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Design Optimization Module for a Hierarchical Research and Learning Environment*

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This paper describes a learning module on design optimization courses within a hierarchical research and learning network. In this environment a hierarchical learning network can be created to link diverse inter- and trans-disciplinary teams from a consortium of universities, industry, government agencies and the providers of learning technologies. It is an approach that builds on computer-based training, intelligent tutoring systems, interactive learning, collaborative-distributed learning, and learning networks. As an example of a learning module in this environment, the present design optimization module has been developed and described. This module allows learners of design optimization to get the course material at their own convenience via either the internet or packaged files. Consequently, it is expected that the learner's ability to understand design optimization and review its pertinent details will be enhanced significantly.

Keywords: asynchronous distance learning; advanced learning networks; sensitivity analysis; concept maps; shape optimization; computational fluid dynamics.

INTRODUCTION TO COURSE DELIVERY AND PEDAGOGY

COMPUTER-BASED LEARNING technology dates back to the 1960s. Passive computer-based instruction systems were built in the 1960s and 1970s. Later developments in that period included learner modeling and more elaborate computer learner interfaces. Addition of expert systems to computer-based instruction resulted in the intelligent tutoring systems (ITS) of the 1970s and 1980s. These systems had explicit models of tutoring and domain knowledge, and were more flexible in their response than computer-based instruction. The advent of intelligent agents, which enabled the learner to manipulate cognitive artifacts from several perspectives, led to the interactive learning (IL) systems of the 1990s. In the late 1990s, a move towards collaborative distributed learning (CDL), with distributed resources, occurred. The current trend is towards using learning networks (LN) for enhancing the effectiveness, access and affordability of learning. In learning networks, extensive use is made of intelligent agents, learning is guided by cognitive systems, and the learner is an active and reflective participant in the learning process [1]. The specific motivation for the present work will be summarized below. The methodology is applicable to a wide variety of engineering fields and subject areas.

NASA and the aerospace industry have and will continue to lose a significant number of their technologists because of an aging workforce and consequent retirements. Also, they face skill gaps in a number of revolutionary technology fields which are needed for the realization of future systems and missions. On the other hand, US colleges and universities are experiencing a decrease in the number of undergraduate and graduate students in technical fields. However, a technically skilled workforce able to work across traditional disciplines is a must in these areas. Thus, there is a need to explore bold new approaches and to devise an integrated plan for preserving the knowledge base during these gaps, and effective ways of educating and training the future workforce. Our hierarchical research and learning network (HRLN) project is a step in that direction.

The hierarchical research and learning network (HRLN) is configured as a neural network of networks [1, 2]. Each of the component networks integrates three learning environments: a) synchronous and asynchronous expert-led, b) self-paced, and c) collaborative. The instructional model used for this learning network varies from instructor-centered, to learner-centered, to learning-team-centered. As the name suggests, in the learner-centered model the learner is at the center of the learning process and calls on many information sources. Learning-team-centered models include virtual classrooms and web-based distance-learning models. The human instructors in these environments serve many roles, including inspiring, motivating, observing, evaluating, and managing the learners, both individually and in distributed teams. Instructors in expert-led distributed learning

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virtual environments serve as facilitators and course managers. They can enhance the critical thinking and creativity of the learners by the use of *what if* questions.

The individual learning environment engages the learner and provides a high degree of tailored interaction. Such interaction can be enhanced by using *virtual instructors* (intelligent software agents) assigned by the human instructors. It can be used to study physical phenomena that can be linked to engineering processes, using advanced visualization, multimedia, and multi-sensory immersive facilities. The individual learning environment can serve to carry out virtual experiments (i.e. computer simulation of physical experiments). Collaborative learning environments teach teamwork and group problem-solving. Instructors and learners can be geographically dispersed. Eventually, they can be brought together through immersive tele-presence facilities to share their experiences in highly heterogeneous environments involving different computing platforms, software, and other facilities, and they will be able to work together on designing complex engineering systems.

An HRLN makes extensive use of intelligent agents developed by the technology providers. Such an agent can be a virtual instructor or a peer learning companion. For virtual instruction, an agent is both an expert and a motivator, rather than being a mentor, because this is the most effective pedagogical role [3]. For a peer or a learning companion, the agent plays many roles such as initiator, suggester ('Let's do it this way'), supporter ('That was great!') or summarizer ('Here is what we have done so far') [4].

