

Knowledge Management Techniques in Experimental Projects

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Abstract

Knowledge integration (KI) and knowledge management (KM) techniques are being recognized as key to improved competitiveness in industry. These principles and techniques enable retention, sharing and systematic application of critical knowledge across geographic and temporal expanses. Five case studies of the application of KI/KM techniques are described, in the context of a university research group including students at all levels from sophomores to PhD candidates. Each case involved a major research experiment involving new measurement techniques, which had to be conducted during a specific time in a professional testing environment. To avoid missing many classes, each student could only participate for two days at most, so that each team member had to be well-informed. The processes used to develop each experiment, train the team and conduct the project are discussed in the paper. KI techniques included development of a Live Test Document, internet-based exchange of experimental details with the customers, mission planning using the internet, and training of the team using scaled mockups of the experimental configurations.

I. Introduction

Figure 1 uses the Knowledge Pyramid¹ to articulate the vision of a major US corporation on the evolving role of engineers. To develop the products of the future technological marketplace, engineers must move ever higher on this pyramid. Along with curricular efforts to integrate knowledge, the university environment must seek ways by which students can gain experience of bringing multi-faceted projects to successful completion under realistic constraints of the professional workplace.



Figure 1: The evolving “Knowledge Worker”. Industry views a progression of the knowledge level of engineers from the “Methods & Analysis” level of the past to the “Analysis & Interpretation” level of today, on to the “Knowledge & Insight” functions of the future¹.

Knowledge management (KM) techniques²⁻⁶ are being recognized as key to improved competitiveness in industry. Where the capture and integration of the relevant knowledge is more important than its subsequent management, “Knowledge Integration” is a more relevant descriptor of the process. “KI/ KM” in this sense refers to principles and techniques which enable retention, sharing and systematic application of critical knowledge across geographic and temporal expanses. In this paper, examples are used to consider how such techniques function in the university environment, in solving problems.

Five case studies of the application of KI/KM techniques are described, in the context of a university research group including students at all levels from sophomores to PhD candidates. Each case involved a major research experiment involving new measurement techniques, which had to be conducted during a specific time in a professional testing environment. The processes used to develop each experiment, train the team and conduct the project are discussed in the paper. The experiment cases are: (1) measurements on a 1/6-scale tiltrotor at Bell Helicopter Textron, (2) Axial-flow rotor tests at NASA Ames Research Center, (3) tiltrotor tests at the Boeing VTOL wind tunnel, (4) A microgravity flight test at NASA Houston, and (5) Engine test cell flow measurements at Delta Air Lines. The measurement techniques included hot-film anemometry, pulsed light sheet flow visualization, and Spatial Correlation Velocimetry.

II. Problem Statement

When flight vehicles are developed, tests have to be performed under realistic conditions. Such testing is expensive, requiring large, specialized facilities and skilled personnel. Time is at a premium in such facilities, so that each test is planned and scheduled in detail. The complexity of such tests is great; as a result, delays and rescheduling are often encountered. Once a test object is installed in the facility, testing must proceed intensively, often occupying a full 2 shifts of work, 6 or 7 days per week.

This environment is substantially different from that of a university research facility where advanced diagnostic techniques are developed through doctoral-level research projects. Here the experimenter must be provided great leeway in setting up experiments, and adjusting measurement systems to perfection over periods of months. The schedules are allowed to be dictated to a large extent by the academic demands placed on the student experimenters. Planning also anticipates the need to go back for further data acquisition after initial analysis of the data from the first set of tests in such facilities. These are all luxuries seldom affordable within the schedule and cost constraints of major facilities.

In the 1980s and early 1990s, the Experimental Aerodynamics Group at Georgia Institute of Technology (GIT)'s School of Aerospace Engineering developed measurement systems to deal with the complex, unsteady flow environment of rotary wing vehicles¹. These diagnostic techniques were initially developed using high-power lasers, which are extremely fragile, expensive and difficult to transport to other facilities. In the mid-90s, the EAG succeeded in evolving, out of these diagnostic techniques, Large Area Visualization (LAV) techniques which enabled measurements to be conducted in large facilities. Instead of high-power lasers, inexpensive machine-vision lights were used, which could be scaled up to cover large areas, necessary to obtain images of full-scale rotary-wing wakes. They also showed that instantaneous flow velocity vectors could be obtained over large areas, using Large Area Spatial Correlation Velocimetry (LASCV).

