

Panel Assembly Line (PAL) for High Production Rates

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ABSTRACT

Developing the most advanced wing panel assembly line for very high production rates required an innovative and integrated solution, relying on the latest technologies in the industry.

Looking back at over five decades of commercial aircraft assembly, a clear and singular vision of a fully integrated solution was defined for the new panel production line. The execution was to be focused on co-developing the automation, tooling, material handling and facilities while limiting the number of parties involved. Using the latest technologies in all these areas also required a development plan, which included pre-qualification at all stages of the system development.

Planning this large scale project included goals not only for the final solution but for the development and implementation stages as well.

The results:

- Design/build philosophy reduced project time and the number of teams involved. This allowed for easier communication and extended development time well into the project.
- All design teams (machine, tooling, automation, controls) collocated and worked together on integration during all stages of development and implementation for the highest level of integration.
- Innovative integration of the tooling and the automated equipment evolved throughout project with the teams working as one group.
- Latest fastening technology using all electric, ball-screw squeeze riveting was developed for high-speed and robust automated fastening.
- Latest mobilization technology was used to make the automated fastening machines interchangeable to reduce MTTR and to enable more PPM activities offline without affecting production.
- More automation was also introduced for tool changing and to the material handling systems for more consistent processing and to reduce operator intervention.
- All systems were developed together for full integration and to enable more safety interlocks and HMI for simplified operation.
- A 30 month schedule for the complete large scale assembly line was maintained to support the new aircraft launch schedule.

The final solution was a coherent, streamlined and efficient assembly line capable of very high aircraft production rates ([Figure 1](#)).

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INTRODUCTION

At the conception of the Panel Assembly Line (PAL), goals targeted not only the final solution but the development and implementation as well. A focus on integrating the latest technologies also required planning at every step.



Figure 1. PAL, automation cell, Line 4, Position 1 (L4P1)

Development and Implementation Goals

During the development and implementation stages, large scale projects suffer from concept divergence and integration challenges when compared to smaller projects. Problems typically exist at the interfaces as the saying goes. With so many subsystems, large scale projects suffer from an abundance of interfaces and staff. Furthermore, incorporating new technologies greatly increases risks to a smooth start-up. Listing developmental and implementation pitfalls for large projects was key to converging on the goals necessary to provide the best solution to realize the original vision while reducing overall project time. Some goals and the associated pitfalls they overcame included:

Integrated Teams: Separating the subsystems into different contracts puts barriers to the flow of the project. By integrating the main technical teams (Tooling, Automation and Material handling), fostered a clearer understanding of the limiting factors or effects of different design decisions that might otherwise be overlooked due to natural separation of responsibilities of each subsystem.

Leadership: Maintaining consistent leadership throughout the project avoids complicating or diluting the original vision and goals. The goal for PAL was to maintain the same leadership throughout the development, implementation and production start-up stages.

Communications: Large scale projects can suffer from communication issues due to an overwhelming number of staff, suppliers and disciplines. New tools needed to be developed to clearly communicate schedule and schedule changes.

Reduce Project Time: Because divergence of goals is exaggerated on lengthy projects, management methods, such as design/build, were required to help reduce the overall project time.

Maximize Development Time: Specific technical solutions might stand on their own merits but may not integrate well or support the overall system if developed independently. Design periods of subassemblies should extend into the build and even into the implementation stages to maximize development and to incorporate changes to the latest possible point in the project.

Mitigate Technical Risk: Reduce the risks of new technologies with concurrent testing programs integrated into the program schedule at the start of the project. Also find ways to avoid risks associated with disassembly of major components for shipping.

Final Solution Goals

The specification for this assembly line was thorough in listing requirements and over-arching goals were also emphasized to suppliers.

Latest Technologies: Incorporate the latest technologies in the areas of Automated Equipment, Tooling and Material handling to increase quality, reduce operator intervention and reduce flow time.

Innovative Tooling: Sleek new tooling, optimized for PAL fastening machine access and cycle time, was required to accommodate new aircraft panels, legacy aircraft panels and all of their variants.

Mobile Machine and Offline MRO: Reduce interruptions to the production line by reducing or removing MTTR.

