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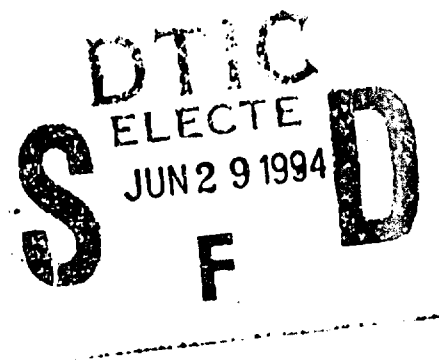
A HYPERTEXT KNOWLEDGE PRESENTATION SYSTEM TO TRANSITION BASIC RESEARCH

by

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1. INTRODUCTION

Background

Department of Defense technical policy has been responding to the changing world situation by seeking to efficiently maintain the technological edge that has been enjoyed by the military while also enhancing the emphasis on domestic economic power. This has led to a major drive to increase the efficiency and effectiveness of defense technology expenditures, and to place strong emphasis on the conversion of defense technology to the private sector. A notable facet of this defense-sponsored technical research is that knowledge and insights are being lost as scientists and engineers retire. There is a need to archive this expertise in order to allow for a rapid response should military acquisition requirements increase in the future.

This contract was initially sponsored by the Office of Naval Technology (ONT) in 1991, when ONT was a parallel organization to the Office of Naval Research (ONR) under the Chief of Naval Research (CNR). There have been three adjustments to the Naval Research organization since then. These adjustments have integrated the formerly separate elements of basic research, exploratory development, and advanced technology demonstration into one organization, in order to conduct a more efficient and effective transition through these research and development stages. This latest organization retains the name ONR.

Research Transition

Increased efficiency in the two-way transfer of current knowledge between research and development is essential to maintain technological competitiveness. It has long been recognized that design engineers and engineering managers need access to recent findings from successful research in order to design systems that are up-to-date, and that the research community must be familiar with the engineering state-of-the-art so that research programs may be directed in the most appropriate manner. However, there is a need to improve the effectiveness of this technology transfer process.

Similarly efficient technology transfer is a critical element contributing to the success of small, commercial R&D firms such as NEAR. In particular, the ability to bridge a communication gap between researchers and engineers is crucial to efficient research transition. The objective of this contract was to develop a model based on the success of NEAR's research transition process and to extrapolate the process to the larger problem of technology transfer between 6.1, 6.2, and 6.3 in the Naval ship design community.

The problem of research transition was addressed with a twofold approach. At the Office of Naval Research, an organizational structure which improves contact between the 6.1, 6.2, and 6.3 communities was achieved through successive reorganizations. At NEAR, this contract addressed the complementary issues related to the varying technical perspectives of each community. A difficulty in technology transfer is that the objectives of one community often will not match the objectives of the other. This will result in communication difficulties, as the information provided by the one group will be inappropriate from the other group's viewpoint.

The research community and the engineering development community have different perspectives on technical knowledge. Typically, basic research topics are chosen based on a fundamental science issue in one specific discipline. A detailed, well-structured approach is used to investigate this issue. Research programs are also intended to provide long-term gains in a particular discipline. In contrast, the development community requires short-term answers, particularly at the conceptual design stage. Engineers work across many different disciplines, and they are accustomed to solving problems with engineering-level solutions which may only be indirectly related to fundamental principles.

The tools used by the research community are not advanced enough to be practical for the real-world problems faced by development engineers. The long transition time it takes for research results to become useful in design (up to ten years, in some fields) discourages members of the development community from actively seeking potentially beneficial research results.

A more formal communication process between research and development which establishes the relevance of a fundamental research topic can be beneficial, especially if it allows the development community to provide comments and feedback on research directions. There should be a means to identify gaps in the research base, or research that cannot be transferred due to its not being relevant to an engineering problem or due to an obstacle or roadblock. This approach is quite beneficial because the development community can see the value of research work and apply it to their own problems. There is a large amount of research knowledge available to development engineers; however, most of it is not relevant to an engineer's immediate concerns or is not presented in the context of a problem at the design level.

In this work, the problems with the varying perspectives of the research and development communities are addressed with an innovative communication tool. The use of a hypertext knowledge system for technology transfer between the basic research (6.1), exploratory development (6.2), and advanced development (6.3) communities is proposed in this work. The objective of this work is to relate research results to a relevant engineering framework, and to use this framework to present both the research and the design communities with information to facilitate research transition. This knowledge presentation system can be used by the engineering development community to access research knowledge that is relevant to a specific design topic and that has the potential for transition. In addition, this system documents the current status of design technology, which can assist program managers in directing research efforts towards those areas that will lead to improved analysis techniques or increased physical understanding at the design level.

The feasibility of producing a hypertext knowledge system for technology transfer was demonstrated during the SBIR Phase I contract (N00014-91-C-0144). An innovative knowledge acquisition technique was used to elicit information from experts in the research and development communities. This was based on an earlier finding at NEAR that in order for two disparate groups to communicate, a facilitating process is needed. This result is also applicable to larger organizations. The information obtained in these sessions was used to determine the differences in perspectives between the research and design communities, and the structure of the knowledge system was based on these differences.

The prototype system developed during Phase I contained knowledge about new research that might be relevant to design concerns, but its major emphasis was on the identification of research and technology roadblocks to the development of new design tools. The Phase II work continued the knowledge acquisition effort, and attempted to clarify the research transition issues that must be addressed to complete the system.

The technical subject of this work originated under the submarine propulsor hydrodynamics Research, Development, Testing and Evaluation (RDT&E) program, in which ONR plays a key role. The choice of the propulsor hydrodynamics program was based on its effective management, so that the organizational role of 6.1 to 6.3 could be clearly discerned. Another factor which governed this choice was that the program is high in military significance.

2. OBJECTIVES

The overall objective of this work was to develop a hypertext knowledge system for transferring technology from the research community to the design community, and for providing feedback from the design community to the research community. In order to accomplish this objective, an investigation was performed in order to determine how best to approach the current problems in research transition, how to acquire the necessary knowledge for the system, and how to structure and present the knowledge in a logical manner.

The hypertext knowledge system includes the knowledge needed for research transition as well as design information, for the purpose of creating links between design problems and new research and technology. The obstacles impeding the incorporation of new technology into the design process were investigated. Additional documentation of the design process was also planned for the purpose of storing design expertise for future engineers. The investigation of a process for storing design knowledge and expertise in order to archive engineering methods was a secondary goal to this research.

3. KNOWLEDGE ACQUISITION

Knowledge acquisition was a primary component of this contract. Knowledge had to be obtained regarding research and development activities related to submarine propulsor hydrodynamics, the design process and tools used, and how potential users of the system would like information to be presented.

During Phase I, a knowledge acquisition technique was used in which an "interrogator" conducted technical discussions with research and design experts and managers.¹ This technique has proven to be very useful in gathering "gateway" information pertaining to design issues and research and design roadblocks. This information was used to determine the issues that must be addressed by this system, and provided a guide to the more detailed knowledge that must be acquired by other means.

Several knowledge acquisition sessions occurred during the Phase II contract. The first series of meetings occurred in November 1992, when the Principal Investigator visited members of the engineering development community for the purpose of gathering general information about the hydrodynamics design process, discussing research transition roadblocks, and eliciting feedback on the hypertext system's knowledge structure.

Some of the more important points that arose from those sessions were:

- The structure of the prototype system developed under Phase I was not particularly useful to design engineers. That program dwelled on specific design requirements and constraints, which change from design to design. A more useful system would be a more flexible one that would be applicable to any design. The access to research knowledge is incomplete and does not provide the user with a motivation to employ that knowledge.
- The design engineers' preferred presentation order of research and technology knowledge is from applied to basic. For example, although an understanding of basic physics may be required in order to improve a prediction method, a user would prefer to access knowledge about prediction methods first, and then investigate the basic physics. A specific motivation is required to hold the user's interest.
- Roadblocks to research transition need to be prioritized, and it is preferable that they be ranked automatically based on user access.
- Code validation is essential for research transition, but there was a lack of long term commitment for code validation. Research goals and funding often changed direction before previous work was entirely completed. This seemed to be particularly true at the 6.2 level.

Further knowledge acquisition sessions occurred in March 1993. Those sessions were more formal than the first sessions, and they employed an "interrogator," whose function was to encourage and facilitate the discussion among the participants. During that trip, the Principal Investigator and the Interrogator conducted two days of meetings at both David Taylor Model Basin (DTMB) and Penn State Applied Research Lab (ARL). The topics of hydrodynamics, hydroacoustics, and structural acoustics were discussed with design engineers. These meetings were instrumental in determining the engineering state-of-the-art in propulsor design, and in obtaining a perspective on the research transition problem from the designer's viewpoint. The results from these sessions are discussed in detail in the following section.

A final series of formal knowledge acquisition sessions occurred in June 1993. In these meetings, 6.1 program managers were brought together with propulsor designers. The intent of the meeting was to investigate the fundamental issues underlying the research transition problem.

Three premises were offered by the interrogator as to why there is a research transition problem:

- (1) Research topics are not relevant to the design community.
- (2) Research topics are relevant, but the performance of the research does not lead to useful results.
- (3) Research transition is not adequate.

One of the purposes of these meetings was to determine which of these premises were supported by participant's opinions, and to illuminate the communication issues in research transition.

The first premise received only limited support from the 6.3 participants, but much disagreement from the 6.1 representatives. There were conflicting perceptions of the value of the 6.1 program to the design community. The statement of the first premise had to be qualified with regard to specific instances before it was accepted by any of the participants, thus indicating that this premise was not valid, in general.

The second premise can be interpreted broadly. None of the participants offered the unqualified view that the research performed at universities is poor. However, there were opinions to the effect that universities have different motivations, thus their work is not focused on design needs. Several participants expressed the prevailing view that 6.1 work need not, by nature, be immediately useful to designers, but that it needs to transition through a 6.2 level first.

The third statement received the most support. In particular, the main problems were: (1) poor communication between groups, (2) the long time scale for useful transition of basic research, and (3) the lack (in the past) of a transition mechanism at the 6.2 level. Much emphasis was placed on the feedback of information from 6.3 to 6.1.

Overall, these meetings were very useful in further defining the issues in technology transfer. These meetings covered topics in both the conceptual design and the detailed design of propulsors. Thus, the topics covered were of a more practical nature than the topics covered during the Phase I knowledge acquisition sessions.

The knowledge acquisition process employing the "interrogator" has been proven to be successful in eliciting certain types of information. However, this method must be combined with other knowledge acquisition techniques in order to obtain the full suite of knowledge that will be included in this system. In particular, the interrogator sessions are not useful for acquiring detailed knowledge about the design process, tools used, or the flow phenomena of interest. This is because it is too time-consuming to cover many details during these meetings, the experts find it difficult to recognize all of the information needed during an oral interview, and the experts need more tangible prompts for information than those they get during an oral interview.

A few additional meetings were held with members of the design community in order to gather detailed information about design methods and tools. However, the task of gathering complete knowledge for the hypertext knowledge system was not finished during the limited time frame of this contract.

4. DESIGN TECHNOLOGY STATE-OF-THE-ART

During the knowledge acquisition sessions, an attempt was made to document the current status of design technology in propulsor hydrodynamics and hydroacoustics. Most of the information elicited during these sessions concerned the conceptual design process in particular. It was found that the level of technology actually used by designers for real-world problems is far removed from that used at the research level. This is particularly true for hydroacoustics design technology, which lags behind that of hydrodynamics.

