SC Aerospace Conference & Expo 2016

ACE'16 TECHNICAL SYMPOSIUM

PROCEEDINGS

Editors:
Ramy Harik
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WEDNESDAY AUGUST 24
Technical Symposium

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Winston Scott, Former NASA Astronaut

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NOVEL THERMOPLASTIC STRUCTURES FOR AEROSPACE

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Abstract

In the past 25 years Fokker Aerostructures invested in the development of a range of thermoplastic structural applications, items of increasing structural significance. Starting with ice protection plates, thermoplastic press-formed ribs and a main landing gear door for the Fokker 50 for example, via resistance welded A340 and A380 wing fixed leading edges (J-Noses) to now induction welded fully thermoplastic elevators and rudders, helicopter stabilizers, and the development of AFP UD tape stiffened skins in the Thermoplastic Affordable Primary Aircraft Structure (TAPAS) program where fiber steering capabilities, high post-buckling strength and increased damage tolerance could offer competitive solutions for a new wide range of more demanding applications.

1 INTRODUCTION

After World War 2, metallic aircraft construction was the way to go. There have been some variations on the subject like metal bonding for thin gauge aluminum structures, metal honeycomb structures, or titanium structures for high speed military aircraft, but 'everything' was predominantly metallic in aircraft structures. Some lessons had to be learned with respect to the downsides of aluminum structures, like fatigue behavior and corrosion resistance, and sometimes these lessons had to be learned the hard way, like the Comet accidents.

In the decades after World War 2, gradually thermoset (epoxy) materials could be considered for items of increasing structural significance. First for secondary applications only, because of the drapeability and relative ease to manufacture compound curvature parts like fairings. Then control surfaces and lots of honeycomb (Nomex) stiffened panels for again control surfaces, cove panels and fairings. Later empennage torsion boxes, wing boxes and even pressurized fuselages. Often lighter structures could be produced using these thermoset (epoxy or BMI) materials, the resin systems improved over the years and ATL and AFP processes helped to automate production more, with the aim to also arrive at a competitive cost level. Again we had to learn to live with some of the downsides of these materials, like impact behavior, moisture ingress, bearing strength, lightning strike protection measures and the poor through-the-thickness strength. There have been quite a few post-buckled thermoset structures but this always required rigorous investigations into the so-called 'stringer pop-off' phenomenon. Fortunately, also through oversight by the airworthiness authorities and the AC20-107A and -107B guidelines, safety levels in commercial aviation could be maintained. We have not always been successful in also achieving competitive recurring cost levels however, the inspection burden during manufacturing is still high, we have not achieved the lbs/hr rates we hoped for in the automated production processes, and it appears these first pressurized fuselage applications do not always make the best of sense in a direct comparison with metallic solutions (metal bonded for smaller fuselage diameters, FML for large fuselage diameters). These developments have led to the formation of so-called 'aluminum mafia' groups within OEM's and tier-1 suppliers, with the aim to make the entire aircraft out of aluminum again. We should learn from this, it should not be our objective in life to make the entire aircraft structure out of aluminum, thermoset or even thermoplastic materials, rather we should strive to find the best material and construction method for every component based on the applicable requirements and desired performance. A combination of technologies will be best in most cases.

2 THERMOPLASTIC STRUCTURES

Thermoplastic materials offer significant improvements for some of the aspects where thermoset materials are not so strong, for example:

- No shelf life or clean room requirement as there is no chemical curing process but a melting and re-consolidation process to create the fiber – thermoplastic resin laminates.
- Ease of manufacturing e.g. press-forming of parts (like sheet metal) based on pre-consolidated sheets with a prescribed laminate stack.
- New assembly methods e.g. resistance welding, induction welding or co-consolidation (the equivalent of co-curing).
- Superior through-the-thickness strength yielding improved impact resistance, excellent resistance against acoustic fatigue (for applications with a high sound pressure level), and excellent post-buckling strength.
- Better environmental knock-down factors and FST (Fire, Smoke and Toxicity) properties.

Of course, also thermoplastic materials (PEI, PPS and PEKK applications will be covered in the presentation) came with some challenges like material cost, high temperature autoclaves and stringent tooling requirements for the welding processes, but the combination of the superior material properties and the innovative assembly methods has led to some interesting applications where the thermoplastic solution could beat the baseline metallic or thermoset solution in terms of weight and recurring cost.

Again, we cannot compromise the current high safety standard in commercial aviation. This means significant investments have to be made to really understand failure modes, long term behavior and damage tolerance aspects. Also in-service experience with applications with a lower structural significance has proved to be essential before more structural applications could be considered. The presentation will focus on the extensive test and (numerical) analysis tasks to certify these structures for aspects like hail strike and bird strike, acoustic fatigue and post-buckling.

Post-buckled designs proved to be essential in order to compete with lightweight thermoset sandwich structures. The disadvantage of these thermoset sandwich structures has always been moisture ingress after impact damage and poor repairability, but the structural efficiency was hard to beat. Allowing post-buckling for monolithic (discretely stiffened) thermoplastic structures comes with some analysis challenges and sometimes discussions with the aerodynamic departments of the OEM, but Fokker has excellent experience now with the thermoplastic leading edges for Airbus, Gulfstream G650 elevators and rudder (buckling at 70% limit load, more than 100,000 flight hours since 2012 with no in-service issues) and the experimental G650 thermoplastic stabilizer TAPAS demonstrator skin (buckling at 120% limit load, no failures up to 240% limit load demonstrating the weight saving potential).

For new applications, the USC / McNair institute and Fokker are working together to help reduce the inspection burden in service, or to detect battle damage, using SHM (Structural Health Monitoring) techniques and also to develop optimization software to deal with the complexity of optimizing AFP structures with unconventional laminates in case of compound curvature structures. Together with the developments in materials (out-of-autoclave thermoplastic materials, or dry fiber deposition / thermoplastic resin infusion) or even hybrid thermoset – thermoplastic combinations there is a lot of potential for more cost-effective solutions in the future.

Category		Failure has no airworthiness consequences, economic impact only	Continued safe flight or landing not compromised, consider size of released elements	Failure could compromise continued safe flight or landing, impacts PSE's.	PSE, failure could result in catastrophic failure of aircraft
2010	Carbon /PEKK				*G650 thermoplastic stabilizer TAPAS demonstrator*
2005	Carbon /PPS		F50 MUC door, A340-500/600 access panels	G650 elevator and rudder parts	
2000	Glass /PPS		A340-500/600 fixed leading edge J-nose	A380-800 J-Nose	
1995	Carbon/PEI	G550 non-pressure floor	G550 rudder trailing edge	G550 rudder ribs, pressure floor	
1990	Glass/PEI	Ice Protection Plates F50, Floor Panels F70/F100			

nonstructural / secondary ⟷ structural / primary

Figure 1: Transition from secondary to primary applications of thermoplastic structures by Fokker.

Figure 2: The Gulfstream G650, a combination of a metal bonded fuselage and vertical fin, thermoset stabilizer and thermoplastic elevators and rudder.

3 REFERENCES

[1] A. Offringa, D. Myers, A. Buitenhuis, "Redesigned A340-500/600 Fixed Wing Leading Edge (J-Nose) in Thermoplastics.", *SAMPE Europe Conference,* Paris, March 2001.

[2] J.W. van Ingen, A. Buitenhuis, "Development of the Gulfstream G650 Induction Welded Thermoplastic Elevators and Rudder.", *SAMPE International Conference & Exhibition,* Seattle, May 2010.

[3] www.tapasproject.nl, TAPAS internet site, site editor Ten Cate company.

[4] A. Blom, "Fiber Placed, Variable Stiffness Composites: The Future of Aerospace Structures?", *JEC Magazine* No. 58, June/July 2010, pp. 38-41.

[5] A. Offringa, J.W. van Ingen, A. Buitenhuis, "Butt-joined, Thermoplastic Stiffness-skin Concept Development.", *SAMPE Journal,* Volume 48, No. 2, March/April 2012, pp. 7 – 15.

Developments on thermoplastic induction welding

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Abstract

Increasingly high performance engineering thermoplastics like PEEK, PEKK, PPS and PEI are combined with continuous carbon fiber reinforcements. The available assembly technologies like mechanical fastening and adhesive bonding are frequently used, but for composites they are not necessarily optimal. KVE Composites (KVE) has developed the KVE Induct technology which is very well suited to assemble thermoplastic composite components. KVE Induct technology lets you control, automate and decrease assembly costs of your continuous carbon fiber reinforced thermoplastic composites.

Keywords

Thermoplastic composites, induction welding

1 INTRODUCTION

1.1 Induction welding process

In induction (radio frequency) welding, heat is being generated by subjecting the material to an electromagnetic field, instead of generating heat by passing an electric current though a welding element (resistance welding). Radio frequency refers to an alternating electric current, which is passed through a conductor (induction coil), which thereby generates an alternating electromagnetic field (e.g. antenna for broadcasting). If a susceptible material is in close proximity of the generated electromagnetic field, this susceptible material will heat up. The susceptible material inside an electromagnetic field can heat up due to three effects, of which two are applicable to induction welding:

- Eddy currents (in conductive materials)
- Hysteresis losses (in magnetic materials)
- (Dipole heating) (in non-conductive materials)

1.2 Induction welding equipment & welding elements

Because of the eddy current heating effect in the carbon fibers, the required electromagnetic field frequency for induction welding can be limited to the LF-MF range (30kHZ – 3 MHz). Attached to the induction generator is an induction coil, through which the alternating current is passed. To prevent overheating of the coil, the coil is manufactured from a material with low electrical resistance (copper) in the form of wound tubing. Through the tubing of the coil water is passed for cooling. The design of the coil determines the shape and strength of the electromagnetic field. By using a clever designed coil the electromagnetic field can be strong where heating is required and less strong in areas not to be heated. KVE has applied Finite Element Analysis (FEA) to evaluate different coil designs. An optimised concept was selected based on a 2D analysis followed by a detailed 3D analysis. Various tests of the designed coil produced were used to further validate and develop the FEA, for final use in designing induction welding tooling. For welding a carbon fiber reinforced assembly, a special welding element is not required. The eddy currents in the carbon fibers generate sufficient heat. When a special welding element is applied, it is also possible to weld glass fiber reinforced thermoplastic laminates. KVE has patented the optimized welding technology and dubbed it KVE Induct.