A step towards the implementation of HRLN is the development of an *adaptive web portal* (Fig. 1), which integrates the three learning environments with a knowledge repository, a learning management system and a customized collaboration infrastructure. It also provides advanced multimodal interfaces and a number of additional facilities for automating all routine tasks and satisfying user preferences.

Each course within the network is divided into self-contained *learning modules*. These self-contained learning modules provide flexibility and interdisciplinary curricula. Advanced instructional technology, modeling, simulation and visualization facilities and authoring tools are used in the development of the modules. The learning modules are then packaged into disciplinary and interdisciplinary courses and training programs to satisfy the needs of diverse groups.

In the individual learning environment, the learner navigates through a large database of course modules with the help of *concept maps*. Concept maps are tools for organizing and representing knowledge. They include concepts and

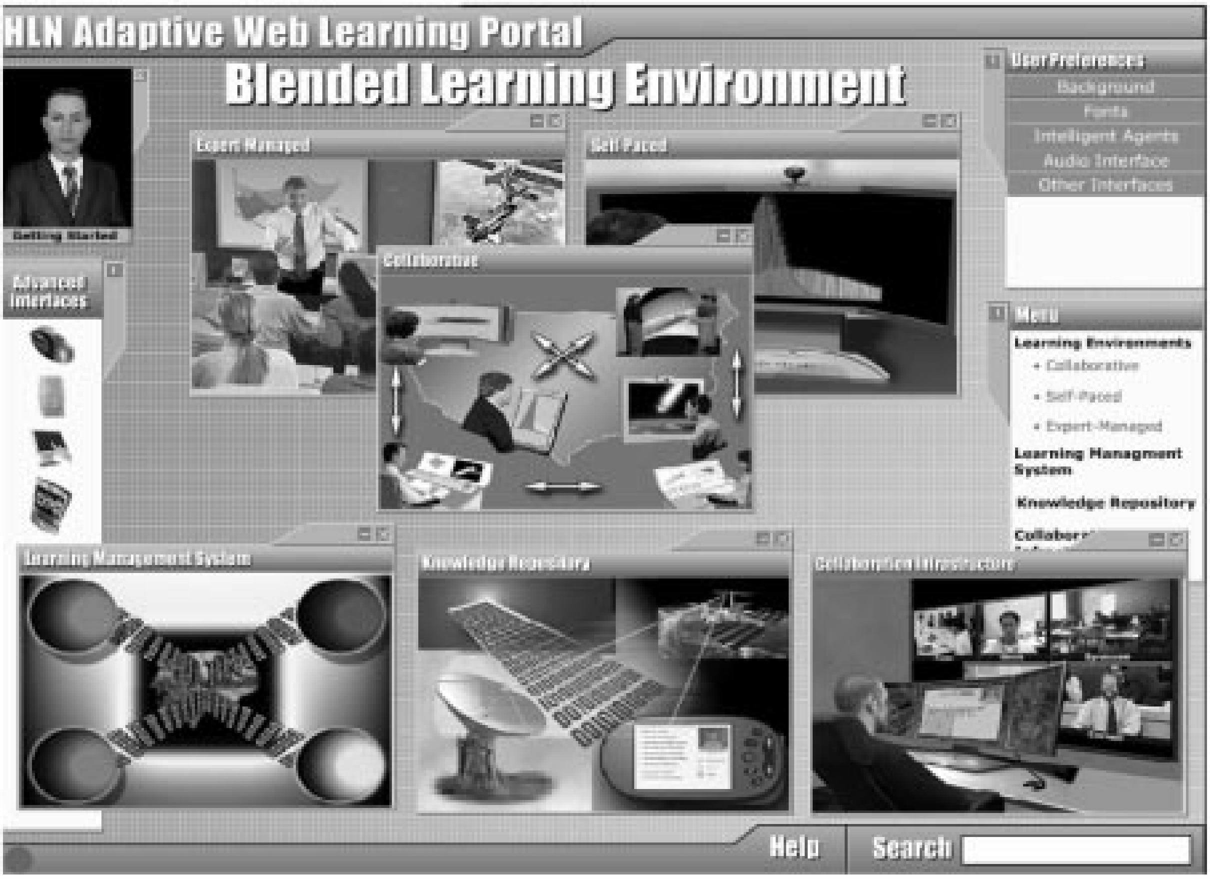

Fig. 1. HRLN adaptive web portal.

