

An Official Magazine of the
American Composites Manufacturers Association

June 2005

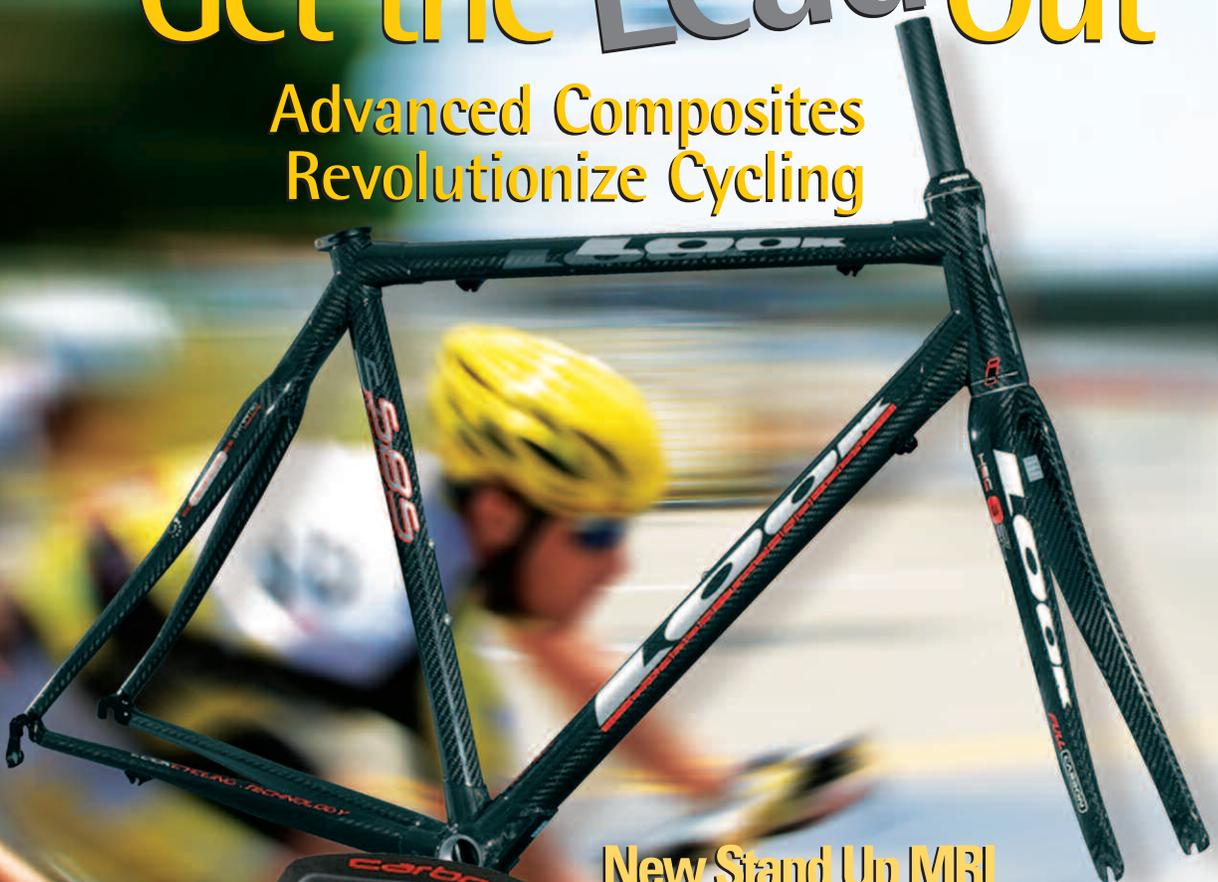
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New Stand Up MRI Design *Saw the RTM Light*

Case Study By Michael Paloian

Due to complexity, functional specifications, cost constraints, aesthetic requirements, and size, medical products have always challenged designers to constantly search for commercially proven manufacturing methods and materials that could transform their ideas into marketable products.