2 APPLICATIONS OF KVE INDUCT TECHNOLOGY

Fokker Aerostructures applies the KVE Induct technology for the assembly of parts for the Gulfstream 6 and Dassault Falcon 5X. For Fokker Aerostructures, the main advantage of induction welding over resistance welding (as applied in the assembly of the wing leading edges on the Airbus A380) is that it does not require additional material in the form of a metal strip or other conductor, thus there is no weight penalty for the weldment. The assembly jig for the Gulfstream 6 rudder consists of two spars with supporting ribs. All are fabricated from TenCate Cetex PPS via compression molding. A jig is 4 to 6m long and features horizontal slots to hold the spars and vertical slots to position the ribs against the spars. With all parts in place, a robot equipped with a KVE induction coil moves into various slots along the jig, welding each rib to the spars.

Figure 1: Gulfstream G650 rudder welding at Fokker

For the Dassault Falcon 5X elevator, Fokker has three jigs, similar to the Gulfstream jig system but improved in the sense that the six jigs are now replaced by only three, using the same induction technology. On these jigs, day shift labor is used to load composite parts into the jig, and then a robot works overnight to induction weld the resulting assembly, a process that takes about six hours.

The Boeing Phantom Eye is a long endurance unmanned vehicle. The rudder of this aircraft is fabricated with TenCate Cetex PPS laminates and induction welded by KVE. This thermoplastic rudder replaces a thermoset design and achieved weight savings for 25% and cost savings of 5%, see Figure 2.

Figure 2: Welded rudder voor de Boeing Phantom Eye

Aviacomp of Toulouse, France applies the KVE Induct technology in the assembly of fuel tank access panels Bombardier C-series, see Figure 3.


Figure 3: fuel tank access panels produced by Aviacomp

Together with KVE, Aerosud has developed a flight control demonstrator. The structure features several innovations like additive manufactured titanium brackets. Next to the carbon fabric reinforced PPS skins and ribs, compression moulded random fibre reinforced PPS rings are produced to strengthen the rim of the access hole. A single layer of fabric at the interface ensures weldability. The welding is done in three phases. The two compression moulded rings are first welded to the skin, the skins are welded together while forming a trailing edge and finally six ribs are welded to the skins. The ribs have ultrasonic welded brackets to install the spar. The goal of welding the demonstrators is to show the capabilities of manufacturing thermoplastic assemblies with the induction welding process and the ultrasonic welding process, see Figure 4.


Figure 4: Compression moulded access rings (left) and resulting demonstrator (right)

3 R&D ROADMAP

KVE participates in the Thermoplastic Affordable Primary Aircraft Structure innovation program (TAPAS and TAPAS-2). This program exists since 2010, and is a highly successful tool for project-based innovation partnership. The TAPAS consortium consists of companies and knowledge institutes in the Dutch aerospace industry working together with Airbus on the development of thermoplastic composite applications in aircraft fuselages, wings and tail sections. The fruitful partnership between Fokker Aerostructures and Ten Cate Advanced Composites with Airbus and the other partners started in 2010 and, following the new extension, will run until end-2017. The innovation partners within TAPAS from Dutch SME's are Airborne Composites, CODET, DTC, KE-Works, KVE Composite Structures BV and Technobis Fiber Technologies. The Netherlands National Aerospace Laboratory (NLR), Delft University of Technology and the University of Twente are the Dutch knowledge partners in this innovation program. The budget for TAPAS 2 is € 24.3 million, and the Netherlands Ministry of Economic Affairs is supporting the ongoing partnership with a loan of € 9.5 million. Within TAPAS, KVE is developing the induction welding technology for components made of large double curved structures made of high performance unidirectional tape like carbon-PEKK. Furthermore, KVE is investigating the possibilities of welding thick laminates (> 10mm) and welding of compression moulded window frames to fuselage panels. Compression moulding of high end thermoplastic compounds is normally associated with long cycle times. KVE is currently investigating industrialization routes to bring down these cycle times.

Figure 5: Welded frame to fuselage panel (left) and compression moulded window frame welded to fuselage panel (right)

KVE is TIER 2 member of the ThermoPlastic composites Research Center (TPRC), a consortium of industrial and academic members active in the thermoplastic composites industry. Induction welding is one of the research topics for the near future. Together with KVE, TPRC will investigate heat development within the weld line using optical fiber sensors. The final objective of this project is to design, build and validate an inline process control. For this, KVE has supplied TPRC with an KVE Induct induction welding tool which is now fully operational. Identical welding tool are present at the McNair Center at the University of South Carolina and at KVE, see

Figure 6.

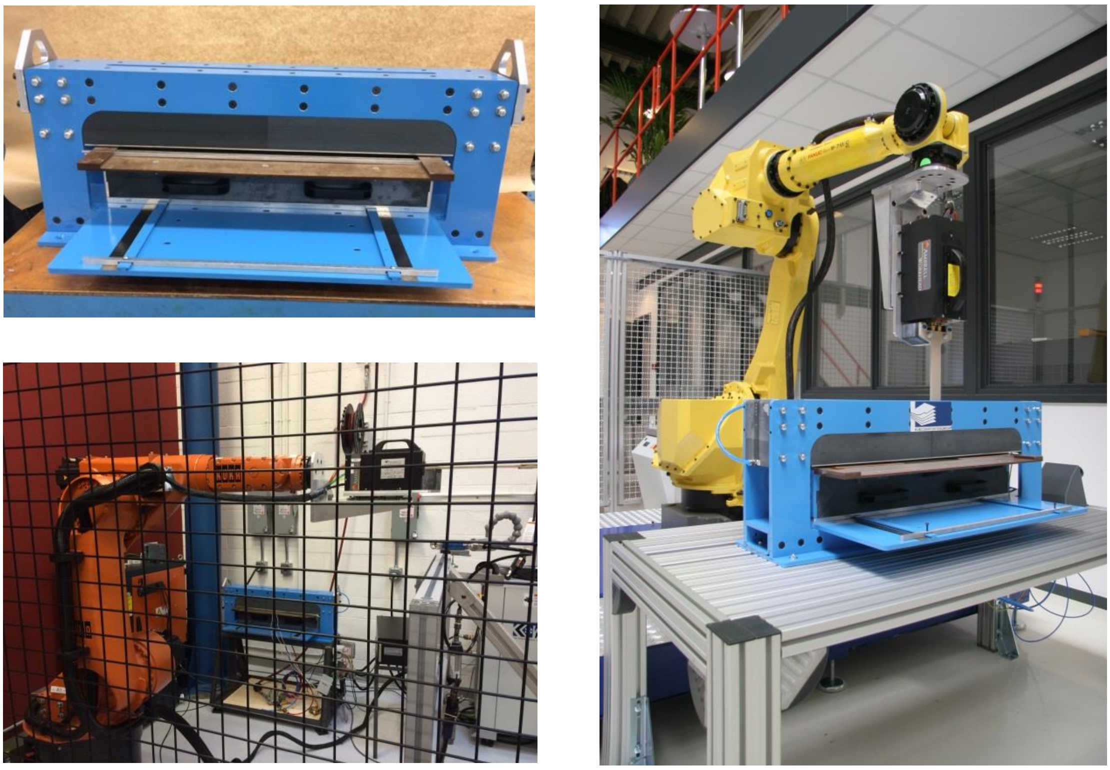

Figure 6: KVE Induct tools at KVE (top left), McNair (bottom left) and TPRC (right)

As a joint effort, a round robin test will be performed using these welding tools to demonstrate the robustness of the KVE Induct welding process. The practical validation will be accompanied by advanced FEA simulations.

Efficient Manufacturing through Process Simulation in the NASA Advanced Composites Project

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Abstract

The Advanced Composites Project (ACP) is a project within the Advanced Aeronautics Vehicle Program within NASA's Aeronautics Research Mission Directorate. The ACP is aligned with the strategic objective of enabling a revolutionary transformation for safe and sustainable US and global aviation through aeronautics research. The ACP is seeking to reduce the timeline for development and certification of state-of-the-art composite materials and structures, which will help make advanced composite components more competitive in the commercial aircraft market. The ACP will accomplish this goal by infusing leading-edge, physics-based tools to improve composite structures characterization and simulations, develop standardized procedures, and optimize fabrication processes. It is predicted that this will enable the reduction of the current ten-year development and certification timeline for aircraft structures by 30%. The ACP will also utilize system-level testing and evaluation to investigate promising concepts and technologies for air vehicle structures and demonstrate the benefits of those technologies in a relevant environment. The goals of the ACP will be accomplished by focusing on specific technology challenges that involve key components of the aircraft development and certification lifecycle. The ACP technical challenges are: 1. Predictive Capabilities for Progressive Damage Analysis, 2. Rapid Non-Destructive Inspection, and 3. Manufacturing Process and Simulation. Specifically, in technical challenge 3, NASA has partnered with the aerospace industry and academia to develop several physics-based process models. In contrast to aluminum alloy part fabrication, composite fabrication involves reactive processing, during which both the part and the material are fabricated at the same time. During the last decade, there have been numerous advances in modeling and simulation of reactive processing. This fact and the enormous advances in computing capability have made Computer Aided Engineering (CAE) for composites manufacturing a reality. Therefore, composite structure manufacturing technology based solely on past experience must give way to new approaches guided by modeling and simulation of the complex reactive processing phenomena. This should allow for the prediction of defects which commonly occur in the fabrication and cure of composite materials. The predictive capabilities of these models under development in the ACP are intended to reduce the degree of trial-and-error currently utilized for process parameter determination during new part development. Utilization of the developed tools is expected to reduce the timeline to develop a stable process for production certification, and reduce part scrap rates and manufacturing rework due to defects. These models will be developed to help reduce tape-buckling defects for composite structure manufactured by automated fiber placement, predict the occurrence of bond-line porosity and fillet geometry during co-cure of sandwich composite structure, and simulate complex laminate cure processes. The goal of the last effort is to predict the processing cycles that reduce porosity and fiber-waviness defects. The status of these ongoing development efforts will be presented.