Semi-Automated Material Handling: Use the fastening machine operators to operate the tooling and material handling systems. Not limited to part damage control, semi-automated material handling reduces required skills and reduces flow time across the entire production process while avoiding dedicated crews.

Increased Safety: Addressing safety not only in each of the project areas, but addressing safety on a complete system level was a requirement.

Once these goals were established, the team selection process was clearer with a good path to realize the project vision.

DEVELOPMENT AND IMPLEMENTATION

Integrated Teams

Prime supplier selection was based on the design/build capability, expecting expertise on as much of the three sub-systems as possible which included: automated fastening equipment, tooling and material handling. Design/build management was a key to reducing some of the many challenges of this large scale project as well as maximizing development time while minimizing implementation time. A supplier that has multiple disciplines can execute concurrent engineering more naturally. Collocating the teams in the same physical space throughout the project greatly reduced the communication issues typical with separate suppliers. System interfaces were more

frequently reviewed and changes were much more closely monitored. Sometimes, challenges in one of the project areas were overcome by making smaller adjustments to other areas. These decisions were based on optimizing potential cost or schedule impacts.

Leadership

Leadership was chosen and required to stay with the program from the start of the design process until the system was in production for several shipsets to ensure that goals and vision were maintained and changes were monitored to reduce divergence. Teams were assigned with only a single layer of management (engineer/project manager) and these teams were co-located during the design and fabrication stages. Only one-for-one contacts were established between customer and supplier.

The opportunity to open communication directly between the leadership from each group was not only recognized but became an important tool as the project reached the point where the three main suppliers would occupy the same space in the construction area. The prime supplier assigned key personnel to oversee individual aspects of the project with the idea that the assigned lead would take ownership and remain with the project through to its conclusion. This required multiyear commitments in some cases but was an important internal goal for meeting the time constraints presented on this program. These commitments helped smooth planning change due to emergent issues.

Communications

Traditional communication or management tools for planning became much too complex for combined detail schedules or too diluted for master schedules.

Constructing the foundation for the assembly line was of particular importance and during the design phase all parties met weekly to detail requirements and verify foundation dimensions and facilities layout. As the project progressed, it became apparent that scheduling interface dates for transitioning control of the construction site was not clearly understood by all teams. To remedy these issues, a simple new tool was developed: the “Integration Exercise”. To support this exercise, critical milestones for the project were identified for the main sub-systems: Automated Fastening, Tooling, Material Handling and Foundation (Figure 2).

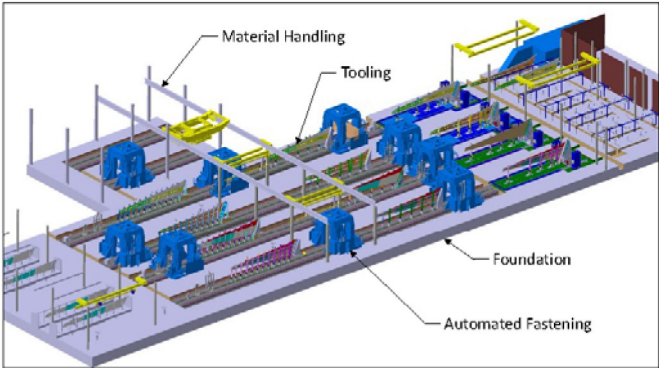


Figure 2. Panel Assembly Line (PAL) Subsystems.

The prime supplier was contracted for the first three subsystems and another supplier was contracted for the foundation. Early in the project, leaders from each area were brought together with the corresponding customer contacts to review the project. The leadership team worked to identify critical dates, however, it became clear that hardware ready dates or foundation ready dates were not enough to plan the project within the required 30 month period. This was because there were multiple zones with varying access needs and the typical finish/start planning was inadequate because sequential planning would have stretched the project out for many more months/years than was required.

Therefore, more attention was paid to understanding need dates and access dates for each stage and in each zone. These dates were often hidden within the different schedules and were far from typical “completion dates”. For example, foundation ready dates were not going to be complete in time to meet overall installation times.

