A Software System for the Preservation and Application of Best Practices for CFD

M.R. Mendenhall, M.C. Hegedus, and P.M. Stremel
Nielsen Engineering and Research
605 Ellis St., Suite 200
Mountain View, CA 94043, USA

mrm@nearinc.com

ABSTRACT

A best practices expert system for the application of CFD tools and methodologies is described. The system provides expert knowledge and guidance in the development of CFD projects and in the use of CFD codes and methodologies. It was developed to preserve corporate memory and best practices to provide a consistent approach to the CFD process and high quality results with reduced uncertainty for a wide range of flow problems. The system contains a repository of expert knowledge, references, and technical information, which can be searched using keywords associated with CFD. The method couples knowledge databases of expert information with specific guidelines and standards for all aspects of the CFD process.

1.0 INTRODUCTION

CFD plays an essential and ever increasing role in the design and analysis of advanced military aerospace vehicles. Any time and cost savings in the CFD process will lead directly to cost reductions in the design and development program. To reduce the uncertainty of the CFD process, unnecessary CFD runs must be eliminated, errors must be minimized, and mistakes of the past must not be repeated.

The process by which researchers apply CFD tools and methodologies is often complex and individualistic, and the predicted results can vary greatly depending on how the tools are applied. These variations in results can occur for individuals with detailed knowledge of the CFD process, but they are most prevalent for the novice user. Many problems with CFD solutions can be traced to inexperienced users producing results with software they do not understand.[1] The BPX system described in this paper addresses the deficiencies of the novice user with respect to the CFD process, and it provides access to a knowledge base for the more advanced user.

For purposes of the present work, the concept of "Best Practices" is defined as a set of specific guidelines to assist in grid generation, the selection of the parameters that control the CFD code execution, the assessment of the resulting solution, the identification of abnormal results, and the process to correct the solution. For many applications, a definitive set of best practices does not exist, but rather an accepted set of recommended guidelines is used. These recommended guidelines are based on the experience of expert users of the application. The best practices guidelines function as a practical set of instructions and a checklist for CFD users. In addition, the guidelines provide a tutorial function for novice users or experienced users unfamiliar with a specific code. These guidelines, which may change with time, need to be available to all CFD users.

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The BPX (Best Practices eXpert) system provides expert knowledge in the use of CFD codes to users, developers, and technology managers.[2-5] The goal of the system is to enable all CFD users to obtain high quality CFD solutions with reduced uncertainty and lower cost for a wide range of flow problems. BPX includes specific guidelines to assist the user in problem definition, code selection, input preparation, grid generation, parameter specification, results interpretation, verification, and validation. BPX couples knowledge databases of expert information with specific rules and guidelines for individual codes and algorithms, resulting in a design that exploits expert user's knowledge so that standards for the use of CFD codes by all users could be established. This will ensure that all reasonable steps have been taken to achieve the highest possible accuracy of a CFD solution and reduce uncertainty. Ultimately, the system of best practices could provide a means for the quantitative estimation of the uncertainty in a CFD solution.

2.0 BACKGROUND AND OBJECTIVES

2.1 Background

The application of and search for best practices in CFD is not new, and several examples of previous efforts are presented in References 6 through 14. Some of these approaches require a skilled CFD user to interpret the results and implement corrective actions. It is the goal of BPX to assist all levels of users with this capability.

2.2 Objectives

The objective of BPX is to provide a state-of-the-art capability for CFD analysis which can be broadly applied by users interested in (1) improving the accuracy and reducing the uncertainty of CFD results, and (2) reducing the time and cost associated with CFD applications. Meeting these objectives requires a means to provide the user with easy access to both general expert knowledge and specific advice on the nuances associated with the use of specific codes. A special software framework is essential to the BPX development, given the quantity and variety of information available. In addition, a system should be intuitive to use, be of benefit to users with a wide range of experience, and be generally helpful by anticipating problems using frequently asked questions and lessons learned.

3.0 TECHNICAL APPROACH

The goal of the technical approach is to develop a system of best practices that will provide state-of-the-art capability for CFD analyses to users of all skill levels. At the core of best practices is the expert knowledge of experienced CFD developers and users.[15] This expert information provides the guidelines for successful setup and execution of CFD calculations, problem diagnosis, and guidelines for correcting solution errors.