While these techniques could be tested piecemeal in moderate-sized facilities at GIT, their full potential could only be exploited in the large facilities for which they were designed: facilities where wakes with large velocity variations were encountered. Thus, the problem of transporting the entire measurement systems to large facilities, and operating under their constraints, had to

be faced. It should be noted that *the full system had to be made to work for the first time in these tests*, since flowfields with adequate extent and velocity ranges to enable proper measurement parameters, could not be duplicated at GIT. The equipment, systems and procedures involved several items which required flexibility from the industry testing staff (i.e., they had to incorporate our constraints into their test planning as well). For example, fog generators were needed to provide seeding for the flow imaging. These had run-times of a few seconds, and their ducting had to be repositioned as needed to get the smoke into appropriate flow regions, often by trial and error. In some cases, test conditions had to be held for 2 or 3 minutes, which was longer than needed in the usual industry tests where only hub loads would have been measured.

Taking a team of full-time students into such a project environment entailed several challenges.

- It is impossible to predict, even 2 weeks ahead, exactly which part of a test program will be done on a given day.
- To avoid missing too many classes, each student can only participate for 2 days at most.
- Thus, each team member has to be well-informed, and competent at a multitude of tasks.
- The students are at different levels, ranging from sophomore through PhD. Their curricular backgrounds are diverse, and do not permit the offering of a standardized course on the project.
- The projects themselves were of a research nature, and involved major uncertainties.
- Such a test was a new experience for the test facility staff, as well as for the university researchers.

Knowledge Integration principles and practices were developed to enable such projects. Here these techniques are tied into the evolving area of Knowledge Management, so that a precedent is established for conducting such experimental projects in future.

III. Knowledge Integration and Management

Engineering Knowledge is defined^{2,3} as “processed information, including engineering models, experience, knowhow, etc.” Central principles of Knowledge Management [2] are listed as:

- “The capture, storage and accessing of knowledge.
- Effective utilization of knowledge
- Identification and Filling of Knowledge Gaps”

A distinction is made⁴ between “*explicit knowledge*” and “*tacit knowledge*”. Tacit knowledge is described^{2,4} as “*personal knowledge embedded in individual experience and involves intangible factors such as personal belief, perspective, and the value systems*”. This includes, to some extent, the rationale behind design decisions, which are often taken before formal documentation of the project commences. Milton⁵ describes explicit knowledge as that which is expressed in language and encoded in procedures and manuals. Tacit knowledge is a more personal form of knowledge, related to individual experience and involving personal factors such as belief systems, values and culture. The terms have evolved in recent times⁵ so that explicit knowledge indicates encoded or recorded knowledge, while tacit knowledge is equated to unrecorded knowledge.

Milton⁵ cites Borghoff and Pareschi [6] in their definitions: “*Explicit knowledge is formal knowledge, found in the documents of an organization: reports, manuals, patents, pictures, images, video, sound, software etc. Tacit knowledge is personal knowledge embedded in individual experience; shared and exchanged through direct eye-to-eye contact. Clearly, tacit knowledge can be communicated in a most direct and effective way.*”

Milton⁵ makes the point that the capture of tacit knowledge is made difficult by the fact that tacit knowledge can include both conscious and unconscious knowledge, and often the knowledge is possessed by teams, rather than individuals in isolation. Techniques for extracting conscious tacit knowledge include⁵:

- Put people in touch with people and allow them to talk.
- Company-wide “yellow pages”.
- Communities of practice built around core competencies.
- Email discussion forums;
- Databases of lessons learnt.

To capture unconscious tacit knowledge, Brain Mining techniques are developed. These are applied, for example, in situations where experience occurs in repeated discrete projects, such as in the case of oil exploration teams and military operations. Procedures for collecting team knowledge include strategies for making knowledge conscious. Examples of tools are:

- US Army After Action Reviews.
- Comparison of a team’s expectation of event with actuality, to find reasons for differences between the two.
- Hard questioning, proceeding in depth to the “Five Whys” to determine true causes.
- Learning-History studies

IV. Application of KI/KM techniques to the Team Project Problem

Issues encountered in the team project problem, and their relevance to KI/KM, are listed in table 1. Many of the issues faced by industry teams setting up “discrete projects”⁵ were faced by the student team as well. Flow visualization in complex air flows, using pulsed light sources, involves some trial-and-error adjustment in any facility. In the tests in question, the imaging areas were of unprecedented extent, and the usage of compact, portable light sources rather than lasers, made the signal-to-noise ratio of the images rather low. A number of parameters thus had to be adjusted before the image quality became good enough to perform quantitative velocimetry. Another feature of the LASCV technique was that the velocimetry required distributed seeding over the entire image area, whereas qualitative vortex flow visualization produced better images with discrete streams of seeding over thin regions.

