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Laser Guidance for Hand Laid Composites: Past, Present and Future

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abstract

This paper will survey the history, current state of the art, and future plans for projecting patterns of laser light onto a variety of tooling surfaces for the purpose of showing assemblers the proper location for pre-cut materials which are being laid up into a laminate.

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Laser
Hand Laid Composites

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Introduction

This paper will survey the history, current state of the art, and future plans for projecting patterns of laser light onto a variety of tooling surfaces for the purpose of showing assemblers the proper location for precut materials which are being laid up into a laminate.

The main drivers of computer controlled laser projection systems in composites manufacturing are:

- Reducing Manufacturing Costs
- Improving Part Quality

Computer controlled laser projection systems are used to replace hardware templates. These templates are made of fiberglass or mylar and are full size. physical representations of the dimensions stored in computers as CAD data. Templates are a major cost center in the manufacture of hand laid composites.

Template costs break down into the following indirect costs (costs not incurred for each part produced) and direct costs (costs incurred for each part produced).

Indirect costs include the material and fabrication costs of the template. Each template is a second tool for each part which will be made. Since a hard template is the same size as a tool. storage requirements are multiplied. Many templates are too big to be carried. This requires the costs of carts and additional storage space. Hand layup of composites occurs in a clean room. The cost implications for manufacturing space with templates are significant. The cost of space in a Class 400 clean room is generally an order of magnitude more expensive than standard warehouse space. In the case of a tool of medium complexity. these non-recurring costs of templates are generally enough to justify the purchase of a laser display system.

Any time there is an Engineering Change Order the template needs to be remanufactured. This process can take weeks from the time that the changes have been defined in CAD.

No template operation adds value to a part which is being manufactured. The template allows the assembler to be ready to add value to the part being laid up. The steps and costs in being ready to lay up with a template are shown in figure 2.

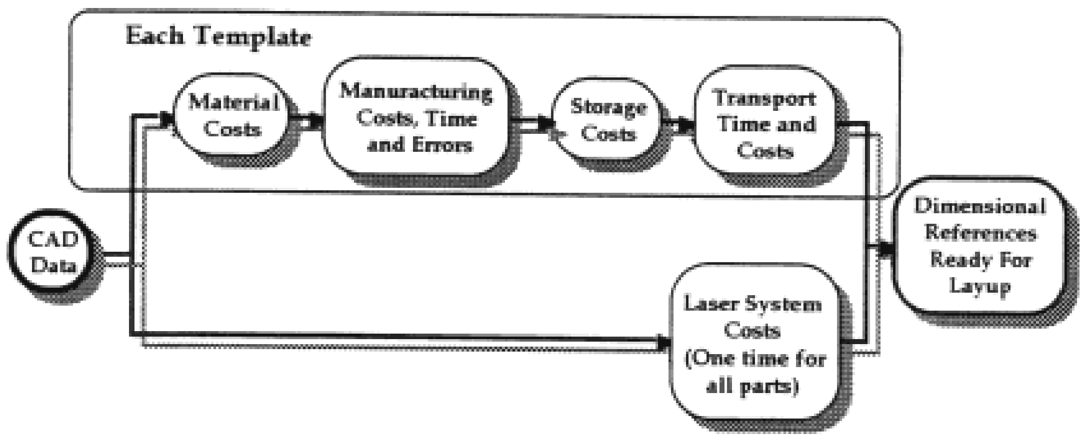


Figure 1: Template and Laser Indirect Costs and Errors

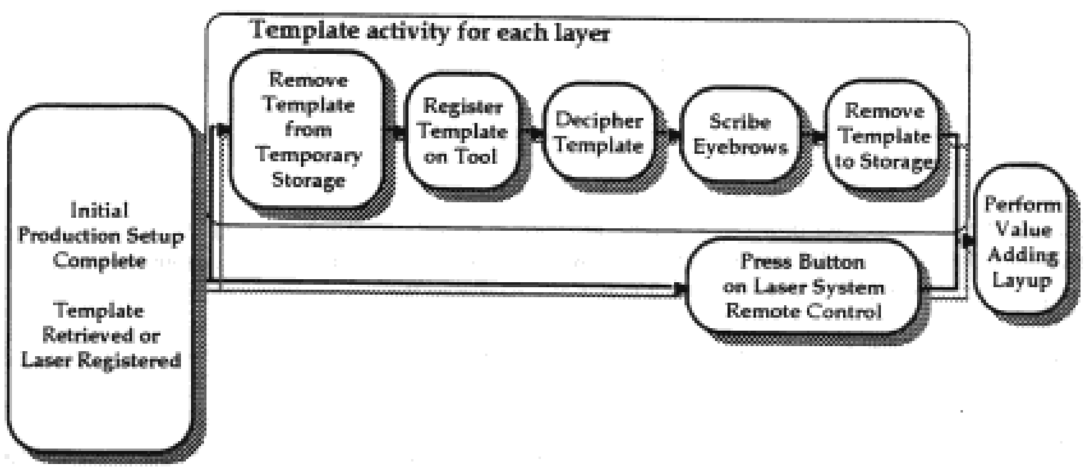


Figure 2: Template costs and errors for each sequence

A computer controlled laser projection system can replace all functions provided by hardware templates. The laser system consists of:

- a laser projector which mounts above the work area
- a user interface computer from which the operator selects the dataset for layup (this may be stored locally or remotely) and steps through the patterns and other instructions
- retroreflective sensors which are placed in tooling holes in the tool

The laser system operator must take the time to select the dataset for the part (analogous in function but much shorter in time to retrieving the template). place sensors in the tool. and steer the laser to each sensor (analogous in function and time to pinning the template to the tool surface).

Once these tasks have been accomplished the operator presses a button on the remote control and the system projects patterns for placement and fiber orientation directly onto the part. The time required to push the button on the remote is very short in contrast to the time required to retrieve the template from storage. mount. decipher. scribe and remove the template back to storage.

One system may be shared among several parts at one time. Systems with multiple projectors can be quickly switched between different projector configurations allowing concurrent work on smaller parts which require only one projector per part and larger or more complex parts which require multiple synchronized projectors for one part. This issue will be discussed in the context of both past and present capabilities and is shown in figures 3 and 5.

The laser system is an output device for applying CAD data to manual activities. The system allows assemblers to use their flexible visual. tactile and reasoning skills to add value to parts by laying up material. and relieves the assemblers of the dimensioning tasks which are difficult for a person to perform well.

Full automation of the layup of prepreg has had limited success. The precut plies of material are sticky and are often elastic. The assemblers must deal with this elasticity and stickiness in the process of achieving the proper boundary, fiber orientation and absence of wrinkles in reference to the layup patterns provided by the template or laser system.'

Much of the activity which determines part quality occurs around the template or laser system steps. Templates or laser systems define the basic shapes of each part in the activities where tooling. datasets. pre-cut material. assembler and layup aid come together. Accuracy and quality issues can be resolved with a minimum of consequence during the layup process. Errors with ply placement can be resolved by simply pulling up plies and re-laying them. Builds can be put on hold while tooling is repaired. Data can be checked for each ply to confirm proper flat patterning and cutting as well as perimeter shape after layup.

Most of the quality issues which are deviations from the "ideal" part (as defined in CAD) also come together around the layup steps. Machine control data is one source of errors in finished parts. While the quality of machine control data has improved significantly in recent years. (flat patterning for the cutting of plies to be laid across complex curved surfaces is extremely difficult) it is still not perfect. All tooling is maintained to be within some tolerance band. These variations are compounded by other variables in the manufacturing system. A template or laser system is a tooling component. While the real world accuracy of a laser system is generally an order of magnitude better than templates. there are still errors introduced into the process by either system. The replacement of templates with a laser system will result in the greatest improvement in accuracy in hand laid composite parts with currently available technology.

The accuracy of a laser system is still dependent on tooling issues such as accurate location of reference sensors. stability of support structure and laser system calibration. An optimal laser system provides the assembler with the most accurate. best defined patterns for layup (templates usually provide only corners through "eyebrows" while laser systems provide perimeters and ply orientation lines). These accurate layup patterns minimize the compounding of layup errors produced by the assemblers who are handling large pieces of sticky stretchy cloth.

Although computer controlled laser projection systems have been available since the late 1980s. their adoption has been relatively slow for several reasons. Laser projection systems for composite layup are a revolutionary change from the methods which have been in place for many years. The lack of mainstream use of these systems. coupled with unsuccessful applications of other automated manufacturing systems for composites. has led to a cautious approach to laser systems. Cutbacks in defense spending have led to the cancellation. delay. or scaling back of many programs which would adopt and prove out new manufacturing systems. The late 1980s and early 1990s saw cancellations or reductions in leading edge composites applications in programs such as the A-12. V-22, LHX, and F-22, to name just a few.

Although the adoption of laser technology has been slow and cautious. the current state of the art has reached a point where the changeover or startup issues are straightforward and the cost savings and other benefits are well documented. Production cost reductions in layup are reported to be as great as 80% in applications with complex template requirements." Future enhancements to laser display technology may extend benefits into other components of a composite manufacturing system.

Past

Bill Lear's Learfan was one of the first sophisticated. all composite aircraft which was planned for production. Although the aircraft never entered production. plans were made to reduce the requirements for templates. John Maguire's 1982 RFQ for an Optically Assisted Ply Locating System'" described the concepts which would evolve into the laser systems which are being used today on composites production lines. The production requirements for the LHX program (an all composite helicopter) also led Sikorshy Aircraft to seek this new manufacturing technology.

Many of the enabling technologies required for laser pattern display were maturing in the mid 1980s. The price of computers was dropping while the performance was improving dramatically. The application of CAD to part definition was improving. and the improvement in speed and accuracy of galvonometric scanners (beam steering devices) was improving.