The development of the BPX system is based on the approaches successfully used for two integrated aerodynamics design and analysis systems called LVX (Launch Vehicle eXpert) [16,17] and RSX (Rocket Sled eXpert).[18,19] These systems incorporate an expert knowledge database, historical design guidelines, and a references database into a knowledge-based system, which is also coupled with legacy analysis methods. The development of BPX was leveraged by the lessons learned during LVX and RSX software development.

3.1 BPX Framework

The framework for the BPX system is shown in Fig. 1. The system incorporates an expert knowledge database that includes the best practices guidelines and a technical references database that includes document citations, both of which can be searched by the user. The CFD solution process is distributed between the twelve areas provided for the user to set up the details of the specific problem under consideration. The user has access to each process area at any time for testing and sanity checking.

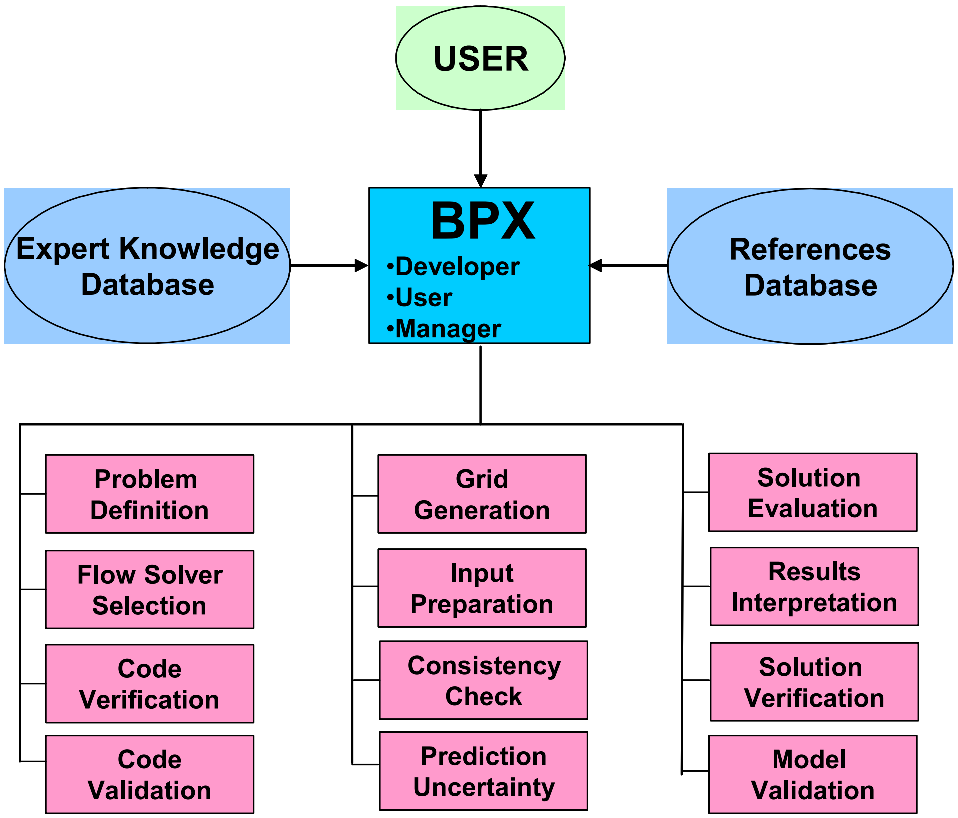


Figure 1.- BPX Framework.

3.2 Keywords

A hierarchical keyword structure is used to organize the expert knowledge, guidelines, and references stored in the databases. Each node in the hierarchy is represented by a keyword that describes a specific technical topic. The hierarchy is a convenient way to organize the information in the databases so that it is easily accessible for editing and maintenance purposes. This model allows the stored information to be linked in a logical fashion, which assists in both the knowledge acquisition and the knowledge retrieval mechanism. There are approximately four hundred keywords in the current BPX hierarchy, and the user can add additional keywords as needed. The keywords have been described in previous documents and will not be shown here.[3-5]

3.3 Databases

The databases in BPX are organized around the keyword structure described above for ease in linking related information and providing a means to search for information. The following sections will briefly describe the various databases in the current version of BPX.

3.3.1 Expert Knowledge

Technical information obtained from numerous interviews with expert CFD developers and users form the basis for the expert knowledge database. The interviews were transcribed and checked for accuracy, and then the interviews were parsed into small packets or nuggets of information. Each nugget of information is tagged with one or more keywords and included in the database in the hierarchy corresponding to the primary keyword.

