Designing an Enclosure for the Concorde –
A Novel Multidisciplinary Team Project

J. Nastasi*, L. Brunell and K. Sheppard*****
**Industry Professor – Product-Architecture Program*
*** Lecturer and Design Coordinator – Civil Engineering*
**** Associate Dean*
Charles V. Schaefer, Jr. School of Engineering
Stevens Institute of Technology
Hoboken, NJ 07030

The evolution of methods and materials of design and engineering increasingly require architects, engineers and manufacturers to work collaboratively from the outset of a project. Further, this has created a need to broaden the education of those who work at the interface of Design and Product-Development to have a more multidisciplinary orientation and knowledge base, including a broader facility with the associated tools. A teaming of students in an innovative new graduate program in Product-Architecture at Stevens with Civil Engineering undergraduate Senior Design students has provided a novel paradigm of collaboration and education in the interdisciplinary design of an enclosure and exhibition for the Concorde supersonic aircraft, located at the USS Intrepid Museum in New York City. The graduate students, who have primarily a background in architecture or industrial design, have coupled the design approach of the architect with the modern tools of engineering, product design and manufacturing. Working with the Museum, they together with the civil engineering undergraduates have taken the design process from concept through feasibility to manufacturability, costing and specifications to meet codes.

Background

Stevens has for some time been a leader in the area of integrated product development (IPD) through its graduate programs and a research center, the Design and Manufacturing Institute (http://www.dmi.stevens-tech.edu). Recently a new graduate program in ***Product-Architecture*** (http://www.stevens.edu/prodarch) was established to push the concept further by bridging between the design worlds of the architect and the industrial designer and that of integrated product development and manufacture. The program's goals are summarized as follows:

- the interdisciplinary study of Industrial Design, Engineering and Architecture with nascent production methodologies and emerging materials.
- the exploration of expressive form and integrated functional capabilities.
- the immersion into advanced digital media and its impact on design
- the performance of interactive physical and digital environments.

As this is a unique program, some details are given below:

The ***Master of Engineering in Product-Architecture & Engineering*** degree program is supported by The Product - Architecture Lab and integrates the study of Product Design, Computational Architecture and Engineering with production methodologies and emerging materials. A Bachelors of Science degree in Engineering, Industrial Design, or a Bachelor in Architecture is needed for acceptance to the master's program. Applicants with undergraduate degrees in other engineering or design disciplines may be required to take appropriate undergraduate courses before being formally admitted into the program.

The Master of Engineering in Product-Architecture and Engineering degree requires 30 credits. Fifteen of the credits (or five courses) form the core. Nine of the credits (or three courses) form the Engineering requirements which focus primarily on Mechanical Engineering topics. The core classes and the recommended courses from the ME department are as follows:

Core Courses	ME Courses (3 of the following)
PAE 610 The Creative Form and the Digital Environment	**ME 520** Analysis and Design of Composites
PAE 620 The Creative Form and the Production Environment	**ME 564** Principles of Optimum Design and Manufacture
PAE 630 Introduction to Interactive Digital Media	**ME 635** Simulation and Modeling
PAE 640 Performative Environments	**ME 566** Design for Manufacturability
PAE 800 Product Architecture & Engineering Design Project	

The remaining two courses (6 credits) constitute the student's elective field and consist of: at least one course of "600-level or higher" given in the Product-Architecture and Engineering program and one course given in another department.

A student may elect to complete a Thesis (PAE 900 Thesis in Product-Architecture and Engineering, 3 credits) in lieu of completing one of the two open electives.

The ***Product-Architecture Digital Media Laboratory*** supports the Masters program. The laboratory focuses on advanced digital design environments including geometric modeling, interactivity, scripting languages and virtual reality. The laboratory is equiped with a full Computer Aided Three-dimensional Interactive Application (CATIA) suite. Interactive Digital Media is explored using scripting capabilities in Maya, Action Scripting and Rhino and the laboratory includes a full set of ceiling mounted cameras, blob tracking devices and projection systems for full scale performative environment studies. Three dimensional scanning technologies are explored using a wide array of devices including a Cyrax - Lidar type scanner and a Roland DGA LPX – 250. Touch Probe Scanning and reverse engineering is also possible using the MicroScribe-G2LX. Non-Linear digital video editing is achieved on 2 dual G-5 Macintosh systems hosting a full Final Cut Pro software suite and DVD Authoring tools. The laboratory is equipped with a 25 seat Virtual Reality Theater, with rear projection stereoscopic projection systems, haptic gloves, head mounted display and a full VR EON Reality scripting suite.