A few years ago, Integrated Design Systems (IDS) was chosen by Fonar to develop a set of covers for Fonar's new stand up MRI system. Project highlights included an opportunity to work with the current president of Fonar and inventor of the MRI, Dr. Raymond Damadian.

This was one of the physically largest and most challenging projects Integrated Design

Figure 2. Photo-realistic CAD rendering.

Systems ever encountered. Since this product represented a revolutionary step forward in medical technology, Dr. Damadian sought a design that incorporated the breakthrough concept of allowing patients to stand within an open frame during scans. His vision for the new product was such that it had to convey comfort, technological leadership, quality, and, most of all, openness. These characteristics also had to comply with the massive inner steel structure that creates the powerful magnetic field used in the imaging process.

Initial Design Parameters

The project was initiated with a few meetings to gain a thorough understanding of the entire system and general principles of MRI technology. This information was compiled into a report that included this abbreviated list of

design parameters:

- Covers must be visually attractive and aesthetically compatible with medical office décor;
- A major objective is to create the illusion of space for the purpose of minimizing or eliminating claustrophobia for patients;
- Covers must apply easily to the existing MRI structure that measures 9-feet high by 10-feet wide and 14-feet long;
- Covers must be easily removed for service;
- Covers must be designed in a non-metallic material;
- Cover manufacturing technology must be conducive for low production quantities and minimal tooling investment;
- The final documentation package must be adequate for constructing all molds and covers;
- Seams must be minimized for visual consistency and sanitation;
- Mounting hardware must be concealed and non metallic;
- Covers must mount to the existing frame, which cannot be altered; and
- Covers must provide adequate clearance for internal components and wiring.

In addition, IDS added the responsibility of identifying vendors, provided Fonar with vendor interface, and assisted Fonar with pre-production project management during assembly of first articles. The design also had to accommodate wire routing and management between the MRI and installation site.

After the product specifications were clearly defined, IDS imported Fonar's CAD file of the inner structure into its CAD system (Figure 1). Concept sketches were created using a printout of the inner frame as an underlay for maintaining proper proportions. Dozens of concepts were sketched, exploring a diverse cross section



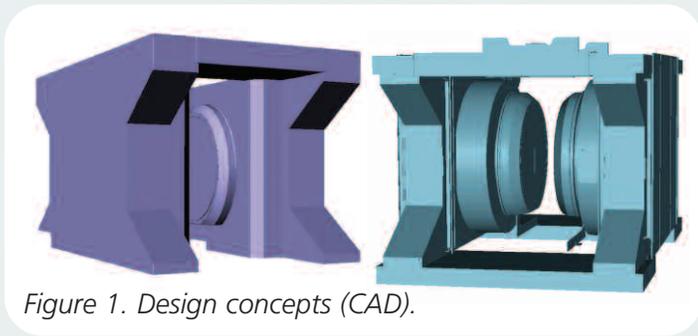


Figure 1. Design concepts (CAD).

of possible enclosure designs.

During this phase, aesthetic intuition was emphasized to nurture imaginative concepts that could capture the desired Damadian's vision. IDS' objectives were focused on creating a design that would provide Fonar with a distinct image that could easily be transferred from one product to another.

Simultaneous with this activity, an exploration of competitive products was conducted to provide points of reference during concept evaluations. Human factors issues also were reviewed to assure proposed designs would accommodate all patient orientations. These preliminary sketches were critiqued with Fonar based on initial visual impact, potential manufacturing options, and estimated cost.

Damadian's Vision

A few of the most promising concept sketches were selected for further refinement using CAD. Overall form, surface details, and proportions of the outer covers were carefully sculpted around the underlying steel structure to insure that the final design could be implemented. Four CAD models were completed and ultimately rendered as photo-real images suggesting surface finish, color and shadow (Figure 2).

Each concept was presented to Fonar in large high-resolution color prints as well as electronic TIFF files and was reviewed based on overall visual impact as well as projected sales, tooling budget, amortization, and number of parts. Service requirements were discussed based on ease of access during field service. Assembly steps were briefly reviewed based on estimated number of parts and proposed attachment methods.

