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A BEST PRACTICES SYSTEM TO ENHANCE CFD USE IN STABILITY AND CONTROL APPLICATIONS

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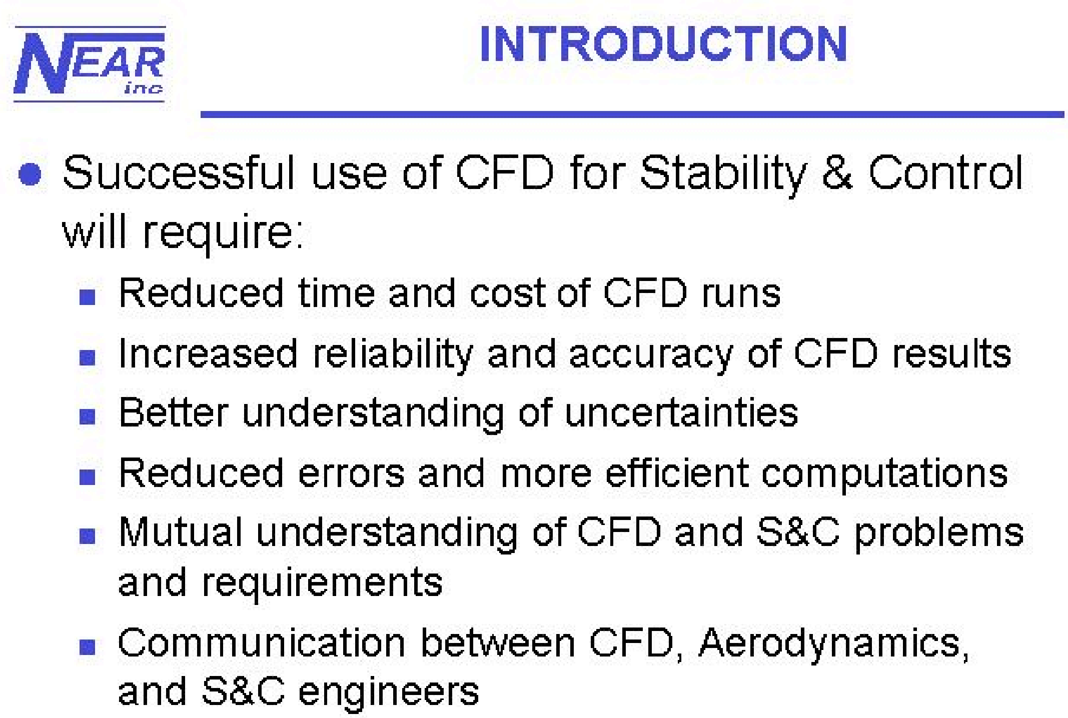
Successful use of CFD to provide aerodynamics for stability and control (S&C) applications will require that the traditional time and costs associated with CFD be reduced and that the errors and uncertainties currently associated with CFD be better understood. CFD will be required to work under a wide range of flow conditions and provide fast and reliable aerodynamics if it is to contribute to this next generation of S&C analyses. CFD solutions have errors and uncertainties due to poorly converged solutions, solution anomalies caused by grids, turbulence models, and parameter selection, and other manifold reasons.

