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MODELING AND SIMULATION RESEARCH AND INSTRUCTION AT THE U.S. AIR FORCE ACADEMY

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Modeling and simulation has become a driving force within the engineering and science communities as the cost of, and time for, experimentation continues to rise. Some areas of study, such as chemistry and biology, may not even have the ability to fully evaluate certain processes experimentally, making modeling and simulation even more important. The situation has led many areas of research to the necessity of modeling and simulating various processes using computers. In addition, the rise in computational capabilities (the supercomputers of a decade ago are outmoded by the PC clusters of today), has led to a paradigm shift from using the computer resources only available to a few researchers to a tool now available to many people. Researchers at the U.S. Air Force Academy are working to bring these modeling and simulation tools into the classroom and laboratories for students to learn the capabilities, and limitations, of modern computational tools. Descriptions of how modeling and simulation is performed at the Academy are included, as well as details about the computational resources being used. Most importantly, descriptions of the methods used to bring these tools to the classroom are described in detail.

I. Introduction

THE U.S. Air Force Academy (USAFA) prides itself on providing high level state-of-the-art instruction in a variety of science and engineering disciplines. Previous publications have detailed innovative educational concepts developed in the Department of Aeronautics,[1] including propulsion,[2] flight mechanics,[3] flight test,[4] and multi-disciplinary design.[5] While the curriculum and facilities of the science and engineering departments are outstanding, several Department of Defense (DoD) agencies and senior Air Force leaders noticed a lack of computational modeling and simulation (M&S) education and research taking place.

During a Defense Modeling and Simulation Office (DMSO) workshop in 2000,[6] U.S. military commanders expressed a concern that young officers were not aware of nor had an appreciation for the benefit of using M&S in acquisition, analysis, experimentation, operations, and training. As a result, workshop participants identified four projects to pursue as part of a Service Academy Outreach Program:

- enhance M&S hardware and software
- enhance educational coursework, leveraging M&S education courses developed by DMSO, the Naval Postgraduate School, and the Air Force Institute of Technology
- fund a cadet/midshipman summer intern program at Joint/Service M&S laboratories and centers
- fund a M&S Visiting Professor at each Academy

Shortly thereafter, two high-ranking U.S. Air Force officials visited USAFA and made similar observations which drove home the conviction that it is essential for the future of the service to have graduates with experience in modeling and simulation:

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"I found research performed at the [USAFA Research] Centers impressive; however, I noted a general lack of computation in research at USAFA . . . I recommend that research introduce the cadets to hands-on modeling and simulation as part of their research experience, to produce a better view of modern science."

Dr Lyle Schwartz, Director
Air Force Office of Scientific Research
June 2001

"I want 2Lt graduates of the USAF Academy who are well grounded in S&T and M&S."

Dr. James Roche
Secretary of the Air Force
Fall 2002

These clear visions for the development of our future aerospace leaders led to the creation of the Modeling and Simulation Research Center (M&SRC) at USAFA, and the Department of Aeronautics' new research capability in computational fluid dynamics (CFD) served as a natural starting point/focus of the center's activities. Specifically, the initial goals of the research center were to:

- build on the success of Department of Aeronautics CFD strengths
- develop USAFA High-Performance Computing Initiative to include all interested disciplines and researchers
- take burden of computer system administration away from researchers
- enhance productivity of faculty modeling and simulation work by providing computational infrastructure and support
- increase basic research in modeling and simulation

This paper will address the progress of both the Service Academy Outreach Program and the M&SRC at USAFA in support of M&S research and education. Two key components of these initiatives are the computational and manning/support resources, and so we'll start with an overview of these areas. The next section of the paper will focus on the research efforts supported by this infrastructure, and the final sections will present an overview of M&S instruction at USAFA with a more detailed discussion of the integration of M&S, specifically CFD, in the Academy's Aeronautics major.

II. Computational Resources

The reality of Moore's Law (computer processor speed doubles every eighteen months), and the associated affordability of personal computers (PC), has led to a paradigm shift in scientific computing over the past decades. Cray 2 supercomputers of the 1980s had good clock speeds and reasonable internal memory (256 million 64-bit words), but the price tag of approximately $15million restricted their use to government labs and shared resource centers. Individual ownership of those computers was unthinkable. Today, PC clusters have similar clock speeds, greatly increased memory, all with a price tag in the range of $100,000 (two orders of magnitude less than the Cray 2). While some people have been slow to realize the importance of this shift, others (especially those at universities and smaller companies), have taken advantage of the cost-effectiveness of PC clusters. In addition, many computer modeling areas have matured rapidly over the past decade, and relatively easy to use codes, algorithms, and capabilities now exist.

