# Organizational Architecture Design and Assessment of Statistical Feasibility for NPM Implementation in an Airplane Subassembly

By

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Bachelor of Science in Mechanical Engineering, Northeastern University, 2013

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of

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**Product and Organizational Architecture Design for Novel Production Method (NPM) Implementation in an Airplane Subassembly**

By

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Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering on May 2020 in partial fulfillment of the requirements for the Degrees of Master of Business Administration and Master of Science in Mechanical Engineering

# ABSTRACT

Company Z is a ubiquitous name and prominent leader in the aerospace industry, maintaining dominance in part by continuously seeking to improve. Company Z is now embracing a charter to become a Global Industrial Champion in manufacturing by developing strategies to improve manufacturing quality, speed, and cost. As part of this effort Company Z is implementing Novel Production Method (NPM) on a new aircraft, Aircraft ABC. This document focuses specifically on Assembly A, a primary assembly in Aircraft ABC. NPM is a process in which all piece part holes are drilled precisely and accurately upon manufacture and later assembled with no match-drilling necessary on the assembly line. This promises to significantly reduce cycle time while simultaneously improving assembly quality and speed.

Accurate tolerance decisions for piece part hole diameters, hole positions, and hole patterns are imperative for NPM success on Assembly A. As Assembly A is in the early design stages, no measurement data exists to aid in determining which tolerances will yield a successful assembly. To supplement this data gap, measurement and pass/fail data from other aircraft were used to simulate Assembly A pass/fail rates using Close Ream, Class 1, and Class 2A tolerance quality tiers. Results from this analysis indicate probable Assembly A NPM success using Class 1 quality hole tolerances for non-complex parts and Class 2A hole tolerances for complex parts.

It is also imperative to restructure Assembly A organizational architecture to accommodate the radical innovation required to implement NPM. The existing organizational model invites many improvement opportunities in communication, collaboration, and shortened learning cycles. A high velocity learning approach is used to examine the current organizational structure and offer adaptation strategies. It is recommended that the current Agile team structure be adapted to include more diverse job functions and to include other Company Z aircraft organizations as well as strategic suppliers as partners. It is additionally recommended that a larger emphasis be placed on data distribution across business units. The implementation of these organizational changes and the aforementioned engineering strategies will vastly improve the efficiency of NPM implementation in Assembly A.

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# Contents

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# LIST OF FIGURES AND TABLES

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# ACRONYMS

3P- Production, Preparation, Process

ART- Agile Release Train

BO- Business Owner

CAD- Computer Aided Design

DBRT – Design Build Research Team

DBT – Design Build Team

DFM- Design for Manufacture

DFA - Design for Assembly

DMAIC- Define, Measure, Analyze, Improve, Control

EST- Enabler Solution Train

FAA- Federal Aviation Administration

FPY- First Pass Yield

GD&T- Global Dimensioning and Tolerancing

GIC- Global Industrial Champion

LSL- Lower Specification Limit

LST – Large Solution Train

NC- Numerical Control

NPM- Novel Production Method

PM- Product Manager

PO- Product Owner

ROI- Return on Investment

SAFe – Scaled Agile Framework

SM- Scrum Master

SME- Subject Matter Expert

USL- Upper Specification Limit

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# 1. INTRODUCTION

The Company Z Company is a leader in the aerospace industry. The company is constantly striving to better products and customer experiences by continuously innovating for improved safety, performance, cost, and delivery. A lesser-known aspiration of Company Z is to become a leader in the broader industrial space as a Global Industrial Champion (GIC) joining the ranks of Toyota in Production System excellence. For the past few decades, Company Z has redoubled efforts to incorporate lean practices into their business in part due to increased urgency from new competitors in the aircraft market (Aldama, 2018).

## 1.1 BACKGROUND INFORMATION

As part of their pursuit of improved aircraft design, Company Z is continuously investing in Research & Development for new aircraft models. This document is focused on one specific organizational effort for the development of a structure in Aircraft ABC.