The Project

The Intrepid Sea-Air-Space Museum in New York City became the home of a British Airways Concorde supersonic airliner when the Concorde fleet ceased operation in the Fall of 1993. The Concorde exhibit is presently housed on a barge moored adjacent to Pier 86 on the Hudson River across from the U.S.S Intrepid aircraft carrier, which is the home of the museum on the west side of Manhatten (see Fig.1 – the barge shown has subsequently been replaced with a slightly larger one). Stevens has partnered with the museum to assist with the preservation of the Concorde and other exhibits and for educational activities. To this end a project was initiated to design an enclosure or pavilion for the Concorde, both to protect it from direct exposure to the environment of the New York Harbor and to house a state-of-the-art exhibition to showcase the aircraft and supersonic flight. The enclosure would be located on Pier 86 itself after major reconstruction of the latter as part of the ongoing upgrade of the West Side waterfront of Manhatten.

The design project provided a wonderful opportunity to assemble a team consisting of graduate students from the first class to pursue the new Product-Architecture Master of Engineering Program together with undergraduate seniors in the Civil Engineering program at Stevens.

Fig. 1 Concorde G-BOAD moored at Pier 86. The edge of the U.S.S Intrepid flight deck is visible in the top left of the figure

The Team

The team comprised four Product-Architecture graduate students, who each had an architecture undergraduate degree, together with five Civil Engineering undergraduate seniors. The project was conducted over the full academic year. At the start of the project the team together with the faculty advisors (the authors of this paper) held a kick-off meeting at the Intrepid to discuss constraints, including the planned renovation of the

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pier which was anticipated to also include some widening that could be valuable to help accommodate the proposed structure. Regulation issues such as limits on the shadow that could be cast on the water (due to concern for the potential impact on fish in the river) were also discussed with senior management.

The primary focus of the Product-Architecture members of the group was the design of the enclosure and an integrated internal interactive exhibit. The Civil Engineering students primarily focused on the construction, regulatory issues, costs and coordination with the planning for the pier reconstruction being conducted by a consulting company.

The students were scheduled to spend one full day per week (Product-Architecture design studio and Civil Engineers capstone design) on the project but undertook additional work at other times. The Product-Architecture students also used the project as part of other course work, especially in the ME 635 Modeling and Simulation course (for which a special section was run for the Program) and in the ME 564 Optimization course. The Modeling and Simulation course actually provided the students with their ideas in proposing design concepts for the Concorde enclosure. In the course they applied fluid dynamics modeling (COSMOS) to visualize the airflow and pressure changes over the Concorde as it passed through various stages of flight from low speed through the sound barrier to supersonic speeds in order to discover why the aircraft is shaped the way it is, especially the unusual wing geometry. Examples of the modeling results are illustrated in Fig. 2.

The students used the modeling results of airflow patterns as design cues that they applied in generating conceptual designs to capture both the aesthetics of the Concorde’s shape and its effects on the air during flight as an integral part of the building design. The results of the pressure modeling were used in developing a dramatic exhibition concept for inside the building as discussed later.