3.3.2 Rules and Guidelines

A separate rules database includes specific information on the application of the CFD codes and methodologies for a variety of flow problems. This information was gleaned from interviews with the developer and expert users and from publications. Rules are included to address grid generation, selection of turbulence models, and other key steps in the CFD process, and these rules are applied during the use of the application to provide guidelines to the user. Guidelines in the form of concurrence, caution, conflict, and information are presented to assist the user in making informed decisions with respect to the CFD process.

3.3.3 References and Documents

The references database in BPX was created as the result of an extensive literature search of the open literature, and this effort produced more than 11,000 citations to technical references that have been included in BPX and tagged with the current keyword list. Other important technical reference documents were identified during the expert interviews. The references were screened to keep the list to a manageable size, and most of the references included are for application to aerospace problems because of the sponsor's interest. It is possible to expand this database to include information from other technical areas as needed.

3.3.4 Frequently Asked Questions

A list of frequently asked questions (FAQ) on the CFD code OVERFLOW, based on actual questions received from typical users, is also included to illustrate this feature. It is anticipated that OVERFLOW users will be able to answer a number of common questions without contacting the code developer directly, thus relieving him of some of the time spent answering questions and providing support to users. This feature can be included for other codes for which information is available.

3.3.5 Code Manuals

Manuals are included for the CFD codes featured in BPX and are accessible directly from the application.

3.4 Verification and Validation

It is important for the user, novice and expert alike, to be consistent and systematic in the verification and validation exercises conducted in the various aspects of the CFD process. BPX can include easy access to data files, geometry information, and sample cases appropriate for the V&V effort.

3.5 Tutorials

Another feature is the capability to include education and training tutorials on selected topics as a means to archive the corporate memory of the user organization.[15] Easy access to this information can increase the efficiency of training new employees, teaching new CFD users, and bringing experienced users up to speed quickly on a new code. For illustration purposes, BPX includes a tutorial on the fundamentals of verification and validation based on an AIAA Short Course by Dr. William L. Oberkampf of Sandia National Laboratories and Dr. Chris Roy of Auburn University. There is also a link to the Drag Prediction Workshop presentations and summaries for easy future reference and access.

4.0 BPX DEMONSTRATION

A brief demonstration of the BPX application is presented in this section. The main window of the BPX application is shown in Figure 2, and from this window the user can log in to BPX or access help.