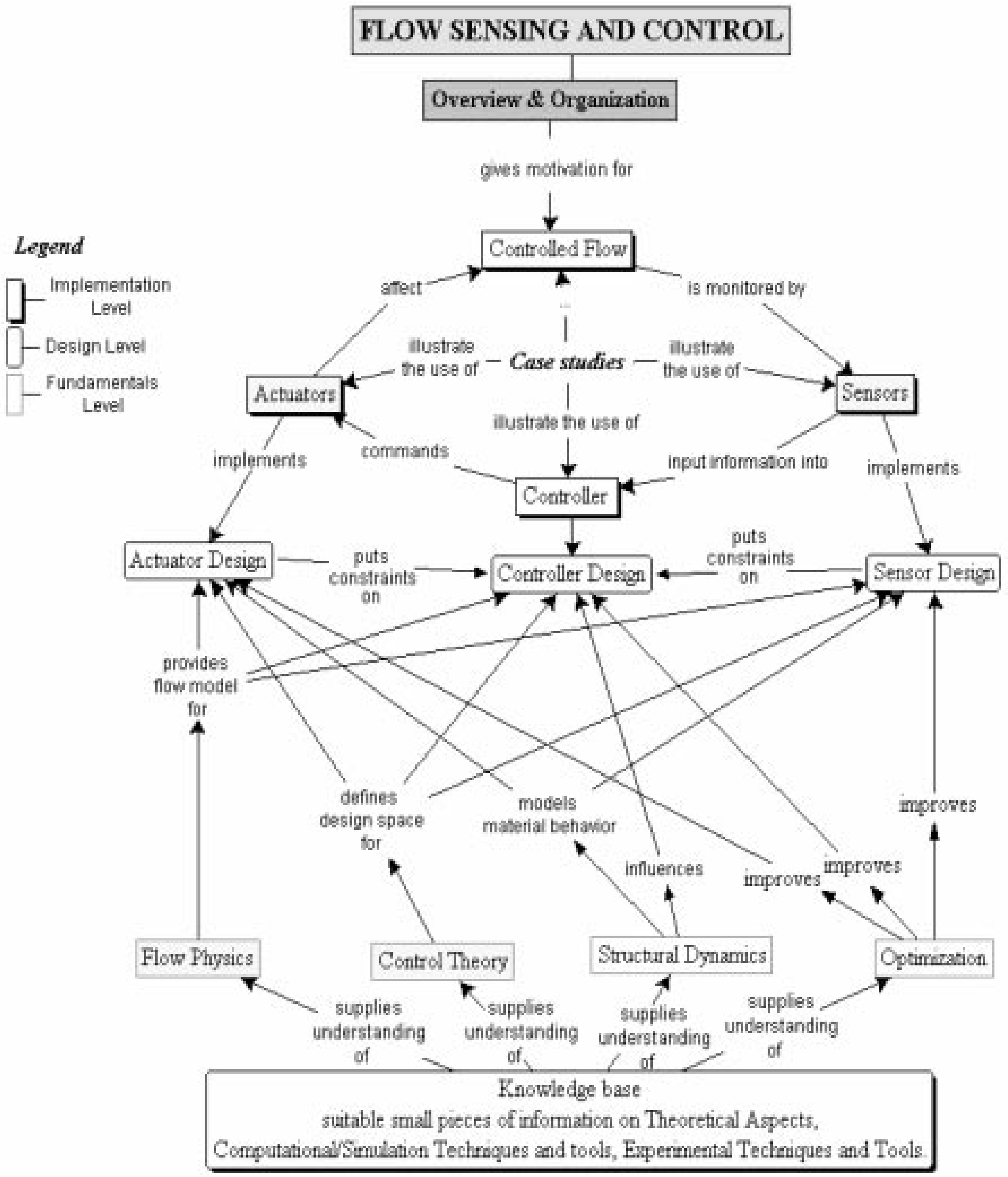

Fig. 2. Concept map to learn flow sensing and control (from HRLN Workshop 2003, Hampton, VA).

relationships between concepts or propositions. Typically, concepts are indicated by words enclosed in boxes and relationships are indicated by words over lines connecting the concept boxes (hence the name 'concept map'). Definitions of a concept and a proposition are given by Novak [5] as follows: A concept is a perceived regularity in events or objects, or records of events or objects, designated by a label. Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected with other words to form a meaningful statement. The concept map presented in Fig. 2 will be explained in the next section.

COURSE CONTENT

The design optimization module is developed and presented here merely as an example it is part of our *flow sensing and control* course. The modules are placed and linked in a way that they can be reached, if and when needed by the learners, through the concept map created for the overarching objective of flow sensing and control (Fig. 2). As shown on the concept map, the design optimization is one of four fundamental levels of the flow sensing and control module.