Aircraft are composed of primary and secondary structures. Primary structures are essential elements for aircraft functionality; they are critical load bearing structures that will fail the entire aircraft in the event of their own failure. Examples include airplane wings and engines. Secondary structures such as exhaust and thrust reverser systems exist to carry smaller loads that do not cause catastrophic failure upon their own failure. Aircraft ABC is comprised of many primary and secondary assemblies. This document will focus on Assembly A, a primary structure on Aircraft ABC that will be used to pilot the introduction of a new design and assembly system.

The research and implementation established with Assembly A will create a blueprint for the subsequent subassemblies in Aircraft ABC which will be developed later in the program timeline. This is the first time Assembly A has been assembled internally with Company Z, adding to the complexity of this effort.

### 1.1.1 ASSEMBLY PROCESS BASELINE

The Assembly A baseline assembly model uses a common assembly approach within the aerospace industry which Company Z defines as a match drill process. In this process, a 2D drawing is rendered from a part model. This drawing is used for part manufacture and as a baseline to qualify each piece part after it is made. Parts then flow through an assembly line where they are temporarily fastened, drilled to Close Ream quality as a custom assembly, disassembled, deburred, and finally reassembled to maintain the tight tolerances specified. This eliminates any need to shim parts, which is a requirement for any major gaps between piece parts. An example of the basic outline of this process can be found in FIGURE 1.

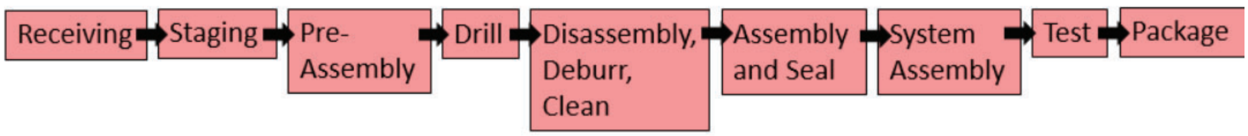


*FIGURE 1: BASELINE ASSEMBLY LINE LAYOUT EXAMPLE*

The baseline assembly design for Assembly A cannot be determined directly. All similar models on other aircraft are manufactured outside of Company Z and use externally proprietary processes. With that hurdle to overcome, the process to design the Assembly A baseline was to examine similar assembly processes for primary assemblies with similar material and size attributes. Factors such as tooling, equipment, personnel, floor space, stations, and timing estimates were evaluated to create a preliminary production line design for a current state model. This model can then be used to create a financial baseline with which Return on Investment (ROI) for any new processes can be measured.

Upon analysis of this baseline model, it was determined that the Assembly A assembly process can be vastly improved for the Aircraft ABC program. Factors affecting financial return such as cycle time, quality (mean and consistency, variance), resources, and floor space contribute to system waste that can be eliminated with an improved assembly approach. NPM has been identified as a way to remove a significant amount of design and assembly process waste in the Aircraft ABC program.

### 1.1.2 NPM DRIVEN ASSEMBLY

Novel Production Method is an assembly method patented by Company Z which uses a 3D model to drive part manufacture. This method of part design and manufacture differs greatly from Company Z's traditional process. A 2D drawing is not produced for manufacture as no dimensioning is needed, and the manufacturing process itself is qualified to predefined internal standards. NPM relies on the use of 3D models in place of 2D drawings. These 3D models relay part information directly to numerical control programming. The manufacturing process qualification is based on the initial, precise tool and part setup. NPM eliminates all assembly line stages needed to match drill parts. This is displayed in FIGURE 2, where light red boxes indicate eliminated assembly steps from the match-drilled process and dark red boxes represent the existing NPM assembly steps. Because of the eliminated work stations facility sizing is reduced significantly, resulting in a savings of multiple millions of dollars on floor space alone. The opportunity for quality issues is greatly reduced due to the reduction in process steps, operators, and equipment. Safety is improved due to the removal of the drilling processes. The implementation of this method requires testing and qualification.