To make the experiment work, uncertainties had to be systematically reduced. Thus, many items which could be left to unconscious tacit knowledge had to be translated into coded, explicit knowledge. This process had to occur by observation of the expert students actually getting parts of the experiment done. Hence we hit upon the idea of assigning someone other than the expert students to document procedures, and then have the PhD candidate review and refine the procedure description. This process immediately revealed the need to provide a glossary of

terms, and description of various parts, to enable non-expert team members to identify parts and their functions.

Problems encountered during preparations encompassed various disciplines, and their diagnoses evolved. When solutions were determined, procedures had to be changed, and all students had to be informed of the changes and their reasons.

Table 1: Relation of Team Project Problem to Knowledge Management Issues

	Student Team Issue	KI Issue
Knowledge Capture	Only 1 or 2 students may actually know the methods used to solve given problems, and conduct given types of measurements.	Retaining & transferring experience before these students graduate.
Effective utilization of knowledge	Experience must be available in documented form for newer users. Best practices must be determined, from knowledge of past experiences.	Tacit knowledge held by PhD candidates must be made available to newer team members when needed to solve problems.
Identification and Filling of Knowledge Gaps	Documentation and “habits” must be checked against repetitive experiments to identify mis-diagnosed phenomena, missed steps, etc.	Capturing experience in sufficient depth to enable generalization of conclusions
	Various measurement techniques and instrumentation types involved: must work together. No student knowledgeable in all the techniques.	Integrating diverse sources of knowledge
	Obtaining everyone’s input on how to solve various problems	Cross-discipline innovation
	Getting students other than PhD candidates to align and operate the experiments	Retaining depth in team capabilities
	Getting all students to be aware of problems which have been solved, and those which remain to be solved, on a daily basis	Synchronizing progress

To deal with these challenges, four KI techniques were developed:

- development of a Live Test Document,
- internet-based exchange of experimental details with the customers and former team members.
- mission planning using the internet, and
- training of the team using scaled mockups of the experimental configurations.

IV.1 Development of a Live Test Document

For each of the cases described below, a Live Test Document was developed. Initially, these were developed using Microsoft Word as a convenient medium available to all the students, regardless of location. More recently, documentation is being shifted to internet / intranet resources and web-based discussion fora. The Test Document was updated daily. Its front pages contained “News” lists, “Task lists” and a “Current Schedule”. Each team member was allowed to modify the document, but had to let everyone know through the News pages. Each team member, regardless of level or specialization, was emphatically told that s(he) would be held responsible for knowing the contents of the TD. Instrumentation manuals, cabling schematics, experiment set-up diagrams, operational procedures, example calculations of parameters, and “mudane” details such as contact addresses, phone numbers, driving directions etc. were all placed in the same document. Team members were constantly urged to go to the TD for all information, and to add information which they found lacking, once they had located it elsewhere. Typically, a test document would approach 50 to 100 pages in length, with more voluminous equipment manuals, etc. being added to a Test Document Folder. By this process, every team member was informed that they were not considered to be “low-level” and hence could not expect to sit around waiting for orders. As students gained experience and confidence with the TD, they became much more versatile at all aspects of the project. Often, critical problems where someone needed to know some obscure detail of a process, were solved quickly because one or more of the team members knew where the answers could be found in the TD.

IV.2 Internet-based exchange of experimental details with the customers and former team members

In 1996, we were new to the internet, but had developed our own web pages for the research facilities. This capability was used extensively in many ways. A web page with an obscure address was set up for each test program. Digitized pictures of our experimental equipment, mockup, method descriptions, and typical results were posted on these pages, so that the industry / government staff members could view our work at leisure and gain a better understanding of what we were planning to do. This was vital because our methods were unique. With people at both facilities logged on to the same web page, telephone discussions could quickly resolve questions and find solutions to problems.

Students also used this technique to capture knowledge from team members who had already graduated. For example, the author here found the following scene in the lab one day: a newer graduate student was conducting a telephone discussion with an alumnus, with a table piled with mechanical and electronic parts in front of her, and a web page with a picture of the pile in front of her. Telephone assistance was arriving on exactly what each piece did, along with precious tacit knowledge on problems which might be encountered, and their solution. This process must have saved months of trial and error.