When the modeling and simulation resources at the U.S. Air Force Academy were first developed, it was obvious that the PC cluster represented "the way to go." Initial computer systems were developed, and as processor were replaced, secondary clusters were established from replacement parts. This has allowed for the use of these cluster systems by undergraduate students, since the cost of the system has already been supported by the researchers who paid for the initial computers. That reality has made it possible for both M&S research and M&S education to take place at the U.S. Air Force Academy.

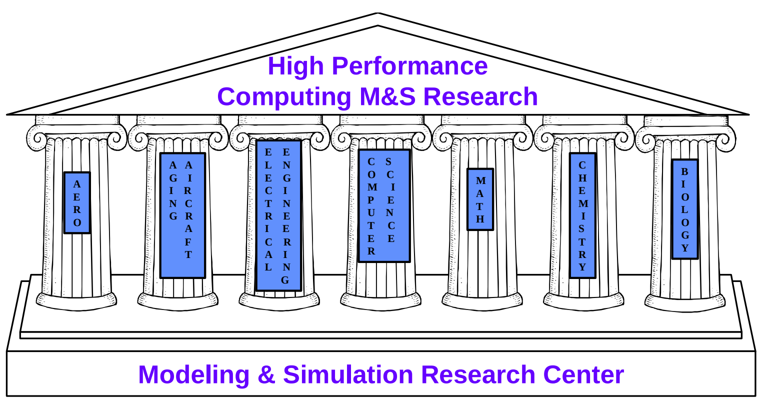
The current production computational resources for the M&SRC include:

- "Blackbird" Linux parallel computer
  - 128 processor Linux cluster (64p- 1GHz, 32 GB RAM, 64p- 2.8Ghz, 64GB RAM)
- "Strato" Linux parallel computer
  - Built Summer '02 from above replacement parts
  - 40 processors, 500 MHz each, total of 10GB RAM
- "Spectre" 64 Processor Origin 2000, 195Mhz R10000, IRIX v6.5.23
  - Shared-memory architecture complements current systems
- "Raptor" 64 Processor Origin 2000, 300Mhz R10000, IRIX 6.5.23
  - Allocated to Aging Aircraft work, shared for USAFA-wide use
- Graphics workstations
  - Purchased with small grants
  - M&SRC advises users on best graphics workstations
- DREN DS-3 Access to DoD High Performance Computing Centers

These resources make it possible both to conduct cutting edge research and to allow undergraduates to learn modeling and simulation concepts within the classroom.

III. Support & Manning Strategy

One of the more innovative aspects of the M&SRC at USAFA is its basic goal of increasing M&S in as many disciplines as possible. Figure 1 helps to visualize the overarching goal of the center by showing the High Performance Computing Initiative of the M&SRC as the foundation for all interested disciplines (currently aeronautics, engineering mechanics, electrical engineering, computer science, math, chemistry, and biology). Instead of requiring all of these disciplines to create and maintain a computational capability, the M&SRC offers logistical support for their research. The horizontal integration also encourages multi-disciplinary research to take place, since everyone is already utilizing the same computer support structure. This enables all disciplines to conduct high-level M&S research without having to worry about the computer support required.



- **Horizontal structure encourages multi-disciplinary research**
- **Creates efficient infrastructure**
- **All research enhanced with minimal funding/staffing increases**
- **Gives DoD HPCMO a single point of contact**
- **Eliminates duplication of effort**

Figure 1. Modeling & Simulation Research Center Concept

Another very important aspect of the center is the concept of the "floating researcher." Since the faculty in interested disciplines may not have the background or expertise to jump immediately into high-level M&S research, the M&SRC supports a faculty member or visiting researcher for 1 to 2 years in a discipline, which enables the various faculty to move up the learning curve, and hopefully develop their expertise to a level that will be able to be self supported through grants at the end of the 1 to 2 year period. The first example of this is in Electrical

