REVIEW REPORT OF THE NIMROD PROJECT

On July 21 - 22, 1998 a panel of four reviewers (list attached) met with the NIMROD team at General Atomics for one day of presentations with discussion, and a half-day of further discussion. The consensus of the reviewers is presented in this report. The NIMROD project aims to develop a code to solve key fusion physics problems in which two-fluid effects are crucial ingredients, and to make the code available and uniquely accessible to users in the fusion community. Thus, the project aims to innovate in fusion physics, in large-scale computation, and in user-friendliness of the code. We find that the goals are extremely worthwhile and the progress has been impressive. These positive findings are summarized in Section I. In Section II we provide recommendations on how to further improve the project. We then provide answers to the questions posed to the panel by OFES.

I. FINDINGS

1. Two-Fluid Physics : Treatment of the plasma as two fluids is essential for many key fusion physics problems including neoclassical MHD instabilities, beta stability limits, resistive wall instabilities, anomalous ion heating, magnetic field generation (dynamo effects), and magnetic reconnection. These issues span tokamak and alternative concept research. A careful and thorough treatment of two-fluid effects is timely for several reasons. First, the problems listed above are all of current interest. Second, computation of three-dimensional, nonlinear, single fluid MHD plasmas has in the past decade become very highly developed and has produced substantial insight into these problems. The next logical step in this development is to introduce two-fluid effects critical to a full understanding of these phenomena. Third, experimental measurements routinely provide detailed information of the separate dynamics of the electrons and ions. Full exploitation of experimental data requires prediction for the individual species behavior. Hence, the physics goals of the project are appropriate.

2. Relationship to Computation Elsewhere: To our knowledge, the only code in the world which is comparable to NIMROD is the MH3D code at the Princeton Plasma Physics Laboratory. We are not aware of any other code which solves the primitive, complete two-fluid equations. There are numerous codes which investigate two-fluid effects using various approximate equations. For example, there is substantial work investigating two-

fluid turbulence. However, in the approximations employed and the focus on small-scale fluctuations such work is quite different than NIMROD. The panel believes that the two-fluid physics problems are sufficiently important that two codes, MH3D and NIMROD, are needed and justified. In addition, the two efforts are distinct and complementary in two respects. The codes have different computational features leading to complementary strengths. For example, MH3D can treat kinetic effect and NIMROD is particularly flexible geometrically (as described below). Second, the two groups have somewhat different and complementary physics interests which will facilitate appropriate coverage of the physics terrain.

3. Novelty of Computational Features: NIMROD has incorporated many features which are novel in the fusion context and which will aid its utility, including parallelism, a poloidal plane consisting of blocks containing a mixture of structured and unstructured meshes, compatibility with any machine with an F90 compiler, and a serious focus on user friendliness. The decomposition of the poloidal plane into blocks is well-suited to parallelism and represents perhaps the first large-scale fusion code which is designed to exploit parallel computing. The poloidal gridding also yields geometrical flexibility; i.e., the code will be able to treat effectively geometrical nuances of tokamaks, such as divertor x-points, and a relatively wide range of toroidal alternative concepts. The compatibility with F90 machines will facilitate portability. Furthermore, the user friendly goal is also manifest in the graphical user interface, the ability to interface to other physics and engineering codes, and the extendibility of the code which is aided by its modularity.

4. User Friendliness: In finding #3, we point out the computational features which aid use of the code by others. In addition, the attitude of the group will encourage this goal. The group desires the code to be freely available to the fusion community and is anxious to provide technical assistance. The combination of computational features and group attitude sets the stage for broad use.

5. Progress: The project was conceived 1-1/2 years ago, and is now beginning to run very simple test cases. Although the code is not yet ready for new physics problems, the progress by the relatively small group has been impressive. It is expected that the code will be ready for users within one year, if appropriately funded. The project has made very effective use of a geographically distributed team (although the co-location of several key individuals has been very helpful).

6. Quality of Technical Work: The technical work is extremely competent and of very high quality in computation, code architecture, and physics choices.

7. Level of Effort: The project estimates that a future allocation of 4.85 FTE, ranging from junior post-doctoral associates to senior personnel, is necessary to accomplish its goals in a timely manner. Although the panel did not perform a detailed cost or staff analysis, it is our impression that this level of effort is about right for the work proposed, and that the importance of this work justifies such an effort within the U.S. fusion program.

II. RECOMMENDATIONS

1. Physics Plan: At this point in the project's development it is timely and important to articulate specific physics problems which the code can solve. The project has listed general problem areas which the code can address (see Finding #1), but it has not yet clearly articulated specifically how the code can advance the state of knowledge in each area. This involves a description of the present state of knowledge in each area and the remaining issues which require a two-fluid treatment. This effort should also include, for illustration, a logical chronology which, for example, divides the physics plan into the very short term, the short term, and the long term. On the very short term (perhaps < one year) the code can be used to produce some results which are not particularly new, but are useful and demonstrate the validity of the code. An example of such an application may be evaluation of the nonlinear evolution of a particular MHD instability relevant to a specific tokamak. On the short term (say one to two years) the code can be used to solve original physics problems which do not require further extensive development of the physics package. An example may be the treatment of resistive wall instabilities, a problem which can be treated with a scalar pressure. On the long term (beyond two years) the code can attack more complex problems, such as neoclassical MHD instabilities which requires use of a stress tensor. Since the code is intended for users, the physics plan is not a work effort to which the group can commit. Its purpose is to demonstrate the possible utility of the code. Furthermore, the group should describe which physics problems project members intend to investigate personally, driven by their own physics interests, and which problems they anticipate are more suitable for user investigation.