COST REDUCING PROCESSES & MATERIALS IN AEROSPACE SANDWICH STRUCTURES

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Abstract

Aerospace structures have come a long way since the early 1900s as materials evolve with technology. In more modern construction, honeycombs in various materials (e.g. aramid paper, aluminum) are used in sandwich panel formats to increase stiffness and decrease weight over previous conventional methods like steel and wood. Diab started in the 1950s to bring foam core solutions to the marine industry – replacing rotting plywood with closed-cell foams. As the notion of composite sandwich structures spread, foam cores were being used in every industry needing a lighter, stronger solution, including wind energy and aerospace. The use of foam cores not only improves strength to weight ratio of the application, it also offers cost and time saving benefits.

Keywords

Composite Manufacturing, Aerospace Structures, Materials, Plastics, Thermoplastics, Sandwich Structures

1 INTRODUCTION

One of the largest factors leading to a relatively heavy honeycomb panel is due to the potting compound used to close out the edges and secure inserts. Due to its open cell structure, honeycomb needs to be edge filled to reduce moisture intake. Moisture can build up within the cell walls of the honeycomb and degrade its integrity, eventually leading to delaminations. The putty typically used for edge fill and potting inserts average 35 lb/ft3 in density, seven (7) times that of the core material.

2 MAIN IDEA

By utilizing foam core materials in place of honeycombs, manufacturers can reduce panel weight by up to 20%. Furthermore, the improved skin aesthetics provided by a continuous surface in foams eliminate the need for sweep and sand secondary operations. These savings in time and materials can yield up to 50% in cost savings.

The use of foam cores also lends to better damage tolerance of the panel itself, along with better thermal and acoustic insulating properties, aesthetics, transparency, and higher reliability.

3 CONCLUSION

There are several foam core manufacturers with FST-compliant products in the aerospace industry. Depending on the application and processing parameters, the use of foam will save cost while providing many other benefits.

A ROBUST UD DRY TAPE PRODUCT FOR AUTOMATED MANUFACTURING OF COMPOSITES

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Abstract

This paper presents a novel PRISM TX1100® dry tape product developed by Solvay that has been optimized for Automated Dry Fiber Placement (AFP). The incorporation of a novel binder system and proprietary veil technology provides enhancements in steerability and permeability performance beyond standard high performance composite technologies. The challenges faced in developing such a material and methods used for optimization are discussed. Laydown performance of the TX1100 tape is demonstrated showing prepreg-like machine efficiency and improved mechanical performance over existing non-crimped fabrics (NCFs). Permeability assessment of the tape is also assessed proving the tapes suitability to large primary aerospace structure manufacturing.

Keywords

Composite Manufacturing, Aerospace Structures, Materials, Automation, AFP, UD Dry Tape

1 INTRODUCTION

Commercial aerospace manufacturers are increasingly turning to resin infusion processing to manufacture large, complex, and integrated composite structures. To meet production rates required by market demand, these manufacturers require automated process methods such as Automated Fiber Placement (AFP) to create the preforms required. Existing dry tape products are not optimized for automated placement which leads to quality and processing issues and decrease productivity which in turn increases manufacturing costs.

Resin infusion processing offers aerospace manufacturers weight and cost savings by allowing out-of-autoclave production of complex, integrated composite structures. Preforms used in resin infusion are often made from standard textiles using labour and time-intensive layup techniques. As aircraft build rates continue to increase, manufacturers are looking to automated methods for creating consistent, high-quality preforms.

Cytec Solvay's PRISM TX1100® is a novel and robust UD dry tape product designed for Automated Fiber Placement for resin infusion processing. The UD dry tape allows the production of resin infusion preforms suitable for high-performance aerospace applications. Proprietary technology improves permeability for resin infusion and mechanical durability of the dry tape resulting in composite performance equivalent to autoclave-cured prepregs. Unique binder technology enhances tape processability ensuring consistent, high-quality preform production with minimal machine interruptions – see Figure 1.

Figure 1. PRISM TX1100® Dry Tape Material Configuration

2 MATERIAL PERFORMANCE

In order to achieve the build rates needed for the next generation of aircrafts, a fast and robust system for layup of material is needed. Table 1 shows the key features which this material provides. TX1100® offers the ability of being deposited thorough AFP which brings reduced manual touch labor, increased inspection, preform compaction during laydown, high performance due to elimination of crimp and threads, and high level of permeability.

Table 1. Key features for UD Dry Tape for Automated Fiber Placement

Key Features
Low Fuzz
Excellent Steer-ability
Low Bulk
Width Control – prepreg tolerances
Permeability enhancement compared to conventional dry tape
Mechanical performance improvement over NCFs
Achievable Vf range 55 – 60%
No distortion caused to tapes when tension is applied
Tailorable FAW and width

Figure 2 shows the manufacturing process for a structure made with UD dry tape. For manufacturing the preform, in general, two routes can be taken: 1) direct deposition of the material on the final shape of the preform, or 2) layup of the material in flat charges that are later hot formed. In the both cases, the material has to be able to conform to the desired shape and be stabilized until the final preform is assembled. In the case of the material discussed herein, the design and configuration has been specifically optimized for hot forming and low bulk so that preform assemblies are near net-shape. After preform assembly, the complete preform assembly is infused or injected with resin and then cured over the prescribed time / temperature. For the infusion / injection step, having the ability of manufacture large components is also built into the design of the material with enhanced and tailorable permeability. The TX1100 dry tape has been developed to be fully compatible with Solvay's one part toughened epoxy RTM resin, PRISM EP2400.

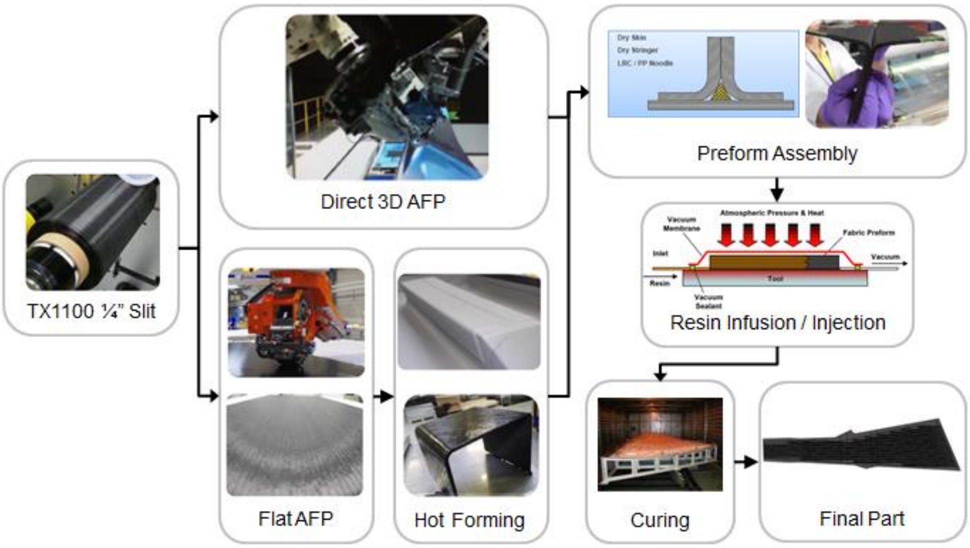

Figure 2. Composite Manufacturing Process using PRISM TX1100® Dry Tape

Mechanical performance of the UD Dry tape as compared to the NCF is shown in Figure 3. From the test results it can be seen that the performance of the material is higher on properties such as open hole tension, unnotched tension, compression, interlaminar shear strength, and bearing strength. Open hole compression and 0° compression is equivalent. This shows that by using a UD dry tape, an increase in mechanical performance is gained without having the scrap rates normally seen with NCFs. On the other hand, test results from UD fiber steering trials performed with TX1100® are shown in Figure 3. These trials show a robust steering-ability useful in the manufacturing of curved components for optimized design.

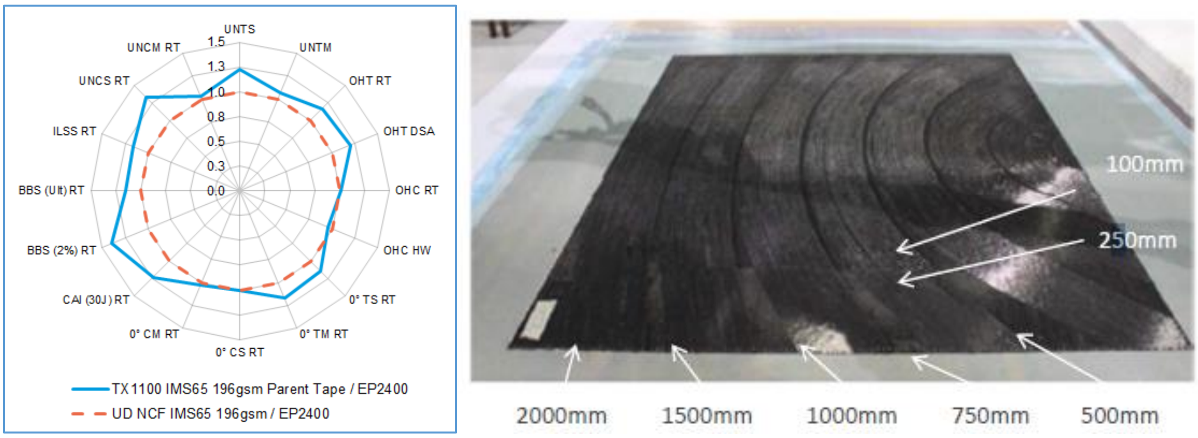

Figure 3. Left: Mechanical Performance Comparison of PRISM TX1100 with Non-Crimp Fabric – Both Configurations use EP2400. Right: Steering tests for TX1100®

3 CONCLUSIONS

PRISM TX1100® dry tape provides a novel and robust solution for manufacturing preforms through Automated Fiber Placement. Main features include higher mechanical performance as compared to NCFs, improved in-plane permeability, inherent tow width stability, steering capability, low fuzz, and low bulk, amongst other. The use of this material allows for a repeatable and robust manufacturing of large, complex, and integrated composite structures.