Engineering, where a floating researcher is helping to create a state-of -the-art research capability in Computational Electromagnetics (CEM) for application to military aircraft. Also, since USAFA is an undergraduate-only institution, visiting researchers are also brought in at the Post-Doctoral and senior researcher levels via various government programs, such as ESEP and the NRC. This enables the regular faculty at USAFA to collaborate on research, while still maintaining their essential roles as educators and mentors to cadets. Finally, graduate students from other universities can be brought in to perform research along with the faculty in order to fill in the research matrix at all levels.
The logistical and manning support strategy for the M&SRC include:

- M&SRC Director
    - Field Grade Officer, PhD
    - Sequential Tour Officer (Longevity)
- System Administrator
    - Contractor (multi-year funding)
- Floating Researcher
    - 1-2 year rotation between faculty departments
- Visiting Researcher Programs
    - ESEP
    - NRC
    - Visiting graduate students

IV. Research

The initial research being conducted in M&S at USAFA was in the area of computational fluid dynamics (CFD). A DoD High Performance Computing (HPC) Challenge project was applied for and funded which has allowed CFD to be extended successfully to predict massively separated flows using Detached-Eddy Simulation (DES), as shown in Fig. 2. The USAFA CFD Group has been making great progress on high resolution, full aircraft simulations at realistic flight conditions. The success of the group in this area is due to the ability to accurately compute turbulent massively separated flowfields with a hybrid Reynolds Averaged Navier-Stokes (RANS)/Large Eddy Simulation (LES) technique called Detached Eddy-Simulation (DES) with the unstructured Navier-Stokes flow solver *Cobalt*. To date, the most noteworthy successes have been a 5% lift, drag, and moment coefficient comparison of simulation with flight test of the F-15 at 65^o angle of attack, the only simulation able to qualitatively capture the F/A-18E Abrupt Wing Stall (AWS) phenomenon, and accurate representations of the buffeting tail loads of an F/A-18C at 30^o angle of attack. This methodology has also been applied to the C-130H aircraft to preliminarily assess Airflow Influence on Airdrop, a missile system with known unsteady oscillations from flight test, and the CV-22 vortex ring state phenomenon with great success. The *Cobalt*/DES method is well suited to accurately computing the unsteady flowfield resulting from bluff bodies such as space launch vehicles and missiles. In addition to unsteady aerodynamics, the group has shown the ability to accurately compute the loads of a generic commercial aircraft configuration with steady-state analyses using the flow solver *Cobalt* with industry standard turbulence models such as Spalart-Allmaras (SA) and Menter's Shear Stress Transport (SST) models.

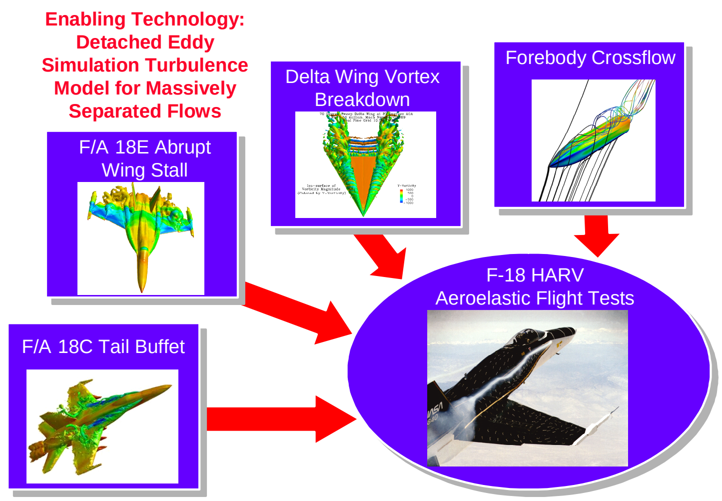


Figure 2. CFD Simulation Development

Some of the specific CFD research projects using the M&SRC facilities are shown in Fig. 3. These projects include:

- Using DES to simulate the flowfield around aircraft at high angles of attack in order to jointly predict the aeroelasticity of the vehicle—this project using the F/A-18C as a test vehicle due to the large amounts of flight test data that are available
- Using DES to simulate the wake of a C-130 in order to determine the impact of unsteady flow on the behavior of parachutes used for cargo air-drop
- The abrupt wing stall characteristics of the F/A-18E were accurately modeled using DES and a full aircraft simulation
- Turbine blade flow control is being studied in the cascade wind tunnel at USAFA and concurrent CFD predictions helped to understand this complex flowfield
- Closed loop flow control is being studied experimentally at the USAFA water tunnel, and CFD predictions coupled with control system modeling is being used to control laminar and turbulent wakes