The dominant theme that came out of discussions on the conceptual design process is that experience is essential to design, and that no amount of formal education can substitute for personalized experience. There is great concern over the fact that experienced engineers leave or retire before they transfer sufficient expertise to younger engineers. The experiential wisdom accumulated and stored by humans cannot be transferred through the publication of formal reports.

In this section, some of the results from the knowledge acquisition sessions with designers are described. These results are derived from information obtained from the transcripts of these sessions.

Empiricism and Experience

At the time of this study (1993), designers still relied heavily on empiricism for physically complex phenomena, particularly for hydroacoustics. Although there was a large-scale effort towards developing numerical prediction tools, these methods either had not been sufficiently validated for use at the design level, or they still required a designer's experience in order to evaluate the results for accuracy. Even in cases where a prediction method can be used to identify a potential design problem, the designer's experience is essential for determining a solution to the problem.

In many instances, designers might have a physical understanding of a particular flow phenomenon, but they would not be able to predict the effects of specific parameter variations such as geometry changes or scale effects. In those cases, they must rely on empirical data. For example, effects such as tip vortex cavitation depend upon variations in the tip loading and in the geometry near the blade tip. Since there is no satisfactory prediction method that can account for these variations, designers will not have confidence in a design unless its parameters fall within an existing experimental database.

There is room for improvement in the understanding of scaling effects. A chief concern regarding the use of empirical methods is that most data is taken at model scale. Scaling adjustments have to be made to the information in the database, but the necessary adjustments may not always be known. For example, designers are comfortable predicting powering performance and inflow using model scale data as long as the experiments meet a certain Reynolds number requirement. However, designers do not feel confident predicting cavitation phenomena using model scale data since cavitation phenomena and shapes at full scale may be different from those at model scale.

The hydroacoustics community has not been systematic in studying geometry perturbation effects on acoustics, and existing knowledge tends to be anecdotal in nature. Due to insufficient empirical data in certain areas of hydroacoustics, a designer's best option is to rely on personal experience. Experience is also essential to anticipate when certain groups of parameters may either individually or collectively be outside the limits of a database. Correction factors to empirical databases may not exist, so if there are large-scale excursions from known data, then experience is required to handle departures from that database. For example, the acoustic performance of a propulsor can be determined as long as the configuration and the noise goals fall within a known parameter range. The geometry and the performance are correlated using a database, and semi-empirical rules are used for handling small deviations from the parameters in the database. The rules are only semi-empirical because they incorporate simple dimensional analysis.

Hydroacoustics designers use experience and rules of thumb to associate the number of blades, the thickness of the blades, and the relative velocity at the tip with acoustic performance. Empirical data is used in describing the unsteady inflow into the rotor, the trailing edge flow noise, blade rate noise, and the low frequency turbulence ingestion noise. Measurements are also the only source for obtaining the spectrum of the turbulent scales used for estimating the turbulence-induced rotor forces. Since equations cannot be used to describe or predict these phenomena, empirical factors are required.

Shortcomings in Physical Understanding

Although hydrodynamics designers have a good understanding of the flow field under straight-and-level conditions, they need to have a better understanding of unsteady effects and Reynolds number effects. Complex, three-dimensional flow phenomena are also not well understood. Some of the flow phenomena that need to be better understood are blade/boundary layer interactions, vortex stretching and intersection of vortices, and the inflow, tip vortices, and cavitation on the blade. This lack of understanding affects the designer's ability to make accurate predictions.

Scale effects take on prime importance, since most experimental data is at low Reynolds number. If the scaling effects are not known, then model-scale data cannot be used to validate high Reynolds number prediction methods.

In acoustics, sometimes the parametric dependence of a phenomenon is not known. Unknown factors may include: whether an excitation causes a response, which response causes a noise, and whether a structure is being excited or is being driven directly. Phenomenological experiments that address these issues are lacking in hydroacoustics.

A lack of knowledge regarding temporal and spatial variations of surface pressures presents a problem for hydroacoustics designers. Since the unsteady pressure data is sparse, they cannot accurately determine the response. In principle a designer can start with a stress distribution and use it to compute the noise. However, that would be a tremendously difficult problem because of the range of frequencies that must be handled, and the need to know all of the inflow's temporal and spatial characteristics. Designers lack the knowledge of how the inflow will interact with the flexible structure and how the structure responds and radiates noise. There is a mismatch between the wavenumber

content of the fluid and the wavenumber to which the structure tends to respond. This needs to be better understood and treated, and is among the many improvements and changes in process that are currently being pursued.

Design Codes

The hydrodynamics design community uses engineering-level prediction codes for the design effort. Since interaction effects are important, designers need to evaluate the entire configuration rather than analyzing or looking in a database for each component separately. Although computational fluid dynamics (CFD) may be used for single component analysis, it has not evolved to the stage where it can be used for multi-component design.

During the early conceptual design process, the prediction methods that could be used include lifting line, lifting surface, and streamline curvature. A three-dimensional lifting surface method with hub and tip boundaries is the most sophisticated code likely to be used in conceptual design. These methods would mostly be steady, but unsteady calculations are occasionally performed. Preliminary hydrodynamics design codes take as input the number of blades, the chord distribution, and the required performance. The codes iterate on the loading distribution, and output a geometry. Most numerical techniques used to predict performance based on hydrodynamic drag or cavitation are also limited to inviscid models, with the viscous effects included empirically.

Conceptual design tools are adequate for designing for efficiency and cavitation goals. However, for more detailed design, unsteady forces still cannot be predicted accurately. Other difficult areas are the higher harmonic contents of the flow, turbulence ingestion, viscous flows, treatment of the gap area, and juncture flows.

There are no good tools for designing to a hydroacoustics noise goal. Hydrodynamics designers must provide information about the flow field to the hydroacoustics designers. In order to provide the acousticians with the unsteady forces for an open propeller, hydrodynamicists use an unsteady lifting surface program along with measured wake surveys. Alternatively, the wake can be predicted using lifting surface theory models. These methods all use potential theory.

During the conceptual design process, the hydroacoustics community mainly uses database information and perturbations from the database. In principle, designers might be able to do a more detailed analysis, but in practice, it would take too long and might not be accurate. There are too many parameters that affect the energy exchange from flow to sound. Designers do not know enough about these parameters to formulate a generalized design tool that eliminates a designer's experience factor.

Hydrodynamics designers believe that the state-of-the-art is very far from providing a general design tool that will mitigate the requirement for an experienced designer. The more sophisticated the design tool (e.g. statistical energy analysis), the more experienced the user must be to determine whether the output is accurate. There are engineering determinations that have to be made at each stage, and these determinations have to be made by a knowledgeable designer. Although there is major work ongoing in this area to

automate the design process, there is still an enormous amount of effort required before complex designs can be done this way.

Analysis Codes

For analysis, the design community is just beginning to use unsteady viscous flow theory. They are going straight from potential theory to Reynolds-averaged Navier-Stokes (RANS) solvers, without taking the intermediate step of combining potential theory with boundary layer theory. Although Navier-Stokes solvers are not used as a design tool, they can help the design process when there is some iteration between the analysis and the design.

A lack of understanding of acoustic phenomena prohibits most numerical modeling efforts. Thus, CFD has not developed to the point where it can be used to perform systematic parameter studies in acoustics. Currently, CFD codes have not been validated for even simple cases involving temporal and spatial unsteady pressure distributions or wavenumber/frequency spectra. They can use some results from steady-state CFD, collapsing the steady-state parameters to back out the unsteady spectra.

Hydroacoustics designers are trying to gain experience in the use of CFD. They do rely on predictions or measurements of the displacement thickness and trailing edge wake. Relevant quantities that they would like to predict for acoustics in the future are kinetic energy level distributions, boundary layer thicknesses, wall shears, separation zones, static pressure distributions, and wake defects. There currently is a development effort to consider these acoustically relevant parameters, to determine empirical functions for them, and to use finite element codes that couple fluids and structural dynamics to make acoustics predictions. There is also an effort to extend finite element methods to handle higher frequencies.

A shorter time period for conducting a Navier-Stokes calculation would help these methods become more widely used in the design process. Although run time is an obstacle to the widespread use of Navier-Stokes codes in the design process, another major bottleneck is the set up time for gridding and code input. Also, any new code must be validated and have calibration studies performed, and that work is often lacking.

Designers find it difficult to trust RANS results. The RANS experts often do not even know whether their results are accurate. A designer will be confident that a solution is accurate only if it is confirmed by a result from experiment or by experience.

5. RESEARCH GOALS AND PLANS

During Phase II, the knowledge acquisition sessions with the research community were not as thorough as those with the design community, since many research topics sponsored by ONR were discussed earlier during the Phase I work. The differences in goals between the research community and the design community became apparent during the Phase II discussions. This section summarizes the results of the knowledge acquisition sessions regarding the research program at ONR.

The goal in the 6.1 community is to uncover fundamental physics that have not been recognized before, and which will have an eventual impact on applied research and on development and design activities. The time frame before successful transition to design activities can occur was recognized to be on the order of 5-10 years. Evidence of this time frame can be found by identifying the 6.1 roots of ideas that are currently being used at the 6.2 or 6.3 level. Unfortunately, the 6.1 origins of many applied concepts become diffused with time, so that they are difficult to recognize as such.

Research Objectives

There are two aspects to the research objectives pursued by the 6.1 program at ONR. One of the goals of basic research is to ensure that fundamental science issues are being investigated, rather than technology issues. This is a challenging area; even the basic research community has recognized the difficulty of identifying the appropriate science issues behind a designer's problem. Another aspect to good research is that the work should eventually result in something useful, such as a tool to help designers do their jobs better. This tool can include greater knowledge and understanding of a physical phenomenon, as well as improved prediction capabilities.

Although it is important for the 6.1 community to look far downstream, they also have to be concerned with the current needs of designers. A mix of work is funded with different payoff time scales. The ONR program managers try to ensure that the Principal Investigators (P.I.'s) are on the right track with respect to Navy goals. ONR sponsors meetings in order to review basic research and to solicit Navy opinions regarding the directions that researchers are pursuing.

One problem facing the 6.1 program managers, in regard to addressing designers' concerns, is that the technology available to the P.I.'s is inadequate for producing immediate answers to real-world problems. The scientific community does not have the technology to achieve a full-scale Reynolds number in the lab or the ability to accurately compute a particular flow field in detail. Thus, much of the foundation work at the 6.1 level does not appear to be immediately useful to the design community, even though it is absolutely necessary.

Current Research Areas

There are several areas of ONR-sponsored research that are relevant to propulsor hydrodynamics. One area under investigation is the mechanism of cavitation inception. This topic is relevant, and it also illustrates the dichotomy between the goals of the design community and the goals of the research community. Designers need to predict cavitation inception, and to do that, they need to understand the phenomena in macroscopic terms. For example, a limitation in the design of supercavitating propellers in a certain speed range is the inability to predict when a cavity will break off from the leading edge of a blade.

However, the approach taken by the research community is to investigate the microscale events that lead to cavitation. As a basic science issue, researchers must discover the microscopic event that causes a cavity to first attach. Once this is accomplished, then a

model built from this event can be used as a basis for a prediction method. Researchers are attempting to discover whether an individual nucleus comes from upstream and gets trapped in a recirculation or a roughness, or whether it is already imbedded in a crevice. They are trying to determine the mechanism by which a cavity starts. This is very far removed from a designer's viewpoint.