Despite warnings by Integrated Design Systems that it was the most expensive design for tooling and overall part cost, Damadian selected the concept shown in Figure 3 as the one coming closest to his vision. Integrated Design Systems now faced the huge challenge of converting this concept into a real product based on a long list of very complex design criteria. Company officials entered this demanding phase of development with open minds to objectively identify materials and processes that would cost effectively reproduce the design without sacrificing aesthetic details.

The first step was to carefully examine overall design and decide where covers should be segmented based on molding, assembly, service, and tolerances. After many hours of brain storming and reviewing proposed options, it was decided to split the covers into the pieces shown in Figure 4. These separation boundaries satisfied most concerns.

Since the side panels were flat and could be specified in a non-ferrous material, fabricated aluminum sheet metal was selected for material and process. A series of flat reinforced 3.5-foot wide by 9-foot high by 1.125-inch thick reinforced aluminum sheet metal modules were designed to repeat along each side of the scanner. This process and material eliminated unnecessary tooling investment and yielded an accurate, structural cost effective part. Sections of the machine that required easy access during field service were identified by our client's service department. These areas were optimized for ease of access by designing covers that could be removed by a field technician within a few minutes. Since the scanner frame was symmetrical left and right as well as front to back, covers were designed

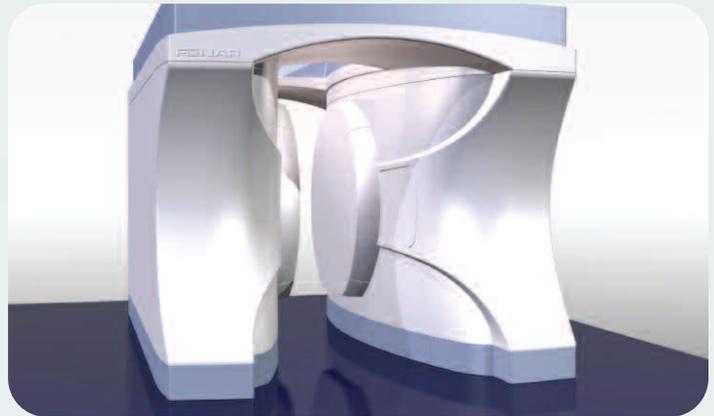


Figure 3 Closest to original vision.

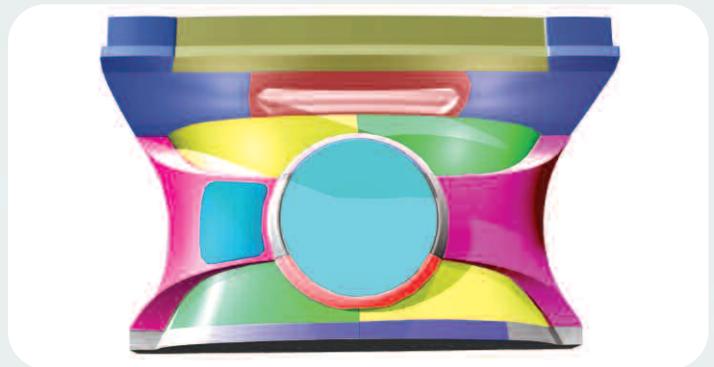


Figure 4

with symmetry to minimize tooling cost. The overall design was now mapped out for further detailing based on a specific process and material.

Selection Parameters for Covers

The major parameters affecting the decision for selecting optimum materials and processes for the remainder of covers are listed below:

- Tooling cost had to be minimized and fall within a specific budgetary limit;
- The molding process had to consistently reproduce very large parts with complex surfaces and tight tolerances;
- The molding process had to yield parts with excellent surface finish; and
- Plastic parts were required to be structural and rigid so they could easily be transported and installed without fixtures.