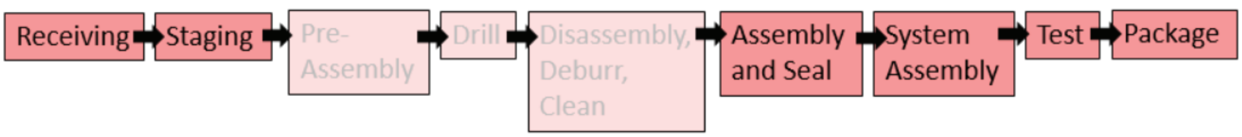


*FIGURE 2: NPM ASSEMBLY LINE LAYOUT EXAMPLE (LIGHTENED BOXES INDICATE REMOVAL FROM THE PROCESS)*

### 1.1.3 NEW AIRCRAFT ORGANIZATIONAL ARCHITECTURE

Of equal importance to the technical benefits of NPM on the Aircraft ABC product and production line are the organizational methods used to implement these efforts. Though NPM has been implemented within other groups at Company Z, it is a completely new concept to the Aircraft ABC organization. It engenders a host of cultural transformations when introduced to a business unit with a preexisting approach to design. It is a complex effort to restructure a group of well-practiced engineering professionals. However, a high velocity approach to learning is a necessary requirement for success. This means that organizational relationships and teams must be examined and restructured to form an architecture that is conducive to a fail fast learning environment (Spear, The High-Velocity Edge How Market Leaders Leverage Operational Excellence to Beat the Competition, 2009).

The traditional organizational structure must be reevaluated and transformed to accommodate the challenges presented by NPM implementation. NPM may require changes. These changes require new teams to interact with one another in a way that is highly cross functional. The Aircraft ABC organization must transform from a traditional organization to a scaled Agile organization to successfully employ the cross functional strategy demanded from a change to NPM. A general industry side-by-side comparison between traditional and Agile organizations can be seen below in TABLE 1. A key part of this project will determine whether existing teams are functioning as desired and what the correct construction of these teams should look like over the lifespan of Assembly A NPM development.

*TABLE 1: TRADITIONAL AND AGILE ORGANIZATION SIDE-BY-SIDE COMPARISON (Yitman, 2018)*

| Traditional Organization | Agile Organization |
|---|---|
| Functional, silo-based structure, task delivery focus | Team-based structure, combining different competencies, value delivery focus |
| Command and control behavior | Collaboration & teamwork emphasized |
| Micro management, directive managers | Servant leaders focusing on providing service |
| Focusing on efficiency and operation. | Focusing on productivity and value |
| Annual, big bang planning | Rolling wave, adaptive planning |
| Think big, work on details, deliver the perfect product | Think big, start small, evolve continuously |
| Bottom up reporting, decisions driven by assumptions and forecasts | Radical transparency, decisions driven by data |
| Long approval procedures and need for authority approval | Empowered teams |
| Limited tolerance for mistakes | Based on experimentation and learning from mistakes |
| Mechanical and cumbersome organizational structure | A living organizational structure that changes shape in line with the company's strategies |
| Focusing on individual performance | Focusing on team-based performance within the scope of business objectives |
| Investor oriented | Employee and customer oriented |

## 1.2 PROJECT MOTIVATION

Company Z is implementing an NPM of assembly to achieve better time, quality, and consistency on Aircraft ABC. Company Z's NPM effort to produce Assembly A is part of a broader goal within the business to produce airplanes using assembly processes that are lean and agile. Their goal is to base manufacturing principles on the Toyota model and use this to eliminate waste, implement a pull based demand system, and coordinate the use of line mobility and signaling to optimize process. NPM contributes to this vision by simplifying the final assembly line for sub-assemblies. Primarily it is a powerful way to eliminate waste as it is a critical part of cycle time and floor space reduction.

NPM implementation in Aircraft ABC is a strategic choice due to its phase of development. Aircraft ABC design is in the early stages and Assembly A is the first assembly structure to be designed for the aircraft. Beginning an aircraft design from scratch is an opportunity to mold technical approaches and team dynamics from the very early stages. The strategy will be documented and used as a blueprint for other Aircraft ABC assemblies and for subsequent airlines to follow as it becomes the norm for Company Z aircraft development. In the more near term, Assembly A specifically will be used as a pilot for NPM development and as a blueprint for subsequent Aircraft ABC subassembly development.

The intention is for Assembly A to work though the technical and organizational hurdles involved in the adoption of the NPM method. This will shorten learning cycles for all subsequent efforts and will better the Company Z aircraft development process overall.