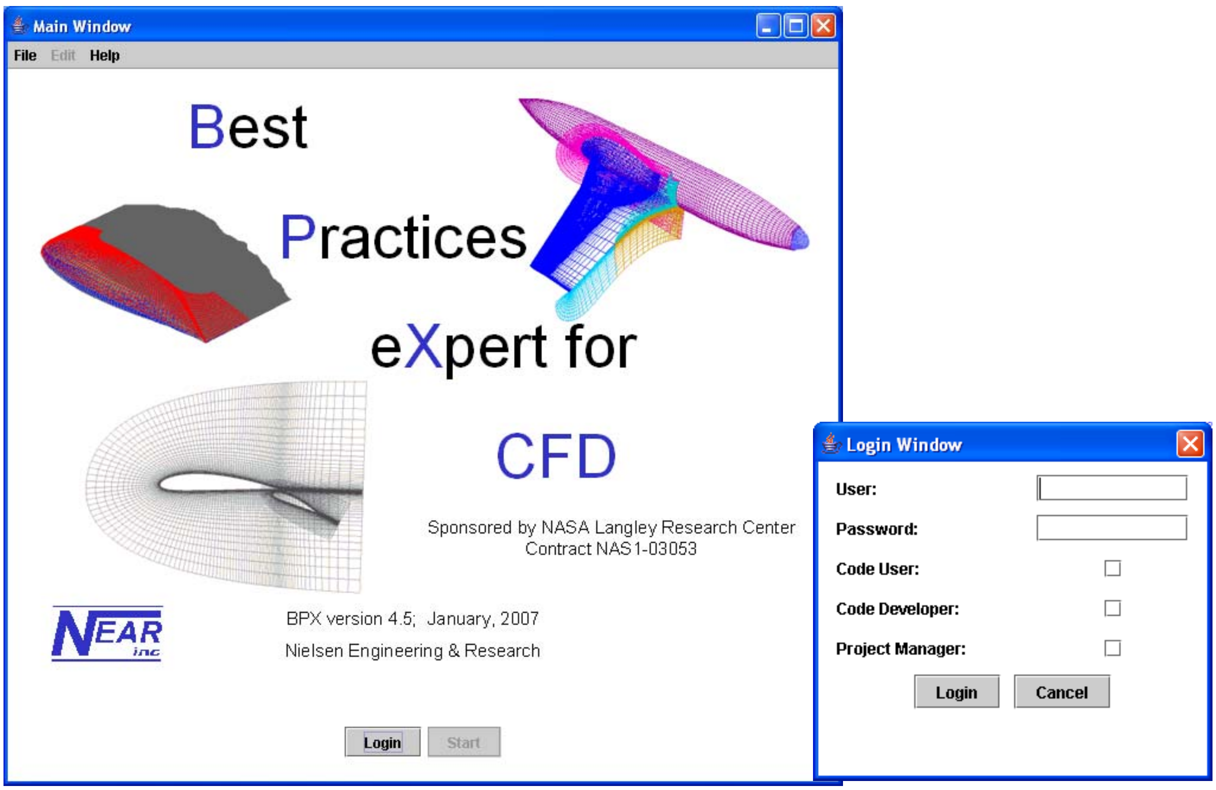


Figure 2.- BPX Main Window.

Notice that the Login Window offers password protection and that the user can login as a code user, developer, or manager. Although not currently configured to do so, BPX could select the level and detail of information for presentation based on the specific needs of the user.

After the user logs in to the BPX application, the BPX-CFD window is displayed. Shown in Figure 3, the BPX-CFD window has access to all the elements of a BPX project. The BPX-CFD window represents a single access point to the best practices information for CFD where the user can create and manage projects, access information about workshops, search for information, and display alert information. The five main components of the BPX-CFD window include the Button Panel, the Tree Panel, the Alert Panel, the Keyword Panel, and the Main Panel as shown in Figure 4.

The Button Panel provides project functionality at a single visible layer. The functionality includes the creation of a new project, project management, search for information, and adding keywords to a project.

The Tree Panel contains the Process Tree of the current project. As the user makes a selection on the tree nodes of the Process Tree, the Main Panel and Alert Panel will be updated to reflect these selections.

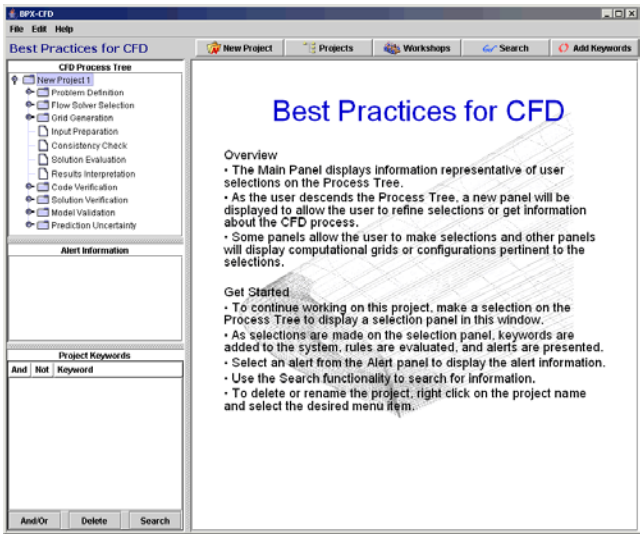


Figure 3.- BPX-CFD Window.

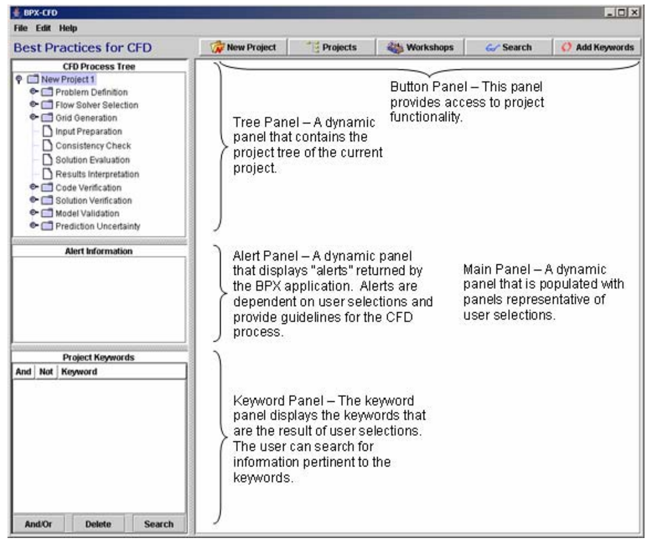


Figure 4.- BPX-CFD Window Components.

