface pressure distributions, internal flow, and other diverse testing applications.

In addition to the research capability of the Trisonic Wind Tunnel, it has been used extensively over the years for academic purposes, especially in two courses: AE241 (Aerothermodynamics) and AE442 (Advanced Aerodynamics). AE241 introduces concepts of isentropic flow, total and static pressure and temperatures, normal and oblique shocks, and converging-diverging nozzle operation. All of these concepts are solidified in an experiment (lovingly referred to as the Viking Probe experiment), where a total pressure probe and a static pressure probe, in addition to the tunnel total and static measurements, are used to estimate the test section Mach number using a variety of methods (see Figure 3).

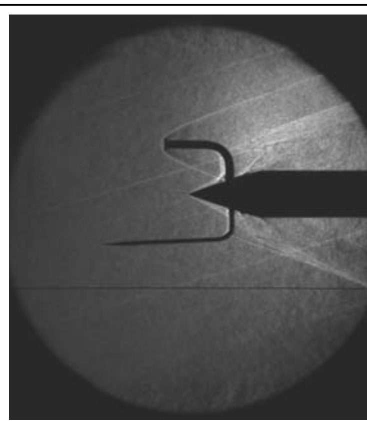

Figure 3: Schlieren photograph of total and static pressure probes in Trisonic Wind Tunnel.

In AE442 a more advanced experiment is performed in the TWT. A rectangular wing with a symmetric diamond wedge airfoil section is run at supersonic speeds in order to demonstrate three dimensional effects in high speed flow. The students measure pressure along two chord-wise rows of pressure taps, as shown in Figure 4. The pressure measurements are then compared with theoretical values as well as computed values using an Euler computational fluid dynamics prediction. The combined theoretical/experimental/computational approach to the experiment makes this project truly unique and valuable to the students, and demonstrates the richness brought to our courses by facilities such as the TWT.

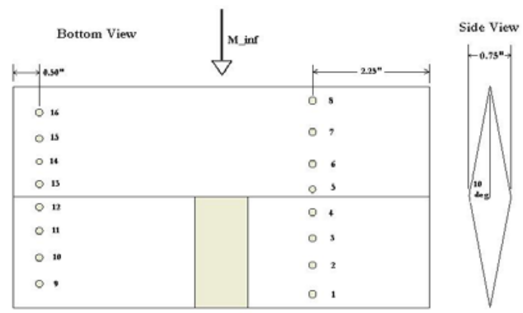

Figure 4: Rectangular wing pressure taps for Trisonic Wind Tunnel test.

3. USAFA Mach 6 Ludwieg Tube

The aerothermodynamic design of hypersonic vehicles, including reusable reentry vehicles and cruise vehicles, requires accurate knowledge of the pressures, skin friction, and thermal loads on various parts of the vehicle. These flow features can also be greatly influenced by boundary layer transition, since laminar and turbulent boundary layers have very different viscous and thermal properties. Being able to model these flows in ground-based facilities is a key issue in the future development of hypersonic vehicles. However, hypersonic ground-based facilities are traditionally very expensive to operate and maintain.

One alternative to traditional, expensive ground-based experimental facilities for hypersonic flow is the Ludwieg tube. Because of their low operational cost and good flow quality, Ludwieg tube blow-down tunnels are of special interest for hypersonic testing. Ludwieg tubes do not require a total pressure control device or large settling chamber which are common for conventional blow-down tunnels (such as the TWT at USAFA). This greatly reduces the size and cost of operating the tunnel, since large compressors, heaters, and pressure vessels are not required for their operation. The operational costs for a Ludwieg tube have been further reduced by the use of a fast-acting valve instead of the traditional bursting diaphragm that was originally part of the tunnel design in the 1950s in Germany[9].

Since no mechanisms are necessary to control pressure or temperature during the run of a Ludwieg tube, the tunnel can be described as an 'intelligent' blow down facility[8]. Here is a description of how the Ludwieg tube works, as shown in Figure 5. The test gas, which is typically air, nitrogen, or helium, is stored in a long charge tube. The charge tube is connected to the nozzle, test section, and vacuum tank via a fast-acting valve. Once the valve is opened, an unsteady expansion wave travels at the speed of sound, a_T, down the charge tube. This expansion wave accelerates the gas to a tube Mach number, Ma_T, which is determined by the area ratio of the tube and the nozzle throat. The expansion wave travels up and down the tube, which creates a constant steady flow to the expansion nozzle with pressure and temperature determined by the one-dimensional unsteady expansion process. Upon the return of the reflected wave from the end of the tube to the nozzle throat, the valve is closed and the test is finished. The length of the tube, L, and the speed of sound in the tube, a_T, determines the run time, t_R, of the tunnel[8].