Knowledge of *design optimization* should allow the learner to work on improving the design of a controller, actuator or sensor. The present design optimization methodology employs computational fluid dynamics to evaluate the performance of a given design. *Computational fluid dynamics* (CFD) can be useful beyond merely simulating a fluid flow, and can be utilized for the purpose of design and optimization in order to cut down the cycle time for a new product [6]. Design optimization is a systematic methodology to create or improve a design. It may produce the 'best' design or just a 'better' design. Design optimization can be a conduit to understanding the design process and the effects of physical phenomena associated with developing shapes or designs [6]. However, cutting down the cycle time for a new product may be prohibitive for the needed computational and human resources if, as often is the case, a large matrix of candidate designs or design variables are involved. Improving the accuracy and efficiency of this process can reduce its cost and increase its effectiveness. There are other compelling and motivating factors that push and pull design optimization, such as the need for a fast response to market changes.

With all of this as an impetus, researchers have been developing new design methods, varying from inverse methods to numerical shape optimization methods. Some of the objectives of such efforts are:

- Automated design optimization with minimal need for a designer-in-loop in a given try.
- Reducing the need for the design expertise and the prerequisite database.
- Improving accuracy, efficiency and practicality.
- Information on the most influencing parameters, which leads to a reduced CFD analysis matrix, requires sensitivities of objectives and constraints with respect to design variables.
- The ability to design with a variety of aerodynamic and geometric constraints and geometric flexibility (i.e. the type and the number of design variables and efficient parameterization).

The next prerequisite is the education and training of graduate engineering students, practicing engineers and researchers, so that they can use these multidisciplinary tools routinely and effectively. However, in the present study, this is not contemplated for traditional in-class pedagogy nor for using the traditional synchronous or asynchronous methods. Rather, the concept of a hierarchical research and learning network (HRLN) is being explored in a NASA-initiated and funded university consortium led by the Old Dominion University's Center for Advanced Engineering Environments [2].

DESCRIPTION OF DESIGN OPTIMIZATION LEARNING MODULE

Design optimization using CFD analysis is a research topic which is not currently included in educational curricula. This module intends to equip sophisticated learners with technical skills and to close the skill gaps, and is encountered in a number of revolutionary technological fields.

The present HRLN module has been developed with the help of an *authoring tool* distributed by a technology provider [7]. Using this tool, one can create, for example, web-based tutorials and sophisticated simulations incorporating audio and video for e-learning.

The methodology differs from traditional in-class learning and distance-learning models (that is, synchronous via television or the internet) by having an asynchronous, self-paced anytime/anywhere e-learning module. It also has hierarchical adjustments to levels of knowledge through its concept maps. In this module, an intelligent agent represents a virtual instructor. Being a virtual instructor, the agent is both an expert and a motivator because this is the most effective pedagogical role [3]. In addition, the agent is animated through the lecture rather than being static. This is because the presence of agent animation significantly improves learning. Another feature of this intelligent agent is that it looks and sounds like a human being. Research on intelligent agents suggests that more an agent looks like a human being more effective it can be [3]. When the agent 'speaks,' the learner can also see the spoken output in a word balloon. It is possible to change the speaking speed of the agent. These features of the agent are provided through a user menu button. Using the top menu button, a learner is provided with the module's table of contents and with hyperlinks to each content item. Hence, a learner can easily navigate through the module. Based on the learner's need for information, it is possible to navigate through the entire module using the concept map (Fig. 2), picking and choosing which paths to skip and those to be followed. Forward and backward buttons are provided for this purpose.

For the remainder of this section, a series of sample screens will be presented. The module begins with the links to its five chapters (Fig. 3): 1) Basics of Optimization, 2) Introduction, Rationale, Motivation, 3) Theory and Formulation, 4) Examples, and 5) References.