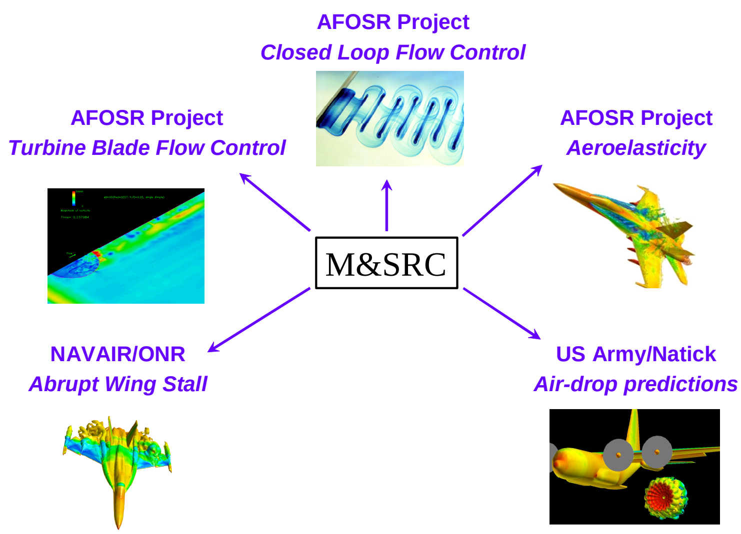


Figure 3. CFD Modeling & Simulation Customers

In addition to the CFD research, which formed the basis for M&SRC work, various new customers have come onboard in the past few years. Figure 4 shows the currently active research projects being conducted with M&SRC

resources, including computational electromagnetics (CEM) in the Electrical Engineering Department, aging aircraft simulation in the Engineering Mechanics Department, fly eye modeling in Biology, computational chemistry, as well as war gaming and modeling human behavior. Student are involved in as many of these projects as possible, and in addition, the Academy's Cadet Summer Research and Faculty Summer Research programs support those interested in spending time at remote locations (like the Maui High Performance Computing Center) to conduct research using resources not available directly at the Academy.

Since many of the research projects listed in Fig. 4 are worthy of research papers of their own, only brief descriptions will be given here:

- The electrical engineering project in CEM solves the Maxwell equations in an attempt to predict the electro magnetic field of an aircraft created by an impinging radar wave. This is of vital importance to the aircraft design community in determining the radar cross section of the vehicle, an important design parameter for military aircraft.
- The aging aircraft work uses finite-element analysis to determine the impact of cyclic loading on high stress points in composite plates and shells. As aircraft age, these loads (due to repeated take-offs and landings, among other things) can cause fractures in composite materials that reduce the life-span of parts, and adversely impact the useful life of an aircraft.
- The fly-eye modeling work uses the parallel processing capabilities of our computers to model the individual "photo cells" of a fly's eye. By doing this, advanced sensors can be developed that take advantage of the fly's ability to remotely determine shapes, an important area of work for advancing sensor capabilities.
- The need to accurately determine the molecular processes taking place within chemical reactions has led researchers in chemistry and bio-chemistry to use computational methods to model these processes and reactions. Greater understanding of the processes will lead to improvements in medical research, drug design, cellular biology, and chemical reactions.
- The human behavior modeling and war-gaming use parallel processing to determine alternative human reactions to various situations with gaming theories and risk assessment techniques. This work is vitally important for homeland defense issues related to non-state actors.