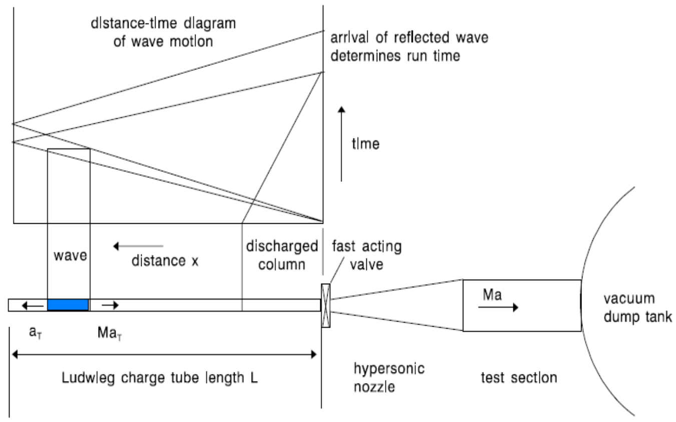

Figure 5: Hypersonic Ludwieg tube operating principle with wave diagram[8].

When compared to a standard blow-down tunnel, the Ludwieg tube provides the following advantages[7,8]:

- an extremely short start and shut off time for the tunnel
- no regulation of pressure and temperature during the run time is necessary
- extremely low mass and energy loss during the tunnel start and shut off
- due to the elimination of regulation valves, the entrance flow to the nozzle can be kept extremely clean, which results in flow with low turbulence levels
- a facility very well suited for transient heat transfer tests
- the tunnel has no “unit Reynolds number” effects like other tunnels
- from the first three advantages listed above you obtain ***an extremely affordable test facility***, requiring only typical laboratory power for operation

The Mach number in the test section is determined by the nozzle and corresponding throat inserts. The stagnation pressure and stagnation temperature can be adjusted from the main control board prior to a shot. The interval between shots can be as low as four minutes (due to the relatively small volume of air in the charge tube), and the shot duration is approximately 100*ms*. The short duration of the shot is the only real disadvantage of the tunnel, requiring high-speed measurement and control equipment to make meaningful measurements of the flow field.

With the relatively simple design and low operation costs, it would be logical to assume that there would be numerous Ludwieg tubes at universities and research centers, but quite the opposite is true. As of a few years ago, only the Ludwieg tubes shown in Table 1 were known to exist or be in operation. Of these existing tunnels, only a relative few are in the United States (and none of them is owned by the DoD), meaning that affordable hypersonic ground-based testing is primarily being conducted outside the United States.

Table 1: Known Ludwieg tubes[6,8,10].

Tunnel	Location	Tunnel Description
RWG	DNW Göttingen, Germany	M = 2.9 to 6.9 0.5*m* diameter test section
Cryogenic Transonic	DNW Göttingen, Germany	M = 0.25 to 0.95 0.4*m* diameter test section
Shock-Wind Tunnel	TU Stuttgart, Germany	M = 1.76 to 4.5 0.8*m* x 1.2*m* test section
HHK	HTG, Germany	M = 6 to 11 0.25*m* diameter test section
ZARM Tunnel	University of Bremen, Germany	M = 6 to 11 0.25*m* diameter test section
HHK	TU Braunschweig, Germany	M = 6 to 11 0.50*m* diameter test section
HHK	TU Dresden, Germany	M = 6 to 11 0.25*m* diameter test section
HTFD	TU Delft, The Netherlands	M = 6 0.35*m* diameter test section
YT1 Tube	Central Aerohydrodynamic Institute, Russia	M = 5 to 10 0.50*m* diameter test section
?	Steliana Institute for Aeronautics, Romania	Operational status unknown
Ludwieg Charge Tube	Pohang University, South Korea	Quiet supersonic
Ludwieg Tube	CalTech, USA	M = 2.3 0.2*m* x 0.2*m* test section
LENS II	CUBRC, USA	M = 3 to 7 1.50*m* diameter test section
Boeing/AFOSR Quiet Tunnel	Purdue University, USA	M = 6 0.24*m* diameter test section
Ludwieg Tube	NASA Marshall, USA	M = 0.2 to 2.2 0.90*m* test section (not operational)

The basic equipment required to operate a Ludwieg tube is shown in Figure 6. The tunnel requires the charge tube (described earlier), which is a stainless steel tube of 10*m* to 50*m* in length, depending on the run time requirements of the tunnel. The charge tube is pressurized by a compressor that usually only requires typical laboratory power and which can be stored directly below the tunnel. The charge tube is separated from the nozzle, test section, and vacuum tank by a fast-acting valve. The fast-acting valve is a crucial aspect of the operation of the tunnel, since the tunnel will not create the desired conditions in the test section if the valve is not correctly manufactured. The nozzle length and shape determine the Mach number in the