## 1.3 PROBLEM STATEMENT

The problem to be solved by this project is to formulate a strategy to convert a new airplane assembly from a well-established match-drilled methodology to an NPM methodology. This strategy can be broken down in to two different parts: NPM feasibility and organizational architecture, with a future planning emphasis on distribution of documentation to future programs.

NPM feasibility involves the assessment of the technical hurdles to implementing NPM in Assembly A on the Aircraft ABC program. Various design elements must be researched and tested. The conclusions of this testing will determine whether NPM is feasible for Assembly A

NPM testing must be completed within tight timelines which also requires a new approach to the Aircraft ABC program organization architecture. As NPM implementation is a big change to traditional Company Z product and process, the Aircraft ABC program must adapt to a high velocity approach if they are to be successful in applying an Agile methodology. This means that organizational relationships and teams must be examined and restructured to form an architecture that is conducive to a fail fast learning environment (Spear, The High-Velocity Edge How Market Leaders Leverage Operational Excellence to Beat the Competition, 2009). Because the Agile structure is a large deviation from what has been done on other Company Z aircraft development programs, the process to transform Aircraft ABC organizational structure will be iterative throughout the program.

Finally, this testing and research must be combined into a cohesive set of documentation that is made available to both the subsequent Aircraft ABC assemblies as well as other aircraft teams.

## 1.4 HIGH LEVEL PROJECT METHODOLOGY

The following project approach creates a strategy for implementing NPM in a production system from the concept phase through the execution phase. This is performed with a DMAIC (Define, Measure, Analyze, Improve, and Control) process as displayed in

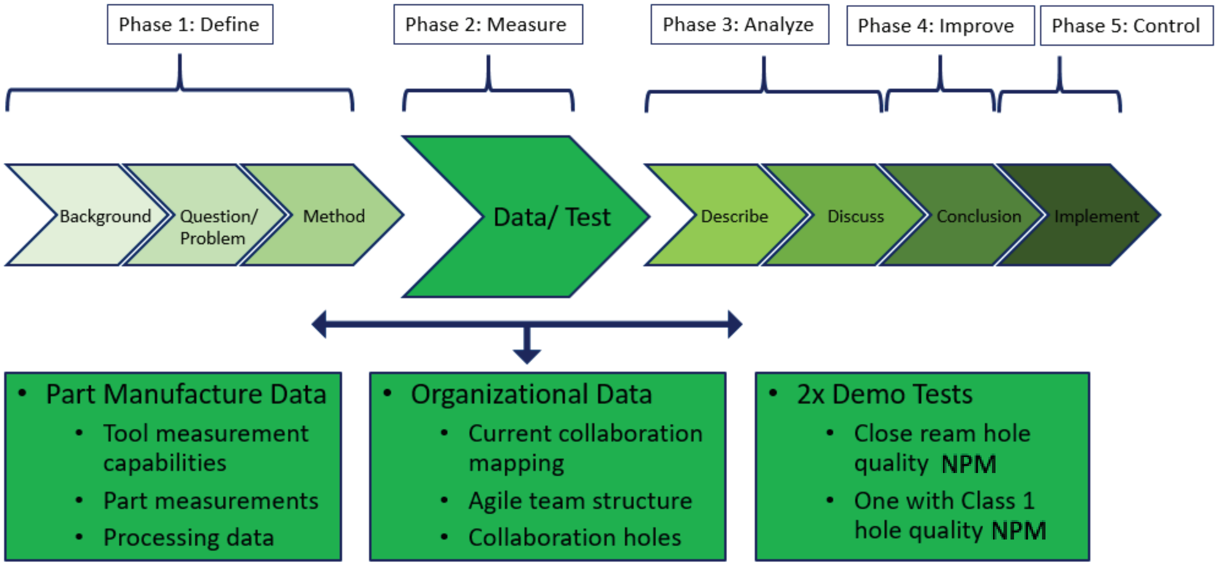


FIGURE 3: THESIS DMAIC METHODOLOGY.

In the Define phase, a problem needing to be solved is established. Some investigative work was required to determine exactly where the inefficiencies were in the Aircraft ABC organization and development processes. After several team interviews it was determined that a strategy was needed for the organizational structure as well as a data based proof of concept for NPM implementation on Assembly A. The full problem statement for this project is outlined in detail in the previous section.