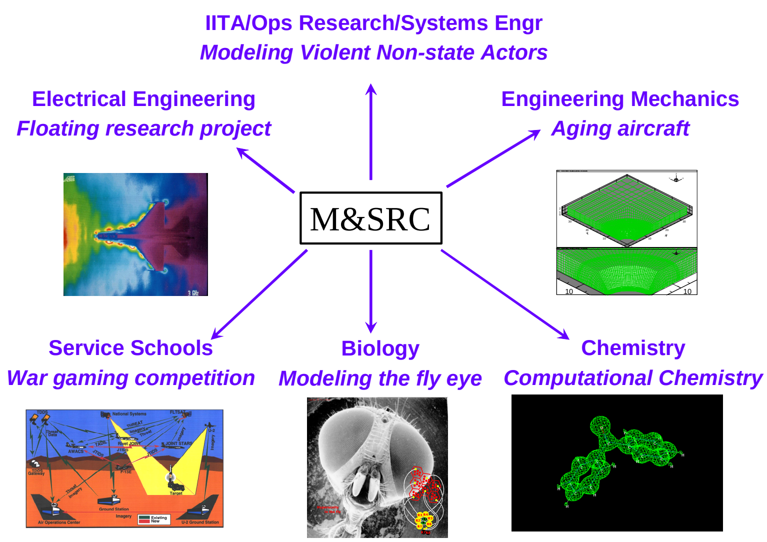


Figure 4. Non-CFD Modeling & Simulation Customers

V. Modeling & Simulation Instruction

A. Overview

M&S instruction at USAFA reflects the great diversity associated with this old yet very new branch of learning. Along with "standard" M&S courses like *Numerical Methods* (several departments have a version of this course), *Computer Simulation* (discrete event simulation), and *Advanced Applied Aerodynamics* (CFD), USAFA has implemented M&S instruction into several non-standard courses such as *Software Development*, and *Unmanned*

Aerial Vehicle Systems. In addition to these non-standard courses, USAFA faculty have also restructured some of the core and major's courses to capitalize on the "newness" of M&S. "Major's courses" does not imply there exist an M&S major at USAFA, and there is no plan to establish such a major. Some schools which do have M&S degree programs include Arizona Tri-University, Daytona Beach Community College, California State University—Chico, Georgia Tech, Old Dominion University, University of Central Florida, the Air Force Institute of Technology, and the Naval Postgraduate School. Rather "major's courses" refers to courses within one of USAFA's 19 science/engineering majors,[7] for example Aeronautics. After discussing the new context which makes USAFA's courses distinctive, we'll briefly show how this context supports the structure of several core courses, and end with a synopsis of how the Department of Aeronautics integrates M&S instruction, via CFD, within their major's coursework.

B. M&S—New Perspective

M&S has always been a problem solving tool. Traditional uses of M&S include supplementing the experiment—theory pattern of research and education, providing an efficient means of training, and analyzing "What if . . . ?" scenarios such as in many operations research problems. In a broader sense, we can look at some common definitions[8] for models (a physical, mathematical, or logical representation of a system, entity, phenomenon, or process) and simulations (implementation of a model over time) and see if there exists an overwhelming number of courses, many outside the "traditional" M&S offerings, at any university which include some aspect of M&S. Sticking strictly to these traditional uses and definitions, though, fails to capture the excitement and innovative applications which we now associate with M&S. Why? Because these uses and definitions don't embrace the contributions which have emerged from the relatively recent advances in scientific computing and computer technology. While the M&SRC provides the physical means for realizing these advances, modern M&S computer hardware is more than just faster computing capability. Indeed, modern computing has introduced a new vocabulary with terms like "virtual reality" and "synthetic environments" and increased the importance of older terms like "fidelity" and "resolution".

To build a bridge between traditional M&S and this new technological paradigm, we will use the DoD classifications[9] of M&S into *acquisition*, *analysis*, and *training* activities or functional areas. These areas focus M&S education on using M&S as a tool. Equally as important, these functional areas define the environment in which cadets will experience M&S during their Air Force careers.

Specifically, *acquisition* includes basic and applied research, as well as a good portion of operations research. It includes evaluating new system/equipment requirements, development, and demonstration; planning efficient production; and sustaining equipment (test and evaluation) in the field. One of the key factors in assessing the usefulness of M&S in the acquisition functional area centers around reducing life cycle costs.

The *analysis* functional area addresses decision making—the "what if . . .?" questions. Key tasks accomplished in this area include: identifying logistical constraints and critical areas, making multiple runs, exploring options, assessing operational plans, validating (did we build the right thing?), and modifying future operational concepts. Wargaming falls within the scope of *analysis* as does anything that will drive changes to doctrine, organization, training, and education, material, leadership, and people in DoD.

The third functional area of *training* embraces the use of M&S to provide realistic and sometimes cheaper methods of instruction to personnel to individually and collectively increase their capacity to perform specific functions and tasks. Flight simulators serve as prime examples of using M&S in this activity. The Commandant of Cadets office operates the USAFA flight simulators, and includes Frasca 241 trainers, a T-37 Instrument Trainer, and 28 separate computer stations serving as simulated aircraft. Though this paper will not discuss the details of these training environments, it is worth mentioning cadets receive extremely valuable instruction in systems management, cockpit discipline, IFR flight rules, and cross country navigation in these programs.