The Boeing Company and Assembly Guidance ran a proof-of-concept laser system on a 757 Main Landing Gear Door in 1987. Although the accuracy of the scanners (beam steering devices) could not meet accuracy requirements for production. the system showed potential.[iv]

A new generation of high accuracy scanners became available in 1989 from Cambridge Technology, Inc. These were designed into the LASERGUIDE 1-11. the first production laser display system to be used on the shop floor in composites manufacturing. This system was run in single and multi-projector configurations on a variety of parts including fan blades. skins panels. nacelles. and ribs. The LASERGUIDE 1-11 could run 3D CAD data. but this data was difficult to generate in a form which would take into account the behavior characteristic; of composite materials as they were being laid up or the surface offsets resulting from ply buildups.

Several refinements to the initial systems resulted from feedback of users and internal work being done at the Boeing Co.[V]

The principal areas of refinement were:

- CAD data generation
- CAD data deliver
- wireless sensors
- improvements in user interface and projector control configuration
- traceable certification and calibration methods

The engineering data which defines ply boundaries does not necessarily contain all of the definition required to drive a laser projector. The flat patterning process required to cut the plies of composite material must take into account the behavior of the material as it is laid up over complex curved surfaces. The flat patterning process must be accurate enough that the material will precisely fit the ply boundary projected by the laser projector. The laser projection data must also take into account the projection surface offsets which result as individual plies are laid up. Without specialized CAD tools it was cliff cult to generate data which would show as accurate boundaries on the plies of material as they were being laid up.

The original laser projection systems were stand-alone. Data was delivered to the systems via floppy disk. This process was slow. cumbersome (especially if the data was generated from a location which was any distance from the projection system). and prone to errors and confusion. Each projection system needed management of which dataset was current. should be kept/deleted. etc.

The original laser systems used calibration sensors which were connected to the controller with fiberoptics or electrical wires. Although these feedback systems supported accurate 3-D registration. they were awkward and cumbersome for tool setup. John Palmateer and the Boeing Company developed one of the first wireless sensing systems for laser projection systems. These wireless sensing systems required that assemblers place retroreflective sensors in tooling holes on the tool surface. The assembler would then use a joystick to aim the laser light at each sensor. This enabled the projector to accurately scan the sensors and calculate a transformation matrix which allow the CAD data to be accurately displayed in the coordinate system of the projector.

The early projection system controllers were restricted to one part. of one projector configuration. at one time. on a system. A three projector system would always function as a single. unified. three projector system. The three projectors could not be used as a unified three projector system at one moment and as three independent projectors in the next moment. Furthermore. the controller could only keep track of one part at a time. If an assembler had room for more than one part under a projector they would still be required to close out one part in order to work on the other. This process required a complete startup sequence each time a different part was activated (operator logon. choose dataset. steer to sensors. select sequence. etc.). This restriction on active parts and projector configurations limited the application of systems. See figure 3.

The aerospace industry is cautious and conservative. Early laser systems were difficult to calibrate and certify. The principal obstacle was the elimination of subjectivity. Without an objective. traceable certification method it was difficult to have full endorsement of quality organizations in the transition process from templates to laser systems. While it is intuitively obvious that a laser system will be much more accurate than templates. the quantitative proof of this capability was difficult to accomplish.

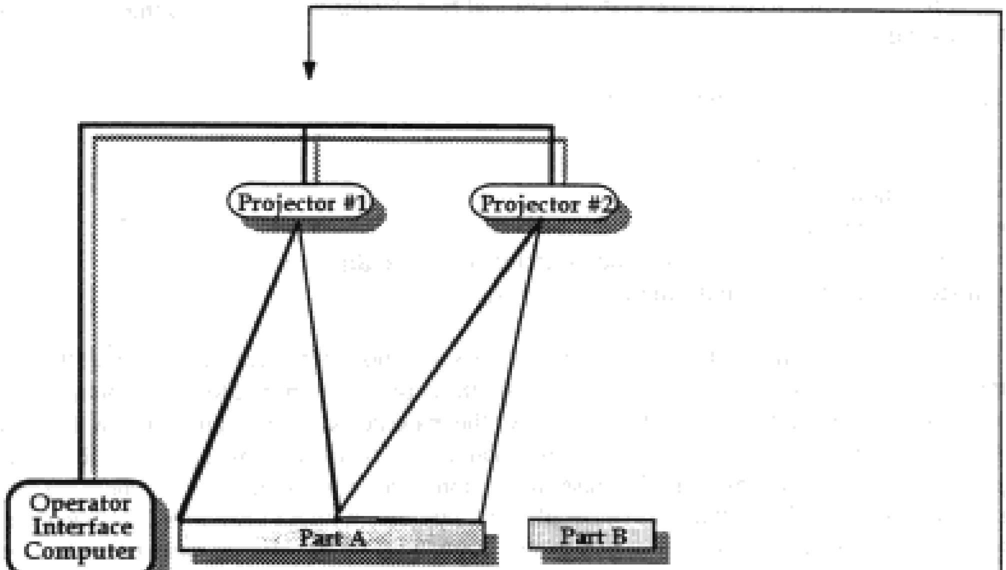
Present:

The current generation of laser projectors for hand laid composites has addressed and refined many of the difficult issues which arose as this technology was being put in place on the shop floor.