The Measure phase breaks the problem down into pieces. The Assembly A design transformation was addressed from both political and engineering standpoints. Methods were explored to determine the proper measurement techniques for these two complimentary issues. Political factors were explored by assessing organizational function and communication. This was performed by deploying a team survey and performing team member interviews to assess both the current state and its effectiveness. Engineering feasibilities were assessed using NPM data from previous airplane assemblies. Thus, this information was gathered to understand the problem quantitatively. This phase is the most time consuming and was planned with careful consideration.

In the Analysis phase, data and test results were analyzed, manifesting as graphs, charts, and statistical analysis that tell a story of predicted NPM assembly behavior and organizational interactions. Organizational architecture data manifested as a more qualitative data set derived from conversations rather than figures. However, waste identification in the organizational process was able to be assessed quantitatively. Statistics were extremely helpful for the engineering feasibility assessment.

The Improve phase discusses major takeaways from data collected and tests performed and allows for appropriate risks to be identified. This project used both the qualitative survey and interview data as well as the quantitative organizational waste data to analyze the organizational architecture.

The conclusion merges with the Control phase where recommended actions are defined for both NPM feasibility and improvements in organizational architecture.

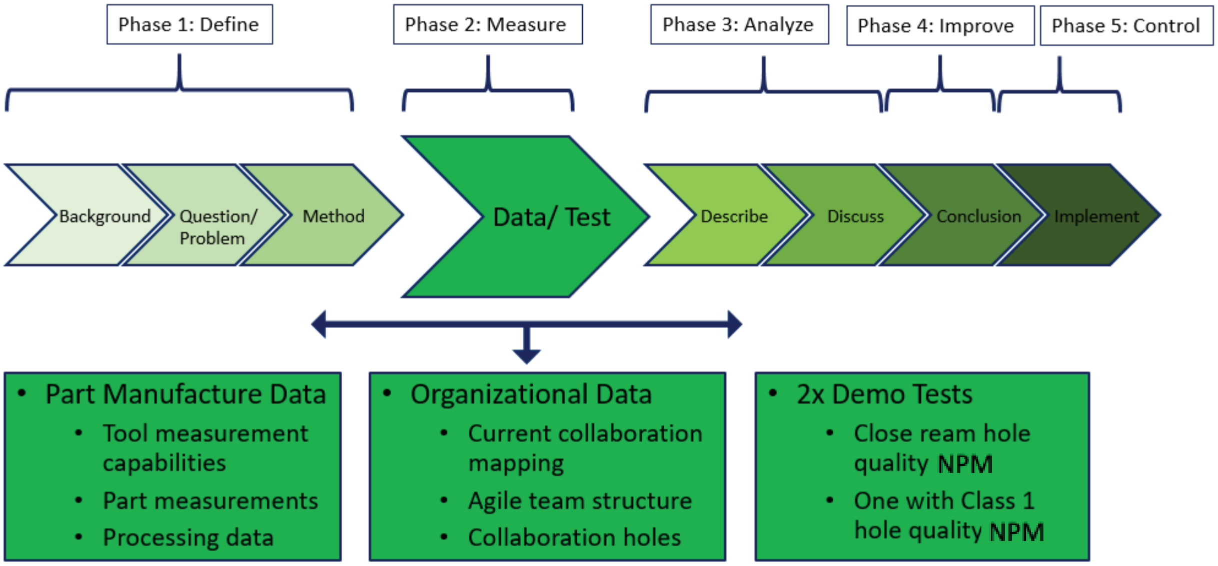


*FIGURE 3: THESIS DMAIC METHODOLOGY*

# 2. LITERATURE REVIEW

## 2.1 AIRCRAFT MATERIAL SELECTION

Aircraft material is an important consideration when assessing NPM feasibility on a piece part and assembly. In the present day, the most popular metals used for airplane manufacture are aluminum alloys, titanium, steel, and other metals such as nickel. Commonly used aluminum alloys for aerospace applications include, AL2024, AL6061, AL7075, and AL7085. A common titanium alloy is 6Al4V common stainless steel is 15-5PH. Piece parts studied in this project have been machined out of 6Al4V titanium. Due to its superior properties, this material is commonly stocked by most metal suppliers, making it easier to procure. As an effect of its common use, 6Al4V metals are also less complicated to manufacture because machine shops and businesses are already equipped and trained with the machinery needed to drill, cut, and form these materials (Giurgiutiu, 2016).