The Alert Panel contains the alert elements of the BPX application. The alert elements are dependent on user selections in the BPX application and provide guidelines for the CFD process. Currently the alert elements include entries for model validation, turbulence, error estimation, solution methodologies, and grid generation codes. These alert elements become visible in the Alert Panel when the appropriate keyword has been selected. When an alert element is selected from the Alert Panel, guidelines for the selected alert will be presented to assist the user in making informed decisions pertinent to that element.

The Keyword Panel contains the keywords associated with the user selections and buttons to search for data related to these keywords. The entries in the keyword panel reflect the user selections in the BPX application. When keywords are added to the project, the expert system will evaluate the keywords and deliver messages to the user in the form of conflicts, concurrences, and information about the user selections. These messages are defined by rules governing the limitations, deficiencies, and attributes of the solution and grid methodologies. These messages, or guidelines, assist the user in making decisions that will result in a consistent approach to a more productive CFD experience.

The Main Panel is a dynamic panel that displays information representative of user selections on the Process Tree. As the user descends the Process Tree, a new panel will be displayed to allow the user to refine selections or get information about the CFD process. Some panels allow the user to make selections and other panels will display computational grids or configurations pertinent to the selections.

All the features of BPX cannot be shown in the space constraints of this paper; however, a few simple illustrations will be discussed in the following sections to show the unique functionality of the software. Other examples have been described in previous publications.[3-4]

4.1 BPX Project

When the BPX application is started, a new project is automatically created which can be saved for future use and modification. In the following demonstration of a fictitious project, the magenta highlights are shown to mark specific features and user selections, they are not shown in the normal use of BPX.

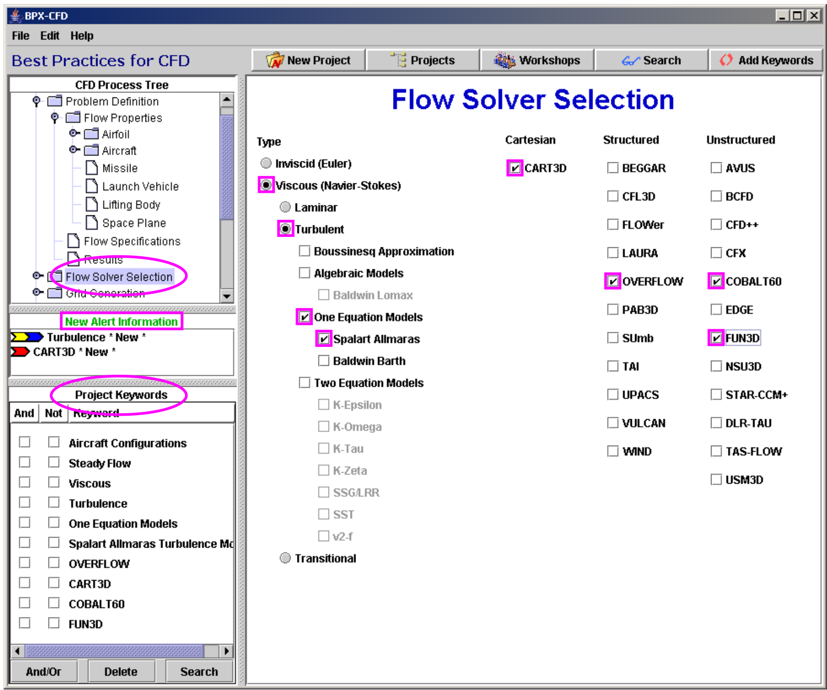


Figure 5.- BPX Project Example.

In the example project shown in Figure 5, the user has made some preliminary selections in the Problem Definition section as noted in the first two Project Keywords, "Aircraft Configurations" and "Steady Flow." In this window, opened by the highlighting of Flow Solver Selection on the CFD Process Tree, the user has made a number of selections for type of flow and flow solvers of interest (shown highlighted). Notice that as each selection is made, the appropriate keyword is added to the list in the lower left corner of the window.

Alert icons, in the form of multicolored chevrons, are displayed in the left center window in Figure 5. This icon indicates that guidelines are available regarding the user selections, and they can be accessed by selecting any element of the Alert Panel displaying the guideline icon. The icon can contain red (conflict), green (concurrence), yellow (caution), or blue (information) chevrons to identify available guidelines. When the user selects an alert element from the Alert Panel, the guidelines associated with the alert element are displayed. For example, in this simplified example, the conflict information associated with the choice of CART3D is displayed because of the choice of "Viscous" in the flow type.