Automation in the Aerospace Industry

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Abstract

Aerospace manufacturing is a complex production system with millions of parts, thousands of suppliers, and more than 150 countries. Automation plays a major role not only in manufacturing, but in the design and post production phases as well.

- In Model-Based System Engineering (MBSE) is where the full spectrum of requirements are analyzed and incorporated.
- In the generation of 3D Model Based Definition (MBD) of parts and assemblies
- In the manufacturing and inspection of parts, wiring, and structures (solid and composite)
- In the assembly of systems, subsystems, and structures into the final product

As manufacturers apply automation throughout the life cycle of the platform, the ability to monitor and adjust processes to maximize efficiency is critical to the bottom line. Data Analytics is playing an ever increasing role in manufacturing automation.

The Boeing Company has many commercial and military platforms in design and production that rely heavily on automation within the life cycle. Each platform provides its own set of automation challenges to increase the efficiency of development and production. This presentation provides some insight into how Boeing is leveraging automation and the critical role it will play in the company's future.

Keywords

Composite Manufacturing, Aerospace Structures, Materials, Data Analytics, Digital Factory, Model-Based Design (MBD), Simulation, Automation

1 INTRODUCTION

Since July 15, 1916, The Boeing Company's been making the impossible, possible. From producing a single canvas-and-wood airplane to transforming how we fly over oceans and into the stars, The Boeing Company has become the world's largest aerospace company.

Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems. As America's biggest manufacturing exporter, the company supports airlines and U.S. and allied government customers in more than 150 countries. Boeing products and tailored services include commercial and military aircraft, satellites, weapons, electronic and defense systems, launch systems, advanced information and communication systems, and performance-based logistics and training.

Boeing has a long tradition of aerospace leadership and innovation. The company continues to expand its product line and services to meet emerging customer needs. Its broad range of capabilities includes creating new, more efficient members of its commercial airplane family; designing, building and integrating military platforms and defense systems; and creating advanced technology solutions.

Automation has increased within Boeing over the decades in both quantity and capability. NC machines started to be heavily used in the 80's. In this time frame, some large scale assembly automation came in for wings and fuselage work. In the late 90's aerospace started looking for opportunities to use smaller "right sized" equipment, including robots. F/A-18E/F leading edge flap was first to use automotive robot for aerospace drilling in an NC-type operation. Today, Drill & Fasten is by far the largest application of automation in aerospace. Boeing has been a leader in advancing aerospace automation through supported R&D, internal research, supplier partnerships, and participation in various manufacturing consortia.

2 WHY AUTOMATION IS IMPORT TO AEROSPACE COMPANIES

The aerospace industry is continually striving to product higher quality products at lower cost, both in terms of the cost of designing our products (non-recurring costs) and producing them (recurring costs). One factor that permits effectively applying automation on a platform is designing for automation from the system-level design (both architecture and requirements) through the 3D modeling that supports automation in the manufacturing. The Boeing Company is working on several internally funded projects to increase the use of design for manufacturing approaches.

MBSE defines the architectures and allocates requirements to the different components (systems, structures, electrical, hydraulics, and so on). The role of MBSE continues to grow in the development of complex systems and increases the quality of the design, partly because it identifies and accounts for the complex interactions with internal and external systems on the platform. For example, a complex component on a fixed winged program modeled about half of the complex functions and behaviors and documented the other, less complex functions using previously established methods. Later in the development process, the number of problem reports associated with the non-model-based method was an order of magnitude greater than what was reported on the Model-Based portion.

MBSE defining and designing a system with automation as a critical trade parameter will (in most cases) drive the cost of manufacturing down. The same holds true in the development of the structure and parts in the digital product definition. For example, development of the wing structure needs to account for the manufacturing of the parts and assembly of the wing to reduce the total cost of the platform. If the optimized wing design is extremely complex to manufacture and assemble on the factory floor, it will drive up the cost of manufacturing the platform. The digital product definition should contain all the information required for the automation (machining, robotics, and so on) as well as the information required by the mechanic on the factory floor.

One of the challenges facing large, complex platform manufacturing is getting the digital product definitions to the factory floor and fully utilizing modern manufacturing hardware. While there are many reasons for this, two of them are recurring themes:

- Level of investments in the digital thread for manufacturing operations, including machine tool control, data handling of production information, or advanced digital model processing to take full advantage of what the manufacturing hardware can do, and many opportunities for automation are overlooked in the process.
- Need to fully leverage statistical process control (SPC) and rigorous specification of assembly tolerances to drive variability of our processes, frequently leading to excessive rework and scrap.

Figure 1: Technology investments focus on replacing hazardous processes to ensure workforce safety

3 AREAS OF TECHNOLOGY RESEARCH AND DEVELOPMENT

Automation is a critical enabler in efficient manufacturing, test, verification, and validation. Some areas of technology research and development include:

1. Advanced non-contact measurement-system technology to enable automated inspection or part processing to aerospace tolerances.
2. Scanning technology for part and system verification. Solutions will move away from post-process inspection and toward in-process inspection and verification of process capability.
3. Automated Non-Destructive Evaluation (NDE) data analysis to reduce or eliminate inspection.
4. Robotic precession painting on large body platforms. Paint solutions must achieve first pass quality and growing expectations of our customers.
5. Continue automation in large-scale additive manufacturing parts and structures.
6. Automation that integrates with human processes to achieve a lean process flow.
7. Increase automatic fiber-placement laydown rates, efficiency, and reliability, and reduce cost.
8. Forming of complex shapes, including high contour hat stringers, blade stringers and fuselage sections. Reduce or eliminate manual labor and increase quality.
9. Automation that supports composite trimming (AGFM, robotic trimming) and drilling of complex composite parts (stringers, small parts).
10. Optimized flow of material and reduction of production line bottlenecks.
11. Innovative solutions that integrate product movement, metrology, and alignment of large joins for assembly.
12. Directly using the MBD data and inspection data to drive the automation at run time. (e.g. automated task sequencing, automated path planning, automatic recovery and re-planning from errors and defects)

Advanced manufacturing facilities generate massive amounts of data at many different points. The challenge is converting that data into useful or actionable information. The role of Data Analytics is expanding in manufacturing of large complex platforms. Integration of Data Analytics enables the assessment in manufacturing line and provides immediate indicators (process complete, duration times, failures, etc.) as well as predictive analytics (assessing historical data of processes or machines under known conditions to predict behavior or expected efficiencies). Data resides in many separate systems and formats. These sources are often independent and unrelated to other data feeds, requiring aggregation at a higher level. Applying Data Analytics techniques to the digital factories will automatically harmonize date into integrated information. This will enable the development of the smart factory, where the right information is available to the right people right away to make the right decisions by representing it in the users' perspective, increasing situational awareness. Encompasses both the factory production equipment information, as well as inventory and material information through technologies like RFID.

4 CONCLUSION

The automotive industry has been working in the model-based environment for years. The aerospace industry is just catching up. There are many differences in the industries, such as time to market, yearly model updates, and production rates. One of the biggest differences is the complexity of the products; aerospace is many orders of magnitude more complex, requiring unique manufacturing approaches. For example, many machines in the automotive industry are single-purpose machines that generate a single part at a high rate, whereas many aerospace-manufacturing machines are multirole machines that manufacture many different parts depending on the need. Automation is a critical component of future expansion in aerospace manufacturing.

Pyndl: Increasing Classical KBE's Reach with a Python-Gendl Bridge

at the ACE'16 Technical Symposium

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Abstract

Within the AGILE project, granted by the European Commission and consisting of 19 partners, KBE systems are used to speed up the time required to solve realistic MDO problems in the field of aircraft design.

CL-based KBE, and Genworks GDL in particular, continue to provide a stable, low-risk platform for capturing corporate knowledge assets. However, the Common Lisp language, and its de facto standard development environment based around the Gnu Emacs editor, present perceived obstacles for new potential developers who are trained in more widely used technologies, such as Python and Java and IDEs such as Eclipse. This perception, combined with the reality of entrenched existing IT infrastructure based on these platforms, has made it difficult for CL-based KBE platforms to gain widespread usage beyond the traditional high-end specialized niches.

A possible way to end this logjam is to make available a convenient, lightweight runtime "bridge," to enable access to the full power of CL-based KBE system from within a more mainstream environment such as Python or Java. To this end, this paper will present an experimental system, currently named "Pyndl," which bridges Genworks GDL and Gendl with the Python environment, as a first proof-of-concept of the idea.

Keywords

Knowledge-based Engineering, Distributed Gendl, GDL, KBE, Common Lisp, meta-programming, Python.

1. INTRODUCTION

The vision of this project is to enable the use of a true KBE system dovetailed with convenient runtime interfacing to currently popular language environments.

1.1. Background

The Gendl Project, and its commercial branch, Genworks GDL, implement a KBE engine and geometric primitives library in the tradition of classical Lisp-based KBE systems. Gendl (and its commercial branch, Genworks GDL) are implemented in ANSI Common Lisp. Genworks GDL is used for mission-critical engineering applications in major aerospace, automotive, and civil engineering organizations worldwide, and forms part of a long lineage of CL-based KBE tools going back to 1984 or earlier. There are many natural subjective and objective advantages to using Lisp, especially ANSI Common Lisp, for a KBE implementation. Subjective advantages include:

- Natural environment for meta-programming. Lisp is a natural programmable programming language, with implicit support for embedded domain-specific languages and customized higher-level language constructs.