When the Basics of Optimization chapter is selected, the learner will be asked whether the basic mathematics pertinent to optimization is needed (Fig. 4). Here the agent plays the role of a coordinator. In this chapter, the math topics that are most often used in optimization are available, such as linear independence, quadratic forms, positive definiteness, sets, functions, continuity, gradient, and the Hessian and Taylor series (Fig. 5). As this is an environment for self-paced

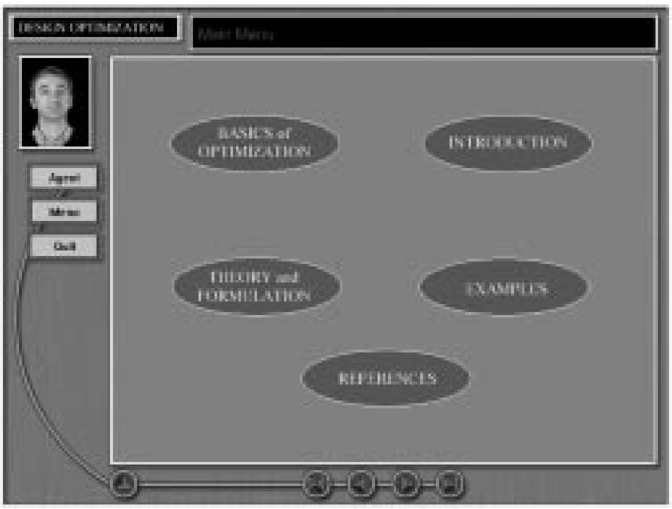

Fig. 3. Main menu for the Design Optimization Learning Module.

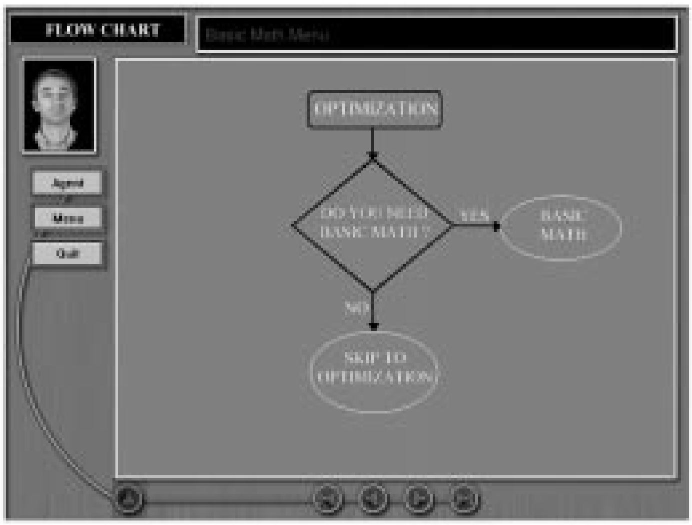

Fig. 4. Basic mathematics menu for the Design Optimization Learning Module.

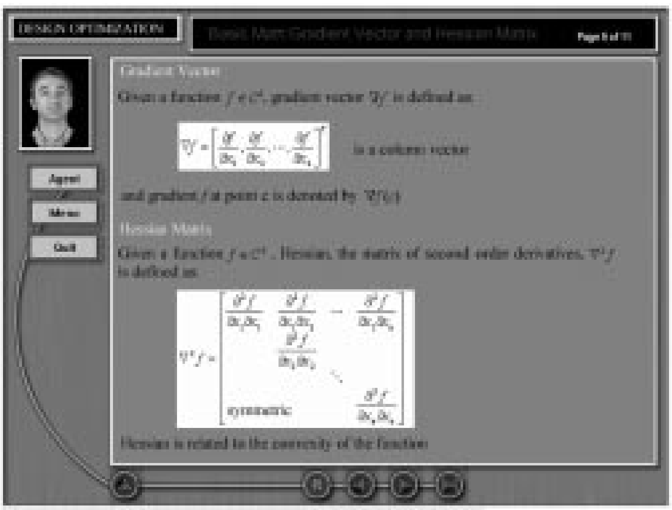

Fig. 5. Sample math page: on the gradient vector and the Hessian matrix.

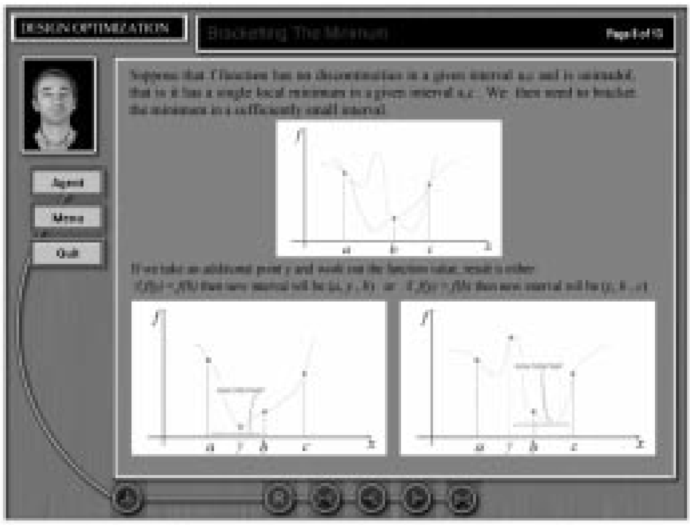

Fig. 6. Sample page for optimization basics: bracketing the minimum.

learning, the learner can choose to repeat any topic as needed. Using the Ⓡ button, a learner can repeat any page as many times as needed.