Integrated Design Systems explored a number of options for molding processes:

Reaction Injection Molding – Although this process is ideal for molding high quality, large complex parts with tight tolerances, tooling costs would have been prohibitive. The investment required for machined aluminum tooling for these very large parts would have easily exceeded one million dollars. In addition, RIM polyurethane parts would have lacked the rigidity and structural integrity required during handling and installation.

Pressure Forming & Twin Sheet Forming – These processes are a variation of vacuum forming, which is based on the deformation of a heated sheet of plastic within a mold. Part depth is limited because material stretches as it conforms to the mold causing thickness variation during processing. Both of these processes were seriously evaluated for some of the shallow parts because of processing limitations. Although tooling prices and part costs were attractive, the process was disqualified because of material and processing limitations. Thermoplastic materials would have been too flexible for these large parts and most parts would have required too deep a draw for these processes.

Rotational Molding – Rotational molding is ideally suited for large

complex shapes. Tooling costs are generally low and part quality can be consistently maintained during production. Parts are typically molded in cast aluminum molds with a hollow core. Unfortunately this process has two significant drawbacks, limited resin selection and poor tolerance control. The majority of resin molded is polyethylene, which is a low modulus material with a waxy surface finish. Tolerance fluctuation is caused by the resin as well as limited process control and tool quality.

Chopped Sprayed Fiberglass – Chopped fiberglass or open mold hand-lay-up of fiberglass also was evaluated during this investigation. Although the process satisfied most of our requirements, it was not used because of concerns for consistent quality and tight tolerance control. Lack of dimensional control caused by inconsistencies in this manually intensive process was confirmed after interviewing a number of processors. Processors were generally apprehensive of tight tolerances, wall thickness consistency, internal surface finish and overall geometry. OSHA and EPA regulations were other factors to consider.

Resin Transfer Molding – Our familiarity with resin transfer molding was limited to a very general overview of the process. After speaking to representatives of the American Composites Manufacturers Association (ACMA), we were directed to a number of qualified experts in RTM, one of whom was John Moore of RTM Composites. During telephone conversations with John, officials from IDS became very impressed with his honesty and thorough knowledge of resin transfer molding. After evaluating project requirements, he suggested the company consider a variation of RTM referred to as RTM light. His description of this process and its success in products like the Viper aroused interest. Although there were a number of questions regarding this process, the major concern was its current lack of wide-spread use within the composites industry and the limited number of experienced molders.

Challenges of Design Details

After evaluating the attributes and limitations of each process, IDS decided to focus its attention on conventional RTM and RTM light. Candidate vendors were identified based on recommendations obtained from the ACMA and suppliers within the industry. This pool of vendors was further analyzed by interviewing key personnel by telephone, receiving samples and examining facility photographs.

The final three candidates were individually evaluated with personal interviews at their facilities and at IDS. Visits to a few facilities helped evaluate the small group of candidates based on equipment, capabilities and experience in molding similar products. One candidate had extensive experience in conventional RTM, another had extensive experience in RTM and RTM light. The third had mixed experience in RTM and polyurethane RIM molding.

Throughout this evaluation, the design was being detailed with features that gradually included attachment methods, seams between covers and molding parameters. After it was decided to select RTM as the optimum molding process, panel details evolved with specific features for that process. During evaluation, questions arose with the candidates concerning specific design details to test their knowledge of the process. Some molders could not commit to specific tolerances and offered vague guidelines. Other molders proposed splitting the front corner cover into two or more pieces which would later be assembled with bonding.

Machining all the molds in aluminum also was proposed by some molders who were doubtful of the RTM light technology. Many of these alternative ideas introduced more problems than solutions and had to be rejected.