As the user makes more selections in defining the project, the keyword and alert information is continuously updated. In Figure 6, the user has selected a "Structured" grid for this project. Notice that "Structured Grids" has been added to the keyword list, but now a number of new Alerts have been added to the list to warn the user about some problem with the combination of parameter selections made. In this simple example, the red chevrons identify a problem with the selection of "Viscous" for the flow solver "CART3D" and the selection of "Structured Grids" for the solvers "COBALT60" and "FUN3D." The user can select the alert information to identify the specific problem at any time, and there is a warning when new information is shown which has not been read.

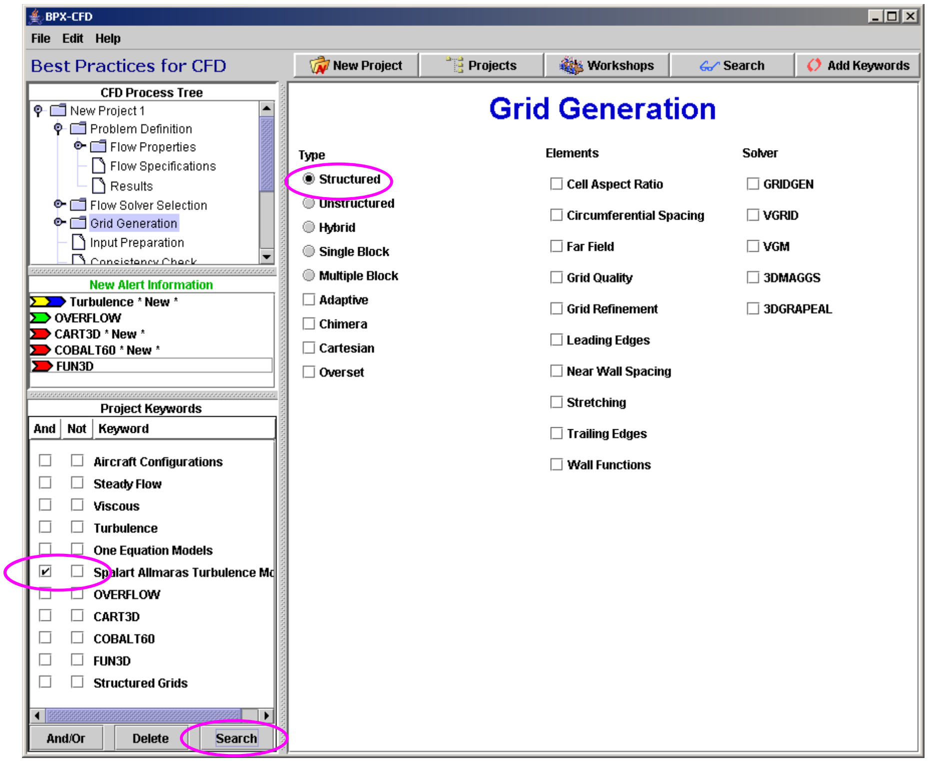
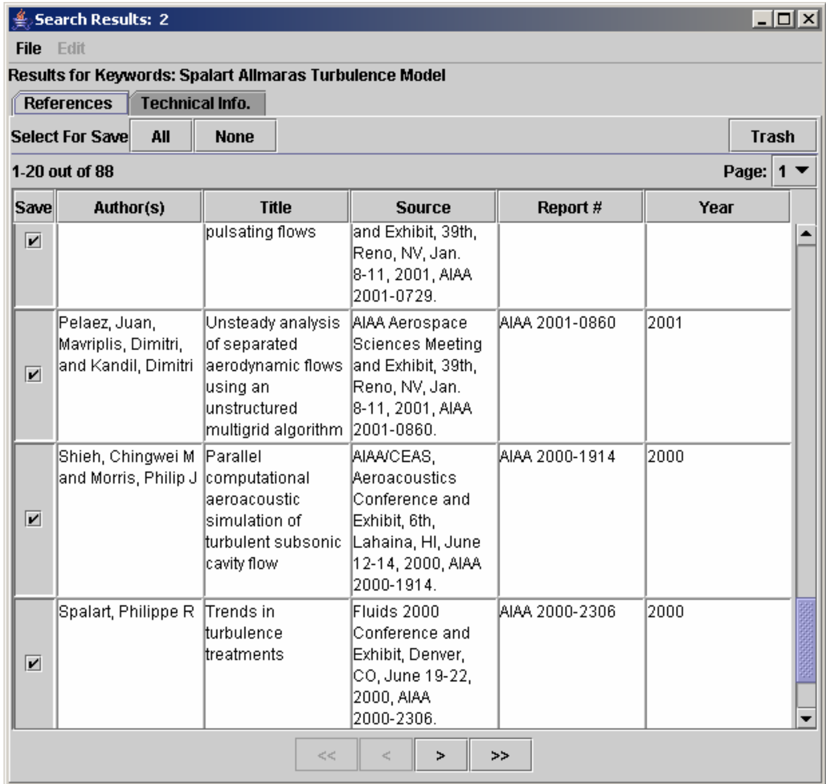