- Mature commercial and free implementations. Common Lisp currently counts at least nine actively maintained implementations, ensuring choice and insuring investment of knowledge assets into the future.
- Stable, unencumbered open standard. The ANSI Common Lisp standard has remained unchanged since 1995, and provides a reliable, predictable foundation for compliant implementations. Unlike languages which are defined by a single implementation, whimsical changes in compiler or runtime behavior do not present significant risk to very long-term viability and accessibility of knowledge assets.
- Vibrant open-source library ecosystem. For the past five years, Common Lisp has seen a blossoming of some 1500 high-quality open-source libraries, managed with the Quicklisp system which can automatically find, fetch, compile, and load validated source code libraries, and their dependencies, from a curated repository on the Internet. Most of the perceived "gaps" in the ANSI standard (e.g. threads, sockets, interoperability) have been filled with defacto standard libraries from Quicklisp.
- Long history, high likelihood of future availability and stability. Lisp has been around in some form since 1959, and it is very likely that Common Lisp programs which work on today's implementations will continue to work on future computing platforms many decades from now.

The following objective advantages have been borrowed from Peter Norvig's recent interview on Quora [1].

- Garbage Collection.
- Rich set of collection types and operations on them.
- Powerful object system with multiple inheritance and generic functions.
- Powerful exception handling mechanism.
- Sublanguage for defining test cases (ok, not an official part of the language, but [straightforward to set up or load from a third-party library]).
- An interactive read-eval-print loop.
- An agile, incremental development style rather than an all-at-once style.
- Introspection into run-time objects and functions.
- A macro system that lets you define domain specific languages.

Although Norvig cites these advantages as ones which have crept into other languages over the years, CL remains the only actively maintained language which provides strong support for all these features as a critical mass - especially the Macro system. Lisp also carries the baggage of several perceived disadvantages. Although virtually all of these are perceived, rather than real, they nevertheless act as obstacles to more mainstream adoption of Lisp-based KBE systems and deployments:

- Lack of developer talent. *In fact, there exists a surplus of talented and passionate Lisp and Common Lisp developers in a vibrant global online community.*
- Lack of support. *In fact, commercial and free, open-source implementations receive ongoing expert support on many levels.*
- Complexity, difficult learning curve. *In fact, Common Lisp is a well-contained, extremely well documented environment which is surprisingly fast and intuitive to learn, if one is willing to cast aside preconceived notions.*

- Cost. *In fact, cost of solutions run the gamut from completely free to competitively priced commercial products with expert personalized technical support. Compared to the cost of developer time or salaries and the cost of failed projects, these implementations are bargains at every level.*
- Slow performance. *In fact, Common Lisp compilers contain decades of compiler optimizations and runtime efficiencies. CL is a language both for writing programs fast, and for writing fast programs.*

2. OVERVIEW OF CLASSICAL KBE

A classical language-based KBE system contains certain core features, including:

- **Functional Coding Style:** programs return values, rather than modifying things in memory or in the model.
- **Declarative Coding Style:** there is no “begin” or “end” to a KBE model - only a description of the items to be modeled.
- **Parent/Child instance relationships:** Items (i.e. “objects”) may be conveniently defined in a hierarchical tree-like structure. As with the List, the Tree is a fundamental data structure which can represent physical assembly structures as well as many other conceptual structures.
- **Multiple Inheritance:** Full multiple inheritance allows an object definition to inherit characteristics from one or more other definitions, allowing for the most flexibility in re-using code and reducing redundant definitions.
- **Runtime Value Caching and Dependency Tracking:** the system computes and memorizes those things which are required – and only those things which are required (no more, no less).
- **Dynamic Data Types:** Slot values and object types do not have to be specified ahead of time. They are inferred automatically at runtime from the instantiated data. Their datatypes can also change at runtime. In fact, the entire structure and topology of a model tree can change, depending on the inputs.
- **Automatic Memory Management:** When an object or piece of data is no longer accessible to the system, the runtime environment automatically reclaims its memory.

Note that some of these features, such as Dynamic data Typing and Automatic Memory Management, are inherent features in many programming languages, including Common Lisp and Python. However, the combination of all of the above features forms a critical mass which constitutes a KBE kernel.
For detailed descriptions with examples of these features in action, see [2]. For a broader overview of classical KBE, see [6].

3. DISTRIBUTED KBE

3.1. Distributed Gendl

In a declarative KBE system, the concept of instantiating a child object, and sending messages to it, is roughly analogous to the concept of a procedure call, or function call, in a procedural language. So in order to implement something like a “remote procedure call” in a KBE system, we take the approach of having the child object “live” on the remote host, and support the ability to send messages to it. “sending a message” in a KBE system essentially means to send a request for a certain piece of information. The

message-passing style in Gendl and GDL has its origins in the Smalltalk language, an object-oriented language with message-passing as a core concept.
For many years, Gendl has had the ability to connect to remote Gendl instances in order to instantiate child objects. Consider the Gendl object definitions in Figure 1.

```
(define-object box-parent ()
  :input-slots ((length 10) (width 20) (height 30))

  :objects ((kid-box :type 'remote-object
                     :remote-type 'mybox
                     :host "localhost" :port 9000
                     :length (the length)
                     :width (the width)
                     :height (the height))))

(define-object mybox (box)
  :computed-slots
  ((linear-size (+ (the length) (the width) (the height)))))
```

Figure 1: Definition of Parent with Remote Child

```
GDL-USER> (make-self 'box-parent)
#<BOX-PARENT #x30200492247D>
GDL-USER> (the kid-box)
#<GENDL::STANDARD-SEQUENCE #x30200495B47D>
GDL-USER> (the (kid-box 0))
#<remote GDL object of type MYBOX>, a.k.a. #<REMOTE-OBJECT #x30200495753D>
GDL-USER> (the (kid-box 0) linear-size)
60
```

For a detailed overview of the Gendl/GDL language and more explanation of the above syntax, please refer to [3].
Regarding the remote child, note the following from Figure 1:

- A reference to `kid-box` will spawn a proxy object on the local host which connects to the “real” child object, which listens on its own host and port.
- For most messages, this `kid-box` instance should respond as if it were of type `mybox`
- Data is serialized using standard Lisp “S-expressions”.
- The `box-parent` and `mybox` definitions must both be present (i.e. compiled & loaded) into the parent instance; on the child (i.e. “server”) instance, only the `mybox` definition has to be present.

3.2. Pyndl

For runtime purposes, we want to allow one KBE instance to connect to others a natural and neutral way. As a first working prototype, we are developing a Gendl parent (client), Python-based server (child). The generic interface/protocol for the distributed version of Gendl opens up the possibility for other servers to play their role in the distributed KBE system.
In this prototype, a Python server which implements the necessary interface will act in the same way as another Gendl instance does, and thus be interchangeable with any Gendl instance. This of course requires the implementation of all the required knowledge on the Python server instance.

4. CURRENT STATUS

The current implementation allows a single-level Python object definition to be used as a remote child object for a Gendl instance. The Python object will answer one or more “messages”, which correspond to well-defined Python functions. The Python functions should be true functions in the Functional Programming sense; that is, they simply perform some computation and return a value, without incurring side-effects.
A simple example was set up for demonstration purposes composed of a Gendl server (master) and a Python server (slave). Figure 2 shows the sequence diagram for the example.
In this example the Gendl server is the client which serves as the user interface to an aircraft model. Therefore it holds the root component which is build up from two components, a fuselage and a wing. One of the components is implemented as a remote object which resides on the Python server and is accessed from the Gendl client.
Figure 3 shows the setup of the test system and shows the distribution of the instances on the two servers. When exploring the root aircraft component, messages are sent between the two server instances to exchange information about the components. In order to illustrate the implemented protocol a detailed description of the process is given by explaining all the actions step by step.

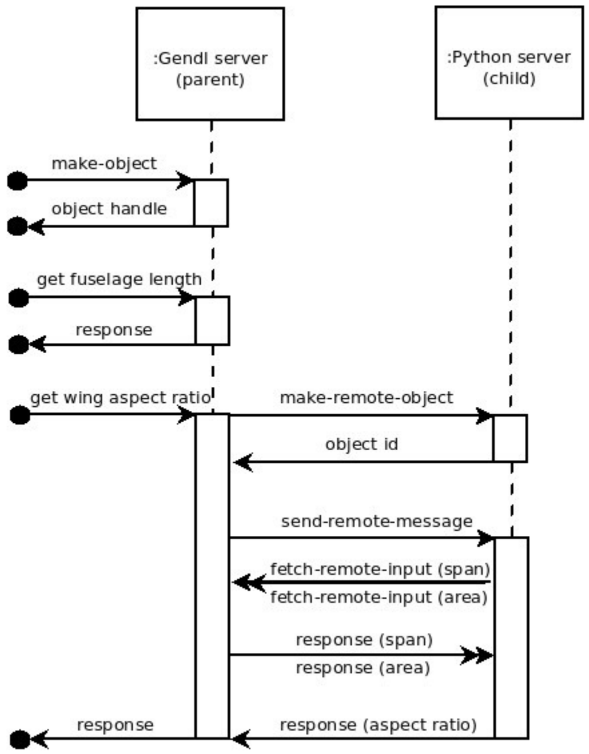

Figure 2: Sequence diagram of example process.

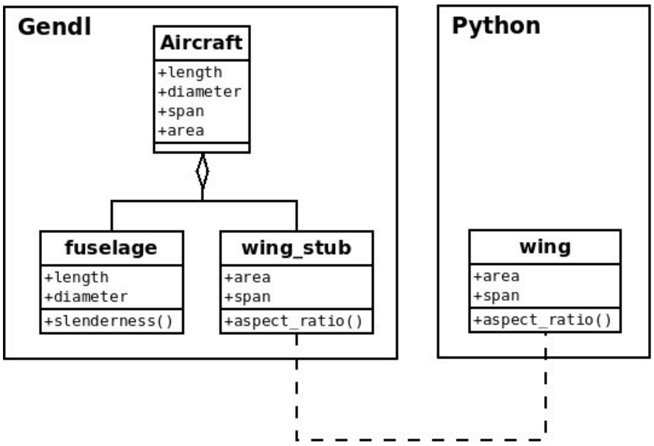

Figure 3: Distributed objects example.