IV.3 Mission Planning Using the Internet

The internet quickly became a central tool in planning each experiment. Maps, hotel and airfare / airport information and driving directions etc. were obtained, and shipping instructions and tracking information were obtained over the ‘net. Places to purchase several items near the industry facility were also identified. A critical item was the rental of large fog generators used

in flow visualization: theatrical supply stores were identified over the web in the vicinity of each test site. A different aspect of Internet usage was to report on the team's progress: this of course was not applied to the high-security test programs at the corporate / government sites, but was used in a later iteration of the undergraduate Microgravity Flight Experiment program.

IV.4 Training of the team using scaled mockups of the experimental configurations.

The development of mock experiments was critical to integrating the knowledge of the team, refining procedures, and improving the success probability of the experiments by identifying numerous potential problems. Next to the Live Test Document, this was the most crucial aspect of the test preparations.

V. Case Studies

V.1 Case 1: Measurements on a 1/6-scale tiltrotor at Bell Helicopter Textron

This was the first set of tests conducted. At the Hover Test Stand at Bell Helicopter Textron's Fort Worth, Texas facility, a half-model of a 15%-scale model of the V-22 tiltrotor aircraft was set up for testing. The tests were to be conducted in May 1996. Facility schematic drawings were FAXed to GIT, in order to design the measurement approach. An approximate mockup of a 15%-scale V-22 was built out of foam, and installed at the downstream end of the 42" low speed wind tunnel at GIT.

The measurement system, consisting of fog generators, light sheet generators, intensified video cameras, pulse generators, recorders, monitors, video mixer, time code generators, and computer, were gradually assembled around the mockup, and problems were tackled one by one. At each step, the measurement system Test Document was updated. Procedures and parts for set-up, alignment and operation of each subsystem were developed in detail. Using the partial results obtained in each attempt, a test parameter calculation scheme was developed, to be used to predict the correct settings to be used for the camera apertures, shutters, time delays, etc. Each team member was encouraged to participate in as many aspects of the experiment as possible. Each was held responsible for reading the Test Document, and updating/correcting it as needed.

Communications with the BHTC facility staff were continued, as ways were found to solve various problems in data acquisition. Searches through the internet identified suppliers of theatrical equipment in the vicinity of the Bell Helicopters facility, and arrangements were made to rent fog generators. Shipping criteria were determined by contacting various package shippers. The test equipment was packed into 17 different cases, each weighing under the limit for a Federal Express / UPS truck driver to be able to load and unload from their truck. Each case was packed for maximum protection of the equipment.

On the Friday before the week of the tests, the equipment was shipped out by Overnight Air Freight. On the Sunday, the first 2 team members flew into Ft. Worth, with the latest version of the Test Document, whose front pages contained driving directions, contact information, and procedures for unpacking and installing the equipment.

On Monday morning, the test team members picked up the rented fog generators on their way to the BHTC facility. By Monday afternoon, they were dealing with preliminary alignment of the

cameras, as the next two team members arrived. By Tuesday afternoon, initial data sets were being obtained with the rotor operating. By Wednesday, data quality was quite excellent, and Thursday and Friday were occupied with intensive testing. By Friday, the BHTC team, having seen the capabilities of the LAVS, developed a series of flow control experiments where they could visualize the flowfield associated with the performance of their ideas for reducing wake-induced download on the wing of the model. On Saturday morning, the remaining team members packed the equipment for shipping by the BHTC staff, and left for Atlanta.

Overall 117 different test runs had been recorded at various conditions and testing planes; most had useful segments of tape which would yield good results upon analysis. The success level of the tests [8] had far exceeded the optimistic projections of the test team, and it became clear that the emphasis before the tests had been so heavily placed on the acquisition of data, that the analysis capability lagged far behind. Analysis of the data continued for the next 6 months, in various stages, as the video grabbing and computational capabilities for analysis were developed.

Various pieces of equipment suffered considerable damage during both legs of the shipping process, and the packing cases showed evidence of rough handling. However, the main lessons learned from this test series were that (1) thorough planning would lead to success and (2) planning had to take into account the possibility of a very high level of success in data acquisition, which in turn implied a huge analysis task.

V. 2 Case 2: Axial-flow rotor tests at NASA Ames Research Center

In October 1996, an opportunity came up to use the LAVS in the newly-developed Axial Flight Rotor Facility at Ames Research Center. The initial objective was to verify the level of unsteadiness in the regions around a 2-bladed rotor during axial flight operations. The facility is



shown in Figure 2. EAG decided to attempt both vortex visualization and LSCV, should opportunity present itself. In the first week of November 1996, a process similar to that used at BHTC was used, with the student team, with a few members replaced due to graduation, flying out to California in stages. Each student except for the team leader (a PhD candidate) could stay for not more than 2 days.