However, the use of flight simulators by themselves is only part of a new paradigm sweeping the Air Force—distributed simulations. By "distributed simulations," as opposed to distributed computing, we mean conducting/combining simulations from geographically separated sites. They use advances in network capabilities and often combine pieces of *live*, *virtual*, and *constructive* simulations as delineated in Table 1 below.

Type of Simulation	**People**	**System**
Live	Real	Real
Virtual	Real	Simulated
Constructive	Simulated	Simulated

Table 1. Examples of Distributed Simulations

The Distributed Mission Operations Center (DMOC) in Albuquerque, NM illustrates the promise of such training. In a typical scenario, DMOC acts as the central coordinator for USAF pilots flying a live training mission in AZ who must interact with both Marine units conducting an exercise in VA and with command and control personnel "flying" in ground simulators in NM. This type of training can provide enormous budgetary and environmental benefits, and from a systems perspective provides increased opportunities for members of different organizations (USAF and Marine personnel) to work together.

In closing this section, one other item of note is the dynamic nature of the DoD's M&S classifications within each of the services. While *acquisition, analysis,* and *training* provide a broad categorization, each of the services has refined these basic categories to better fit their specific requirements and goals. For example, the Air Force has also added the areas of *experimentation, operations, test and evaluation,* and *wargaming.*[10] For the purposes of this paper, we will include *operations* with *training,*[11] *T&E* under *acquisition, wargaming* within *analysis*, and *experimentation* as part of all three DoD classifications.

C. M&S in the USAFA Core Curriculum—Renewed Emphasis

USAFA students come to their first day of class with a substantial amount of computer experience and high expectations with respect to computer use. Several National Education Center for Statistics[12] and Census Bureau,[13, 14] studies record the use of computers for all ages, and noted in 1996 almost 85% of all 11th graders who reported using a computer at home or school used the computer to play games. By August 2000 only 10.4% of school-aged children didn't have access to a computer either at home or at school. More recently, the Entertainment Software Association has reported over 239 million computer and video games being sold (almost two for every household) in 2003.[15] It is more likely than not that USAFA freshmen have used high quality software products similar to "America's Army"[16] and Microsoft® "Flight Simulator". Therefore, the role of the USAFA core courses with significant M&S components is to capitalize on this preliminary knowledge to provide depth and context to the new computer technology.

In pursuing this goal, a renewed "demonstration-application" structure has naturally arisen as students progress from their freshman course, *Introduction to Computers*, through the junior core option course, *Systems Analysis*, and, finally, the senior course, *Introduction to Joint and Multinational Operations*. All students take the freshman and senior courses, while approximately a third take the junior-level course. The Department of Aeronautics core course, *Fundamentals of Aeronautics*, taken by all students in either their sophomore or junior years, lays the foundation for the demonstration-application organization in the department's major's program presented later in this paper.

Introduction to Computing provides an introduction to principles, applications, capabilities, and limitations of computer systems, in which 2 of the 42 lessons are devoted specifically to M&S. The material discussed during the M&S lessons includes:

- an introduction to M&S in DoD and the US Air Force
- the capabilities and limitations of M&S
- demonstrations of basic M&S techniques to facilitate problem solving
- demonstrations of the value of the *validation, verification,* and *accreditation (VV&A)* process

Students see a turn-based simulation to improve market position and complete a spreadsheet exercise to determine the expected completion time of a project which depends on different precedents. For example, an aircraft maintenance facility which performs 50 hr and 100 hr inspections requires different, though similar, sequences of checks and maintenance depending on the type of inspection. Students can use the simulation to perform various sensitivity analyses to address optimizing system throughput.

Students who take, *Systems Analysis*, build on the M&S spreadsheet exercise from *Introduction to Computers* and further develop the ability to use spreadsheets for simple simulations to answer "what if . . .?" types of problems. The course provides an introduction to rigorous quantitative modeling methods that have broad application, and focuses on the mathematics of the models, the computer implementation of the models, and the application of these models to practical decision-making scenarios.[17] Specific topics include: decision analysis and utility theory, linear and nonlinear optimization, project management, queuing theory, simulation, and the systems approach to engineering and decision-making. The Department of Management administers this course taken primarily by non-engineering students.