The evaluation eventually narrowed the selection to one candidate, Phoenix Industries of Crookston Ltd. Crookston, Minnesota, headed by Jeff Burgess at that time. Mr. Burgess is now with Acrylon Composites in Grand Forks, ND. Jeff's extensive experience in RTM and RTM light was demonstrated by the size, complexity and number of different

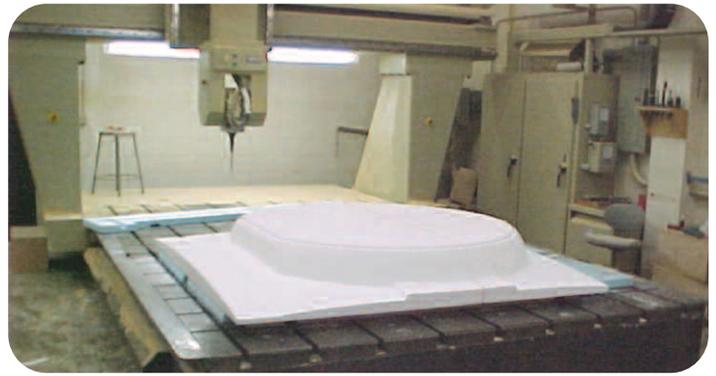


Figure 5.

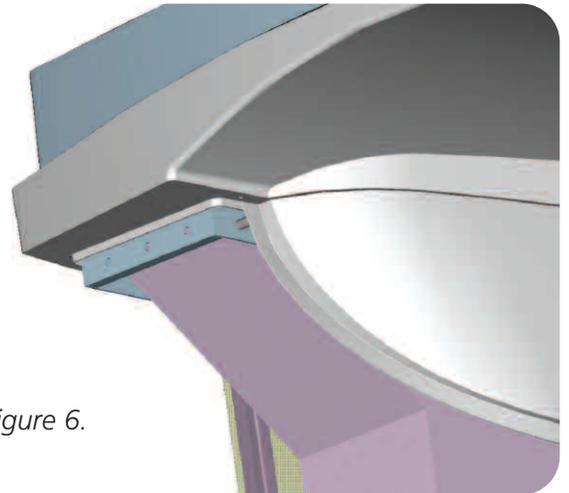


Figure 6.

products that were manufactured in his plant with these processes. The other candidate specialized in molding conventional RTM parts that were glass filled, “non appearance” products with demanding structural requirements. These applications required expensive machined aluminum molds and large clamping presses which would have been cost prohibitive for this application. The third candidate seemed to be overloaded with other contracts.

Once Phoenix was selected as the molder, as the design evolved, CAD files were emailed to their tooling and processing engineers. When the design was approximately 80 percent complete, a project meeting was held at Fonar with representatives from Fonar, Phoenix, Integrated Design Systems (www.idsys.com), and Ketco (www.ketco.com). Ketco was a major contributor to this project based on their unique capabilities of CNC machining of extremely large patterns and models directly from CAD fields within very tight tolerances (Figure 5).

During this critical meeting every design detail was honestly, thoroughly, and objectively presented by IDS for input from the group. Issues discussed:

- Overall design was reviewed based on aesthetics and assembly methodology;
- Molding issues pertaining to specific covers and how the mold would be parted were examined;
- Draft angles and depth of draw were discussed;
- Surface finish also was reviewed based on molded color with a gel coat or post operations such as painted polyurethane;
- Ketco described its machining capabilities and how the company could machine and deliver an interim, non-functional model for an up-coming trade show within 4 weeks;
- Methods for attaching mounting blocks to the inside of molded covers also were reviewed; and



Figure 7a.



Figure 7b.

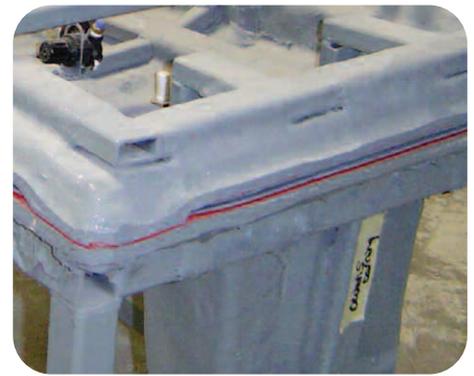


Figure 7c.

- Overall schedule was discussed based on risks, backup plans, and critical milestones.

At the end of this very productive meeting, a clear set of common objectives were established for the remainder of the project.