Figure 2: Rotor Axial Flight Test Facility at the Ames Research Center.

The researchers at Ames were keen to study various aspects of the flowfield. Several innovations were developed during the course of these tests. A traversing fog-stream rig was developed using pieces scrounged from Ames, enabling injection of fog straight into the region where it would be entrained into tip vortices. This in turn enabled very clear vortex imaging. EAG students used knowledge gained in their Flow Control course to develop a solution for a problem with flow-induced vibrations of certain components. By Friday, the testing had progressed to the point where a unique experiment could be designed. Results from the testing conducted on the Friday night have since led to a major advance in the modeling of rotor wakes^{9,10}. Again, analysis of the data took many months, but was performed in various stages for different purposes.

V.3 Case 3: Tiltrotor tests at the Boeing VTOL wind tunnel

The culmination of these series of LAVS and LASCV experiments on rotorcraft, came with a test series at the Boeing VTOL tunnel in Philadelphia in the first week of December 1996. In fact these tests had served to provide the design criteria for the LAVS and LASCV, with the other tests enabled using subsets of these.

The Boeing VTOL tunnel has a 20' x 20' test section. However, when rotary wing tests are conducted in hover, the test section is removed, opening up a chamber in the shape of a vertical cylinder, 80 feet in diameter and roughly 80 feet high. The model, in this case a full twin-rotor 15% scale model of the 609 Civil Tiltrotor, is sting-mounted from the edge of the tunnel diffuser. The rotors were powered by air-motors operating at 75000 rpm, and the rotors were not synchronized. The light sheet generators had to be roughly 40 feet away from the measuring plane, and the cameras were 40 to 60 feet away. The fog generators were attached to the edge of the contraction section of the tunnel.

In addition to LASV and LASCV, measurements using hot-film anemometer probes was also planned. For this purpose, a traversing mechanism developed at GIT was attached from the tail section of the aircraft model. Special materials and structural components had been developed on the mockup at GIT to minimize vibrations of the probe. A custom software package was developed to automate the data acquisition, storage, and probe traverse functions. Development of this software proceeded at a fast pace, under very tight time constraints. Due to recurring problems with the traverse, this software system could not be tested fully until shortly before the shipping time.

Hot-film anemometry and LSVS/LASCV in the Boeing VTOL tunnel in December posed several unique challenges. Hot-film sensors must be calibrated in a flow environment with the same static temperature as the data-taking environment. In Philadelphia in December, this was expected to be a sub-freezing temperature. A portable calibration device was developed, so that the calibration could be run on-site. The time needed for the calibration of angular sensitivity of the sensors was gradually brought down, so that an adequate number of sensors could be calibrated to survive the expected sensor attrition, during the time when the rest of the team would be setting up and aligning other system components. Similarly, tests had to be conducted to verify that the fog generated for flow seeding would not settle and dissipate when exposed to

the sub-freezing temperatures expected. These tests had been conducted using various lengths of ducting, in the courtyard of the AE School at GIT in the previous February.

While the technical challenges of these tests were extreme, the data quality obtained in the LASCV and LAVS was also excellent, and again over 100 test conditions were recorded¹¹. The hot-film tests were only partly successful: problems plagued the probe traverse, requiring a



change in testing procedure. An error in the software led to many of the generated data files being overwritten with the altered test procedure.

Figure 3: GIT team members and Boeing wind tunnel crew on the last day of the tests.

IV.4 Case 4: Microgravity flight test at NASA Houston

In November 1996, while preparations for the Boeing tests were underway, a team of sophomores got together to develop a proposal to participate in the NASA Microgravity Student Flight Opportunities Program. Following a fast-paced proposal development process, the team learned in late December that they would be participating in flight tests to be conducted at the beginning of April. Here the challenges were again unique:

- The selected experiment involved the testing of hypotheses based on acoustics and fluid mechanics theory: none of the student team had taken any courses in these areas.
- The hypothesis could not be tested in the normal 1-G environment: it required micro-gravity.
- The experiment involved several fine adjustments, which had to be performed in the time-limited and uncomfortable environment of the aircraft executing parabolic trajectories.
- The settings to be used in flight experiments had to be developed through a detailed program of ground experiments, using sophisticated measurement techniques which the sophomores could not be expected to master in the available time.
- Design and fabrication of the experiment chamber, validation of numerical predictions, development of measuring systems and procedures, and other experiment aspects had to be developed concurrently, involving a team of many students.
- The experiment had to work first-time, in the flight environment, away from the home laboratory.