All teams met to refine understanding of each step of the installation. Dates were identified for access or semi-access where different teams would overlap. It also became necessary to define the priorities with one team starting while another team was still finishing. Once interface dates were understood and agreed to by all teams, the dates were captured in the tool below and became contractual (Figure 3). Although there were many “minor” dates that could change throughout the project, maintaining these milestone dates would be key to a successful execution and understood by all parties.

VPAL Schedule Integration		EI REVISED Install Sequence & Flows Integrated with Skanska 8/7/13											
		Pos 0		Pos 1		Pos 2		Pos 3		Pos 4			
		Start	Comp	Start	Comp	Start	Comp	Start	Comp	Start	Comp		
Maint	Machine Install			6/26/14	10/6/14								
enance	Pos #3				12/13/13								
Shed &	Stabilize Foundation				5/14/14								
Machine	Stab on Grade				3/2/14								
#1	Ready for Crane/Transporter				4/24/14								
	Ready for Bed Install												
	Crane / Transporter Bridge Install				4/24/14	5/2/14							
	Bed Install				5/2/14	5/6/14	14/7/14	1/18/15					
	Fiber Install				5/2/14	5/20/14	1/18/15	2/7/15					
	Sled Install				5/9/14	5/25/14	1/18/15	2/2/15					
	Machine Install				5/26/14	1/9/14							
	FAT & Qual				1/9/14	11/25/14							
	Ready for Use				11/25/14								
Line 4	Lever RH Startup				11/25/14	12/10/14							
Far East	Pos #3					3/1/14							
	Stabilize Foundation												
	Stab on Grade												
	Ready Transport/Material Install				7/7/14	5/5/14	5/5/14	9/9/14			9/23/14		
	Transporter Install				5/5/14	5/27/14	5/5/14	5/27/14					
	Material Install				7/1/14	7/2/14	5/5/14	5/27/14	8/9/14	10/9/14	9/23/14	11/17/14	
	Beds Install (rough in & final align)				7/27/14	6/19/14	5/20/14	5/20/14					
	Fiber Install				5/20/14	5/1/14	5/4/14	5/24/14					
	Tooling Install				5/13/14	11/19/14	5/25/14	11/2/14	10/2/14	12/29/14	11/18/14	12/15/14	
	SteelComp				10/12/14	10/26/14	10/26/14	11/6/14					

Figure 3. Partial view of Integration Exercise document

Once the overall plan was defined, implementing and tracking required great focus and more communication tools for the leadership. In an effort to map out site control areas, the teams agreed on a template to communicate needs in certain zones (Figure 4 and Figure 5). The necessity to establish area control was based on how critical the task was to the whole of the project. It was agreed that the end user would drive these decisions. These changed over the course of the project but the idea was to lay out a frame work as a starting point and maintain the open communication about ongoing tasks required in each area. Using this tool it was possible to complete concurrent work in areas normally subject to sequential tasks. As the foundation came together areas were highlighted and labeled as under the jurisdiction of particular vendors in weekly meetings. Figure 4 and Figure 5 illustrate the control zone layout concept.

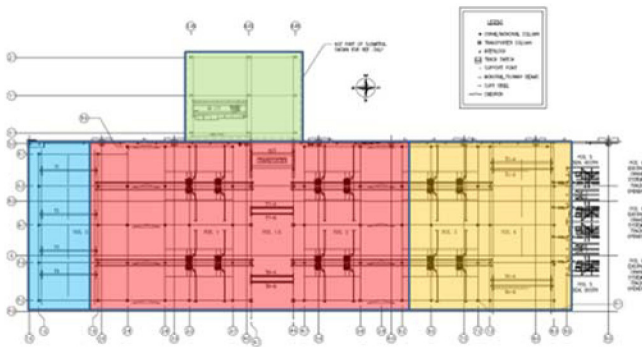


Figure 4. General layout of cell used as template for establishing control zones. Base color indicates general access area only available once final concrete pour had been done.