In other technical areas, recent advances in computational hardware are allowing old problems to be reexamined in greater detail. One such area is turbulence modeling. ONR sponsors the study of nonequilibrium turbulence, which includes such complex phenomena such as pressure gradients, curvature effects, and three-dimensional effects.

There is little or no emphasis on developing computational tools for specific flows, e.g., the flow about the trailing edge. However, research into computational turbulence simulations is being supported. Direct Numerical Simulation (DNS) of turbulence is supported, and this technology has revealed much about the basic physics in turbulent flows, despite its drawbacks and limitations.

Work in the field of Large Eddy Simulation (LES) could have long-term benefits, in terms of producing a better prediction method for turbulent inflow. LES has brought about advances by increasing the Reynolds number range for unsteady turbulent predictions, but its greatest limitation is the treatment of the wall. LES research is heavily supported by ONR, and it is anticipated that it can be useful to applied engineering areas within five to ten years. In particular, it is hoped that within five years this work will allow better Reynolds-averaged Navier-Stokes (RANS) turbulence models to be developed, by providing more detailed information about the flow field. There is an emphasis on higher and higher Reynolds numbers, and an objective is to achieve LES capabilities at the model-scale Reynolds numbers that are currently being used for tests. In the long run, it is planned that LES will replace RANS.

ONR also supports research in Reynolds-averaged modeling in complex flows. Although RANS can be considered an applied method and thus should have high transition potential, it has yielded disappointing results to date. This is probably because too much emphasis in the past was placed on low Reynolds number coherent structures, and those results are not applicable to engineering problems at high Reynolds numbers.

In addition to the research in computational methods and modeling, there are several topics in turbulence that are currently under investigation. Knowledge of the turbulence ingestion into a propulsor is incomplete. Also, the turbulent boundary layer has not been solved yet. Current research is in three-dimensional flows, since two-dimensional flows are not useful in the long run. Although three dimensions is more complicated, it is also more applicable to the real world. Scientists currently cannot handle real-world rough wall effects at high Reynolds numbers.

Experiments are being conducted to investigate scale effects in hydroacoustic phenomena. Advances in high Reynolds number, high quality flow wind tunnels will allow basic research work in turbulent flows.

Comments on Research Programs

During the knowledge acquisition sessions, several comments regarding ONR's 6.1 program and its perceived usefulness to the design community were made. One of the major problems with research transition is the long time periods involved before a research topic becomes developed enough to be useful as an applied tool. This time period presents two problems. The most obvious problem is that the designers have to wait a long time for new technology. The second problem is one of perception. When transition does occur in 10 years or so, 6.1 will not get the credit because the results are diffused over time. People will not remember that 6.1 was the originator of many concepts.

The opinions relating to the time scale of research transition were varied. On one end of the spectrum was the view that it is not necessary for all research to be perceived as relevant by everyone in the design community, because some research is long-term and will not be relevant to current designers. The other viewpoint expressed was that the 5-10 year payoff for research transition demonstrates a disparity between the 6.1 interests and the present needs of designers. Although the need for ONR to support both long-term and short-term research was mentioned, there were disagreements about whether short-term issues are fundamental enough in their nature to be considered part of the 6.1 mandate.

The need for immediate relevancy of 6.1 research programs to the design community was debated. Historically, an important aspect of 6.1 research is that it contributes to a pool of general information. If the funding climate changes so that all 6.1 work must be specifically tied to 6.2/6.3 problems, then that precludes the ability to sponsor research that is not obviously relevant at present, but may become relevant in the future. All 6.1 work (and also 6.2) should not have to lead to useful results, since it should, by its nature, be high risk. However, due to changing priorities at ONR, in the future there will need to be a higher end-use payoff from 6.1 than there has been in the past. Ideally, ONR should fund a mixture of directed and undirected research.

The types of research organizations and personnel that should be supported by ONR 6.1 were debated. In particular, the differences between universities and Navy-supported labs were discussed. The ONR research managers believe that the university atmosphere is more conducive to basic science research than a Navy lab. Proposals in the 6.1 area from the labs are often not perceived to be at a fundamental science level, so they do not get supported. Although the labs can identify the relevant issues regarding the design process, they may not be able to produce a proposal at the appropriate 6.1 science level. By ONR's definition, science is not strongly related to the pragmatic solutions that designers want. ONR's definition of science includes well-structured, analytical approaches, which are far removed from the design world.

The 6.1 program managers did not believe that having graduate students perform 6.1 work contributes to the long time-scale problem in research transition. Conversely, research programs defined by ONR are meant to have a longer time scale than the average Ph.D. program. However, universities are perceived to be isolated from the design world, and their goals and compromises are different from those of designers. Although the academic community is not perceived as being able to deal with real-world problems, the fault lies more with the current state of technology than with the university environment.

In general, it was agreed that there is nothing wrong with researchers and designers having different talents to apply to different types of problems. Rather, it is a necessary element for getting the job done. Although it is true that by its high-risk nature some 6.1 work is never going to be relevant, that is not something that can or should be avoided. Choices are made based on the current perceptions of the unknowns, and there is no way to predict those unknowns correctly all of the time.

6. TECHNOLOGY TRANSFER CONCEPTS

Most of the issues investigated related to technology transfer can be traced to a problem with communication. This communication should be two-way: researchers must transition their results to the design community, and designers must provide feedback about their needs to the research community. At the time of this study, a means for facilitating this communication process was lacking. Although there have been attempts to bring members of one community to planning and review sessions in the other community, these efforts often did not bring about their intended result.

Many comments made by designers regarding the lack of relevancy of 6.1 sponsored work stemmed from a lack of communication. This perception originated from the practice of describing 6.1 work without including a statement regarding the work's relevance to a design problem. Communication channels did not exist by which the 6.1 managers could explain to the designers how a research program was a necessary building block to the solution of a design problem. The critical channel by which a designer could provide feedback regarding their problems to the research community was also missing. Designer reviews for the research community were recommended.

Research Transition from 6.1 to 6.2 to 6.3

The research transition problem is commonly thought of as consisting of the transfer of knowledge from the research community to the design community. The flow of knowledge from 6.1 to 6.2 to 6.3 is considered in this section. During the knowledge acquisition sessions, problems with research transition and possible solutions to the problems were discussed. These problems and potential solutions are described here.

Two possibilities were mentioned as to why research performed at the 6.1 level might not easily transfer to 6.2 and 6.3. Research at the 6.1 level is mostly performed at universities, and neither graduate students, with their desire to complete a degree program within a specified time frame, nor professors, with their pressures to publish, are allowed to report a negative result. Thus, the research topics chosen by the academic community tend to be conservative, with a greater perceived probability of success. As a result, research may be focused more on simplified situations, and may avoid real-world problems which might not be tractable within a short (2-3 year) time frame.

A second problem with the research being performed in a university environment is that the academic community is generally removed from the real-world issues concerning the Navy. The requirement that the description of the problems and the results be in the

public domain (unclassified) may prevent university researchers from performing relevant work. There also might be a long inception period before a research center is brought up to speed in a relevant technical area.

Although university researchers could be briefed by Navy personnel, this probably would not solve the problem. Navy researchers would not be able to discuss classified material, and outside researchers would not understand the Navy perspective. People tend to view subjects from their own perspective, and if university people are far removed from the design world, they will not have the ability to clearly see the relationship between basic research and a design problem. ONR's efforts to integrate the 6.1-6.3 communities may improve this situation, if given enough time.

Although these issues are important, the quality and relevancy of research were not thought to be the main obstacles to research transition. Rather, the time frame for transition to occur and the path that the research takes after it leaves the 6.1 community were thought to be more critical issues.

The lack of validation for research concepts is another major obstacle to research transition. Scientific results must be developed to the stage where they can be applied to problems by other users. If the science community stops at just coming to an understanding of a phenomenon, it has not produced anything usable by the Navy. Some of the validation responsibilities lie within 6.1, but much of the work has to be done at the 6.2 level, since the 6.1 community does not have the appropriate resources. This responsibility can be divided so that validation of physics is a 6.1 issue, while validation of concepts and codes is a 6.2 issue.

The design community will accept new ideas, but only if the ideas are properly communicated and if the intermediary work is done to validate and extend the 6.1 research to the point where a designer can use it. However, the design community will not trust 6.1 results in a real-world situation if the research it is based on uses an idealized situation or configuration. This issue also applies to codes that may have been validated in a context other than that for which a designer would use them. Two-way communication between code developers and code users is particularly important in the area of validation.

The peer review process in 6.1, via refereed journal articles, is necessary to uphold the technical quality of basic research. However, a problem is that the reward system in 6.1 is based on the number of papers published. This problem is one of degree, not of concept. There are too many papers published on a range of topics that is too narrow. From the designers' perspective, technology transfer through literature sources is a major roadblock to research transition, because designers feel they often do not have enough time to keep up with the published literature. Another problem with transferring 6.1 results through journals is that some useful information does not get included; for example, mistakes, failures, and alternative methods tried. Negative results need to get more exposure, and validation of results is often missing, even from 6.2 papers.

It is much easier to transfer relevant information by discussing topics face-to-face than by reading papers. However, this approach can create difficulties if two parties attempt to communicate without having similar agendas. The success of meetings depends on the

individual personalities, since some people can naturally span the gap between 6.1 and 6.3, and others cannot.

Another obstacle to research transition is the mismatch in objectives between the design community and the research community. Designers have to work in an interdisciplinary environment, and they have to deal with trade-off situations. Propeller design is an art, in the sense that some of the things designers are concerned with cannot be reduced to a set of equations. Designers can work without knowing all of the detailed mechanisms. This perspective differs substantially from the research community's perspective. Science is concerned with detailed mechanisms, and a researcher in the 6.1 community typically works in a single discipline. Although advances in a scientific discipline should provide relevant information for design, a designer's perception of the usefulness of that research may be influenced by the narrow focus of that research.

An alternative approach to research transition is to modify the design process rather than the research environment. There might be an innovative way to change the design process so that it makes better use of the products of research. Technology coming from an unanticipated direction might be able to allow designs to be created in a way that includes more science.

ONR has recently implemented vertical integration of programs, with the intention of improving technology transfer. Vertical integration within management is necessary for reviews and program determinations. This integration can also be accomplished through the close association of a lab and a university. The relationship between ARL and Penn State University is a good example.

The implementation of vertical integration must account for the problems that might arise if the programs are unable to function independently. For example, scheduling difficulties will arise if the 6.2 community is ready to begin work, but the 6.1 community has not completed its results due to the problem being more difficult than originally thought. Consideration must also be given to resolving the differences in objectives between the two groups, otherwise it is possible that forcing the separate communities to work together will result in the groups agreeing on how they are going to disagree. A final issue affecting the implementation of vertical integration is that technical merit cannot be overlooked. Basic research as such cannot survive if a prerequisite for all work is approval from the 6.2 and 6.3 communities.

ONR needs to emphasize the value and relevance of work produced by 6.1, in order to increase the motivation to employ existing basic research results in design. Currently, ONR uses the 1498 guide to describe ongoing research projects. However, further filtering of the contents may be required before the 1498's become truly useful. A summary of the important results contained within the book, with special emphasis on relevance and transition potential, would make the guide more attractive to the design community.

The research transition process should involve the mingling of personnel from the separate communities in order to accomplish an expertise mix. This would require that each community be willing to lend its personnel to the other community, to ensure that their work will get the necessary exposure. A good example of this interactive approach was the

Hydrodynamics Coordinating Group. Their approach successfully integrated input from 6.1, 6.2, and 6.3 to identify science issues in hydrodynamics.