Again, the Test Document Approach was used to keep the project moving in a focused manner. Two teams (a total of 6 students) taking a senior-level course on Flow Diagnostics, were assigned to perform flow visualization and acoustic field measurements to validate the prediction model. Meanwhile the sophomore flight experimenters were assigned to design and build the flight experiment chamber, develop hazard evaluations, and otherwise prepare for the flight experiment. A mockup of the critical aspects of the KC-135 interior was laid out in the 42" wind tunnel facility, and the flight team trained using a mock G-indicator (a voltmeter indicating output from a sinewave generator adjusted to the approximate period of the flight parabolas) to perform the required tasks within the available intervals.

The ground experiments succeeded in validating the prediction model for acoustic nodal planes of the chamber, and the flight experiments were totally successful. Procedures were refined, and the final test sequence laid out the night before the first flight test. The experimenters performed their tasks smoothly, and completed all planned experiments within the first 26 of the total 40 parabolas. A second flight test the next day was also equally successful. Results from these tests, and their continuation in following years, have been documented¹²⁻¹⁴.

The experience of getting the students to use the Test Document and communicate, was interesting. The sophomore team had no difficulty with this concept. However, the teams of seniors taking the course had much more difficulty accepting this mode of project management, where they were expected to read what others were doing, determine what tasks to do next, and most importantly, to document what they had done. The habit of treating the class teacher as the



central source of detailed instructions was hard to break. The idea of being held responsible for reading and knowing what was written in the document, and for updating that knowledge based on more recent findings, was quite traumatic to some of these students.

Figure 4: GIT student team use documentation to adjust instrument settings on a NASA KC-135 in free fall.

IV.5 Case 5: Engine test cell flow measurements at Delta Air Lines

The final test case considered here is a 2-day test program conducted in the engine test cells of Delta Air Lines in Atlanta. Here the challenge was to make flow measurements in cells where commercial jet engines are tested. High flow velocities and very high turbulence levels were expected; the facility reached high temperatures, and the experimenters had to be extremely careful to avoid the presence of any small items which might get ingested into the engines, causing damage. The entire set-up, alignment, measurements and packing/removal had to be accomplished within two days. The test team in this case included several members with experience from one or more of the previous industry tests, and the process of developing the

Test Document, doing mockup tests, shipping, and testing went off much faster and smoother than in the initial experiments¹⁵.

VI. Summary Discussion

Table 2 shows how Knowledge Management / Knowledge Integration concepts were incorporated into the problem of conducting off-site experiments using advanced diagnostics and teams of students. The idea of a central Test Document has served very effectively. Web-based communication of test set-up geometry, instrumentation requirements, and data have proven effective. A proven base of experience has been accumulated on conducting major experimental programs with student teams, involving large uncertainties, within the time-constrained environment of professional-grade facilities.

Table 2: Relation of Team Project Problem to Knowledge Management Issues

KI issue	Approach
Retaining & transferring experience	Test Document and intranet resources
Determining best practice	Brainstorming sessions using mockup tests
Communication between team members	Test Document: task list
Integrating diverse sources of knowledge	Test Document: integrate user manuals, equipment specs, and procedures into one manual.
Cross-discipline innovation	Students encouraged to discuss project with teachers and others; mockup tests.
Retaining depth in team capabilities	Require each member to participate in mockup tests and to read Test Document
Synchronizing progress	“Status Update” pages at beginning of Test Document

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IX. Biography

Dr. Narayanan Komerath, Professor in AE and director of the John J. Harper wind tunnel, leads the Georgia Tech Experimental Aerodynamics Group (EAG). He has taught over 1600 AEs in 19 courses in the past 15 years. He is a principal researcher in the Rotorcraft Center of Excellence at Georgia Tech since its inception in 1982. He is an Associate Fellow of AIAA. He has won GT awards for Outstanding Graduate Student Development, Outstanding PhD thesis advisor, and Most Valuable Professor (GTAE Class of '91). EAG research projects have enjoyed the participation of nearly 100 undergraduates over the past 14 years. EAG is a leader in multidisciplinary team-oriented projects, including the Aerospace Digital Library Project at Georgia Tech: <http://www.adl.gatech.edu>