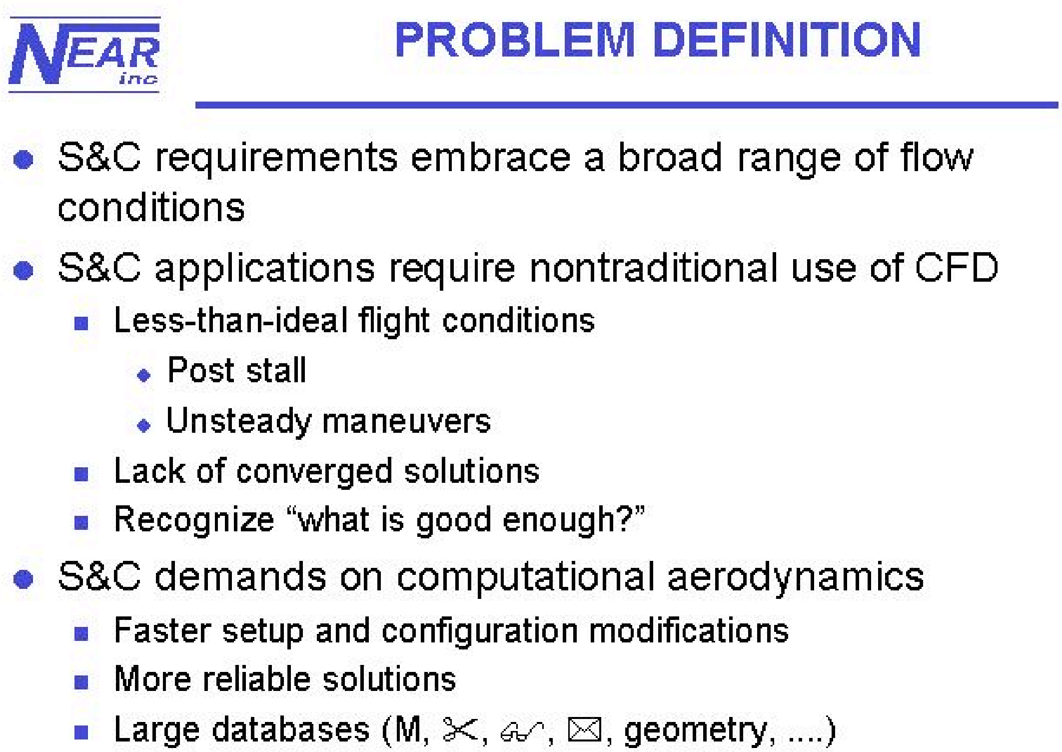
In addition to the above problems, there will be a requirement for communications between the CFD expert and the S&C expert and possibly experts from other related disciplines. The CFD



expert may not understand the technical problems associated with S&C, and it is almost certain the converse is true.

Some problems to be anticipated in using CFD for stability and control involve the need for aerodynamic characteristics for a broad range of flight conditions. These flight conditions may include flow regimes that are very difficult to handle with CFD; for example, post stall flight and unsteady flow conditions. It may be necessary for the CFD engineer to use solutions that are not converged and glean the best possible aerodynamic characteristics from this information. It will be essential to know and understand the quality of the solution and the uncertainties that must be associated with the aerodynamic coefficients.

In addition, the large number of points required to complete an aerodynamic database will put strong demands on the stability and control budget. It will be necessary to set up and complete



runs faster and more efficiently to keep costs down. It will be important to eliminate incorrect runs and avoid unnecessary repeat runs. A typical aerodynamic database may require hundreds if not thousands of runs. This large quantity of data may require automated techniques to evaluate the results.

The CFD user has a critical role in current CFD processes, and the quality of computational aerodynamic results is subject to significant variability. Many problems can be traced to inexperienced users producing results with software they do not understand.[1]

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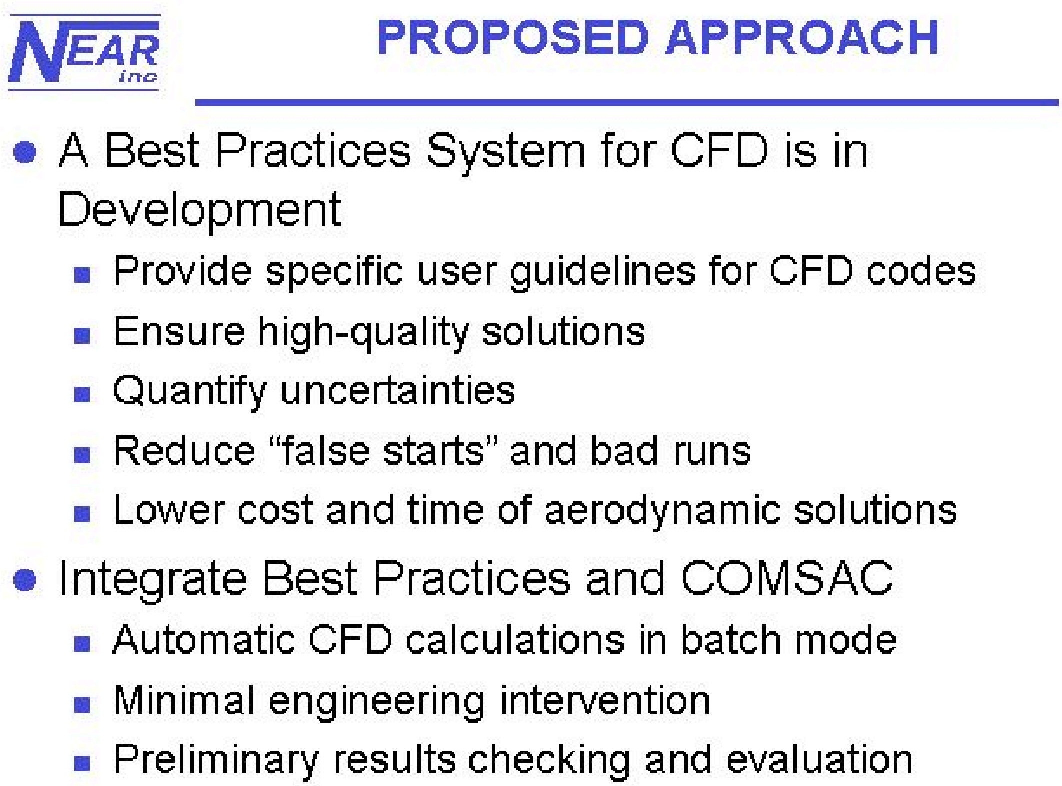
OTHER PROBLEMS