Figure 6.- BPX Grid Generation Window.

4.2 Database Search

At anytime in the use of BPX, the user has access to the expert knowledge database and the references database. For example, in Figure 6, the user has selected the keyword "Spalart Allmaras Turbulence Model" and then the Search button, as highlighted. BPX now searches the databases for all entries with this keyword, and the results from the References Database are shown in Figure 7.

The search results from the References Database show that 88 total entries are available that have the specific keyword "Spalart Allmaras Turbulence Model." Each citation is shown in the table, and these can be sorted by Author or other column heading. The user can edit the list with the Save column and then print the list or save it to a file for future use. Selecting the "Technical Info" tab in Figure 7 will produce another window with the information from the expert knowledge database that has been tagged with this keyword.



Search Results: 2

File Edit

Results for Keywords: Spalart Allmaras Turbulence Model

References | Technical Info.

Select For Save | All | None | Trash

1-20 out of 88 Page: 1

Save	Author(s)	Title	Source	Report #	Year
☑		pulsating flows	and Exhibit, 39th, Reno, NV, Jan. 8-11, 2001, AIAA 2001-0729.		
☑	Pelaez, Juan, Mavriplis, Dimitri, and Kandil, Dimitri	Unsteady analysis of separated aerodynamic flows using an unstructured multigrid algorithm	AIAA Aerospace Sciences Meeting and Exhibit, 39th, Reno, NV, Jan. 8-11, 2001, AIAA 2001-0860.	AIAA 2001-0860	2001
☑	Shieh, Chingwei M and Morris, Philip J	Parallel computational aeroacoustic simulation of turbulent subsonic cavity flow	AIAA/CEAS, Aeroacoustics Conference and Exhibit, 6th, Lahaina, HI, June 12-14, 2000, AIAA 2000-1914.	AIAA 2000-1914	2000
☑	Spalart, Philippe R	Trends in turbulence treatments	Fluids 2000 Conference and Exhibit, Denver, CO, June 19-22, 2000, AIAA 2000-2306.	AIAA 2000-2306	2000

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Figure 7.- BPX Search Results.

4.3 Input Consistency Check

Another feature of BPX which will not be shown in detail here is the capability to check the input parameters for consistency. Since the emphasis of the current version of BPX is on the code OVERFLOW, the user can use BPX to create an input file for this code. After selecting the appropriate input parameters, the user can execute a Consistency Check on the input data. The consistency check will compare the input parameters with the other selections made in the problem definition to search for the obvious errors that are usually not found until the initial runs are made.

4.4 Sample Grids

A number of sample grids for airfoils, multiple-element airfoils, and wing-body configurations are included to provide the user with insight into proper and erroneous grid characteristics. An example transonic airfoil grid is shown in Figure 8 where the magenta highlighted areas illustrate some of the features to help train the user to evaluate important features of a computational grid. A sample complex multiblock grid for a wing body is shown in Figure 9. The user can examine the individual blocks by removing grids, changing colors, zooming, and rotating to better understand the nuances of a good computational grid.