Currently, there is insufficient time and funding to achieve an adequate mix of personnel. A provision is needed for a design consultant to work with 6.1, or a 6.1 consultant to work with 6.3. These consultants would need to be involved from the start of a project, they need to be motivated to make it successful, and the process should involve formal commitments for funding and time.

The Hydrodynamics/Hydroacoustics Technology Center (Tech Center) is intended to bring the research and design communities together to shorten the transition time frame. At the time of this study (1991-1993), the Tech Center had fallen short of that goal. However, with the proper support, it is possible that the Tech Center's task of creating an integrated design facility and maintaining certified software will improve transition. It must be realized, however, that the codes that will reside at the Tech Center are just tools, and will not contain the entire design knowledge base.

Feedback from 6.3 to 6.2 to 6.1

An important component of technology transfer for research transition is the feedback of important issues from the design community to the research community. Without this feedback, the areas targeted for research sponsorship will not be relevant to design concerns.

It is difficult to identify issues in basic science that stem from problems in the design stage. ONR 6.1 requires that the basic science issue be defined before sponsoring research in an area. However, in some instances the designers cannot formulate their problems in such a way as to make the underlying science issues clear. Designers are able to identify deficiencies in the design process, but they often are unable to determine the science issues since their experience is better suited to devising engineering solutions to problems.

Another difficulty is that the definition of science problems is subject to a difference of opinion. Science issues in the opinion of the 6.3 community will probably be considered technology issues by the 6.1 community. Particularly in hydroacoustics, the design community is accustomed to thinking in terms of parameterization studies and anecdotal events, and this makes the identification of science issues even more difficult.

Hydroacoustic phenomena are very complicated and multidisciplinary. If a phenomenon cannot be predicted, it is difficult to know whether the problem is a lack of computational capability (6.2 level), or whether there is some physics missing from the algorithms (6.1 level). If some physics is missing, it is difficult to identify the missing element. One method is phenomenological testing, but that is time-consuming, expensive, and may not yield the true nature of the physics.

An additional problem that arises from the lack of feedback from the 6.3 community is that the people who evaluate 6.1 proposals might not realize how immature a particular technology is. They might think that the propulsor design process is mature, but in actuality, there is a lot of "art" required. There are so many unknowns associated with

propulsor hydrodynamics that there are only a handful of people in the country that completely understand the problems. Unfortunately, these designers cannot express their problems in terms that would provide 6.1 researchers with appropriate information.

There have been attempts to invite designers to comment on ONR-sponsored research programs. However, some of these attempts in the past have not been successful. There were several actions that can be taken to better ensure success in this area. First, prior to the meetings, it should be made clear to the design community why they should participate and what their role should be. Before the fact, there must be adequate communication regarding the purpose of the meetings, and the invitations that are issued to designers must provide the proper background. If members of the design community perceive that the 6.1 review meeting is to be made up solely of university researchers, with little participation from the Navy, then there would be little motivation for them to attend. The desire to obtain feedback from the design community must be properly communicated. The design participants must feel that they will have influence on the outcome of these meetings, and that they will be able to articulate their needs.

One issue that must be resolved is the stage in a 6.1 research program at which the design representatives should provide input. Early in a research initiative, the 6.1 program managers might feel that the effort should concentrate on fundamental issues. They believe that feedback is more desirable in the later stages, when problems of a more applied nature are studied. However, the design representatives feel that they would have insufficient influence on a program that has been ongoing for a few years. If the decision about what to fund under an initiative is made without their input, then they might not agree that the topics are relevant from the design viewpoint. The role of the engineering community must be made clear early in the program, so that designers do not get the impression that design directives were added to the program as an afterthought, years after the program was underway.

A design consultant to a research initiative should understand the work being done, should know who is getting funded, and should have the authority to get the researchers to change direction. Another necessary component of this idea is that the 6.2 and 6.3 people should have a professional stake in what is happening in 6.1 and in the transition between research and design. The benefits of the 6.1 research need to be made clear to the design community, and there should be a program in place to assist design projects until the new results from 6.1 are made available.

7. HYPERTEXT KNOWLEDGE PRESENTATION SYSTEM

The innovative approach taken in this work is the application of a hypertext knowledge presentation system to technology transfer. Hypertext knowledge systems have the potential to overcome the communication problems of knowledge presentation, knowledge filtering, and knowledge availability; therefore, a prototype system was developed to illustrate the use of these systems for improving technology transfer between the 6.1, 6.2, and 6.3 communities. In particular, it was demonstrated that a knowledge presentation system could be used to address the issue of different technical perspectives between disparate communities.

Hypertext systems are computer programs that can provide information in a nonlinear fashion. They can be programmed to link various topics in a way that models the topics' logical relationships, and these relationships form a knowledge tree. Hypertext knowledge systems may also support various search facilities, and can present information at different levels of detail or with a different emphasis depending upon the needs of the particular user. Their contents are easily updated as new information becomes available, and are easily reproducible and accessible, as most systems can run on a desktop computer.

The primary emphasis of this approach was on the knowledge presentation. A properly designed presentation ensures that the appropriate context for the knowledge is available, dependent upon the user's needs. If the user is in the engineering development community, basic research knowledge must be presented in the context of development efforts, so that only relevant research results are presented once a development topic is identified. For users who are research program managers, the system must identify and prioritize any inadequate analysis techniques or insufficient physical understanding at the development level, so that the focus for future research efforts may be determined. This approach allows knowledge to be perceived as useful and relevant to the user of the system, and links development problems with research that has the potential for transition.

The versatility of the hypertext interface allows for a logical presentation based on a particular user's needs. Different levels of detail can be accessed; for example, a nonexpert may require features such as a technical glossary or basic engineering code descriptions. Information search facilities can accommodate users who wish to directly locate knowledge about a specific topic, or users who wish to browse through a path connecting several topics that are related. By including a wide variety of information in one source, a hypertext system can overcome issues of scheduling conflicts, goal conflicts, and personality conflicts that present difficulties with interpersonal communications.

Two-way communication is an essential element of a research transition hypertext system. Both the research and the engineering development communities provide expert knowledge about their own areas, and they are also recipients of the other community's knowledge. The technology transfer system contains this knowledge from both the research and the engineering communities. The differing viewpoints of the two communities are used to determine the context and knowledge structure in the system, to determine problem areas from either recipient community's viewpoint, and to identify relevant information from the providing community.

The knowledge in the system is obtained from written publications as well as from oral interviews. The system's potential users are also asked to check the system for accuracy and to provide feedback on the organization and presentation of the system.

Prototype Structure

The prototype hypertext system was designed to link research knowledge with state-of-the-art design technology. An information framework was developed so that research knowledge could be related to design requirements and methods. This structure allows a user to access a description of design technology in order to learn about the current status of

development tools and about the most useful direction for further research. Alternatively, a user who is already familiar with this knowledge may identify a specific design technology problem as a means of then accessing research information that is relevant to that problem.

The research knowledge in the prototype system is presented in the context of a particular aspect of the design process. This knowledge is structured so that it will be relevant to a designer's concerns. In the field of hydrodynamic propulsor design, control of the flow field is a primary concern of designers. Research results in flow control, ranging from new propulsor concepts and configurations to small-scale control schemes, are presented to the user. Designers are also concerned with the improvement of design and analysis tools and with understanding the flow physics. Further research results are presented that provide relevant background knowledge and have the potential to advance the state-of-the-art in prediction techniques and physical understanding.

The hypertext knowledge system developed in this work, named TRACKS (Transitioning Research: An Accessible Knowledge System), contains both a vertical and a horizontal structure. The vertical structure follows the path described above, from applied information to basic knowledge. This chain of information is presented in the following order:

- A. General Topic
- B. Technical Issues and Drivers
- C. Design Capabilities
- D. Flow Control Issues
- E. Prediction Methods
- F. Interactions/Cause-and-Effect (for multiple phenomena)
- G. Basic Physics (individual phenomena)

The General Topics provide the horizontal structure, and they cover the broad topics of design requirements. The General Topics under propulsor hydrodynamics are:

- 1. Efficiency and Powering Performance
- 2. Maneuvering and Off-Design Performance
- 3. Hydrodynamic and Hydroacoustic Signatures
- 4. Overall Configuration
- 5. Detailed Configuration

Under each topic, the vertical structure from design to research can be followed. First, the user accesses the technical issues and drivers relevant to the general topic. These issues and drivers may consist of relevant hydrodynamic phenomena that must be addressed in some fashion by a designer. Other issues might be performance specifications or specific propulsor component flows.

Once the user identifies a technical issue that is relevant to his problem, he can then access information on design capabilities. This knowledge will include the methods currently available to designers to address the associated technical issue; these methods could be empirical correlations or design-level prediction codes. This section may also include the goals of the design process, as well as how present-day designers meet those

goals. Potential areas of improvement, as well as roadblocks to the achievement of those improvements, will also be documented. The current status of the validation effort for each new design concept will be provided.

These first three levels of the system allow a user to identify a specific problem that needs to be solved. This is necessary so that research and technology knowledge can be targeted specifically for the user's problem. The following four levels of knowledge in the program are the research and technology knowledge structure. Flow Control Issues refer to technologies to control the flow field, such as the geometric configuration or some other means. Prediction Methods consist of computational analysis tools and associated issues. The description of basic flow physics is divided into two levels: interactions between multiple phenomena and the physics of individual phenomena.

For each of the four topics in the research and technology knowledge structure, information is provided in four areas: (1) state-of-the-art in the technology, (2) future work that is currently planned, (3) description and status of validation efforts, and (4) roadblocks to future results and also to the transitioning of technology to the next level (e.g., roadblocks to transition the knowledge of basic physics to the development of new prediction methods).

A preliminary outline of the research transition knowledge structure is given in Appendix A. This outline is based on the organizational work performed by the Hydrodynamics Coordinating Group at ONR. The knowledge structure is applicable to propulsor hydrodynamics and hydroacoustics design, and is intended to outline a complete system. However, the prototype system that was produced during this work includes only a subset of this knowledge structure. The prototype system is limited to the straight-and-level performance of single-stage propellers. An outline of the prototype system is given in Appendix B.

Due to the limited time available to complete the prototype system, most of the effort was directed towards context development and the knowledge framework. The specific technical knowledge contained within the developed framework is incomplete. It should be noted that due to the complexity of the knowledge framework (Appendix A), the complete documentation of the knowledge in the system would require a great deal of effort.

Additional Features

In addition to the research transition knowledge structure described above, TRACKS includes other program features designed to assist the user in searching for information, in changing the level of detail of the presentation, and in updating the knowledge content. The facilities developed for the prototype system are described below:

Links

If the current topic is strongly related to a topic on a different branch, then the user will be able to access the knowledge on the related topic as well. These horizontal links allow a user to examine a subject area from different technical viewpoints. For example, the subject

of cavitation written from the different perspectives of straight-and-level performance, maneuvering performance, and hydroacoustic signatures can be compared.

Path

This facility displays the path taken by the user since entering the program. Any topics previously viewed can be revisited from the menu presented in Path.

Codes Compendium

This facility provides information related to specific codes used by propulsor designers. For each code, the compendium should cover the limitations of the method, the physical assumptions made, the experience or knowledge required to use each method and to determine the accuracy of the results, and expert suggestions (intuitive or heuristic) for physical checks that can be used to validate the results from that method.

Index

If a user has a specific topic in mind and does not want to follow a long chain of information to find that topic, he may go directly to the topic after locating it in an index or on a knowledge tree branch (displayed upon request). The index may contain subjects that appear in multiple locations in the program. In that case, all references to that subject are listed, and the user may choose which reference to examine.