- Quality of CFD results depends on user experience
- Many problems can be traced to inexperienced users producing results with codes they do not understand

[1.] Lee, J. R., "Certainty in Stockpile Computing: Recommending a Verification and Validation Program for Scientific Software," SAND98-2420, Sandia National Laboratories, November 1998.

NEAR is currently working to develop a system of best practices for CFD. The purpose of this work is to provide a set of user guidelines for running CFD codes to assist all users in obtaining high-quality solutions with reduced uncertainty and at lower cost.[2] The system includes specific guidelines for problem definition, input preparation, grid generation, code selection, parameter specification, and results interpretation. The objective of the best practices system is to ensure that all reasonable steps are taken to achieve the most accurate and reliable CFD solutions possible.

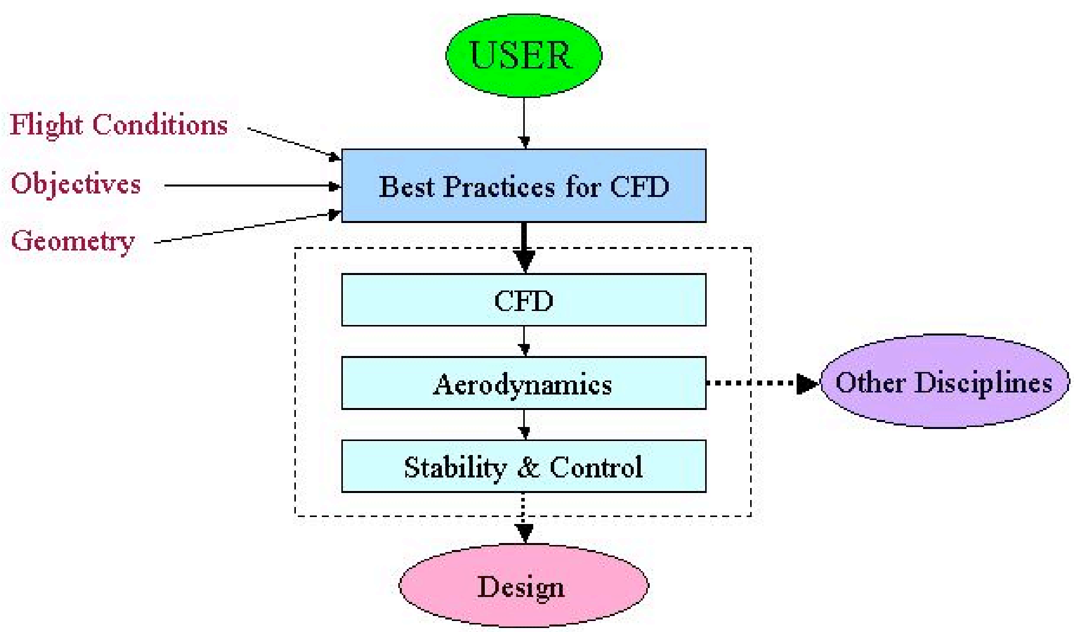


[2] Mendenhall, M. R., Childs, R. E., and Morrison, J. H., “Best Practices for Reduction of Uncertainty in CFD Results,” AIAA 2003-0411, January 2003.