<u>Data Generation. Delivery, and Verification</u>

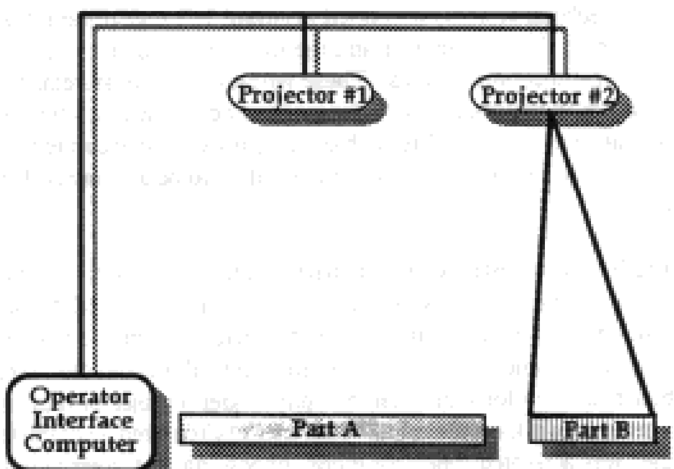
Accurate data generation has become routine in recent years. Several companies ha, e developed CAD packages and postprocessors which address the issues of accurate ply cutting, accurate boundary definition on projection surfaces which are continuously offset as plies are laid up, and seamless compatibility between CAD data output and laser system input.[V']

Manufacturing datasets are conveniently updated for local storage or transparently downloaded as each part is manufactured. It is now possible for operators to barcode or click datasets from menus and have the dataset immediately running on the laser



In order to use the system on Part B instead of part A, the following tasks must occur:

1. Stop Projecting on Part A
2. Reconfigure the Operator Interface Computer for Single Projector Operation (the location and sequence of Part A is now lost)
3. Teach the system the location of Part B and register
4. Select the sequence for Part B
5. Operate Projector #2 only



In order to use the system again on Part B instead of Part A, the following tasks must occur:

1. Stop projecting on Part B
2. Reconfigure the Operator Interface Computer for Double Projector Operation (the location and sequence of Part B is now lost)
3. Teach the system the location of Part A and register
4. Select the Sequence for Part A (remembered or written down)
5. Operate Projectors #1 & #2 as a unit

Figure 3: Limit of one active part and configuration at a time

controller. Network data transfer has evolved to the point where no activity beyond simple identification of the dataset is required. This capability eliminates typing and any requirement for the operator to be involved in the details of the transmission of the dataset. Operators can now spend more time in layup. the value adding process, instead of dealing with typing confusing strings of data and communication commands.

Operator interfaces have the capability to look directly at the data to verify several items. Viewing header data allows the operator to compare data generation date. time, programmer. media file. and other revision information. Direct viewing of data can also quickly identify transmission garbage. Functionality errors (which may correspond to incorrect revision, also identifiable from the header) can be quickly established if conflicts occur between plies or ply shapes, tooling, and kitting order when compared to the laser patterns. Direct data viewing resolves problems because the operator has the ability to view and compare each process component at its most fundamental level.

An example of a problem quickly resolved by direct data viewing would be one where the operator still has plies to be laid up but no laser patterns. By browsing the dataset the operator can see if a proper end of file command is present at the end of the dataset. If it is not, they can repeat the download of the dataset to see if a transmission error has occurred. They need not be running the projector to accomplish this troubleshooting. If the file has not been corrupted in transmission they can contact the programmer directly. viewing his or her name from the data header. This ability to view all types of information related to the location of each ply assures that startup and production run as quickly and smoothly as possible.

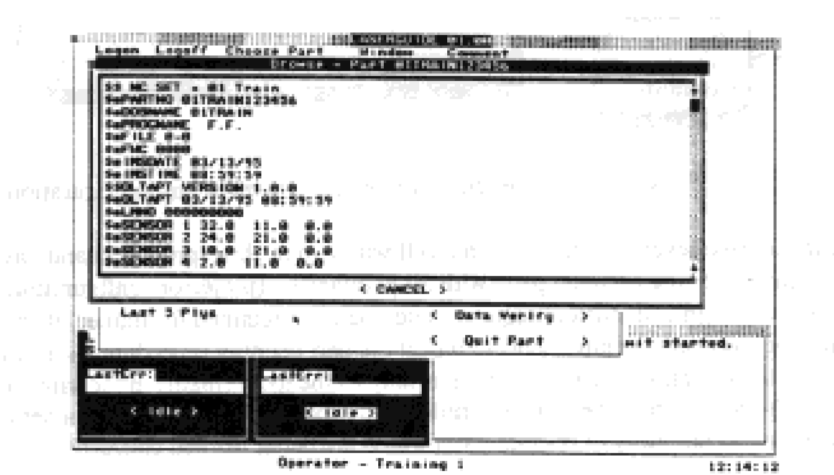


Figure 4: Browse Data

Supporting Multiple Active Parts and Projector Configurations with a Single System

A single group of projectors can be concurrently operated as a synchronous set or asynchronous individual projectors. Early systems supported only one active part at a time. A system with two or three projectors was dedicated as a two or three projector system unless the system was rebooted with a different configuration file. See figure 3.