A chapter on the basics of optimization is also provided. In this chapter, fundamental concepts of optimization, such as defining an objective function, design variables, and constraints, are provided to the learner. Following the fundamental concepts of optimization, a section is provided on how to perform one-dimensional unconstrained minimization or general unconstrained minimization, or constrained minimization. Some of the concepts given in this section are the definitions of optimum design point, necessity conditions, and finding the minimum (Fig. 6). Topics such as when and why there is a need for design optimization, and different approaches to design, are provided in the Introduction section (Figs 7–8). This section should enable the learner to decide which approach is best suited for the need at hand.

The Theory and Formulation section starts with a flowchart of the choices of design approach for this module (i.e. automated design optimization) (Fig. 9). Different formulations for design optimization and sensitivity analysis are also presented as a section in this chapter. In this section, some important steps are highlighted for the learner's convenience. First, the formulation of an optimization problem is defined (Fig. 10). Then algorithms to obtain the sensitivities are provided (Figs 11–12). As an example, a sensitivity equation for steady Euler equations is given in Fig. 13. Some additional topics covered in this section are: a gradient-based approach, direct numerical optimization, formulations of optimization, direct and adjoint formulations, and sensitivity analysis.

In the final chapter of the module, the learner is provided with a menu of examples (Fig. 14). The examples are selected in relation to the overarching topic of flow sensing and control. The titles are hyperlinked to the pages containing these examples. This chapter consists of five sections: airfoils,

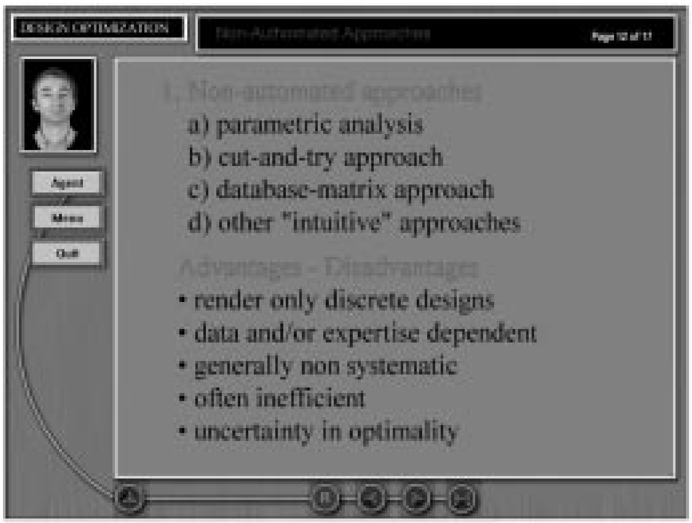

Fig. 7. Sample page from the motivation for studying design.

Fig. 8. Sample page from the overview of design methods: non-automated approaches.

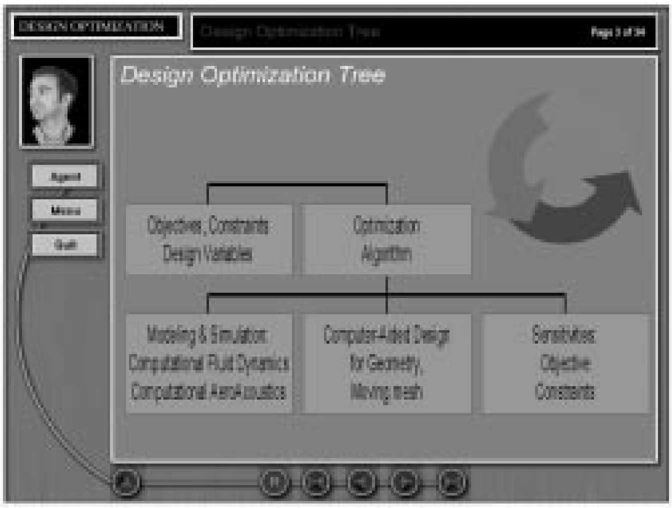

Fig. 9. Flowchart of automated design optimization methodology.