This is a diagram of a proposed approach to integrate Best Practices and COMSAC. The user will specify the flight conditions of interest, the objectives of the design, and the geometry of the configuration. Best practices will use this information, along with the expert CFD knowledge in the system, to specify a number of guidelines for setting up the CFD runs to provide the best possible aerodynamics information. These aerodynamic characteristics will be available to the stability & control area as needed for design purposes. In addition, the up-to-date aerodynamics can be made available to other disciplines in a similar manner.

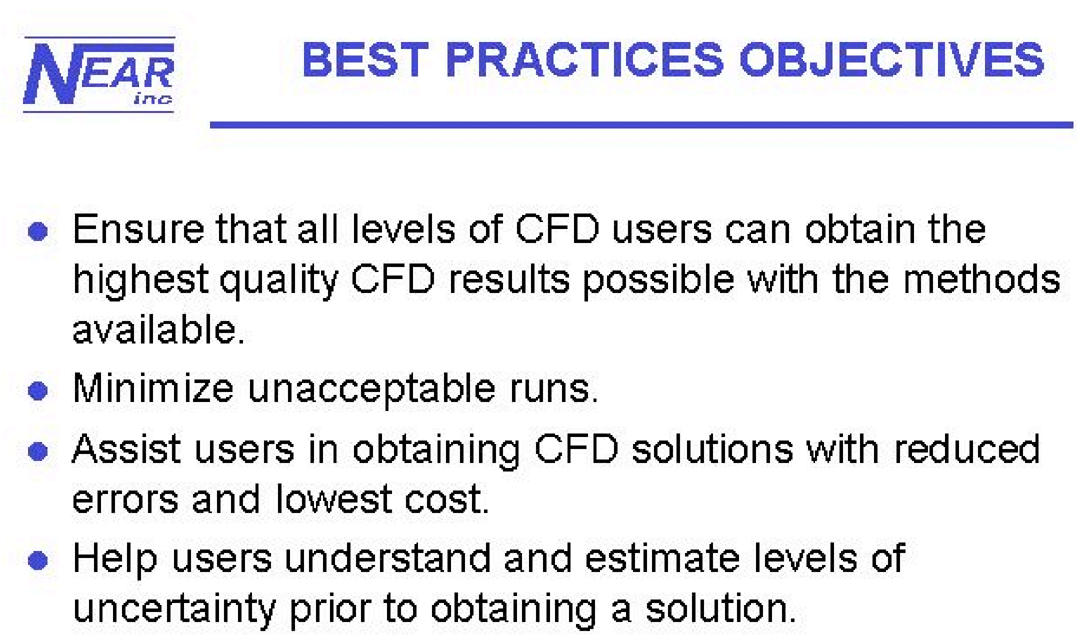
In the diagram, the dashed box represents COMSAC. The aerodynamic information generated for COMSAC can be shared with other disciplines.

BPX + COMSAC



The objective 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. Best Practices must include the following:

- Provide an intuitive process for general acceptance by the CFD community.
- Demonstrate ease of use for all levels of users.
- Provide information appropriate for all CFD users to achieve more reliable CFD results with less effort.
- Provide a comprehensive compendium of procedures and expertise that should be followed to get the required accuracy from CFD.
- Evolve with advancements in CFD algorithms and codes.
- Choose a framework for best practices applicable to all algorithms and solvers that developers and/or



users are willing to support.
- Permit individual users to customize details of best practices to support specific needs and provide for proprietary versions of the system.
- Provide a self-critical system by noting the relative confidence in specific guidelines and characterizing the aspects of CFD practices that are poorly understood.
- Provide the flexibility to evolve into a future system which may require highly automated CFD quality assurance algorithms, including automatic grid generation and solution interrogation algorithms.