It is now routine to have several parts active in a cell with two or three projectors and have these projectors instantly switching between parts with all parameters (projector configuration: single. double. triple. etc.. tool location in cell. current sequence and operator) retained for immediate activation. This capability eliminates operator requirements to repeat the part opening procedures (select part. select projector. steer to sensor. choose sequence. etc.) as long as the tool remains in the same location in the cell. This is similar to switching between multiple word processing documents on a personal computer. You should not have to put away or re-open parts which are being worked concurrently.

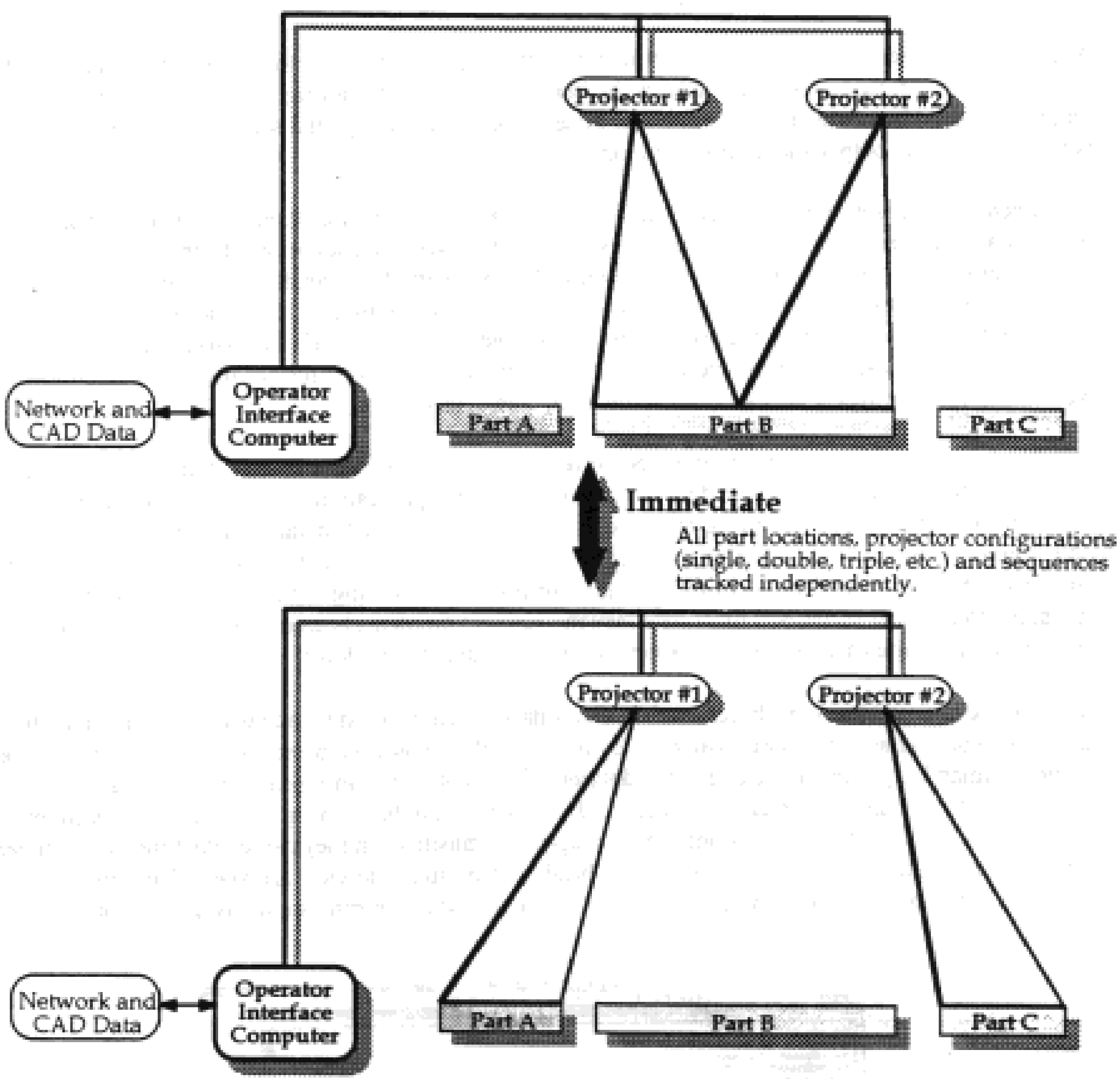


Figure 5: Switching between multiple active parts in any configuration

It is also common to support asynchronous layup of multiple parts on a single tool. Many components such as upper and lower skins are built in pairs. Current systems recognize a common set of sensor definitions between two independent datasets and allow the operator to skip tool registration for the second part. The multiple active parts capability allows both simultaneous projection and bouncing between active parts. See figure 5.