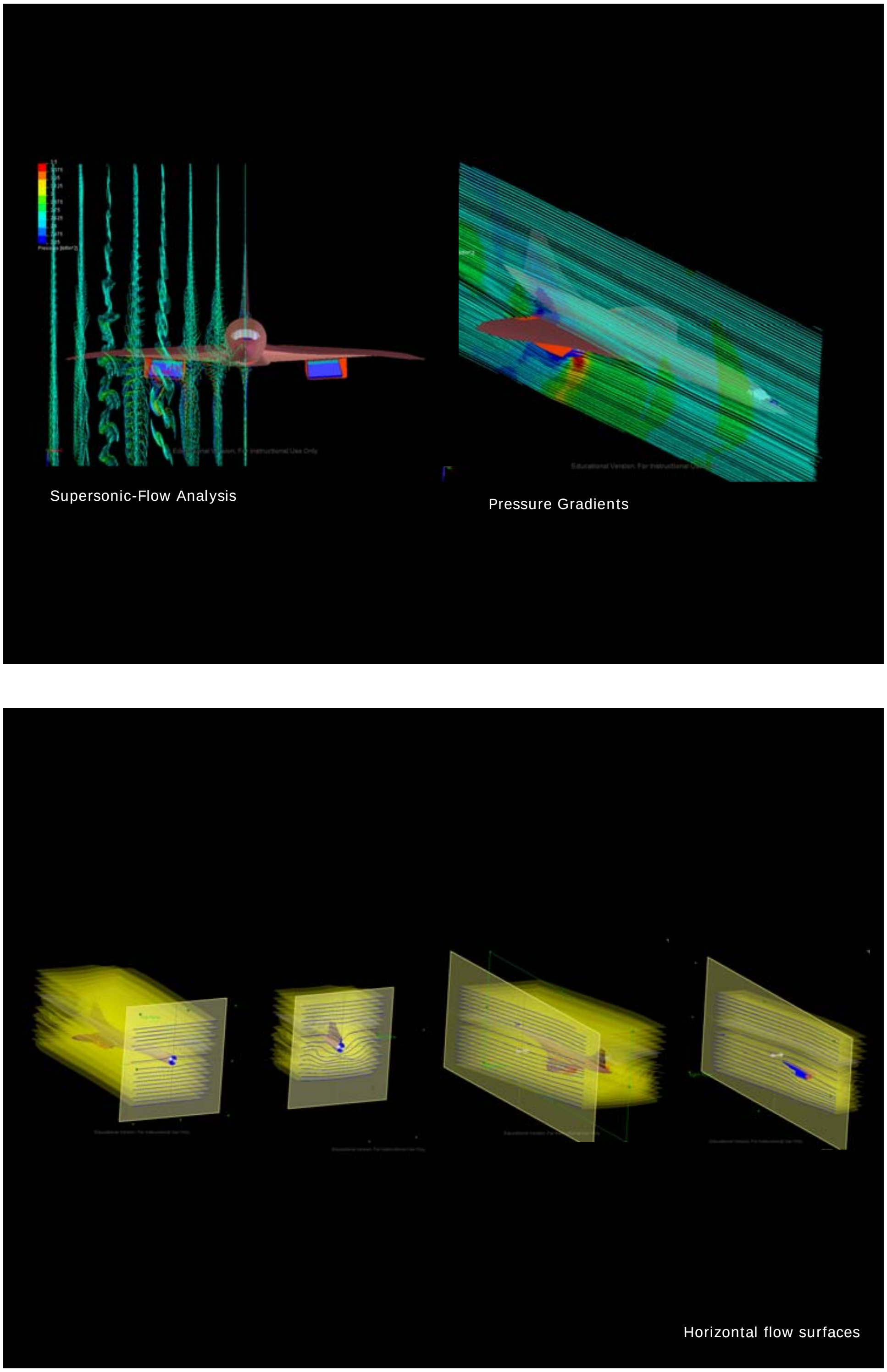

Fig. 2 Modeling results of airflow and pressure over Concorde

The Design

Using aesthetic concepts based on the aircraft's shape and airflow, the team created a number of design alternatives for the building. As part of this process they also examined innovative designs that have been applied elsewhere for aircraft hangars and museums exhibiting aircraft. Providing significant transparency of the wall structures and concern for sightlines outside and inside the building were also important considerations.