Since different CFD codes have strengths and weaknesses in different areas, the approach to best practices is to include information and guidelines tailored for specific codes. The knowledge database will be obtained from experienced and successful code developers and users. Links to references will provide the user with sources of additional information. A number of standard runs which can be used for validation purposes will be included. The system will be easily updatable since knowledge and experience with the codes is always changing.

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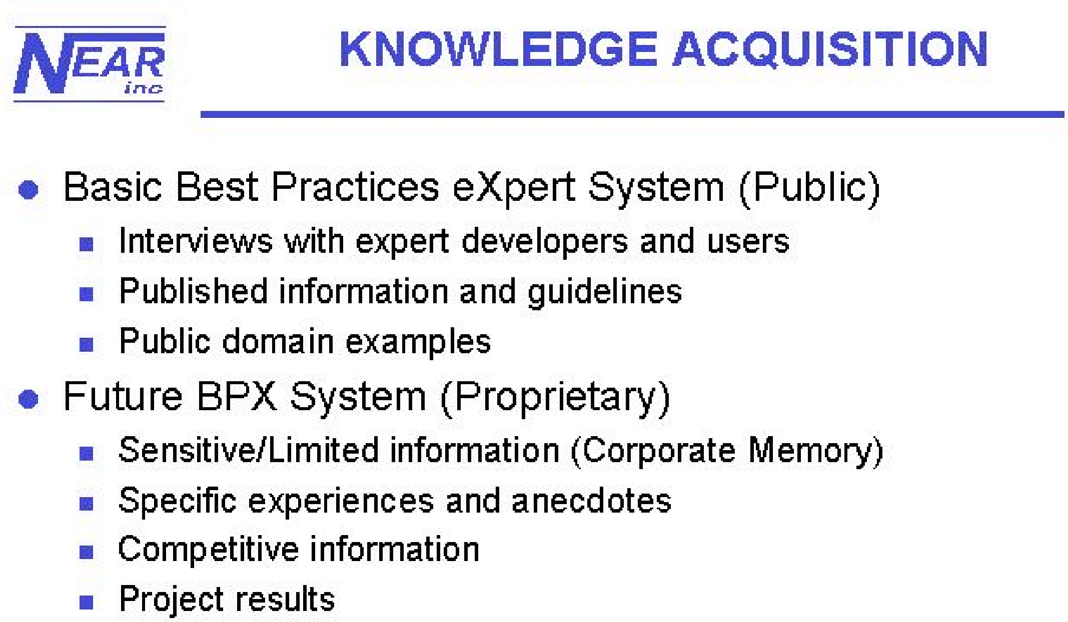
BEST PRACTICES APPROACH

- Include Specific Code Information
  - Recommendations
  - Warnings
- Expert User Knowledge Preservation
  - Knowledge and experience from successful developers and users
  - Historical documents and technical references
  - Validation benchmarks and examples
- Dynamic and Updateable System
- Public and Proprietary Versions

The expert knowledge for best practices is obtained through personal interviews with expert users and developers. The recorded interviews are transcribed, checked for accuracy, and edited before the information is distributed in the knowledge database. The information is linked by a framework of keywords. The knowledge database is also linked to a references database containing citations to published information. When a keyword is selected by the user or automatically chosen by the best practices system, a search will identify the appropriate expert knowledge and related technical references.

The initial best practices system will be a public version for unlimited distribution. Future systems developed for commercial or government organizations will include proprietary



information. These systems will contain the corporate memory of the organization, and it may also include sensitive and competitive information for restricted use.

A hierarchical keyword structure is used to organize the knowledge stored in the databases. Each node in the hierarchy is represented by a keyword that describes a topic. This model allows the information stored to be linked in a logical fashion, which assists in both the knowledge acquisition and the knowledge retrieval mechanism. The user can add additional keywords as needed.

For purposes of this discussion on best practices, a high-level hierarchy of keywords is shown above. This list is just the major topic areas, and the order shown is not important. The user can enter the system at any location in the hierarchy.