1. The user starts the design with the **creation of the aircraft instance** on the Gendl server using the `make-object` command which will trigger the creation of the aircraft object defined in Figure 4. One might expect that this should trigger the creation of all the sub-components, but due to the lazy evaluation, objects are only created at the moment they are actually queried. Thus during this step no messages are send through the network.
2. When the user **queries the fuselage** for its `length`, the fuselage object is instantiated. Since in the fuselage `diameter` and `length` are linked to the aircraft input slots, the default values used are the ones from the aircraft input slots. Therefore the fuselage `length` received by the user is `10m`.
3. **Querying the wing** for its `aspect_ratio` is more interesting when observing the network messages send. Analog to the fuselage, the wing is not yet instantiated, and since it is a remote object, the `make-remote-object` message is send to the Python server (see Figure 5).
4. After the successful creation of the wing object, the object ID is returned to the Gendl server. There the ID is saved to point to the remote wing for subsequent references. And since the initial request for the wings `aspect_ratio` is still pending, a `send-remote-message` message is send to the python server containing the id of the created wing object (see Figure 6).
5. Since the `aspect_ratio` is computed from two input-slots (`area` and `span`) they need to be retrieved from the Gendl aircraft object. Therefore two separate `fetch-remote-input` messages are sent to the Gendl server, which will return the respective values (see Figure 7).
6. Once the python server has received the input values, the `aspect_ratio` is computed and the answer is returned to the Gendl server.

```
(define-object aircraft ()
  :input-slots ((length 10)
                (diameter 1.5)
                (span 20)
                (area 45))

  :objects ((fuselage :type 'fuselage
                      :length (the length)
                      :diameter (the diameter))
            (wing :type 'remote-object
                  :remote-type 'wing
                  :host "localhost" port 9000
                  :span (the span)
                  :area (the area))))

(define-object fuselage ()
  :input-slots ((length 15) (diameter 2))

  :computed-slots ((slenderness (/ (the length) (the diameter)))))

;; stub for the wing class implemented on the Python side
(define-object wing ()
  :input-slots (span area)

  :computed-slots ((aspect_ratio)))
```

Figure 4: Aircraft object definition.


```
{":package": "pyobjects",
 ":current-id": null,
 ":type": "wing",
 ":host": "localhost",
 ":parent-form": {":index": null,
                  ":id": "c9467026-3b37-463a-8816-7bf4e3fbe81",
                  ":host": "localhost",
                  ":port": 9025}}
```


Figure 5: Wings `make-remote-object` message, serialized with standard JSON.


```
{":args": null,
 ":remote-id": "77925f81-4281-42bb-8b62-d948ccb9c10a",
 ":message": "aspect_ratio"}
```


Figure 6: Requesting the aspect ratio through the `send-remote-message` message, serialized with standard JSON.

```
{":index": null,
 ":id": "c9467026-3b37-463a-8816-7bf4e3fbe81a",
 ":part-name": "",
 ":port": 9050,
 ":message": "span"}

{":index": null,
 ":id": "c9467026-3b37-463a-8816-7bf4e3fbe81a",
 ":part-name": "",
 ":port": 9050,
 ":message": "area"}
```


Figure 7: `fetch-remote-input` messages required for computing `aspect_ratio`, serialized with standard JSON.

4.1. Example: Python Definition of Child Object

The Python KBE server was implemented using the `BaseHTTPServer` module from Pythons standard library [4]. It includes two base classes for the implementation of a simple HTTP server. Currently the Pyndl interface uses the GET-method for sending and receiving messages. It implements the three main interface functions `make-remote-object`, `send-remote-message` and `fetch-remote-input` as defined by the distributed Gendl system (see 4.3). As the host for all local objects, the server stores all the objects instantiated and accesses them to answer received queries.

In addition to the server implementation the class definition for all the supported object types need to be present on the server. A KBE object as defined in Gendl consists of input slots and computed slots (neglecting nested components for now). Input slots are references to input values of the parent object. The input slots can be used in computed slots for the implementation of knowledge.
All input slots used in a computed slot need to be fetched at runtime from the parent object. Thus the python functions needs to send the `fetch-remote-input` message to the parent for each input. Once all the inputs are collected, the slot value is computed and the result is transferred back to the parent object.

Since this behavior needs to be implemented by all the KBE objects which should be integrated in the distributed KBE environment, the `BaseObject` class is defined which implements the required behavior and is used as the base class for all the KBE objects on the Python server. This `BaseObject` holds the parent form describing the connection to the remote parent object and the names of all input slots. Keeping a separate list of the input slots is necessary in order to send the `fetch-remote-input` message to the parent object when the value is needed. In order to retrieve the value of a slot, input or computed slot, the `get_value` method is implemented in the `BaseObject` class which, in case of a remote input slot, sends the `fetch-remote-input` message automatically. This simplifies the user interface for fetching slot values to a single function.

The implementation of a wing class using the `BaseObject` class as the base class is shown in Figure 8.

```
class wing(BaseObject):
    def __init__(self):
        BaseObject.__init__(self)
        self._input_slots = ['span', 'area']

    @property
    def aspect_ratio(self):
        span = self.get_value('span')
        area = self.get_value('area')
        return span**2 / area
```

Figure 8: Wing class definition, python-side.

4.2. Under-the-Hood Function Definitions

This section gives an overview of the low-level functions required in order to implement Distributed KBE in general, and Pyndl specifically. This section is not necessary to understand in order to use the system, but may be interesting for those considering helping to extend the Distributed KBE functionality to other language environments.

- `make-remote-object`: Runs in Server (i.e. child). Instantiates the object of the specified type, with the parent object being defined on the caller (the client). Returns a unique object identifier for the instantiated object.
- `send-remote-message`: Runs in Server (i.e. child). Computes the requested message on the specified object (which was created with make-remote-object as described above). Returns the computed value, or a special form indicating an error condition.
- `fetch-remote-input`: Runs in Client (i.e. parent). Computes the requested input value for the remote child object in the Server (parent). Returns the fetched input value.

5. NEXT STEPS

With the presented Pyndl interface the first step was taken towards a smooth and natural runtime bridge between Gendl and Python.
Enabling the development of KBE knowledge in Python opens the world of KBE systems to a wider audience.
Within the AGILE project, where methods for the development of collaborative, multi-disciplinary and multi-fidelity aircraft design processes are developed, the implementation of the Pyndl interface is one of the approaches investigated.
Connecting existing functionalities implemented in Python to a sophisticated KBE language could open up new possibilities for the implementation of highly automated collaborative design processes.
For example, easy use from Gendl of CPACS-related functions implemented in Python, such as provided by the cpacsPy library [5], could be promising.

Further investigation is necessary in order to determine the level of effort needed for wrapping and connecting to existing code, and to determine how many of the benefits of a KBE system can be kept if the connected code is not following all the guidelines/ features of a KBE system as defined by [2].

A logical next step in proceeding the current research would be to support Python instance as client (parent), supporting child objects in Gendl. Implementing this direction of the interface would require the Python-based KBE DSL to be developed further, to allow for the concept of Child Objects to be captured in the Python environment. Further next steps involve Implementation of more complex examples which are closer to real-world KBE applications. If the principle proves to be successful, following steps can also include adding additional language wrappers, e.g. Java, C#, VB to reach an even wider community.

BIBLIOGRAPHY

[1] P. Norvig, "Quora Interview," https://www.quora.com/session/Peter-Norvig/1, May 2016.

[2] Dave Cooper, Genworks International; Gianfranco LaRocca, Delft University of Technology, "Knowledge-based Techniques for Developing Engineering Applications in the 21st Century," in *7th AIAA ATIO Conf, 2nd CEIAT Int'l Conf on Innov and Integr in Aero Sciences,17th LTA Systems Tech Conf; followed by 2nd TEOS Forum Belfast*, Northern Ireland, 2007.

[3] G. International, "GDL: A User's Manual," http://genworks.com/downloads/tutorial.pdf, 2016.

[4] P. S. Foundation, "The Python Standard Library," version 2.7, https://docs.python.org/2/library/index.html, May 2016.

[5] Jepsen, J., Ciampa, P. D., Nagel, B., Gollnick, V., "Design of a Common Library to Simplify the Implementation of Aircraft Studies in CPACS," DLRK, Rostock, 2015.

[6] G. La Rocca, "Knowledge based engineering: Between AI and CAD. Review of a language," *TU Delft, Elsevier, Advanced Engineering Informatics,* 16 March 2012.

AIRCRAFT WING DESIGN VIA NUMERICAL OPTIMIZATION: ARE WE THERE YET?

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Abstract

Wing shape is a crucial aircraft component that has a large impact on its performance. Wing design optimization has been an active area of research for several decades, but achieving practical designs has been a challenge. One of the main challenges is the wing flexibility, which requires the consideration of both aerodynamics and structures. To address this, we proposed the simultaneous optimization of the outer mold line of a wing and its structural sizing. The solution of such design optimization problems is made possible by a framework for high-fidelity aerostructural optimization that uses state-of-the-art numerical methods. This framework combines a three-dimensional CFD solver, a finite-element structural model of the wingbox, a geometry modeler, and a gradient-based optimizer. This framework computes the flying shape of a wing and is able to optimize aircraft configurations with respect to hundreds of aerodynamic shape and internal structural sizes. The theoretical developments include coupled-adjoint sensitivity analysis, and an automatic differentiation adjoint approach. The algorithms resulting from these developments are all implemented to take advantage of massively parallel computers. Applications to the optimization of aircraft configurations demonstrate the effectiveness of these approaches in designing aircraft wings for minimum fuel burn. The results show optimal trade-offs with respect to wing span and sweep, which was previously not possible with high-fidelity models.