The senior-level core course with a dedicated M&S component, *Introduction to Joint & Multinational Operations*, is very popular among the students. Based on case studies and wargame exercises, students examine joint U.S.

military doctrine and employment concepts for each of the services (Air Force, Army, Navy, and Marines) in a variety of scenarios. The wargame exercises employ the commercially available game *Empire Earth*® which through its robust campaign editor has provided a framework for instructors to create learning modules. Students use these modules as they work in teams of five to six members against either a computer opponent or another student team to address "what if . . .?" scenarios. The ability to try different solutions and apply different techniques to their problems offers a highly effective learning experience and brings historical records and theoretical concepts to life.

D. M&S as part of an Academic major—Reinforced Learning

An example of how M&S is integrated in the aeronautics program is shown in Fig. 5, which describes how we take cadets from demonstrations in early coursework to application in senior-level coursework. Since CFD plays such a pivotal role in aeronautics, we begin students with demonstrations of basic aerodynamic concepts in their basic courses (such as AE 315, a core course taken by all cadets). A new course, AE 342 (which is being taught to all junior-level Aeronautics majors for the first time this year) introduces students to the basics of computational aerodynamics, including numerical methods, grid generation, post-processing, and best practices in simulating aerodynamics using CFD. Finally, senior-level students are then able to take their CFD knowledge and apply it in aircraft design (AE 481/482) and independent-study research projects, where they work with faculty on real-world problems using CFD.

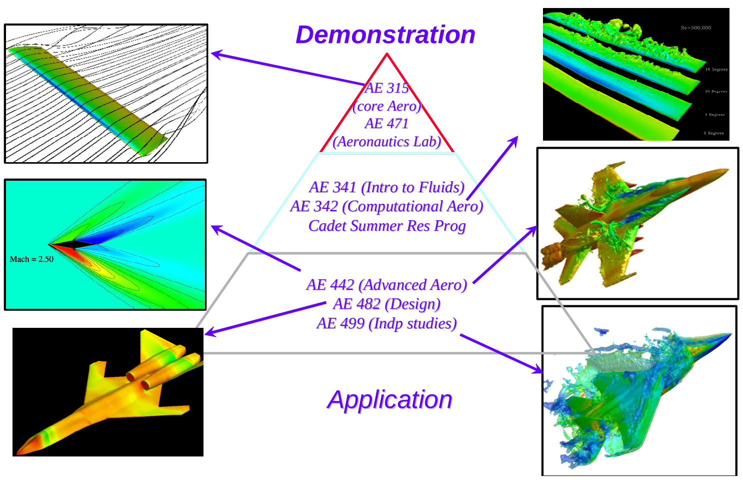


Figure 5. CFD Integration into Department Courses

Specifically, the newly created course in CFD (AE 342) includes all of the steps necessary for accurate simulation of the flowfield around a flight vehicle. The students are introduced to the four-step CFD process as shown in Fig. 6, and then they proceed to learn how to do each step, including geometric modeling, grid generation, obtaining a flow solution on a parallel processor computer, and post processing of results. The course has an ambitious set of outcomes, which shows the importance of both the M&S capability and the desire to have the students learn about the subject matter they are simulating. The course outcomes include:

- Understand aerodynamic concepts such as lift, drag, vortical flows, viscous effects, and shock waves.
- Generate structured (2D) and unstructured (2D,3D) grids around moderately complex shapes:
    - Be able to determine the necessary underlying geometry requirements for a specific aero analysis.
    - Be able to determine required grid spacing for viscous and inviscid calculations.
    - Be able to perform grid refinement studies.
- Perform a Computational Fluid Dynamics calculation:
    - Understand the basic theory behind CFD in order to be an intelligent code user.
    - Be able to determine what level of CFD is required (Potential methods, Euler, Navier-Stokes, or Reynolds-Averaged Navier-Stokes).
    - Understand issues of spatial and temporal accuracy.
- Analyze the results from a CFD calculation using graphical and non-graphical tools:
    - Be able to identify non-physical results.
    - Be able to identify salient flow features.
- Produce accurate written, oral, and graphical communication

These objectives insure that the students who learn CFD will be both intelligent users of M&S, but also critical thinkers who know the questions to ask when someone presents M&S results. Several of the students who took the first full offering of AE 342 spent the summer at government labs or in industry design groups and were able to quickly make contributions to modeling and understanding aerodynamics due to their education in CFD.