Attach Panels Without Fixtures

The project proceeded with the design details to include draft, clearances, inserts, shut-offs, and all other molding features required to produce RTM parts based on accepted specifications. The ultimate objective was to provide Fonar with a complete set of production part files based on the technical requirements of the RTM light molding process (see Figure 6 example).

IDS planned to release these files to the molder and tool maker to cut patterns directly from unedited CAD files. Solutions to design challenges required imagination, keen awareness of manufacturing tolerance limitations, and extensive technical knowledge in mold design. IDS project engineers routinely corresponded with engineers at Fonar for comments on proposed design alternatives.

The objective was to attach panels without fixtures. This concept required a careful analysis of cumulative tolerances resulting from RTM parts, sheet metal, and machined parts based on different design alternatives. Tolerance limits were verified with each vendor, including Phoenix to ensure that molded parts would fit together as anticipated. Phoenix was confident that it could hold +/- .06" over 9 feet. Although IDS officials had reservations about this very tight tolerance, Jeff Burgess guaranteed the parts would comply with this specification. A .125-inch clearance between all covers was left.

It should be noted that the RTM light process has many inherent advantages for yielding cost effective, high quality parts with tight tolerances and consistent surface finish. The process which has been perfected by JHM Technologies (<http://www.rtmcomposites.com/home.html>) is based on a pressure balanced system of molds and resin transfer equipment. Internal mold pressure is initially evacuated to 6 to 8 psi (approximately 1/2 atmospheres or 14.7

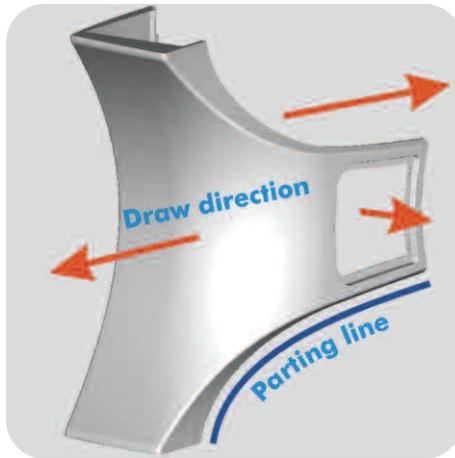


Figure 8.

psi) and monitored by a transducer, located approximately at the center of the mold.

As resin is injected into the mold, injection pressure is regulated by the feedback from the transducer's measurements of internal mold pressure. The balanced pressure system permits the use of low cost, minimally reinforced molds that will not blow apart or distort. Precut glass mat is placed in the cavity half of the mold without obstructing the gasket. Molds are kept closed by a high vacuum around the perimeter of the mold between two sealed gaskets. This principle is the key difference between conventional RTM and RTM light (Figures 7a - 7c).

Undercuts within some of the parts were reviewed with Phoenix and Ketco to discuss tool and part design. The most difficult part was the front corner cover which required complex twisted surfaces to be swept in the direction of tool draw. Despite efforts to avoid undercuts, this part required a few removable pieces in the mold to create the desired appearance and function (see Figure 8 example).

Concurrent with this development, design options for registering and fastening covers to comply with service, assembly, and tolerance requirements for this room sized 14-foot by 10-foot by 10-foot instrument were examined. After reviewing all the design specifications, it was decided to reference all the covers to mounting points on the inner machined steel



Figure 9.

frame. The inner steel frame was comprised of a few monolithic precision machined blocks that could be modified for adding attachment hardware. Since all covers were symmetrical about the center axis of the imaging area, it was determined to use this central point as the zero datum. At this point, a precision machined fiberglass reinforced structure was designed to mount to the steel frame. This frame would accurately support covers around the imaging area.

Once these covers were properly positioned on the frame, additional symmetrical covers could be registered and added to the substructure. This assembly scheme provided a means of assuring that all covers would be symmetrical about the center of the instrument without fixtures.