2. "Marketing" Plan: At present, knowledge of NIMROD in the general fusion community is scarce and sometimes misinformed. It is important for the project to become better

integrated into the overall community (tokamak and alternatives components) so that potential users become aware and accurately informed of the capabilities of the code. Fusion physics users will be most readily attracted by a physics message. Hence, recommendation #1 will aid in this endeavor. We suggest that the project improve and fine-tune the delivery of the "message," and seek greater input from potential customers.

3. Advisory Group: We recommend that the project appoint an informal advisory group to provide input on both technical matters and programmatic issues such as that discussed in recommendation #2. The group may consist of perhaps three persons and meet perhaps once per year.

4. NIMROD and MH3D Cooperation: We recommend that the NIMROD and MH3D groups cooperate strongly including, for example, an open exchange of computational information, an absence of proprietary protocol, cross-checking of data, a sharing of physics information, and an overall cooperative and perhaps collaborative relationship. Such an approach will optimize the productivity and prosperity of both groups.

5. User Choice of Gridding: The poloidal mesh is complex. We recommend that a hierarchy of grids be available to the user so that a grid structure appropriate to a particular physics problem can be chosen. For example, geometrically simple problems should be able to employ a simple grid (perhaps even a Fourier analysis option).

6. Nonlinear Free Boundary: We recommend that a significant priority be given to development of a capability for a nonlinear free boundary. This capability does not, to our knowledge, exist elsewhere and it is important for treatment of external kink modes and resistive wall instabilities.

7. User Friendliness: It is difficult to measure the extent of user friendliness of the code. As one slightly quantitative measure we suggest that the “time-to-use” for a potential user be employed.

8. Scaling to Future Machines: One expressed guideline for the project is that the code be easy to maintain in the face of uncertainty regarding future computing machines. We are unclear how this guideline is reflected in the code design. Clarification in future discussions is recommended. It is also unclear to us the extent to which the code will be

compatible with future machines which may require thousands of parallel processors. The code at present is oriented for use of several tens of processors.

9. Nonfusion Applications: Single fluid MHD computation developed within the fusion community is now having significant effect in the larger scientific community, such as plasma astrophysics (indeed some of the project members have contributed to this development). We recommend that the project spend a modest effort investigating the possible use of NIMROD in areas outside of fusion. Clearly, any additional application of NIMROD is beneficial, and is also consistent with the restructured fusion program.

RESPONSE TO DOE QUESTIONNAIRE ON NIMROD PROJECT

1. Scientific and Technical Merit of the Project

Does the project address an important problem in plasma and fusion science. Are the objectives of the application original and innovative? Is similar work being done elsewhere? What is the likelihood that the project will lead to new or fundamental advances in its field?

NIMROD is addressing an array of important plasma problems for which two-fluid effects are critical (see Finding #1). The objectives, both in computational features (see Finding #3) and in physics effects are original and innovative. The only similar work being done elsewhere is the MH3D code (see Finding #2). Given the above, we expect that it is highly likely that NIMROD can yield fundamental advances relating to many key fusion problems.

2. Approach

Does the project employ novel concepts or methods? Are the conceptual framework, methods, and analyses developed and appropriate for the proposed project? Does the project recognize potential problems and consider alternative strategies?

Novel computational methods are incorporated into NIMROD as outlined in Finding #3. There is additional novelty in the team approach and the goal of making such a complex research tool available as a user code. The methods employed are appropriate. The team approach is particularly effective at spotting potential problems and instilling self-criticism into the project. However, further integration with and input from the larger fusion community would be useful at this time.

3. Investigator Competence and Performance in Previous Research

Please comment on the qualifications and recent research experience of the team. Have they done similar work in the past?

The key investigators have extensive experience in computational physics (including large-scale fluid computation), MHD theory and computation, and alternative concepts. The senior personnel have a long record of important contributions in these areas, and the team is fortunate to have attracted some excellent younger computational physicists.

4. Research Environment

Please comment on the scientific environment in which the work will be. Does the project take advantage of unique facilities and capabilities or make good use of collaborative arrangements? Are the proposed facilities, budget, and staffing levels reasonable to carry out the project?

The somewhat unusual collaborative team approach has proven successful, and the proposed staff is reasonable to carry out the project.

5. Relevance

Is the proposed project relevant to the Department's plasma science and fusion science programs? Will the project help to maintain U.S. excellence in an area of plasma science or fusion research? Could the projects work lead to a significant contribution to another field?

As described above, the physics topics are highly relevant to plasma science. To our knowledge there is no comparable code being developed outside the U.S.; thus, the code will maintain U.S. leadership in this area. We anticipate that the code likely has the potential to contribute to other areas of physics (such as plasma space and astrophysics); it can contribute as a scientific "user" of parallel computing and provide early lessons on the application of parallel computing to large-scale scientific problems. However, we suggest that the project investigate nonfusion applications of NIMROD, and confirm or deny our speculations.

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