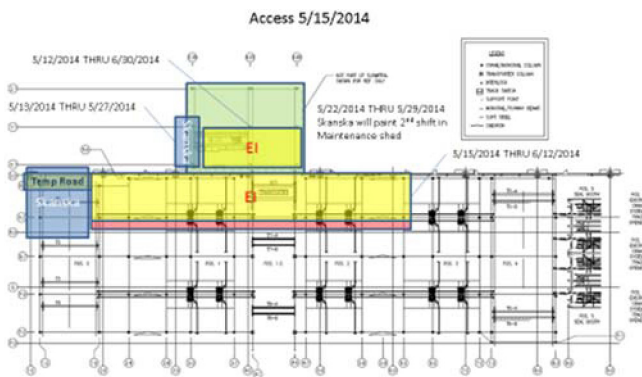


Figure 5. Example of identified control zones. Zones not colored indicated areas under the jurisdiction of concrete contractors.

Reduced Project Time

By using the design/build management method, design completion dates became significantly more flexible. Tent pole items were identified and planning used these items as trigger points. All of the subcomponents or subsystems could “float” in planning around the tent pole items. As mentioned, sequential planning would have increased the overall project schedule significantly. Managing development, fabrication, test and installation as finish/start tasks may have simplified planning but only to increase delivery time of the system. Instead, using the Integration Exercise tool allowed the teams to implement systems in a more just-in-time fashion with design, fabrication, construction, testing and installation occurring concurrently in most cases.

Maximized Development Time

By using the design/build teams, design teams could focus on designing tent-pole items of each subsystem first, then address the other subassemblies well into the fabrication stage and even into the implementation stage (Figure 6). This accommodated concurrent engineering of the new aircraft as well as delaying some subsystems designs as late as possible to allow for changes or challenges that surfaced during the progression of the project.

For example, tooling bases were very long lead and so were designed with systematic interfacing that could be determined early. Tooling posts and indexes could be concurrently designed along with the automated fastening head and the new aircraft at a later date without delaying the main tent pole item of the system.

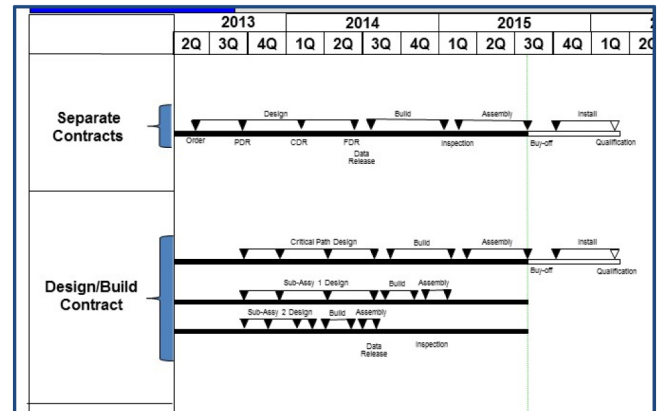


Figure 6. Example master schedule comparison

Risk Mitigation: Fastening Process Test Bench

Utilizing new technologies inherently introduces risks that need to be mitigated as early as possible in order to assure on-time implementation. Table 1 lists several technology risks and the pretesting efforts used to mitigate them.

Table 1. PAL technology risks and the pre-testing methods used to mitigate them.

TECHNOLOGY RISK	MITIGATION METHOD
Pre-Qualification Drilling & Fastening Process Recipes	Process and Clamp Table Test Bench
Fastener Injector Reliability	Injector Test Bench
Pre-Qualification Clamping Sequences	Integrated System Test
Pre-Qualification Rivet “No-Wink” Software Algorithms and Hardware	Process and Clamp Table Test Bench and Integrated System Test

The PAL test bench (Figure 7) was the primary enabler of prequalification efforts. It utilized production fastening heads mounted on a fixed structural frame to allow development and testing prior to the full machine completion. The test bench system was then installed in the customer's factory to allow development to begin for all of the pre-qualification items listed in Table 1.

The test bench was successful in reducing the overall development time as designs were refined and some process parameters were developed in advance of the actual machine ready dates.

As a general rule, a test bench should represent the actual machine it is intended to emulate as closely as possible in order to avoid unanticipated technical problems. Because the test bench did not include the massive positioning axes and structure necessary to move the tool point to all fasteners in a wing panel, it differed significantly from the production machines (Figure 8). Instead of positioning axes and structure, the test bench incorporated only simple structure and a