Location

At any point in the program, the user can find out his location on the knowledge tree.

Help

This facility is intended for users who do not have a detailed technical background in the topic areas. A basic definition and description of terms relevant to the technical topic are provided. Currently, the help topics are divided into seven areas:

- (1) acoustics
- (2) computational methods
- (3) experimental techniques
- (4) geometry
- (5) hydrodynamics
- (6) materials
- (7) structures

Comments

For every topic addressed by the system, the user has the opportunity to add comments to the knowledge provided. These comments may be used to correct the knowledge content or to add additional information relevant to a topic as it becomes available. This is a useful facility for updating the information in the system. Comments

provided by individuals are identified by author name and date. Previous comments may be viewed by any user. It is envisioned that as the comments for a particular topic become extensive, a committee of experts on that topic will incorporate the remarks into the main text. This provides a means for the users of the system to actively provide feedback and update the knowledge content.

Although only a simple ability for users to provide input into the system is available through the Comments facility, this concept, if extended, would be a very powerful means of facilitating a community discussion on research transition issues. As described in earlier sections, communication issues are the largest roadblock to research transition. An electronic bulletin board would provide a means to store informal but valuable experiential knowledge, and would open a channel of communication on specific topics in the knowledge structure.

Print

This facility will generate a written report by printing the text content for a specific section or by printing a comments file.

8. CONCLUSIONS

Many issues in technology transfer were studied during the course of this work. Differences in objectives between two separate communities are responsible for the different perspectives between the groups, and thus, for many of the difficulties in technology transfer. There is a need to facilitate the communications between the research and the design communities, and to ensure that the transition of knowledge occurs within a context that is appropriate to either group. The hypertext knowledge system developed addresses this need.

It should be noted that the knowledge presentation system developed during Phase II differs substantially from the system that came out of the Phase I work. The Phase I demonstration system was structured to follow the order of information as accessed by an engineer during the design process. However, the emphasis on design requirements and constraints was found to be inappropriate as a lead-in to the research knowledge base. The system's organization was also found to be limited in regard to the links between design technology and research knowledge. The research knowledge and the roadblocks were included as separate facilities from the main body of the system, and thus the connections between that knowledge and the design process were not clearly defined.

The reorganization of the system in Phase II was intended to strengthen the links between design technology and research knowledge, and to incorporate a two-way communication process. A vertical structure was developed that connected design technology and design needs to research knowledge. The design requirements were included as a horizontal organization, and within each broad requirements section, the vertical structure from design to research can be followed. Search tools allow the user to locate related knowledge in either a vertical or a horizontal fashion. Roadblocks are closely integrated within each technical subject area. The organization of this system was well

received by the R&D community during tests with potential users. In particular, the interactive comments facility was highly rated by the design community.

The critical features of the hypertext knowledge presentation system are:

- (1) Knowledge is presented to the user in the appropriate context
- (2) Design state-of-the-art is linked to relevant research topics
- (3) Knowledge framework is structured from practical to basic
- (4) Knowledge is filtered and search facilities are implemented
- (5) Provision exists for a two-way communication channel
- (6) User is allowed to select search facility and level of detail

A prototype system was developed to cover a subset of the knowledge needed for the propulsor hydrodynamics research transition problem. This system was successful in creating a communication media to facilitate technology transfer among the 6.1, 6.2, and 6.3 communities.

It should be noted that the complete knowledge structure, as given in Appendix A, is extremely complex. The number of relationships represented in this structure, as well as the different perspectives needed for individual topic descriptions as a result of the overall design requirements, is impressive. This highlights the fact that the management of these technical elements requires significant resources. The current generation at ONR is effective in handling the complexity of these elements, but as individuals retire, the expertise to manage this program and to maintain the oversight required may become lost unless there is adequate documentation of the program elements and their relationships.

In order to complete the hypertext knowledge presentation system, future efforts should be directed towards further knowledge acquisition and the inclusion of both design technology and basic research knowledge, towards the modification of the program structure and facilities as appropriate based on user feedback, and towards the expansion of the subject area of the system to include the entire knowledge structure relevant to propulsor hydrodynamics.

Improvements in the interactive comments facility in the hypertext knowledge system will also enhance communications between the research and design communities. The concept of an electronic bulletin board for relating concepts, experiences, suggestions, and feedback will provide an additional communication channel for technology transfer that is currently lacking.

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APPENDIX A

Research Transition Knowledge Base

A detailed outline of the preliminary knowledge base for TRACKS is included here. The subtopics listed are meant to be a guideline to the contents of the parent topics, rather than the actual subtopics in the computer program's knowledge structure. Much of the information presented here was obtained from the Submarine Hydrodynamics Coordinating Group.

Topics marked with a # have a link with another topic. The linked topics are provided in parentheses after the topic name. Topics marked with a * are identical to other topics, as indicated.

I. PERFORMANCE

A1 Efficiency and Powering Performance (straight-and-level operation)

B1 Technical Issues and Drivers

B1a flow features affected by/affecting powering performance (3-d flows, viscous, incompressible, steady and unsteady)

B1a1# propulsor inflow (B2a1, B3a, B4d)

B1a1a high Reynolds number turbulence

B1a1b pressure gradients

B1a1c high vorticity gradients

B1a2# internal through flow (B2a2, B3a, B4e, B5a)

B1a2a flow separation

B1a2b cavitation

B1a2c high reduced frequency

B1a2d blade loads

B1a3# wake flows (B2a3, B3b)

B1a3a hull/appendage wake

B1a3b propulsor wake

B1b design specifications

B1b1 cavitation limit: nonacoustical specifications, i.e. performance, structures

B1b2# weight restriction (B4c)

B1b3# depth restriction at flank speed (B2c)

B1b4# mass flow (B4e)

B1b5# noise limit; including cavitation (B3a)

B1b6 hydrodynamic loads

B1b7 cost

C1 Design Capabilities

C1a# optimize efficiency/powering performance early in design process (C2a, C3a)

C1b# decrease sensitivity of powering performance to operational transients (C2b, C3b)

C1c# develop optimum configurations using validated design process (C2c, C3c)

C1d# conduct parametric studies to determine effects of resistance and propulsion on propulsor design (C2d, C3d)

C1e optimize performance parameters

C1e2 thrust/torque/RPM control

C1e3 cavitation inception

C1f develop resistance and propulsion concept alternatives

C1g# empirical correlations of cavitation inception with trailing edge blade sections (C3h)

C1g1 revisit correlations of cavitation inception using computational tools

C1h# computer-aided design (C2g, C3i, C4c, C5b)

C1h1 integrate design tools into an interactive design and analysis environment

C1h2 final product should provide the capability to conduct

C1h2a conceptual designs and tradeoffs

C1h2b detailed hydrodynamic, hydroacoustic, and structural designs

C1h2c definitions of surface geometry for manufacture

C1h2d evaluations of the total performance by conducting a numerical experiment prior to in-water evaluations

D1 Control Issues

D1a evaluate resistance and propulsion control alternatives (conduct experiments and use existing data to identify hydrodynamic phenomena to be controlled to achieve improved powering performance)

D1a1# MHD boundary layer control (D2a7, D3a6, D4a4, D5a1b, D5a2b, D5c1)

- D1a2# active prop blade boundary layer control (D2a6, D3a5, D4a3, D5a1a, D5a2a)
- D1a3# high blade loading and criteria to prevent flow separation (D5a1)
- D1a4# LEBUs (D2a10)
- D1a5# vorticity generators (D2a1)
- D1a6# blowing (D2a11)
- E1 Prediction Methods
 - E1a results from prediction methods
 - E1a1 predict effect of propulsor modifications on powering performance
 - E1a2# predict outflow from propulsor (E3a4)
 - E1b inviscid prediction
 - E1b1# vorticity fields (E2b2)
 - E1b2# hull/appendage forces (E2b3)
 - E1c viscous prediction
 - E1c1# turbulence modeling for Navier-Stokes computations (E2c1, E3c1, E4c1, E5c1)
 - E1c1a no pressure gradients and adverse pressure gradients
 - E1c1b vorticity gradients in 3-d
 - E1c1c turbulence models can be generic or empirical
 - E1c2 hull inflow
 - E1c2a turbulence model for hull inflow
 - E1c3# 3-d propulsor flows (E2c2)
 - E1c4 junction flows
 - E1c5 tip flows
 - E1c6 gap flows
 - E1c7 internal flow-through with high vorticity gradients
 - E1c8 empirical/generic turbulence model
 - E1d* generic tools (E2d, E3d, E4d, E5d)
 - E1d1 CAD/solid geometry modeling
 - E1d2 grid generation
 - E1d3 high-performance supercomputers
 - E1d3a faster with increased memory, parallel processing
 - E1d3b computations of viscous flow in complex geometries
 - E1d3c allow use of Navier-Stokes computations in design within five years
 - E1e# validation (E2e, E3e, E4e, E5e)
 - E1e1 validate computational capability against existing data and model and full-scale experiments
 - E1e2 conduct parametric model experiments to provide data to validate codes and define physical phenomena
 - E1e3 establish the range of applicability of flow prediction codes
 - E1e4 development and verification of flow models using unsteady flow experiments and new quantitative visualization techniques
 - E1e5 unsteady incompressible Navier-Stokes with Reynolds-averaged turbulent stresses
 - E1e5a ready for validation with two-dimensional unsteady problems by FY93.
 - E1f# roadblocks to prediction and between prediction and control (E2f, E3f, E4f, E5f)
- F1 Interactions/Cause-and-Effect
 - F1a sensitivity of powering performance to variations from straight-and-level operation
 - F1b# effect of powering on maneuvers (F2b, F3e)
 - F1c# high Reynolds number database, in excess of $2 \times 10^{**6}$; current data is at blade Reynolds numbers less than 500,000 (F2f, F3f, F4b, F5c)
 - F1c1 database should include both time-mean and time-varying flows
 - F1c2 database should demonstrate interactions of the propulsor components
 - F1d# effect of high blade loadings on hydrodynamic and hydroacoustic performance (F2g, F3g, F5a2)
 - F1d1 need 3-d criteria as a function of spanwise loading and vorticity gradients to define limiting values of blade loading
 - F1d2 include effects of unsteady inflows
 - F1e# high-frequency unsteadiness of 3-d interactive flow field within propulsor; $5 < \omega < 25$ (F2h, F3d, F4c)
 - F1f# fluid/structure interactions contributing to vibration (F3a)
 - F1f1 understand the physics which result in response of a complex structure to a 3-d, viscous, time-varying flow
 - F1f2 quantify the time-varying spatial and temporal flow through propulsor at high frequencies (5 - 25 times BPF)
 - F1f2a time-varying surface pressure distribution
 - F1f2b total pressure (losses)
 - F1f2c trailing edge flows (separation and Kutta condition)
 - F1f2d effects of turbulent inflow (homogeneous and nonhomogeneous)
 - F1f2e blade-to-blade and blade row interactions
 - F1f2f quantify effects of structural response on the flow and vice versa

G1 Basic Physics

G1a* experimental techniques (G2a, G3a, G4a, G5a)

G1a1 Particle Displacement Velocimetry

G1a1a understanding of flow that causes pressures and forces

G1a1b quantify the flow field and visualize flow structures

G1a1b1 large scale vortex structures

G1a1b2 separation

G1a1b3 turbulence

G1a1c measurements of time-varying surface pressure, shear stress, and separation

G1a1d current application in small-scale towing tank

G1a1e full-scale implementation within next two years, funded by DARPA.