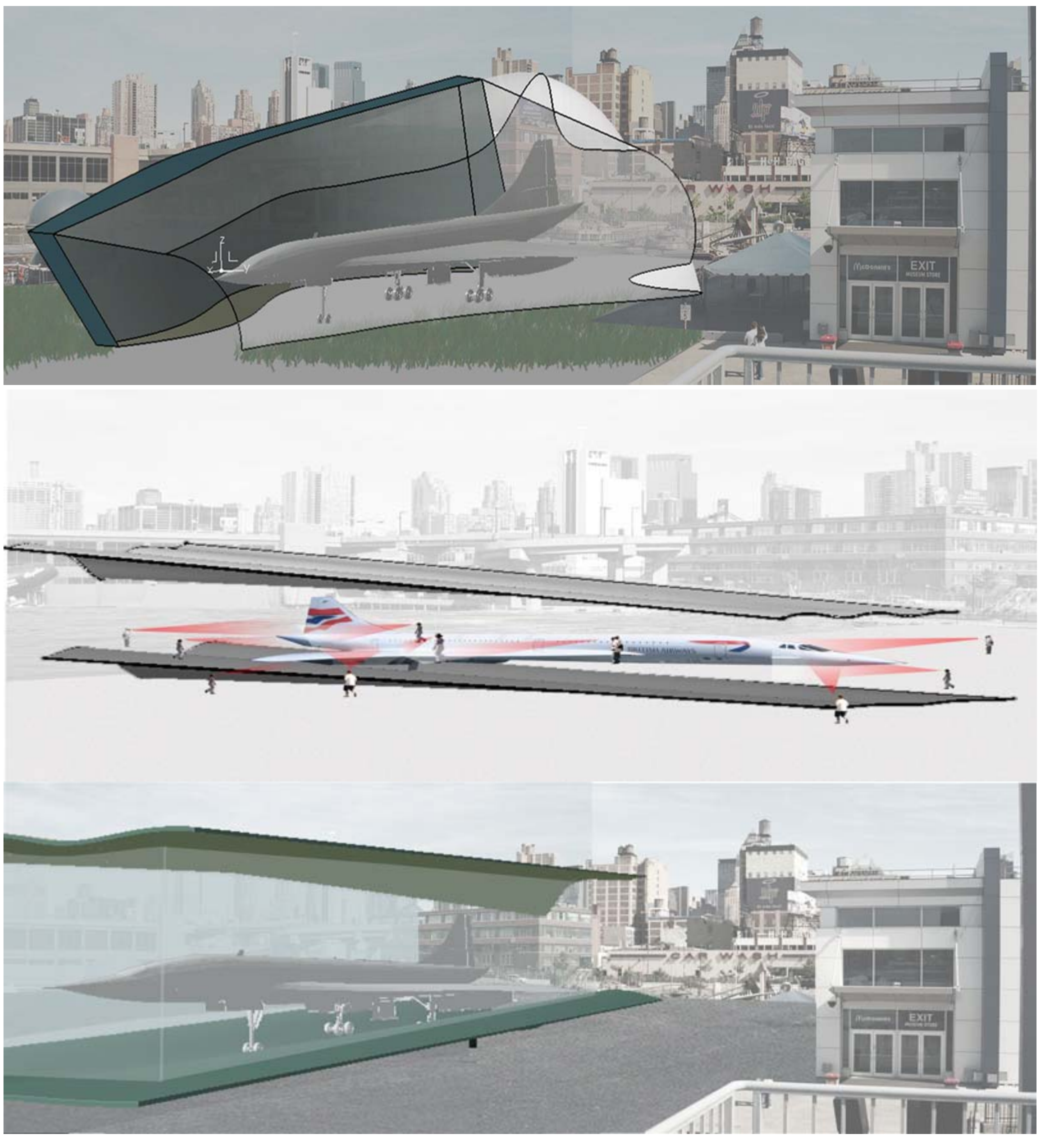

Fig. 3 Design concepts

The design of the building was chosen to reflect the above concepts but also meet practical constraints on the potentially significant wind and snow loading on the structure. The design leverages the existing Visitor Center at the entrance to the Museum to provide an integrated structure with a balcony and views from the Center as can be seen in Fig. 4. CATIA was used for the design and structural analysis. A virtual video walk through of the building and exhibit was produced with Adobe Premier.

Fig. 4 The proposed building design showing the integration of the existing Visitor Center and location relative to the U.S.S Intrepid

The ability to use virtual engineering tools was critical to both the design process and communication within the team and to the client. The ability to provide the client a virtual experience of the structure and exhibit superimposed on the existing site had tremendous impact.

The structural design process benefited from the ME 564 Optimization course and highlighted the concept of form-fit-function. MatLab was used in the optimization. The truss system was optimized to the loads which in part were supported by the shaped ceiling structure that followed from the airflow pattern cues. Thus the separation of the trusses is optimized with closer spacing away from the heavily curved section of the ceiling. This is shown in Fig. 5.