A NASA LANGLEY PERSPECTIVE ON SPACE TECHNOLOGY – DRIVING SUCCESS THROUGH COLLABORATION

David Dress

Abstract

The term "Space Technology" encompasses a wide range of capabilities needed to provide efficient access to space, mobility while in space, and the ability to live in space based on mission requirements. In recent NASA terms, this is termed the "Technology Path to Pioneering Space" where we will Go, Land, and Live.

At the Agency level, Space Technology encompasses topics like:

High Power Solar Electric Propulsion

Mars Entry Descent and Landing Systems

Lightweight Space Structures

At the field centers, we match up our expertise to work these topics, both with other NASA centers as well as with industry and academia. At NASA Langley, we have been proactive in developing our space technology thrust areas that best match up our expertise with the needs of NASA's Space Technology, Exploration, and Science Mission Directorates. In addition, we believe there is great value to our Agency in collaborating and developing partnerships with industry and academia that meet the needs of all parties. Working together drives innovation, produces results more quickly, and provides an infusion path for NASA missions, a commercialization path for industry for their customers, and robust research opportunities for universities.

The thrust areas we currently focus on at NASA Langley are Entry, Descent, and Landing; Lightweight Transportation Systems; In-Space Assembly and Manufacturing; and Habitation Systems. Entry Descent and Landing technologies permit more capable science and access to other planets or bodies for both humans and spacecraft (including equipment). At NASA Langley, this includes hypersonic aerodynamic decelerators, advanced materials for thermal protection, retro-propulsion, and instruments and sensors.

Lightweight Transportation Systems is mostly focused on reducing mass to allow more carrying capability per launch. This includes reducing the mass of launch vehicles through the use of composites, nano-materials, and other lightweight materials.

In-space assembly involves developing advanced concepts and enabling technologies for the assembly of very large structures. This includes joints and joining (manual and robotic), jigging robots, e-beam welding and additive manufacturing, long reach robotic arm manipulation, and autonomous control.

Our focus for habitation systems is advanced structures and materials including composites, nano-materials and inflatables. We are also focusing on radiation protection. This radiation work includes the analysis of radiation environments and the use of prototypes to explore system configurations to reduce and minimize astronaut risk.

In summary, Space Technology is a very broad and somewhat imposing topic with many challenges. By focusing our efforts based on our expertise and combining this with others through collaboration and partnerships, NASA Langley is addressing difficult problems and impacting the future of space travel.

TOWARDS IMPROVEMENT OF EPOXY-THERMOPLASTIC JOINTS

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Abstract

Single structural elements consisted of thermoset and thermoplastic parts are currently being considered for aerospace applications. In this respect, the strength of the epoxy-thermoplastic phase boundary has crucial role in defining properties, reliability, and functions of the elements. Hence, formation of reliable and predictable bond between the thermoplastic zones (called implants) and the epoxy zones within the structural elements is of critical importance. To this end we have investigated how nanoscale layer of epoxy-containing macromolecules anchored to the surface of PEEK (prior to the assembly) affects the adhesion strength. We found that, in fact, the level of interfacial adhesion can be increased with the polymer grafting after plasma treatment. The resulting technique is expected to be transferable to other thermoplastic materials (such as PEI and PEKK).

Keywords

Adhesion, Composite Manufacturing, Aerospace Structures, Materials.

1 INTRODUCTION

Combining thermosets and thermoplastic within the same structural elements offers significant design flexibility. The combination opens new pathways for "welding" the elements together enabling more complex part configurations to be assmebled.[1] This hybrid polymer approach can produce lighter, stronger and less expensive composite parts. However, poor understanding of reliable bonding between thermoplastics and thermoset materials has limited the use of multi-polymer composites in aerospace structures. To this end, we have investigated employment of intermediate nanoscale interfacial layers for bonding of thermoplastic parts to thermoset parts in a hybrid polymer composite component.

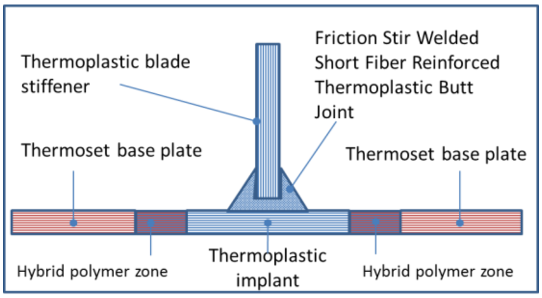

Figure 1. Butt-joint for thermoplastic matrix composite stiffened shells.

2 STATE OF ART

The introduction of extensive chemical bonding at the thermoplastic-thermoset interface is a feasible strategy to improve the overall adhesive strength. Uncured epoxy resin has vast numbers of reactive groups that can form permanent bonds (with epoxy, amino and carboxy groups). However, the surface of many thermoplastics, such as PEEK, is chemically inert. Hence, an activation step for the thermoplastic surface is required. Plasma-activation is the most common pathway to achieve this goal[2], however combined action of ozone and UV-treatment has also been demonstrated to be effective[3]. Using reactive polymer coatings is also a well-established pathway to improve the bonding at the interfaces which offers a great diversity of functional groups that could be combined within the same layer[4].

3 MAIN IDEA

Our idea involves the pretreatment of the thermoplastic implants using polymer grafting to create surfaces that allow reliable bonding of the implants to the epoxy based composites in a hybrid polymer composite component. In essence, to activate polymer surfaces the thermoplastic substrates (pre-treated with corona and/or plasma) are modified with a nanoscale anchoring layer of epoxy containing macromolecules [poly(glycidyl methacrylate) (PGMA), its copolymers, or epoxidized polybutadiene (EPB)].[5-7] The polymers contain numerous epoxy groups, which, upon mild temperature activation, are known to be highly reactive.[8] The anchoring layer is self-cross-linked via epoxy groups, providing its stability. At the same time, a large number of unreacted epoxy groups are available for further reactions. The versatility of the PGMA base layer allows for further assembly of the multilayered systems. Here, we investigated the effect of UV treatment, plasma treatment, PGMA, polyacrylic acid/PGMA and polyethylene imine/PGMA polymer layers on the interfacial strength of the one-component epoxy/PEEK adhesive joint. The significant improvement is demonstrated for the treated samples as compared to untreated PEEK.

BIBLIOGRAPHY

1 Van Tooren, M. J. L. Method for bonding a thermoplastic polymer to a thermosetting polymer component. Patent: WO2012161569 A1 (2012).

2 Dupuis, A. *et al.* Improving adhesion of powder coating on PEEK composite: Influence of atmospheric plasma parameters. *Applied Surface Science* **357**, 1196-1204, doi:10.1016/j.apsusc.2015.09.148 (2015).

3 Mathieson, I. & Bradley, R. H. Improved adhesion to polymers by UV/ozone surface oxidation. *Int. J. Adhes. Adhes.* **16**, 29-31, doi:10.1016/0143-7496(96)88482-x (1996).

4 Awaja, F., Gilbert, M., Kelly, G., Fox, B. & Pigram, P. J. Adhesion of polymers. *Progress in Polymer Science* **34**, 948-968, doi:10.1016/j.progpolymsci.2009.04.007 (2009).

5 Luzinov, I. A., Swaminatha Iyer, K. L., Klep, V. Z. & Zdyrko, B. V. Surface graft modification of substrates, US patent 7,026,014 B2, Apr. 11, 2006. (2006).

6 Zdyrko, B. & Luzinov, I. Polymer Brushes by the "Grafting to" Method. *Macromolecular Rapid Communications* **32**, 859-869 (2011).

7 Galabura, Y., Soliani, A. P., Giammarco, J., Zdyrko, B. & Luzinov, I. Temperature controlled shape change of grafted nanofoams. *Soft Matter* **10**, 2567-2573, doi:10.1039/c4sm00055b (2014).

8 Zdyrko, B., Iyer, K. S. & Luzinov, I. Macromolecular anchoring layers for polymer grafting: comparative study. *Polymer* **47**, 272-279 (2006).

HEALTH MONITORING AND SMART PREDICTIVE SYSTEMS THROUGHOUT THE PRODUCT LIFE CYCLE

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ABSTRACT

Industry 4.0 leverages the Internet of Things (IoT), cloud computing, and predictive maintenance to create a "smart factory" consisting of cyber-physical systems that recreate a virtual copy of all machinery on the manufacturing floor and will make decentralized decisions. Utilizing IoT, these systems can communicate to one another and give an update on their status to the proper personnel in real time. Industry 4.0 relies on four main components to achieve a more efficient manufacturing system (as seen in Figure 1). The first is leveraging the technology at the physical factory and connecting machines to one another through vertical integration. This idea is then expanded horizontally to enable everyone from suppliers to customers to be connected to the manufacturing process and make decisions. Customer feedback is incorporated into the manufacturing and design process to remediate any flaws in design that were once overlooked. The final part of Industry 4.0 to ensure it is successful in taking advantage of new "exponential" technologies including computing, sensors, and additive manufacturing. The addition and integration of these technologies will provide immediate benefits and set Industry 4.0 up for success as new systems or processes that take advantage of the technology are introduced in the future.