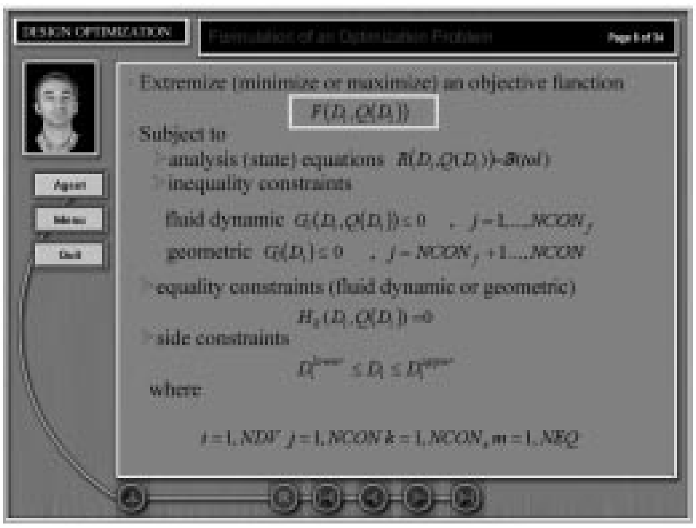

Fig. 10. Sample for text highlighting during the lecture (problem definition page).

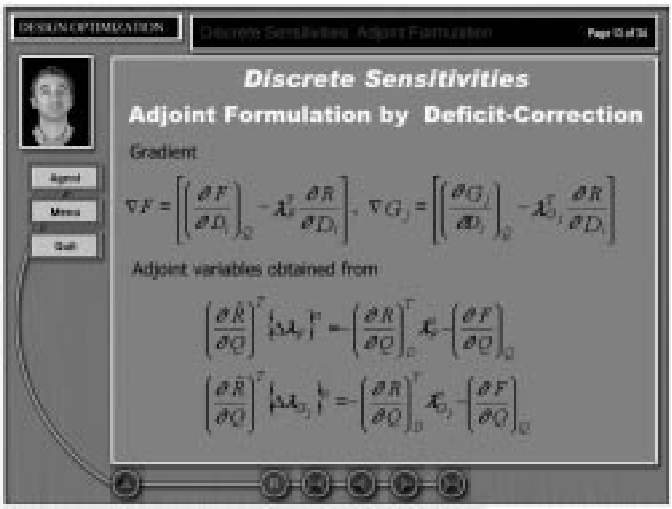

Fig. 11. Sample page for discrete sensitivities (adjoint formulation).

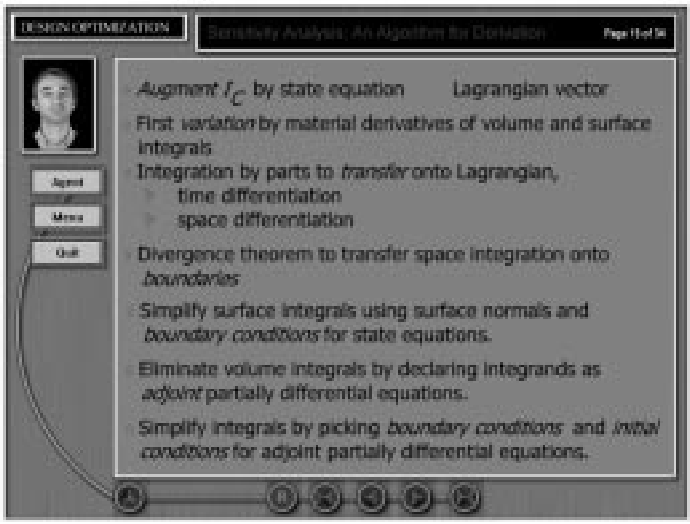

Fig. 12. Sample page for continuous sensitivities (step by step algorithms for their derivation).

nacelles, nozzles, wings and noise barriers. The subtitle for each example contains a brief explanation.

Finally, as an initial assessment of the effectiveness of the present approach, a non-scientific study has been conducted to collect meaningful feedback and opinions from a wide variety of individuals. The module described here was presented either in part or in its entirety at four different forums [8–11]. In addition, the module was presented to the Aerospace Engineering graduate students at Old Dominion University in several consecutive seminars. Because of the nature of these workshops and conferences, the majority of the audience were engineering educators, graduate students or practitioners with aerospace or mechanical engineering backgrounds.