G1a2 experimental unsteady boundary layer facility

G1a3 experimental quiet flow facility

G1a4 improved flow visualization

G1a4a particle image velocimetry

G1a5 scale effects

G1b physical phenomena (experimental and numerical)

G1b1# time-dependent, viscous, three-dimensional flows (G2b1, G3b1, G4b1, G5b1)

G1b1a incompressible and turbulent

G1b1b turbulent boundary layers

G1b2# turbulence (G2b2, G3b2, G4b2, G5b2)

G1b2a turbulent boundary layers

G1b2a1 growth

G1b2a2 stability

G1b2a3 details of separation

G1b2a4 flow behavior after separation

G1b3# vortex flows (G2b3, G3b3, G4b3, G5b3)

G1b3a vortex growth on the hull and appendages

G1b3b vortex shedding from TBL and from appendage tips (large eddies of ship dimensions down to thermal vorticity)

G1b3c vortex transport and migration

G1b3d unsteady vortex interactions

G1b3e strong vorticity gradients

G1b4# unsteady effects (G2b4, G3b4, G4b4, G5b4)

G1b4a gust flow and moving lifting surfaces

G1b5 skin friction

A2 Maneuvering and Off-Design Performance

B2 Technical Issues and Drivers

B2a flow features affected by/affecting maneuver (3-d flows, viscous, incompressible, steady and unsteady)

B2a1# propulsor inflow (B1a1, B3a, B4d)

B2a1a separation

B2a1b cross-flow

B2a1c vorticity gradients

B2a2# internal through flow (B1a2, B3a, B4e, B5a)

B2a2a propulsor tip flows and secondary flows

B2a2b blade separation

B2a2c cavitation

B2a3# wakes (B1a3, B3b)

B2a3a hull/appendages

B2a3b propulsor wake

B2b# the operation of propulsor at off-design conditions must be understood and modeled (B3a, B3b)

B2b1 acceleration/deceleration

B2b2 backing/turning

B2b3 diving/out-of-trim

B2b4 reverse shaft rotation

B2b5 high angles of incidence

B2b6 forces and pressures, e.g. very high blade loadings, in transient mode of operation

B2b7 shock impact

B2c# sea effects and environment (B1b3, B3a, B3b)

B2c1 spatial attenuation of wavelengths with depth

B2c2 temporal changes in apparent spectrum with speed of advance

B2c3 effect of hard boundaries e.g. hard bottom, ice sheets

B2c4 effect of surface fouling

B2d# effect of propulsor type (B4a)

B2d1 open

B2d2 shrouded

C2 Design Capabilities

C2a# optimize maneuvering performance early in design process (C1a, C3a)

C2b# decrease sensitivity of maneuvering performance to operational transients (C1b, C3b)

C2c# develop optimum conceptual hydrodynamic and hydroacoustic configurations using validated design process (C1c, C3c)

C2d# conduct parametric studies to determine effects of maneuvering performance on propulsor design (C1d, C3d)

- C2e predict effect of propulsor modifications on maneuvering performance
- C2f develop safe maneuvering systems and procedures
- C2g computer-aided design (C1h, C3i, C4c, C5b)
 - C2g1 integrate design tools into an interactive design and analysis environment
 - C2g2 final product should provide the capability to conduct
 - C2g2a conceptual designs and tradeoffs
 - C2g2b detailed hydrodynamic, hydroacoustic, and structural designs
 - C2g2c definitions of surface geometry for manufacture
 - C2g2d evaluations of the total performance by conducting a numerical experiment prior to in-water evaluations

D2 Control Issues

- D2a evaluate alternative maneuvering force effectors, both active and passive (conduct experiments and use existing data to identify hydrodynamic phenomena to be controlled to achieve improved maneuvering and off-design performance)
 - D2a1# vorticity generation and control (D1a5)
 - D2a2# thrust vectoring (D4a2)
 - D2a3 flap assisted control surfaces
 - D2a4 propulsor mass flow
 - D2a5 small and large surface control actions
 - D2a6# active prop blade boundary layer control (D1a2, D3a5, D4a3, D5a1a, D5a2a)
 - D2a7# MHD boundary layer control (D1a1, D3a6, D4a4, D5a1b, D5a2b, D5c1)
 - D2a8 cyclic pitch propellers
 - D2a9 low-speed ship control
 - D2a10# LEBUs (D1a4)
 - D2a11# blowing (D1a6)

E2 Prediction Methods

- E2a results from prediction capabilities
 - E2a1 predict sub's trajectory during extreme maneuvers
 - E2a2 predict effect of propulsor modifications on maneuvering performance
 - E2a3 develop non-empirical capability to predict maneuvering forces and moments
 - E2a4 off-design analysis tools for a given propulsor geometry e.g. radial-, mixed-, and axial-flow
 - E2a5 overall performance characteristics (thrust, torque, power, cavitation, etc.)

- E2a6 micro-scale flow details (tip flows, surface variations, i.e. geometry effects, etc.)

- E2a7 stability and control of the propulsor/vehicle combination

E2b inviscid prediction

- E2b1 inviscid/panel prediction

- E2b2# vorticity fields (E1b1)

- E2b3# hull/appendage forces (E1b2)

- E2b4 maneuvering forces

- E2b5 propulsor secondary and tip vorticity

E2c viscous prediction

- E2c1# turbulence modeling for Navier-Stokes/separated flow (E1c1, E3c1, E4c1, E5c1)

- E2c1a no pressure gradients and adverse pressure gradients

- E2c1b vorticity gradients in 3-d

- E2c1c turbulence models can be generic or empirical

- E2c2# predict viscous, 3-d, unsteady, separation (E1c3)

- E2c3 hull/appendage flow field and wake

- E2c4 hull boundary layers

- E2c5 cross flows

- E2c6 inter/intrablade flows

- E2c7 endwall and leakage flows

E2d* generic tools (E1d, E3d, E4d, E5d)

- E2d1 CAD/solid geometry modeling

- E2d2 grid generation

- E2d3 high-performance supercomputers

- E2d3a faster with increased memory, parallel processing

- E2d3b computations of viscous flow in complex geometries

- E2d3c allow use of Navier-Stokes computations in design within five years

E2e# validation (E1e, E3e, E4e, E5e)

- E2e1 validate computational capability against existing data and model and full-scale experiments

- E2e2 conduct parametric model experiments to provide data to validate codes and define physical phenomena

- E2e3 establish the range of applicability of flow prediction codes

- E2e4 development and verification of flow models using unsteady flow experiments and new quantitative visualization techniques

- E2e5 unsteady incompressible Navier-Stokes with Reynolds-averaged turbulent stresses

- E2e5a ready for validation with two-dimensional unsteady problems by FY93.

E2f# roadblocks to prediction and between prediction and control (E1f, E3f, E4f, E5f)
 E2f1 lack of adequate computational tools
 E2f2 no predictive capability

F2 Interactions/Cause-and-Effect

F2a identify phenomena/interactions for different situations

F2a1 vorticity generation, transport, and control as it influences out-of-plane forces during maneuvers
 F2a2 nonlinear phenomena which influence hull and lifting surface forces

F2b# sensitivity of maneuvering performance to variations from straight-and-level performance (F1b, F3e)

F2c effect of different propulsors on hull dynamic performance

F2d time-mean and unsteady trajectories of shed wakes and vorticity

F2e sea environment effects

F2e1 near- and free-surface interaction on nonlinear motion of sub
 F2e2 bottom/ice interference
 F2e3 effect of sea state

F2f# high Reynolds number database, in excess of $2 \times 10^{**}6$; current data is at blade Reynolds numbers less than 500,000 (F1c, F3f, F4b, F5c)

F2f1 database should include both time-mean and time-varying flows
 F2f2 database should demonstrate interactions of the propulsor components

F2g# effect of high blade loadings on hydrodynamic and hydroacoustic performance (F1d, F3g, F5a2)

F2g1 need 3-d criteria as a function of spanwise loading and vorticity gradients to define limiting values of blade loading
 F2g2 include effects of unsteady inflows

F2h# high-frequency unsteadiness of 3-d interactive flow field within propulsor; $5 < \omega < 25$ (F1e, F3d, F4c)

G2 Basic Physics

G2a* experimental techniques (G1a, G3a, G4a, G5a)

G2a1 Particle Displacement Velocimetry
 G2a1a understanding of flow that causes pressures and forces
 G2a1b quantify the flow field and visualize flow structures
 G2a1b1 large scale vortex structures
 G2a1b2 separation
 G2a1b3 turbulence

G2a1c measurements of time-varying surface pressure, shear stress, and separation

G2a1d current application in small-scale towing tank

G2a1e full-scale implementation within next two years, funded by DARPA.

G2a2 experimental unsteady boundary layer facility

G2a3 experimental quiet flow facility

G2a4 improved flow visualization

G2a4a particle image velocimetry

G2a5 scale effects

G2b physical phenomena (experimental and numerical)

G2b1# time-dependent, viscous, three-dimensional flows (G1b1, G3b1, G4b1, G5b1)

G2b1a incompressible and turbulent

G2b1b turbulent boundary layers

G2b2# turbulence (G1b2, G3b2, G4b2, G5b2)

G2b2a turbulent boundary layers

G2b2a1 growth

G2b2a2 stability

G2b2a3 details of separation

G2b2a4 flow behavior after separation

G2b3# vortex flows (G1b3, G3b3, G4b3, G5b3)

G2b3a vortex growth on the hull and appendages

G2b3b vortex shedding from TBL and from appendage tips (large eddies of ship dimensions down to thermal vorticity)

G2b3c vortex transport and migration

G2b3d unsteady vortex interactions

G2b3e strong vorticity gradients

G2b4# unsteady effects (G1b4, G3b4, G4b4, G5b4)

G2b4a gust flow and moving lifting surfaces

G2b4b unsteady and steady lifting surface loads

G2b4c bluff body unsteady separation

A3 Hydrodynamic Signatures, Acoustic and Nonacoustic

B3 Technical Issues and Drivers

B3a# acoustic signature phenomena (B1a1, B1a2, B1b5, B2a1, B2a2, B2b, B2c)

B3a1# propulsor blade rate (B5a)

B3a1a spatial and temporal 3-d distortions

- B3a1b propulsor unsteady response (direct radiation)
 - B3a1b1 lifting surface high reduced frequency
 - B3a1b2 modulation and random response
 - B3a1c cavitation inception
 - B3a2 propulsor broadband
 - B3a1a broadband vibration noise
 - B3a1b lifting surface turbulent boundary layers
 - B3a1c unsteady inflow
 - B3a1d near-wake
- B3b# nonacoustic signature phenomena (B1a3, B2a3, B2b, B2c)
 - B3b1 surface wave trains from slow speed operation near surface or high speed operation at large depth
 - B3b2 surface swirls from turning maneuvers, depth changes, and acceleration near surface
 - B3b3 surface wave fields and slicks i.e. surfacing of wake, surfacing of vorticity from propulsor
 - B3b4 submerged disturbances e.g. thermal waves, free vorticity, fields of turbulent intensity, all levels of vorticity from ship-sized eddies to thermal agitation, vorticity gradients from hull flow and lifting surfaces, viscous wakes from lifting surfaces
- B3c detection technologies and capabilities