Keywords: Industry 4.0, Internet of Things, Structural Health Monitoring, Predictive Maintenance, Predictive Analytics

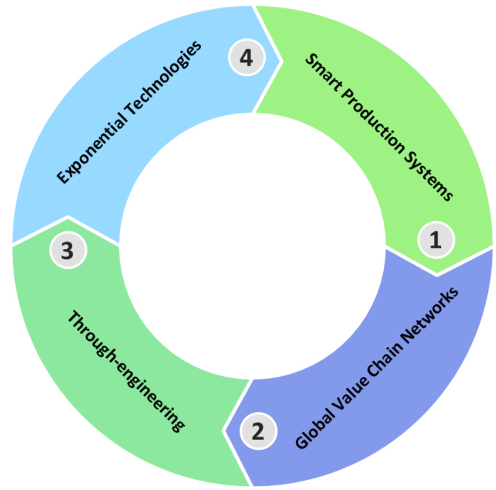

Figure 1. Four characteristics of Industry 4.0

1 INTRODUCTION

The University of South Carolina (USC) is currently working on advancing the third component of Industry 4.0, through-engineering. Developments in cost and performance of sensors as well as big data based predictive analysis are bringing many new opportunities to designers of complex systems. Predictive maintenance, in-flight structural health monitoring, production system health monitoring and many other systems promise to become widespread because of their affordability. Each system requires a different approach for the various phases of its life cycle. Figure 2 shows the life cycle, which involves the design, manufacturing, and use of a component. In this paper three cases along a product's life cycle will be discussed to improve a manufactured item. This begins with structural health monitoring of a composite control surface, then discusses health monitoring of composite manufacturing plants, and finally summarizes work being done on the predictive maintenance of dynamic systems.

Figure 2. The life cycle of a manufactured part

2 STRUCTURAL HEALTH MONITORING OF COMPOSITE CONTROL SURFACES

The first case study involves the effect of structural health monitoring on the lifecycle of the product and how to account for sensors in a component before the design has been finalized. Impact events produced by operating conditions or human errors can cause delamination in composite structures. Structural health monitoring (SHM) systems are well-suited for incorporation with traditional maintenance procedures for vehicles, such as aircraft, where such damage may be overlooked in visual inspection as well as for future systems where the traditional SHM is used to determine the condition of a structure by the use of sensors, replacing the human inspector and/or replacing the Barely Visible Damage (BVID) concept with a Barely Detectable Damage (BADD) concept. USC has been working with and for Fokker Aerostructures BV to develop a feasibility demonstrator for a passive SHM system. The goal is to show that a passive monitoring system can be built with the following attributes: lightweight, small footprint, minimal structural property changes, electrical magnetic interference resistance, and high reliability in detecting events.

Software has also been developed to setup the system before flight as well as performing data processing after flight (or at any other time). The approach is already seeing positive benefits in its low cost and effectiveness. Future development will aim to improve data analytics and provide faster, more complete data acquisition that would aid in improving predictive maintenance for SHM.

3 PREDICTIVE MAINTENANCE OF DYNAMIC SYSTEMS

As part of the end-user phase in the life cycle of a product, data is still being collected long after the manufactured item has left the assembly line. Advancing technology as part of the Industry 4.0 model allows the manufacturer to quickly make use of this data in many ways, from redesigning the component entirely to fine-tuning the assembly. However, this data can easily lose its value if it is not properly collected, stored, and transferred. As depicted in Figure 3, there are three major steps to implementing a successful predictive maintenance program in industry. The first step is assessing current procedures, creating a strategy to maximize reliability while minimizing investment, and developing an easily executable plan. The next step

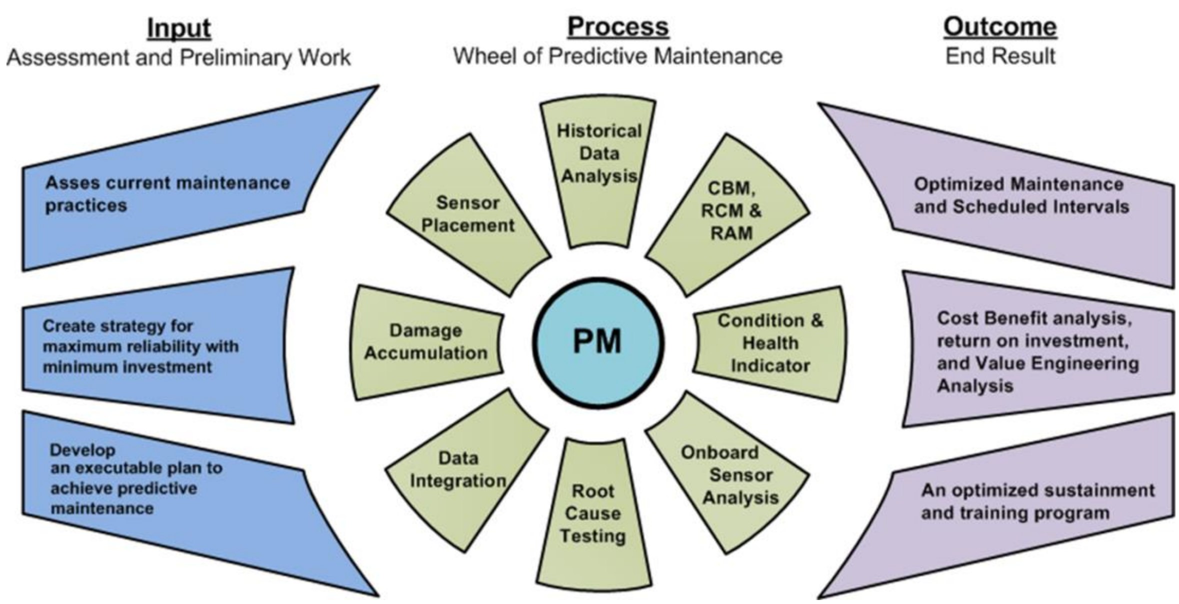

Figure 3. The process for an effective predictive maintenance program

is analyzing the different needs of the program, which has been the focus of CPM's research projects. The outcome should be an optimized scheduled maintenance plan that is based on sound engineering and will have a high return on investment.

Optimal placement of a sensor on a component (gearbox, rotor blade, transmission, etc.) is necessary to provide the highest quality of collected data. The next challenge is to determine the rate of data collection to ensure no faults go undetected. After collection from the component, all data should be properly stored for easy readability. By properly implementing this program, data originating from multiple sensors on the component can be integrated using tools like data fusion. Varying sensor signals will be processed through appropriate feature mapping tools and analyzed to create sets of condition indicators. This allows the health of the entire structure to be determined and monitored. After the health of the component has been determined, sensor data is evaluated to ensure that the correct parameters are being collected. If sensor data is not complete, further testing is necessary to gain a full understanding of the component's functionality. When integrated with historical data, the predictive maintenance program can be used to its fullest capacity to determine items such as remaining useful life and the proper maintenance action to repair a fault. Historical data allows predictive maintenance to capture the human factor, including operational experience from working on the component and knowledge of how a component will react when a certain maintenance practice is performed. Historical data can come from a variety of different sources in the form of maintenance records and OEM technical manuals.

4 AUTONOMOUS MACHINE HEALTH AND PREDICTIVE ANALYTICS

The goal of this research is to find solutions for two of the main issues with automated manufacturing. First, single point failures of factory infrastructure can negatively impact production rates if they are not being monitored. Second, for the factory operations that are monitored, there is no existing capability to transform data into actionable information to manage factory health. McNair has developed a framework to enable predictive maintenance for critical factory infrastructure and enable real-time predictive analytics on factory health management solutions. The capabilities of the McNair Center along with the Center for Predictive Maintenance (CPM) are such that robotic automation and automated fiber placement are selected as guides to the solution development. Diagnostic and prognostic algorithms are being developed to eliminate production line interruptions due to observable failures. Using the developed algorithms, McNair is working together with CPM to demonstrate the feasibility of using advanced data analytics tools (i.e. IBM Watson) to predict process and equipment machine status. This also allows for an easy implementation in an Industry 4.0 environment because of the cloud-based features. The computing and predictive analytics could then be done individually for each robot and then shared with other machines to make-up for a potential failure. CPM has been using these ideas to create new algorithms to monitor vital components, as well as techniques to better analyze historical data text. CPM has been successful implementing this process within the Department of Defense. The successes include increasing component life, cost avoidance, and aircraft readiness.

MACHINE WORK SPACE PLANNING IN ADDITIVE MANUFACTURING FOR SINGLE-PART-LAYER CASE

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Abstract

Additive Manufacturing (AM) is a kind of new shape forming method which uses one or several type of energies (laser, electric, heat, ultrasonic wave, etc.) to join one or several different raw materials in a successive way (spot by spot, line by line or layer by layer) to form 3D physical parts though the use of virtual 3D CAD models. This additive manufacturing manner enables AM to build extreme complex parts without obvious increase of cost related with shape complexity. And further, AM can realize the simultaneous fabricating of a group of parts with same of even different shapes without using additional fixtures or tools as required by conventional processing technologies. These advantages make AM being developed quickly recently. Except for one of its main functions, prototyping, AM has evolved too much that it can build functional parts for end use and even digital multi-functional parts, e.g. gradient components. The application fields of AM also expanded, from prototyping to automotive, aerospace, medical implant, art sculptures, tissues, etc. However, the industrialization of AM is still not satisfied. One of the key obstacles is the relatively high cost, especially the investment for machine purchase and maintenance as well as raw materials. Hence, to reduce the cost per part, improving the machine utilization is the most intuitive way. AM production service bureaus usually build parts in group by group way but not one by one per setup, which will reduce the build time and cost. To obtain a high packing compactness and guarantee the production quality, technicians need to align each part model along its optimal build orientation and place the part group in an optimal layout. However, this is quite difficult to operate manually in a virtual CAD environment. And this preparation task will become an NP-hard problem when the number of part models is large. Therefore, orientation and nesting or packing tools are required. To solve this problem, a couple of works had been done in the past. 3D and 2D classical packing methods were proposed. However, some of them could only obtain a high nesting compactness but could not guarantee the production quality, which is meaningless for AM production. Others proposed to transfer the nesting problem into classical pure 2D nesting problems through the use of projection method. These methods can reduce the computation but have reduced too much of the original solution space since DOFs of part models in the nesting procedure were reduced, which cannot guarantee global optimality. To deal with these drawbacks, in this presentation, a new parallel nesting method, which uses changeable projection profiles in nesting procedure to realize full DOFs of part models but compute with 2D cost to solve one class of the packing problem in AM, single-part-layer nesting, will be introduced. The propose method can obtain high nesting compactness with less computation and guarantee the production quality through orientation optimization for individual part model. A couple of examples will be presented for demonstration.

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