The audience was asked at random to comment on the following: (a) the module's responsiveness to different backgrounds and levels of knowledge in the subject matter, (b) the ease of understanding the content, and (c) novelty of the delivery method. The overwhelming response to all three attributes has been very positive. Although this is very encouraging, a future study should prove useful, whereby the learning outcomes from this approach are compared to those when the same topic is covered in a traditional distance-learning format. It should be noted, however, that a traditional pedagogy would have to assume that all the students have the same level of knowledge in the subject matter and an instructor was available when and where needed. The present approach requires neither.

CONCLUDING REMARKS

A hierarchical research and learning environment module has been developed for aerodynamic design optimization. This environment is intended to enhance the convenience and the effectiveness of learning significantly. In this environment, learners access the course lectures at their convenience

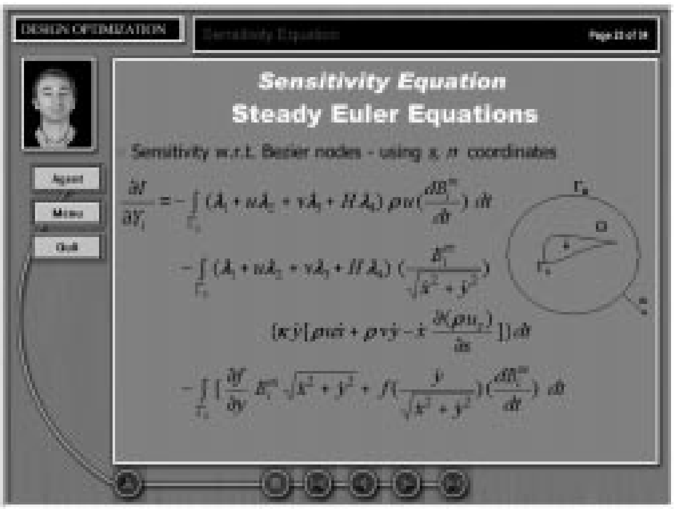

Fig. 13. Continuous sensitivity equation for the steady Euler equations.

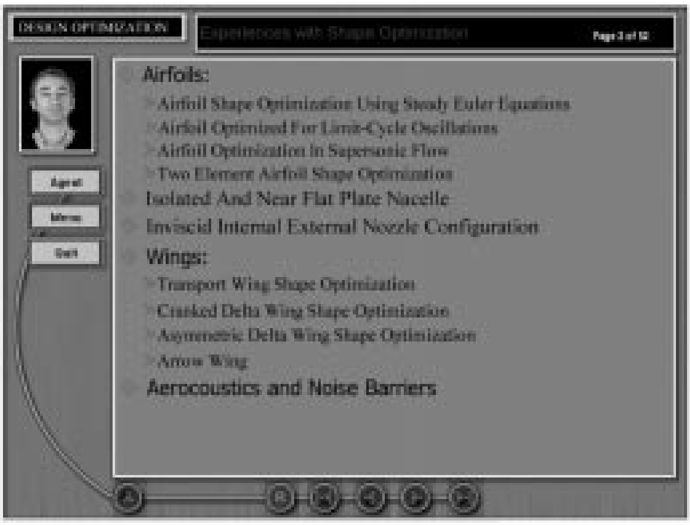

Fig. 14. Menu of available examples for shape optimization.

either via the internet or packaged files. Using these packaged files, the learners can access the course whenever and wherever they want. The interaction in this module is enhanced by the optional use of virtual instructors (intelligent software agents) assigned by the human instructors. The environment lends itself very well for individual or group study and discussions. Another feature that enhances learning is the learner's ability to navigate through the lecture material in order to study only what is deemed necessary for the individual's level of knowledge. With the help of the concept map and the menu buttons, one can navigate through the entire module.

In the case of learners who need to refresh their mathematics, the module provides the basics in mathematical concepts that are commonly used in optimization. In the introduction menu, the learner is provided with the reasons for using design optimization and an overview. The agent helps to retain the student's attention by asking questions at the beginning of each section. The manner in which the agent lists the reasons for why and when there is a need for design optimization is intended to motivate and guide the learner.

It is important for a learner to compare and decide which type of design -optimization procedure is most suitable for their needs. For this reason, a brief explanation of different methods of design optimization, including their advantages and disadvantages, is provided. After the theory and formulations, a list of examples is provided. Finally, the module includes a reference section for those who require detailed explanation of the related topics.

Finally, to assess its effectiveness, a study needs to be conducted to compare the learning outcomes from this module and those from the same topic covered in the traditional distance-learning format.

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