Structure

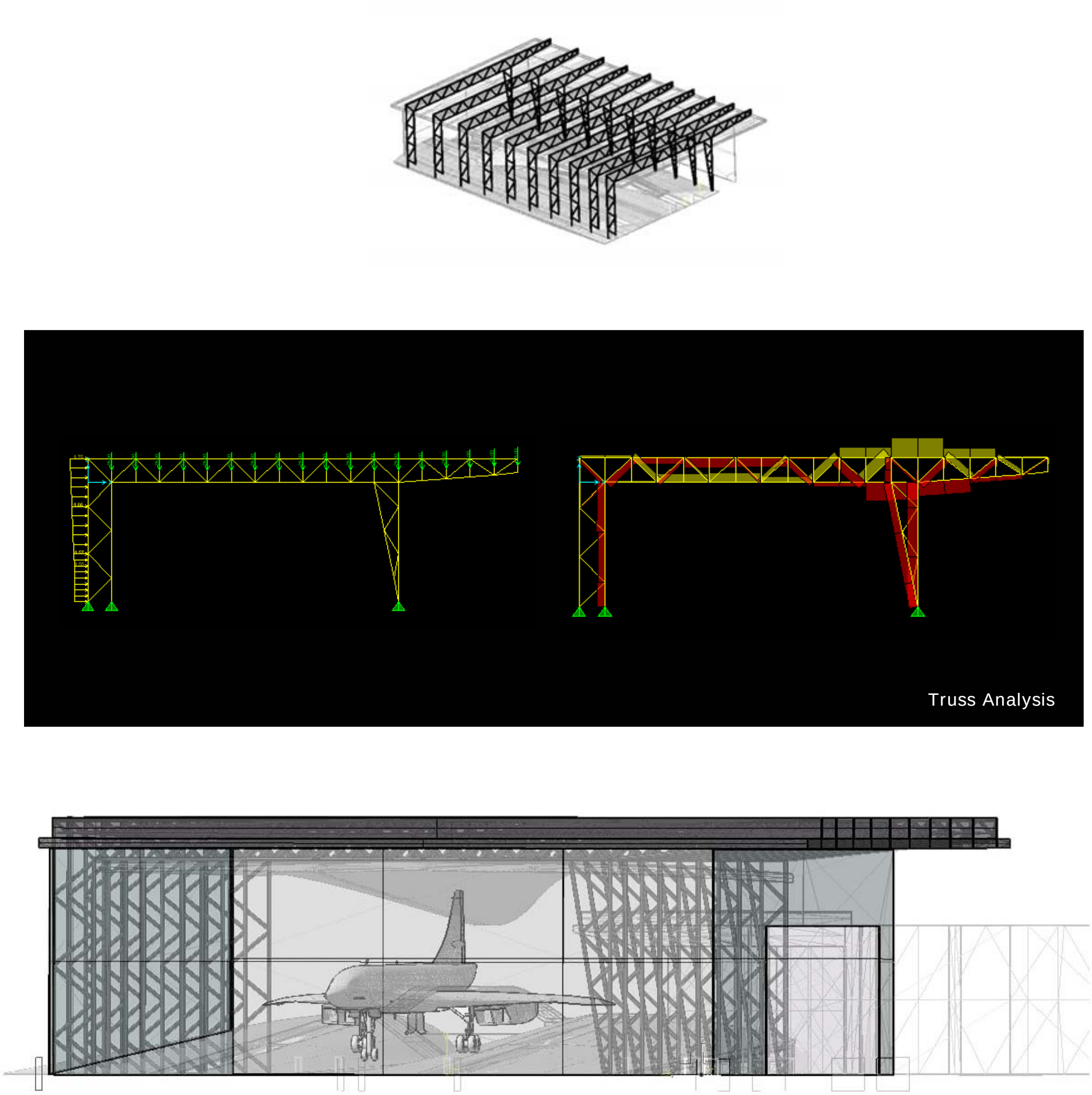

Fig. 5 Truss structure showing variable spacing from optimization and the stress analysis using CATIA

While details have not been included here, the civil engineers developed detailed designs for the roof structure, the glass curtain walls, integration of the anchoring of the structure into the pier, construction costing and code compliance.

The Interactive Exhibit

As previously indicated the team also developed designs for an integrated exhibition. One key feature of this was to provide an experience in sight, sound and color of the simulated flight from take off through the sound barrier as it effects and is affected by the innovative form of the aircraft design. To achieve this the students coupled advanced computational fluid dynamics with non-linear digital video editing to create a projected color mapping of the pressure changes across the aerodynamic surfaces synchronized with the sounds of the engines and ultimately the sonic boom as Mach 1 is achieved. Research into integrating current mist projection systems suggested that this can be achieved full scale directly onto the aircraft itself without adverse effects on the latter or the viewing public. This represents a state of the art approach in the project's attempt to deliver scientific information to a media savvy audience for whom traditional exhibition design is not engaging. Thus boundaries between architecture, engineering, science and entertainment dissolve providing a metaphor for the future of design and engineering education.