C3 Design Capabilities

- C3a# optimize signature performance early in design process (C1a, C2a)
- C3b# decrease sensitivity of acoustic performance to operational transients (C1b, C2b)
- C3c# develop optimum conceptual hydrodynamic and hydroacoustic configurations using validated design process (C1c, C2c)
- C3d# conduct parametric studies to determine effects of acoustic performance on propulsor design (C1d, C2d)
- C3e evaluate low signature design options
- C3f develop low signature operational guidance
- C3g# identify new signature mechanisms related to hydrodynamics (C4b4)
- C3h# empirical correlations of cavitation inception with trailing edge blade sections (C1g)
 - C3h1 revisit correlations with computational tools
- C3i# computer-aided design (C1h, C2g, C4c, C5b)
 - C3i1 integrate design tools into an interactive design and analysis environment
 - C3i2 final product should provide the capability to conduct

- C3i2a conceptual designs and tradeoffs
- C3i2b detailed hydrodynamic, hydroacoustic, and structural designs
- C3i2c definitions of surface geometry for manufacture
- C3i2d evaluations of the total performance by conducting a numerical experiment prior to in-water evaluations

D3 Control Issues

- D3a evaluate alternative signature control techniques (conduct experiments and use existing data to identify hydrodynamics and hydroacoustic phenomena to be controlled to achieve improved signature performance)
 - D3a1 effect of small roughnesses on surfaces
 - D3a2# effects of fillets and fairness (D5b)
 - D3a3 effects of geometry changes
 - D3a4 effect of camber and loading on blade wakes
 - D3a5# active prop blade boundary layer control (D1a2, D2a6, D4a3, D5a1a, D5a2a)
 - D3a6# MHD boundary layer control (D1a1, D2a7, D4a4, D5a1b, D5a2b, D5c1)
 - D3a7# inflow control (D4a)
 - D3a8 active/passive blade modification
 - D3a9 TEB
 - D3a11 wake control
 - D3a12 trailing edge blade sections to control pressure distribution and boundary layer flow

E3 Prediction Methods

- E3a results from prediction capabilities
 - E3a1 predictions of broad band noise originating in steady and unsteady turbulent boundary layers (on moving or fixed propulsor elements)
 - E3a2 predict effect of propulsor modifications on acoustic performance
 - E3a3 predict how maneuvers can be accomplished to minimize signatures
 - E3a4# predict outflow from propulsor (E1a2)
 - E3a5 prediction of unsteady forces and pressures that drive the radiated noise
 - E3a6 predict effects of appendage, hull, and propulsor flows on acoustic and wake signatures
 - E3a7 improved simulation of 3-d, viscous, unsteady flow fields within the propulsor, including response of solid structure to the flows and the resulting acoustic field
 - E3a8 prediction/modeling of acoustic radiation

- E3a8a surrounding structure
 - E3a8b the insertion of acoustic control/absorption devices
 - E3a8c hydrodynamic sources
 - E3a8d structural response
- E3b inviscid prediction
- E3c viscous prediction
 - E3c1# turbulence modeling for Navier-Stokes computations (E1c1, E2c1, E4c1, E5c1)
 - E3c1a no pressure gradients and adverse pressure gradients
 - E3c1b vorticity gradients in 3-d
 - E3c1c turbulence models can be generic or empirical
 - E3c2 lifting surface wakes
 - E3c3 unsteady inflow
- E3d* generic tools (E1d, E2d, E4d, E5d)
 - E3d1 grid generation
 - E3d2 high-performance supercomputers
 - E3d2a faster with increased memory, parallel processing
 - E3d2b computations of viscous flow in complex geometries
 - E3d2c allow use of Navier-Stokes computations in design within five years
- E3e# validation (E1e, E2e, E4e, E5e)
 - E3e1 establish the range of applicability of flow prediction codes
 - E3e2 development and verification of flow models using unsteady flow experiments and new quantitative visualization techniques
 - E3e3 unsteady incompressible Navier-Stokes with Reynolds-averaged turbulent stresses
 - E3e3a ready for validation with two-dimensional unsteady problems by FY93.
- E3f# roadblocks (E1f, E2f, E4f, E5f)
 - E3f1 lack of adequate computational techniques
 - E3f2 current predictions are semi-empirical and limited to the existing database of configurations
 - E3f3 methods that capture 95% of flow through simplifying assumptions but fail to predict the 5% that is exciting the structure will be inadequate
- F3 Interactions/Cause-and-Effect
 - F3a# fluid/structure interactions (F1f)
 - F3a1 understand the physics which result in response of a complex structure to a 3-d, viscous, time-varying flow

- F3a2 quantify the time-varying spatial and temporal flow through propulsor at high frequencies (5 - 25 times BPF)
 - F3a2a time-varying surface pressure distribution
 - F3a2b total pressure (losses)
 - F3a2c trailing edge flows (separation and Kutta condition)
 - F3a2d effects of turbulent inflow (homogeneous and nonhomogeneous)
 - F3a2e blade-to-blade and blade row interactions
 - F3a2e quantify effects of structural response on the flow and vice versa
 - F3a3 cavitation
 - F3a4 geometry
 - F3a5 indirect radiation
 - F3a6 propulsor broadband structural response
- F3b# acoustic interaction of lifting surfaces encountering abrupt changes in incoming velocity; direction and/or magnitude (F3c, F5a3)
- F3c# acoustic interaction of lifting surfaces encountering vortices from upstream, both steady and unsteady vortices (F3b, F5a3)
- F3d# high-frequency unsteadiness of 3-d interactive flow field within propulsor; $5 < \omega < 25$ (F1e, F2h, F4c)
 - F3d1 high-frequency unsteady lifting surface response
- F3e# effect of maneuvering on signatures (F1b, F2b)
- F3f# high Reynolds number database, in excess of $2 \times 10^{**6}$; current data is at blade Reynolds numbers less than 500,000 (F1c, F2f, F4b, F5c)
 - F3f1 database should include both time-mean and time-varying flows
 - F3f2 database should demonstrate interactions of the propulsor components
- F3g# effect of high blade loadings on hydrodynamic and hydroacoustic performance (F1d, F2g, F5a2)
 - F3g1 need 3-d criteria as a function of spanwise loading and vorticity gradients to define limiting values of blade loading
 - F3g2 include effects of unsteady inflows
- G3 Basic Physics
 - G3a* experimental techniques (G1a, G2a, G4a, G5a)
 - G3a1 Particle Displacement Velocimetry
 - G3a1a understanding of flow that causes pressures and forces
 - G3a1b quantify the flow field and visualize flow structures

- G3a1b1 large scale vortex structures
- G3a1b2 separation
- G3a1b3 turbulence
- G3a1c measurements of time-varying surface pressure, shear stress, and separation
- G3a1d current application in small-scale towing tank
- G3a1e full-scale implementation within next two years, funded by DARPA.
- G3a2 experimental unsteady boundary layer facility
- G3a3 experimental quiet flow facility
- G3a4 improved flow visualization
 - G3a4a particle image velocimetry
- G3a5 scale effects
- G3b physical phenomena (experimental and numerical)
 - G3b1# time-dependent, viscous, three-dimensional flows (G1b1, G2b1, G4b1, G5b1)
 - G3b1a incompressible and turbulent
 - G3b1b turbulent boundary layers
 - G3b2# turbulence (G1b2, G2b2, G4b2, G5b2)
 - G3b2a turbulent boundary layers
 - G3b2a1 growth
 - G3b2a2 stability
 - G3b2a3 details of separation
 - G3b2a4 flow behavior after separation
 - G3b2b inflow turbulence
 - G3b3# vortex flows (G1b3, G2b3, G4b3, G5b3)
 - G3b3a vortex growth on the hull and appendages
 - G3b3b vortex shedding from TBL and from appendage tips (large eddies of ship dimensions down to thermal vorticity)
 - G3b3c vortex transport and migration
 - G3b3d unsteady vortex interactions
 - G3b3e strong vorticity gradients
 - G3b4# unsteady effects (G1b4, G2b4, G4b4, G5b4)
 - G3b4a gust flow and moving lifting surfaces
- G3b5 blade forces
- G3b6 wake physics
- G3b7 material transport
- G3b8 cavitation inception
- G3b9 flow-induced vibration

II. CONFIGURATION

A4 Overall Configuration

B4 Technical Issues and Drivers

- B4a# open or shroud (B2d)
- B4b number of stages
- B4c diameter of propulsor (B1b2)
- B4d# inlet/inflow characteristics (B1a1, B2a1)
 - B4d1 upstream vorticity and wake, spatial- and time- varying
 - B4d2 turbulent flow separation on hull and upstream appendages
 - B4d3 crossflow influences
 - B4d4 effect of upstream control surfaces, quasi-steady and unsteady
 - B4d5 adverse pressure gradients
- B4e# mass flow through propulsor (B1a2, B1b4, B2a2)
 - B4e1 appendage wakes
 - B4e2 boundary layer growth

C4 Design Capabilities

- C4a propulsor configurations
 - C4a1 mixed- and radial-flow propulsors
 - C4a2 single- or multi-stage
- C4b configuration design and analysis tools
 - C4b1 loss models
 - C4b2 effects of loading on hydroacoustics
 - C4b3 unsteady flows
 - C4b4# definition of acoustic sources (C3g)
 - C4b5 asymmetric flow analysis method
 - C4b5a current methods assume axisymmetric flow except in the case of large volume computations
 - C4b5b need to analyze asymmetric flows with varying blade geometries in the circumferential direction (a modern-day version of a parallel compressor method)
 - C4b5c methods for axisymmetric blade row in an asymmetric flow due to vehicle angle of attack
- C4c# computer-aided design (C1h, C2g, C3i, C5b)
 - C4c1 integrate design tools into an interactive design and analysis environment
 - C4c2 final product should provide the capability to conduct
 - C4c2a conceptual designs and tradeoffs
 - C4c2b detailed hydrodynamic, hydroacoustic, and structural designs