Current systems utilize remote controls which free assemblers from having to return to the control computer for each action. Once a part. projector and remote (multiple remotes can be supported on a single system) are selected. the operator can perform all normal operations at the tool utilizing the remote. Multiple remotes drive the switching between active parts with retained projector configurations and sequence indexing.

Calibration and Certification

It is now possible to calibrate and certify systems traceable to a standard. This capability provides nonsubjective documentation to satisfy customers. Quality Organizations and the FAA.

The certification process is accomplished using all normal operating parameters. Earlier certification methods were either subjective or measured system components which did not take into account all sources of error. With current capabilities measurement tooling resembles production tooling with production retroreflective targets and the process occurs at the place of production without removing the projector from its support structure. A well calibrated laser system can provide projection accuracy to approximately one part in eight thousand (placing the projector closer to the work surface improves accuracy).

Current certification involves MST-traceable measurement of the reference tooling. This tooling is placed anywhere in the projection field and the operator steers to six reference sensors. The laser system performs a registration and transforms the surface data as it would in production. It then proceeds to measure the location of each retro-reflective sensor in a matrix on the tool surface. The as-found locations are compared to the as-measured locations of these sensors and the difference is listed in the certification document. Certification documentation. automatically created by the system. is available for each step and component in the calibration and certification process. This documentation includes calibration tooling documentation. documentation of how the relationship between the calibration tooling and the projector was established. the complete nonlinearity correction table. and the certification results.

The certification process can be repeated throughout the field for each projector. This process provides a non-subjective. full-field measurement of the projector relative to a NIST-traceable reference.