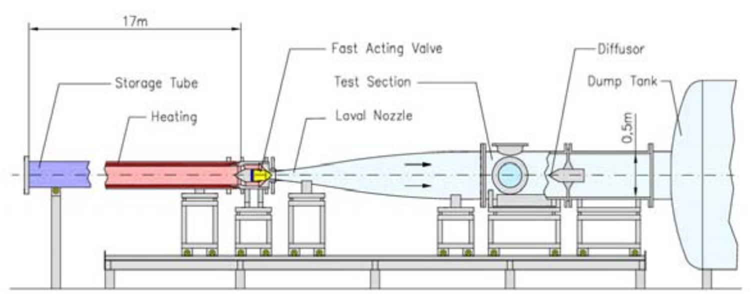

Figure 6: Ludwieg tube at Technical University of Braunschweig[7].

test section, and are also typically manufactured from stainless steel to keep the tunnel clean. The test section, including the optical access windows, is where the vehicles of interest are placed and data collected. This is immediately followed by a diffuser and the vacuum dump tank, which is typically a standard pressure vessel. The entire tunnel is a combination of typical sections that could be manufactured in most modern laboratories (the charge tube and vacuum tank) and precision manufactured sections that must meet exacting specifications in order for the tunnel to operate correctly (the valve, nozzle, and test section).

The current design for a M = 6 Ludwieg tube at USAFA is being completed by Hypersonic-Technology-Göttingen (HTG) in Germany. The tube will have a 0.5*m* diameter test section and a charge tube of 24*m* in length, which will produce a run time of 90*ms* and a shot time of several minutes. The charge tube will be staged (see Figure 7), with a heated section useful for heat transfer measurements. This will allow the tube to be used for both transition testing on cones and blunt bodies, as well as heat transfer testing on blunt bodies. A 5 to 6 m^3 vacuum tank will be required and will need to maintain 1 *mbar* of pressure after the run. The useful life of such a facility will be decades (as evidenced by our current TWT which was built in the 1950s).

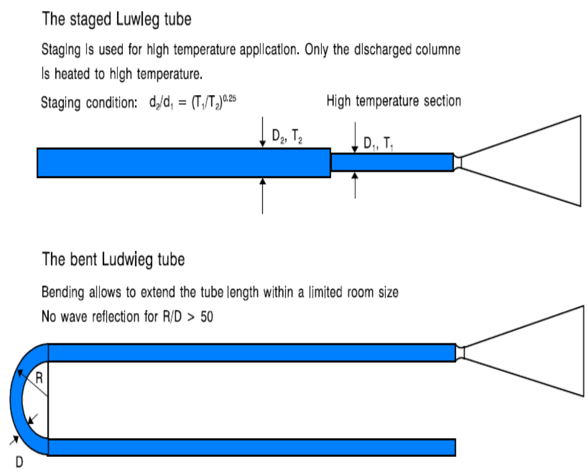

Figure 7: Staged and bent Ludwieg tubes[8].

4. Collaboration Opportunities

A Background Oriented Schlieren system is currently being developed for the tunnel, an excellent example of the type of collaborative research available with the new tunnel. A French Air Force officer visiting USAFA, and working with cadets and faculty on this project, will fulfill his master's degree project requirements. Other collaborative research possibilities include development of the thermal imaging camera system for heat transfer measurements, development of the high speed pressure measurement system, as well as the initial flow quality survey of the tunnel. Once the tunnel and instrumentation is fully developed, numerous research and educational opportunities will exist with the tunnel, as we envision this tunnel as a national resource available for collaborative research with academia and government labs.

The extensive facilities, including those described here, are primarily in place to enhance the education of the cadets at USAFA, an undergraduate-only institution. This is accomplished through a mandatory research experience in their junior or senior year. Typically, two students are paired with a faculty member or researcher in the solution of a unique, current and relevant research effort over the course of a semester. Students participate in experiment planning, conduct and reporting with their senior partner, often resulting in conference and journal publications where they are co-authors. This program of integrating research into the undergraduate curriculum has paid significant benefits in terms of student development and preparation. The partnership with a senior, experienced engineer ensures their development and mentorship, while producing quality research products for sponsoring agencies and partners.

To that end, and because there are no local graduate students to provide this mentorship, the Department of Aeronautics continually seeks collaborators through a range of programs. These include faculty on sabbatical, post-doctoral fellowships through the National Research Council, summer faculty fellowships, the Engineer and Scientist Exchange Program for employees of allied governments, graduate student internships, and occasionally, direct hires. Typically, a collaborator will bring a larger research program to the institution, and involve different student teams in the work on a semester-by-semester basis. The partner gains access to these highly capable facilities which may otherwise be cost-prohibitive, along with machine shop, technician and engineering expertise to support their experiments. USAFA and the students gain from the collaborator's experience, knowledge and mentorship. Potential partners wishing to make use of the facilities and support the development and commissioning of the Ludwieg Tube are encouraged to contact the authors through the email addresses above to discuss opportunities for collaborative research.

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