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BEST PRACTICES GUIDELINES

- Problem Definition
- Code Selection
- Input Preparation
- Grid Generation
- Parameter Specification
- Solution Evaluation
- Results Interpretation

The hierarchy is a way to organize the information in the databases so that it is easily accessible for editing and maintenance purposes. It is important that the keyword list be comprehensive and as complete as possible; however, the actual position or location of the topics in the hierarchy is not critical to the best-practices process. There are many links and connections between keywords at all levels in the hierarchy so that the interdependence between topics is maintained without regard to their physical position in the hierarchy.

Although the best practices system currently under development is aimed at the CFD user, it will be equally usable by technical managers or the engineers in S&C (or other discipline) to better understand the problems and difficulties associated with achieving good CFD results. It is conceivable that a future system which includes expert knowledge and experiences from S&C or other discipline could be equally useful to the CFD engineer. A future COMSAC capability could include a coupled system of best practices and expert knowledge from S&C, CFD, and other related disciplines.

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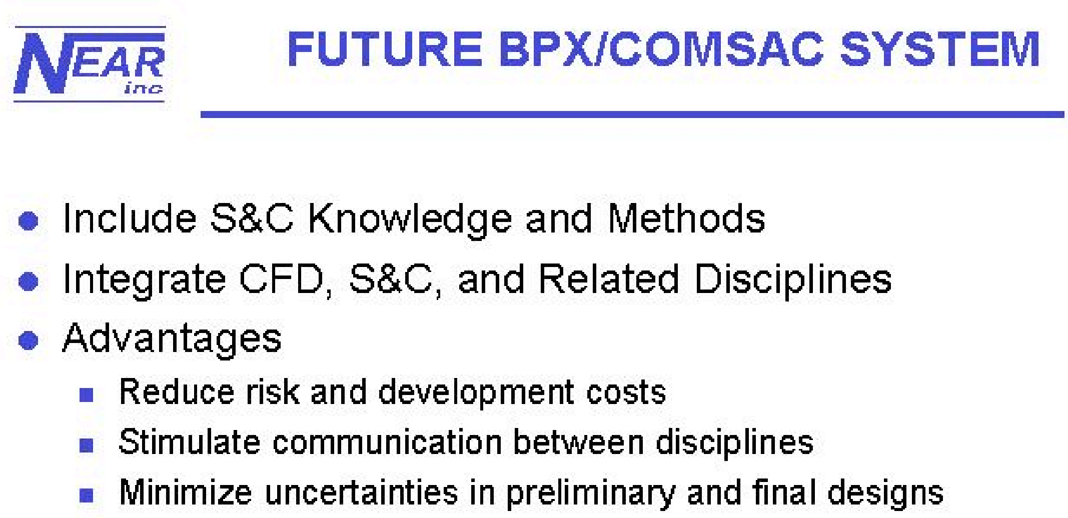
USE OF BEST PRACTICES

- Code Developers
  - Identify specific problem areas
  - Understand uncertainties
- Design Applications
  - Provide experience (new code, new engineers, ...)
  - Assist at all levels of use
- Technical Managers
  - Understand technical issues and problems with CFD results
  - Quantify uncertainties and potential errors
  - Understand CFD capabilities and quality of results

A future BPX/COMSAC system could include an expert knowledge database with stability and control knowledge and prediction methods. This would be a way to preserve the corporate memory in stability and control for use by future generations of engineers. The advantages of having this information available for training purposes and for use in future designs are manifold. First, it is a way to reduce cost and risk on future programs by eliminating the mistakes that have already been made. Second, it provides a way to train the new engineers who may not have access to the senior engineers who did the original work. Finally, it will maintain the organization experience base as engineers retire or otherwise become unavailable to the technical discipline.



This chart illustrates a future integrated design and analysis system with several related disciplines shown for example. The computational aerodynamics discipline will be run by a best practices system described previously. Similarly, the stability and control discipline could have its own best practices system as suggested on the previous chart. The two disciplines could be linked by an overall best practices framework that will permit them to work together efficiently. The complete system could be expanded incrementally to include the other disciplines to provide a multidisciplinary expert design system.