The data generated in this process supports the tracking of both the components of the current certification process and the performance trends for the laser system.

```
$AutoCertification Results
$ISN=011796.CRT
$01/19/96
$19:22:44
$#1 on Thursday RHS
$SER#1
$TOL=0.015
$MMD=0.500
$ X tool   Y tool      Z      X calib  Y calib     dX        dY
  -7.621   27.071 -120.174   -7.560   27.224    0.000     0.003  1
   1.879   26.852 -120.169    1.925   26.977   -0.000     0.006
  11.371   26.626 -120.164   11.401   26.722    0.000     0.011
  20.870   26.404 -120.155   20.875   26.470    0.001     0.001
  30.367   26.179 -120.147   30.338   26.201    0.008     0.003
  39.666   25.958 -120.143   39.811   25.928    0.007     0.004
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Figure 6: LASERGUIDE AUTOCERT

<u>Integration and Other Applications</u>

A laser projection system is an output device for CAD data. The projector can be controlled by any system which can provide data along with command messages for registration, quick check (looking for tool movement) and display. Integration with tape layers, filament winding systems, and compaction systems can be accomplished so that the benefit of accurate locational references for assembly can be combined with the capabilities of the host system.

Laser projectors with vision capability have been integrated with fabric cutters. One method of reducing the cost of composite parts is to reduce the material cost. Material cost reduction can occur if multiple kits are nested in the cutting process. The capability to mix kits in a highly efficient nest has been available for several years. However, when multiple kits are nested the unloading process becomes extremely complicated. Piece two of kit one can end up more than thirty five feet away from piece one of kit one. This complexity results in a slow unloading process that has a high opportunity for error.

Laser projection systems with integrated vision systems have been installed which utilize label data to drive a laser pointing reference on the cloth. The operator sets the origin with the laser and the projector then automatically draws a line from the most recent ply which was picked up to the next ply to be picked up in the sequence. The vision system is an automatic remote control which recognizes when the correct ply of material has been picked up. If the correct piece of material has not been picked up the system will not advance. This capability both speeds the unloading process and prevents kitting errors.

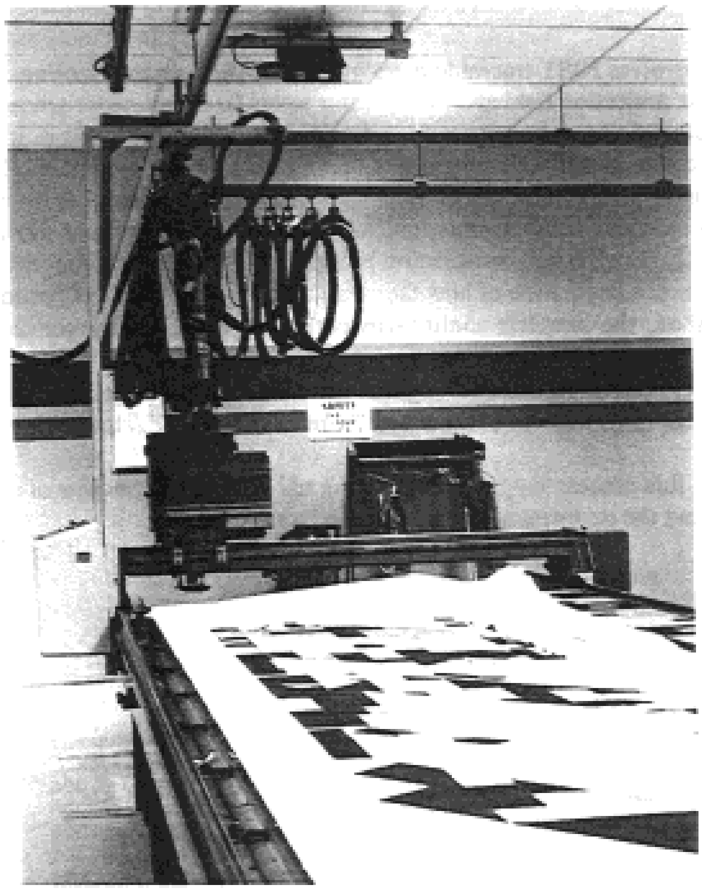

Figure 7: KitGuide on cutter table

Future:

The future of laser guidance for hand laid composites is dependent on continued system cost reductions and quality improvements. Cost reduction will be accomplished with systems which perform more value-added functions while requiring less activity which does not add value (overhead operations).

A major opportunity for added value with dimensional projection systems is in the area of in-process quality, monitoring. Laser systems contain the ideal definition for the process being carried out on the tool surface (CAD data) along with real-space references for the process as it is being carried out. By automatically monitoring the layup of each ply during layup the system can verify and document proper placement and orientation of each ply. This function would assure that quality is achieved during fabrication. not through later costly inspection and rework. See figure 8.