- C4c2c definitions of surface geometry for manufacture
 - C4c2d evaluations of the total performance by conducting a numerical experiment prior to in-water evaluations
- D4 Control Issues
 - D4a# inlet/inflow characteristics (D3a7)
 - D4a1 lateral forces and changes in moment
 - D4a2# thrust changes (D2a2)
 - D4a3# active prop blade boundary layer control (D1a2, D2a6, D3a5, D5a1a, D5a2a)
 - D4a4# MHD boundary layer control (D1a1, D2a7, D3a6, D5a1b, D5a2b, D5c1)
- E4 Prediction Methods
 - E4a results from prediction capabilities
 - E4a1# predictions of 3-d inflow distortions; numerically and from prior design data (E5a1)
 - E4a2# predict incoming flow to propulsor (E5a2)
 - E4b inviscid prediction
 - E4c viscous prediction
 - E4c1# turbulence modeling for Navier-Stokes computations (E1c1, E2c1, E3c1, E5c1)
 - E4c1a no pressure gradients and adverse pressure gradients
 - E4c1b vorticity gradients in 3-d
 - E4c1c turbulence models can be generic or empirical
 - E4d* generic tools (E1d, E2d, E3d, E5d)
 - E4d1 CAD/solid geometry modeling
 - E4d2 grid generation
 - E4d3 high-performance supercomputers
 - E4d3a faster with increased memory, parallel processing
 - E4d3b computations of viscous flow in complex geometries
 - E4d3c allow use of Navier-Stokes computations in design within five years
 - E4e# validation (E1e, E2e, E3e, E5e)
 - E4e1 development and verification of flow models using unsteady flow experiments and new quantitative visualization techniques
 - E4e2 unsteady incompressible Navier-Stokes with Reynolds-averaged turbulent stresses
 - E4e2a ready for validation with two-dimensional unsteady problems by FY93.
 - E4f# roadblocks (E1f, E2f, E3f, E5f)
- F4 Interactions/Cause-and-Effect
 - F4a inlet/inflow characteristics
 - F4a1 scale effects not understood
 - F4b# high Reynolds number database, in excess of $2 \times 10^{**6}$; current data is at blade Reynolds numbers less than 500,000 (F1c, F2f, F3f, F5c)
 - F4b1 database should include both time-mean and time-varying flows
 - F4b2 database should demonstrate interactions of the propulsor components
 - F4c# high-frequency unsteadiness of 3-d interactive flow field within propulsor; $5 < \omega < 25$ (F1e, F2h, F3d)
- G4 Basic Physics
 - G4a* experimental techniques (G1a, G2a, G3a, G5a)
 - G4a1 Particle Displacement Velocimetry
 - G4a1a understanding of flow that causes pressures and forces
 - G4a1b quantify the flow field and visualize flow structures
 - G4a1b1 large scale vortex structures
 - G4a1b2 separation
 - G4a1b3 turbulence
 - G4a1c measurements of time-varying surface pressure, shear stress, and separation
 - G4a1d current application in small-scale towing tank
 - G4a1e full-scale implementation within next two years, funded by DARPA.
 - G4a2 experimental unsteady boundary layer facility
 - G4a3 experimental quiet flow facility
 - G4a4 improved flow visualization
 - G4a4a particle image velocimetry
 - G4a5 scale effects
 - G4b physical phenomena (experimental and numerical)
 - G4b1# time-dependent, viscous, three-dimensional flows (G1b1, G2b1, G3b1, G5b1)
 - G4b1a incompressible and turbulent
 - G4b1b turbulent boundary layers
 - G4b2# turbulence (G1b2, G2b2, G3b2, G5b2)
 - G4b2a turbulent boundary layers
 - G4b2a1 growth
 - G4b2a2 stability
 - G4b2a3 details of separation
 - G4b2a4 flow behavior after separation
 - G4b3# vortex flows (G1b3, G2b3, G3b3, G5b3)

- G4b3a vortex growth on the hull and appendages
 - G4b3b vortex shedding from TBL and from appendage tips (large eddies of ship dimensions down to thermal vorticity)
 - G4b3c vortex transport and migration
 - G4b3d unsteady vortex interactions
 - G4b4# unsteady effects (G1b4, G2b4, G3b4, G5b4)
 - G4b4a gust flow and moving lifting surfaces
- A5 Detailed Configuration
- B5 Technical Issues and Drivers
- B5a# blades (B1a2, B2a2, B3a1)
- B5a1 lift on blades
 - B5a2 flow speed over blades
 - B5a3 turbulent boundary layers
 - B5a4 separation
 - B5a5 geometry
- C5 Design Capabilities
- C5a blades
- C5a1 need to define maximum loading limits
 - C5a2 relationship between time-averaged blade loading (lift), chordwise pressure gradient, blade pressure distribution, and the occurrence of flow separation must be accurately defined for 2-d and annular cascades of blades in terms of blade design parameters
 - C5a3 a 3-d separation criteria, similar to the 2-d Diffusion Factor, must be developed
 - C5a4 the effect of time-varying inlet flows on these separation criteria must be defined
 - C5a5 high blade loading and criteria to avoid flow separation
 - C5a6 correlations between blade section shapes and cavitation inception
- C5b# computer-aided design (C1h, C2g, C3i, C4c)
- C5b1 integrate design tools into an interactive design and analysis environment
 - C5b2 final product should provide the capability to conduct
 - C5b2a conceptual designs and tradeoffs
 - C5b2b detailed hydrodynamic, hydroacoustic, and structural designs
 - C5b2c definitions of surface geometry for manufacture
- C5b2d evaluations of the total performance by conducting a numerical experiment prior to in-water evaluations
- D5 Control Issues
- D5a blades
- D5a1# lift on blades (D1a3)
 - D5a1a# active prop blade boundary layer control (D1a2, D2a6, D3a5, D4a3, D5a2a)
 - D5a1b# MHD boundary layer control (D1a1, D2a7, D3a6, D4a4, D5a2b, D5c1)
 - D5a2 flow speed over blades
 - D5a2a# active prop blade boundary layer control (D1a2, D2a6, D3a5, D4a3, D5a1a)
 - D5a2b# MHD boundary layer control (D1a1, D2a7, D3a6, D4a4, D5a1b, D5c1)
 - D5a3 effects of streamwise pressure gradient, time-averaged and time-varying blade loading (lift), and trailing edge shape on noise sources
 - D5a4 skew
 - D5a4a effects of blade skew on hydroacoustic performance
 - D5a4a1 the influence on the radial pressure gradients generated by different types and amounts of skew (lean) need to be determined
 - D5a4a2 the effects of the flows at the blade trailing edge need to be quantified and controlled
 - D5a4a3 the effect of skew on separation, tip flows, secondary vortices, and losses need to be quantified
- D5# fairness (D3a2)
- D5c RPM of rotor
- D5c1# MHD boundary layer control (D1a1, D2a7, D3a6, D4a4, D5a1b, D5a2b)

E5 Prediction Methods

E5a results from prediction capabilities

E5a1# predictions of 3-d inflow distortions; numerically and from prior design data (E4a1)

E5a2# predict incoming flow to propulsor (E4a2)

E5b inviscid prediction

E5c viscous prediction

E5c1# turbulence modeling for Navier-Stokes computations (E1c1, E2c1, E3c1, E4c1)

E5c1a no pressure gradients and adverse pressure gradients

E5c1b vorticity gradients in 3-d

E5c1c turbulence models can be generic or empirical

E5d* generic tools (E1d, E2d, E3d, E4d)

E5d1 CAD/solid geometry modeling

E5d2 grid generation

E5d3 high-performance supercomputers

E5d3a faster with increased memory, parallel processing

E5d3b computations of viscous flow in complex geometries

E5d3c allow use of Navier-Stokes computations in design within five years

E5e# validation (E1e, E2e, E3e, E4e)

E5e1 development and verification of flow models using unsteady flow experiments and new quantitative visualization techniques

E5e2 unsteady incompressible Navier-Stokes with Reynolds-averaged turbulent stresses

E5e2a ready for validation with two-dimensional unsteady problems by FY93.

E5f# roadblocks (E1f, E2f, E3f, E4f)

F5 Interactions/Cause-and-Effect

F5a blades

F5a1 time-mean and unsteady lifting surface loads in 3-d, viscous flow with strong vorticity gradients

F5a2# effect of high blade loadings on hydrodynamic and hydroacoustic performance (F1d, F2g, F3g)

F5a2a need 3-d criteria as a function of spanwise loading and vorticity gradients to define limiting values of blade loading

F5a2b include effects of unsteady inflows

F5a3# unsteady turbulent boundary layers in blade row cascades (F3b, F3c)

F5a3a characteristics of an unsteady turbulent boundary layer quantified in terms of its time-averaged characteristics and its temporal characteristics

F5a3b effects of streamwise pressure gradient, time-averaged and time-varying blade loading (lift), and trailing edge shape quantified for both 2-d and 3-d flows

F5a3c results used to identify noise sources and incorporated into the design process

F5a4 skew

F5a4a effects of blade skew on hydroacoustic performance

F5a4b the influence on the radial pressure gradients generated by different types and amounts of skew (lean)

F5a4c the effects of the flows at the blade trailing edge need to be quantified and controlled

F5a4d the effect of skew on separation, tip flows, secondary vortices, and losses need to be quantified

F5b RPM

F5b1 model scale vs. full scale effects

F5c# high Reynolds number database, in excess of $2 \times 10^{**6}$; current data is at blade Reynolds numbers less than 500,000 (F1c, F2f, F3f, F4b, F5c)

F5c1 database should include both time-mean and time-varying flows

F5c2 database should demonstrate interactions of the propulsor components

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G5a1b quantify the flow field and visualize flow structures

G5a1b1 large scale vortex structures

G5a1b2 separation

G5a1b3 turbulence

G5a1c measurements of time-varying surface pressure, shear stress, and separation

G5a1d current application in small-scale towing tank

- G5a1e full-scale implementation within next two years, funded by DARPA.
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 - G5b4# unsteady effects (G1b4, G2b4, G3b4, G4b4)
 - G5b4a gust flow and moving lifting surfaces

APPENDIX B

Structure of Prototype System

The knowledge structure for the TRACKS prototype system is provided here. The subtopics listed show the actual knowledge tree included in the system. The prototype system is limited to single-stage propeller design in straight-and-level operation.

Propeller Design - Efficiency and Powering Performance

- A1 Efficiency and Powering Performance
- B1 Technical Issues and Drivers
 - A. requirements
 - 1. powering performance
 - 2. cavitation performance
 - B. flow phenomena
 - 1. inflow
 - 2. propulsor flow
- C1 Design Capabilities
 - A. hull/inflow
 - B. propulsor flow field
 - 1. performance-to-geometry
 - a. empirical
 - b. analytical
 - 2. geometry-to-performance
 - a. empirical
 - b. potential
 - c. potential with viscous corrections
 - d. Navier-Stokes
 - C. hull/propulsor interactions
 - 1. empirical
 - 2. semi-empirical
 - 3. potential
- D1 Flow Control Issues
 - A. configuration
 - B. flow control devices
 - 1. inflow
 - 2. propulsor flow
- E1 Prediction Methods
 - A. Grid Generation
 - 1. Structured-grids
 - a. Potential flow or Euler
 - b. Navier-Stokes
 - c. Solution adaptive
 - d. Dynamical solution adaptive
 - e. Boundary layers
 - f. Full domain
 - 2. Unstructured-grid
 - a. Euler
 - b. Navier-Stokes
 - c. Static or dynamical solution adaptive
- B. Viscous/inviscid interaction methods
 - 1. Potential flow methods
 - a. Grid-based methods
 - b. Panel methods
 - c. Steady
 - d. Unsteady
 - e. Steady shed vorticity
 - f. Unsteady shed vorticity
 - 2. Euler flow methods
 - 3. Boundary layer prediction methods
 - a. Flow solver/Numerical methods
 - b. Turbulence modeling
 - c. Unsteady
 - 4. Viscous/inviscid interactions
 - a. Weak interaction for no separation
 - b. Strong interaction for separated flows
 - c. Time accurate
- C. Euler methods
 - 1. Steady, accuracy
 - 2. Unsteady, computational speed & accuracy
 - 3. Structured-grid methods
 - 4. Unstructured-grid methods
- D. Navier-Stokes methods
 - 1. Euler methods
 - 2. Steady
 - 3. Unsteady
 - 4. Turbulence modeling
 - 5. Structured grid
 - 6. Unstructured grid
- E. Turbulence modeling
 - 1. Transition to turbulence
 - 2. For steady mean hydrodynamics
 - a. Attached flow
 - b. Separated flow
 - c. Complex flow/multiple strains
 - 3. For unsteady mean hydrodynamics
 - 4. For turbulence fluctuations & acoustics
- F. Large-Eddy Turbulence simulations
 - 1. Algorithm & code development
 - 2. Sub-grid-scale turbulence modeling
- G. Computer science
 - 1. Data structure & handling
 - 2. Parallel processors
 - 3. Vector processors
- H. Full configurations

1. Computer science
2. Zonal interactions/boundary condition methods

F1 Interactions/Cause-and-Effect

- A. high blade loading
- B. tip flows
- C. cavitation
- D. juncture flows
- E. wake

G1 Basic Physics

- A. scale effects
- B. viscous effects
- C. boundary layers
- D. vorticity
- E. cavitation