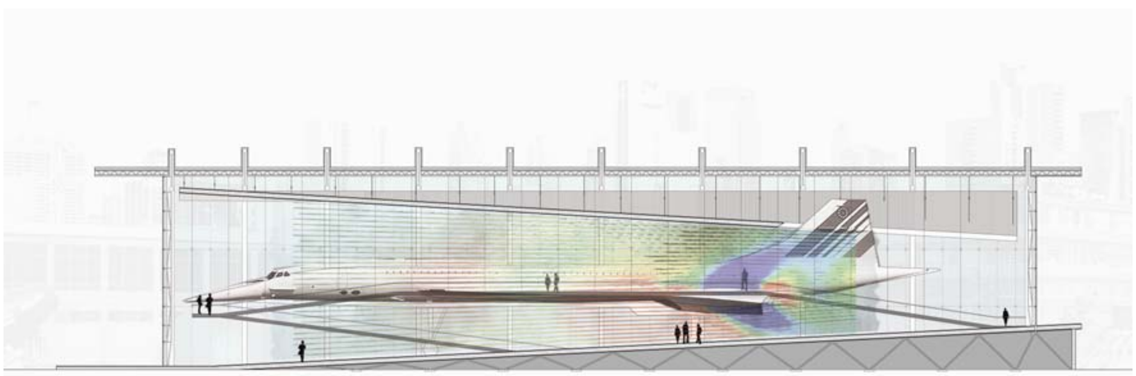

Fig. 6 Full-scale digital projection of pressure distribution during flight

Team Dynamics

One of the key outcomes of the project that was attributable to the grouping of graduate students with undergraduates is that the team was essentially self managed. Extensive experience has shown that this is rarely achieved with purely undergraduate teams. In addition to their maturity in terms of creating effective team dynamics, the graduate students also raised the level of professionalism compared to what one typically finds with undergraduate teams, not just in terms of the quantity and quality of work performed but also in bringing their experience to the creation and delivery of the presentations to the clients. The effect was to raise the bar for the undergraduates in a positive peer-driven manner, not through faculty pressure.

In reflecting on these dynamics we consider that an important factor in the self management of the team is the background of the architecture graduate students. Here, students come from primarily a project-based curriculum where design studio forms the core of an architect's undergraduate experience. They have a more evolved level of confidence in decision making and in open ended projects where the advisor does not neccessarily hold the answer to some of the issues at hand. This confidence and skill was infectious to the undergraduate students and removed the dependency that these students typically display towards their advisor.

Evaluation

Two external modes of evaluation served to provide feedback to the project team. The first was the client. Presentations were made to the CEO of the Intrepid Museum during key milestones throughout the project. The group also presented to Mr. Arnold Fisher, the chairman of the Intrepid Foundation which is the governing organization for the Museum, and the source of potential funding , from whom they received outstanding feedback to the extent that the design was subsequently presented to the full board for potential funding.

The second mode was a review panel of four architects and three engineers from the New York area. Feedback was overall very positive with specific suggestions for improvements to the underlying strategies.

Conclusions

The creation of a new graduate program, that fuses the design culture normally associated with architecture and industrial design with the engineering institution, has presented the opportunity to better prepare students for a paradigm in which design, engineering and its application merge as an interdisciplinary, collaborative endeavor. In turn this graduate program has been a catalyst to draw in undergraduates in a traditional engineering discipline to this new mode in interdisciplinary education that also bridges the gap between: undergraduate and graduate education, visual design and engineering disciplines, and the academic and the professional setting.

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JOHN NASTASI is a practicing architect and design educator. He currently serves as Director of the Product-Architecture Lab, and Program Coordinator for the interdisciplinary Graduate Program in Product Design, Architecture and Engineering (which he created) at Stevens Institute of Technology. He is also the Founder and Creative Director of the award-winning Hoboken-based design build studio, Nastasi Architects. Mr. Nastasi is a graduate of Harvard's Graduate School of Design, a recipient of Harvard's Rice Prize for advancement in Architecture and Engineering and a 1996 recipient of the Young Architects Award from the Architectural League of New York among other honors.

LESLIE BRUNELL is a Lecturer in Civil Engineering, Senior Design Coordinator and Director of the Water Resources Graduate Program at Stevens Institute of Technology. She earned her B.E. in Civil Engineering and Ph.D. in Civil/Environmental Engineering form Stevens Institute of Technology. Prior to joining Stevens she was a Water Resources Engineer in New Jersey.

KEITH SHEPPARD is a Professor of Materials Engineering and Associate Dean of Engineering at Stevens Institute of Technology. He earned the B.Sc. from the University of Leeds, England and Ph.D. from the University of Birmingham, England, both in Metallurgy. As Associate Dean, Sheppard is primarily responsible for undergraduate programs. He is immediate past Chair of the ASEE Design in Engineering Education Division.