Steering to sensors is an overhead task which must be eliminated. This is a task required to register the projector to the tool's location in the projection field. Current systems require operators to steer a cursor of light to numerous fiducials for each projector. This is not a value adding task. Systems of the future will automatically register themselves to the tools in their projection field.

Another area for improved application and cost reduction is portability. To obtain maximum value from a system. the system should be able to be used in as wide a variety of applications as possible. Products such as nacelles require multiple projectors configured to project at angles of approximately 60 degrees. A long wingskin may require multiple projectors projecting from directly above. Some layup environments may have conflicts with cranes which would require the movement of projector support structures to meet facility requirements. In some applications. such as displaying alignments on a partially assembled aircraft. it may be more convenient to bring the laser system to the work than to bring the work to the laser system. Future laser display systems will be able to be set up and configured by one person in a matter of minutes.

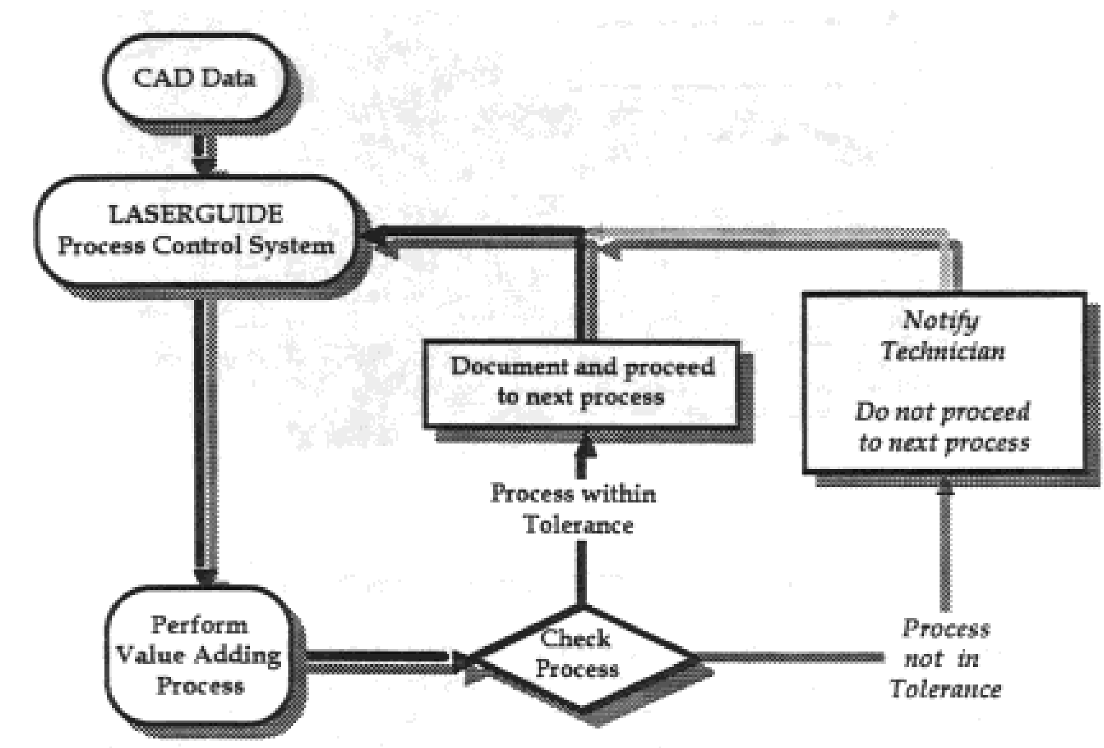

Figure 8: In-process quality monitoring

Another opportunity for added value with laser/computer systems lies in the area of pictorial planning. The laser system is a major component in the manufacturing information system infrastructure on the shop floor. The laser system should show assemblers what they should be doing while it is showing them where they should be doing it. Graphic Work Instructions and Pictorial Planning are currently done electronically and should be supported on the shop floor on the user interface of the laser system. There should be no need for additional monitors, keyboards, barcodes and remote controls at any assembly station with a laser display system.

This integration with GWI/PP is only one aspect of integration which will occur in the future. Future laser systems will have the capability to be integrated in any capacity requiring dimensional display or verification and documentation.

These future capabilities are being implemented in a next-generation system being developed by Assembly Guidance, the U. S. Air Force Manufacturing Technology Directorate, Hexcel Structures and Bell Helicopter Textron. Next generation systems will come on line in the first quarter of 1997.

Laser projection systems have many applications beyond replacing templates for hand laid composites. The true function is to provide accurate dimensional references for manual processes in areas where it is difficult to identify locations. This is a common problem which runs the scale from probing dense printed circuit boards, building wiring harnesses, positioning appliqués on vehicles, aligning structural components in building construction, and lofting for large metal products. The early application of laser guidance to manual activity is in aerospace composites. New applications for this manufacturing technology will evolve as the success in cost savings and quality improvement continues.

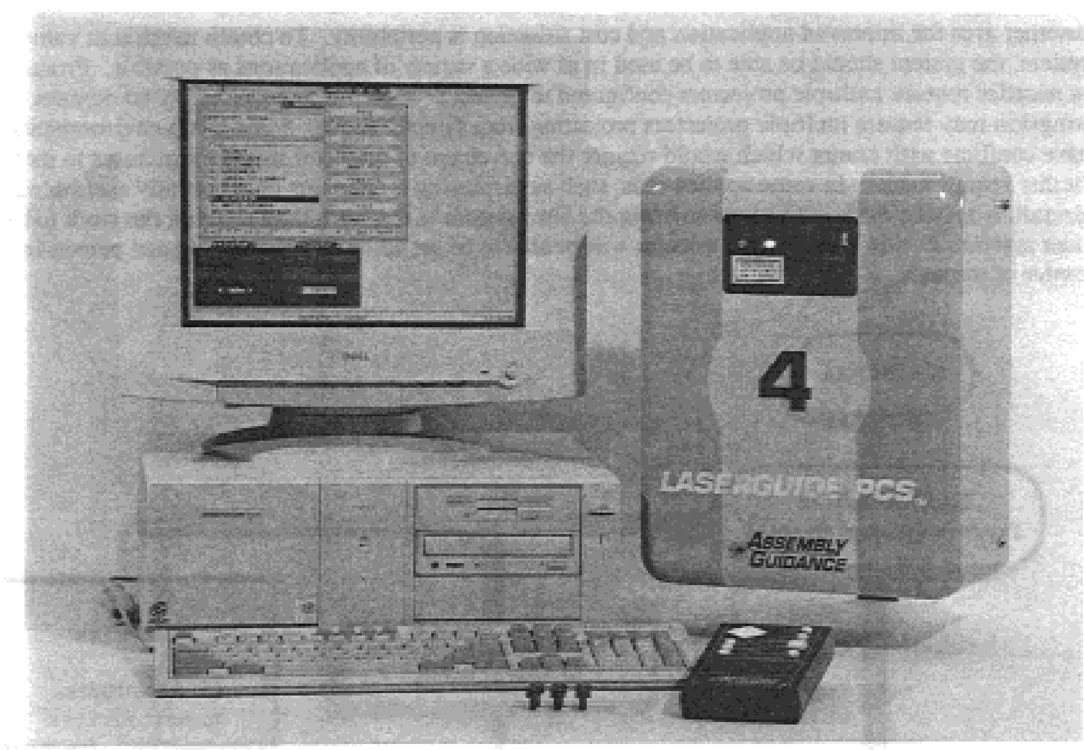

Figure 9: LASERGUIDE Process Control System

Conclusion

The application of laser guidance to hand laid composites has matured to the point where all of the startup or changeover issues are well resolved. A clear cost justification has been established. and manufacturers can see system payback periods of less than one year. Next generation systems will build on this foundation to continue to lower the cost and improve the quality of composite parts.

Acknowledgment

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