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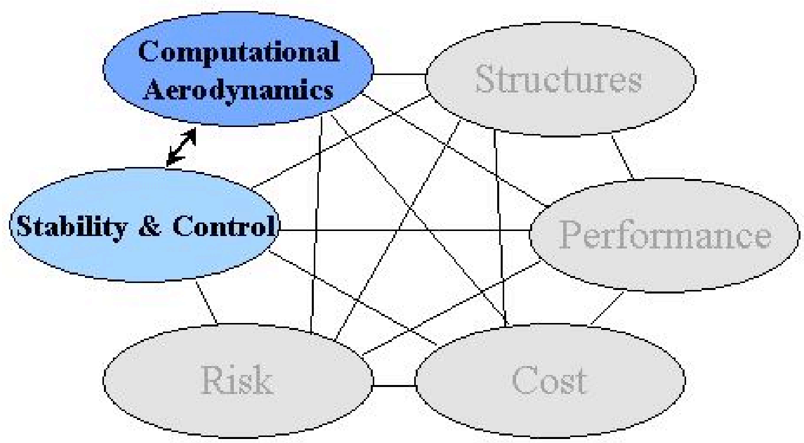
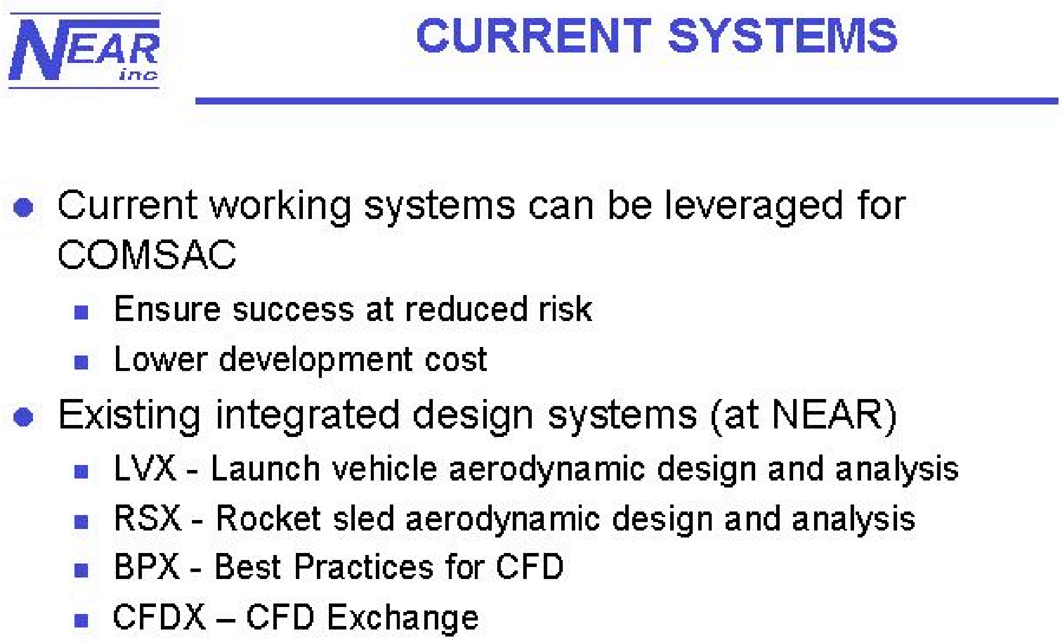
FUTURE INTEGRATED SYSTEM



The approach of coupling expert knowledge and prediction capability has been demonstrated successfully by NEAR in other technical areas. LVX is a system for the aerodynamics of launch vehicles which couples expert knowledge, corporate memory, design experience, and aerodynamic prediction methods.[3] RSX is a similar system based on the same computational framework for the aerodynamic design and analysis of rocket sled test vehicles.[4]



[3] Mendenhall, M. R. and Hegedus, M. C., "LVX – An Integrated Aerodynamic Design and Analysis Method," ICAS 2002-0234, September 2002.
[4] Mendenhall, M. R. and Hegedus, M. C., "An Engineering Analysis Tool for Rocket Sled Aerodynamics," NEAR TR 582, February 2003.

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CONCLUSIONS

- Best Practices eXpert System
  - Feasible for use in COMSAC applications
  - Potential to increase efficiency of CFD solutions
  - Means to understand and quantify uncertainties
  - Possible leveraging of previous work
    - Reduce risk
    - Lower cost
- COMSAC Will Require a Best Practices Tool to be Useful, Reliable, and Practical
- Extension to Other Disciplines Possible