Maintain Aesthetics

One important goal was to attach all covers with concealed hardware to maintain the desired aesthetic details. This objective was achieved by establishing a priority for assembling covers in a specific order. Placement of one cover over the mounting flange of another allowed for the location of non-metallic fasteners behind the most recently attached panel.

RTM parts provide rigid, net-shape shells devoid of any mounting features on the inside. Molded parts must be subjected to a few

secondary operations before they can become functional covers. One of these operations is trimming. Trimming simple two-dimensional planar edges is relatively simple and can be achieved with a simple fixture or two axis CNC routers.

However, these large complex parts with +/- .06-inch tolerances required 5 axis CNC routing with trimming programs based on part CAD files. Trimmed edges were designed along non-visible edges to minimize rejects due to potential cosmetic irregularities. This design detail yielded parts with molded features on all visible surfaces and along all dimensionally critical edges. (See Figure 9). Extruded aluminum mounting rails were bolted along the exterior walls of the internal steel structure. Specially designed mounting hardware was attached to these rails that supported sheet metal panels.

Mounting blocks were added to the rear side of the covers permitting attachment of fastening hardware on precision machined flat reference surfaces. These mounting blocks required their surfaces to be matched to the complex inner surfaces of the covers. Since repeated CNC machining for each block would have become cost prohibitive, we suggested that blocks should be cast in a net shape using high-density

polyurethane foam. The molded contoured block would be matched to the inner wall of the cover for which it was intended and securely bonded with a structural adhesive. After the blocks have been bonded in position, mounting holes for hardware and locating pins would be CNC machined using the CAD data files.

The final design can be viewed in the photos that illustrate many of the details cited in this article (Figures 10a & 10b). In conclusion, IDS would like to thank all those who participated in this project. Exciting projects such as this can only be realized by a cooperative team of

dedicated individuals who share a common vision and determination to make it happen. In addition to the people involved in this program, this design would have been impossible to manufacture without RTM light technology. This derivative of RTM provided the perfect balance of tooling cost with part quality, size, complexity, and structural integrity. **CM**

Michael Paloian, president, Integrated Design Systems: 516.482.2181, ext. 101; paloian@idsys.com. Michael Paloian is scheduled to speak at COMPOSITES 2005.

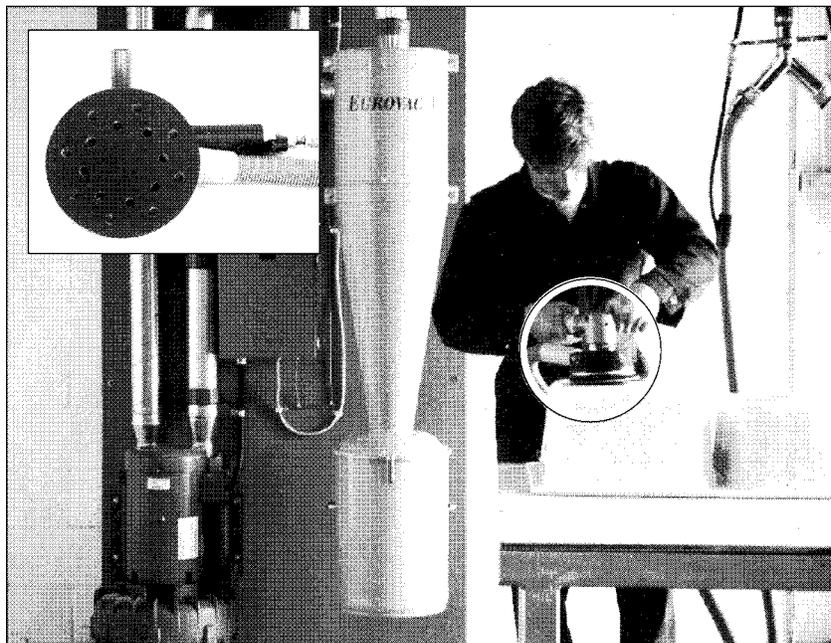


Figure 10a.



Figure 10b.

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