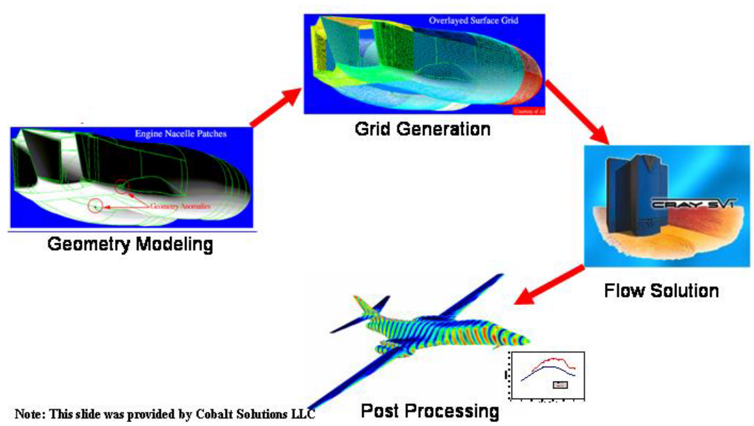


Figure 6. CFD Four-Step Process Taught in AE 342

VI. Conclusion

The M&SRC at USAFA is currently operational and actively conducting research into a variety of areas, including CFD, CEM, Aging Aircraft, Wargaming, Computational Biology, and Computational Chemistry. New research areas are being brought on board via the floating researcher concept, and the computational resources are being continuously updated. Students are being actively involved in M&S in the classroom and via independent research projects. The continued growth and success of M&S at USAFA is essential to the future needs of the Air Force, and is being greatly enhanced by the M&SRC.

Acknowledgments

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References

1. D.N. Barlow, S. Nowlin, and D. Bossert, “Falcons Soaring: USAFA Department of Aeronautics Contributions to Aerospace Power During a Century of Manned Flight,” AIAA Paper 2002-0564, Jan. 2002.
2. B.A. Haven, A.R. Byerley, D.N. Barlow, “An Undergraduate Gas Turbine Engine Program Enhanced by Design and Research Trends,” ASME Paper GT-2002-30588, June 2002.
3. D.E. Bossert and T.R. Yechout, “A MATLAB-Based Flight Simulator for Flight Mechanics Education,” AIAA Paper 2002-4876, Aug. 2002.
4. J. Wolf and A. Sansone, “The U.S. Air Force Academy's Flight Test Course: Preparing Tomorrow's Flight Testers,” AIAA Paper 2002-1048, Jan. 2002.
5. R.M. Cummings and A.R. Byerley, "A Multifaceted Approach to the AIAA Foundation Undergraduate Team Aircraft Design Competition," AIAA Paper 2003-947, Jan. 2003.
6. https://www.dmso.mil/public/pao/storiesm_04/7-1-7.
7. USAFA Curriculum Handbook, 2003-2004, pg 77.
8. DMSO MSFAC Reference CD, “M&S Fundamentals.doc”, July 2003.
9. DMSO MSFAC Notes, July 2003.
10. DMSO, “Preliminary Needs Assessment of DoD Professional Education for Modeling and Simulation—DRAFT”, AB Technologies, Inc, July 7, 2004.
11. Air Force Agency for Modeling and Simulation, “Professional Development”→“Basic Modeling and Simulation Information (BMSI)”→”Organization,” https://www2.afams.af.mil/ .
12. National Center for Educational Statistics, “Student Computer Use,” http:www.nces.ed/gov/pubs98/ condition98/c9803a01.html 1998.
13. United States Census Bureau, “Computer Use in the United States: Population Estimates”, http://www.census.gov/prod/99pubs/p20-522.pdf 1999.
14. United States Census Bureau, “Home Computers and Internet Use in the United States: August 2000 Special Studies,” http://www.census.gov/prod/2001pubs/p23-207.pdf 2001.
15. ESA Media Center, “Top Ten Industry Facts”, http://www.theesa.com/pressroom.html.
16. “America’s Army”, http://www.americasarmy.com/.
17. USAFA Curriculum Handbook, 2003-2004, pg 298.