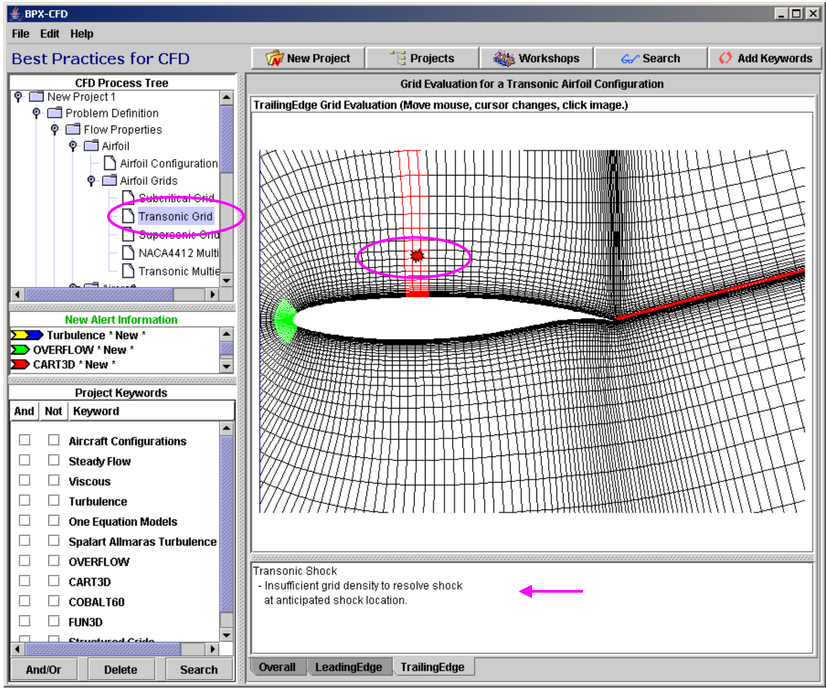

Figure 8.- Airfoil Grid Example.

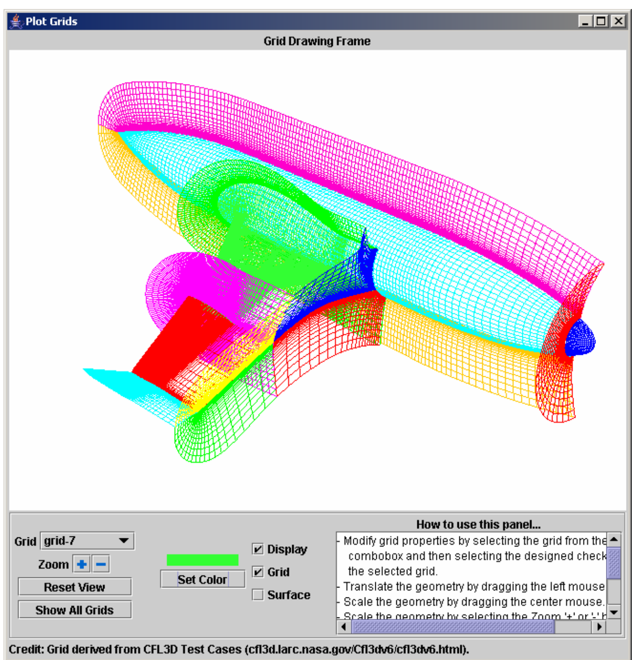

Figure 9.- Wing-Body Grid Example.

5.0 CONCLUSIONS

A best practices system to assist CFD users, developers, and managers in obtaining reliable CFD results with reduced uncertainty has been described. The rules and guidelines are based on expert knowledge obtained from the experienced CFD user and developer community, while continued advances in CFD knowledge and technology can be added to future BPX systems. The BPX system has application as a tool to assist the CFD engineer in making decisions that will lead to more accurate computational results in less time and at lower cost by reducing errors and unnecessary runs. Additional applications include use as an educational tool and as a repository for the corporate memory or expert knowledge archives of the CFD organization for which the system was built.

6.0 ACKNOWLEDGEMENTS

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Paper No. 18

Discusser's Name: P. Raj

Question: What do you see as the principal barriers to the widespread use of the BPX System?

Authors' Reply: The barriers to the use of best practices are:
1. Lack of perceived need
2. Cost to generate initial system
3. Cost or desire to maintain system
4. Hesitancy to spend money in current budget to develop a system which will not show a benefit or return on investment for one or two years in the future.

Discusser's Name: A. Cenko

Question: I recently had a CFD expert (with no previous experience in store separation) do a calculation for a store load on the F-18 at M=0.95 and he got a C_n=12. Would BPX help in a case like this?

Authors' Reply: If the BPX expert knowledge database included this information on reasonable values to expect or if the rules imbedded in BPX include a range of expected values for aerodynamic parameters, then BPX could warn the user about anomalies in results. The BPX knowledge database could also provide the user with a list of possible problems or suggestions of what could be wrong. For example, if the pitching moment coefficient is out of range, check the CG location. If both the pitching moment and lift coefficient are out of range, check the reference area used.