It is important to consider that today's airplane designers must consider the following factors when designing, and this becomes a constraint of NPM feasibility:

- Is the material **lightweight**?
- Are the **ultimate and sheer strengths** suitable for the application?
- Is the material **durable**?
- Is the material **fatigue resistance** suitable for the application?
- Does the material need to be **corrosion resistant**?
- Is it **manufacturable**? Considered factors include ductility and ease of welding.
- Can the material be **heat treated** if needed?
- What is the **material cost**?
- How difficult is it to **source** the material?

TABLE 2 below contains data for Ultimate Strength, Yield Strength, and Density for some of the most common airplane metals available to aerospace engineers today (Prospector Materials Database | UL IDES, 2019). Additionally, this table calculates the ratios between ultimate tensile strength and density as well as yield strength and density. In aerospace there is a tradeoff between the strength of a material selected and its weight. These ratio values help to quantitatively display which materials are more ideal. A material with a high strength to density ratio means that there is high strength per unit weigh and is thus ideal. The ratios for each material are shown in columns E and F.

*TABLE 2: METAL TENSILE AND YIELD STRENGTH VS. DENSITY*

| Metal | Tensile Strength (Ultimate) | Sheer Strength (Yield) | Density | Ultimate Strength/ Density | Sheer Strength / Density |
|---|---|---|---|---|---|
| | [ksi] | [ksi] | [lbs/in3] | | |
| 2024-T3 | 62.9-64.0 | 41.9 | 0.1 | 640.0 | 419.0 |
| 6061-T6 | 50 | 42.1 | 0.098 | 510.2 | 429.6 |
| 7050-T7451 | 74 | 64 | 0.102 | 725.5 | 627.5 |
| 7075-T6 | 74.0-84.0 | 62.9 to 69.0 | 0.102 | 725.5 | 616.7 |
| 6Al4V | 131 | 125 | 0.16 | 818.8 | 781.3 |
| 15-5PH | 190 | 170 | 0.282 | 673.8 | 602.8 |
| TiAl | 136 | 126 | 0.16 | 850.0 | 787.5 |
| Al-Li | 77 | 73 | 0.0936 | 822.6 | 779.9 |

Ultimate strength and sheer strength material properties are important factors when selecting the correct material for an application. Tensile strength describes a material reaction to forces applied in tension. Ultimate tensile strength is thus the amount of stress that a material can withstand prior to fracture. This property is expressed in kilo pounds per square inch, or ksi. Yield strength of a material is the point at which plastic (permanent) deformation begins (What Is Ultimate Tensile Strength?, 2017). Both ultimate and yield strength are important factors to consider when designing an airplane. Ultimate tensile strength is more commonly cited as critical for airplane design, as any breakage of structural materials could result in a catastrophic airplane failure event.

Aviation requirements stipulate that airplanes must be designed to a 1.5x minimum factor of safety level. This means that the ultimate tensile strength of any material used on a structural assembly must be 1.5x higher than the maximum expected load. This factor of safety covers any inadvertent loads greater than the design limit that could compromise structural integrity. This safety factor does not cover analysis errors or poor design practice and great care must be taken to ensure the correct material is selected for each application (Modlin, 2014).

## 2.2 HIGH VELOCITY ORGANIZATION

Steven Spear, a Senior Lecturer at MIT and business advisor to this document, has composed many academic works detailing high velocity organizational structure and how companies can succeed using this philosophy. The high velocity approach details how successful organizations remain ahead of competitors by limiting waste and building fast learning cycles intrinsic to day to day operation. He writes, "While high-velocity organizations put great effort into developing the technical competency of various functions, they are equally and always concerned with the way the work of individuals, teams, and technologies will contribute to (or impede) the process of which they part. The process orientation of high-velocity organizations is in contrast to the 'siloization' of so many other organizations in which the departments may talk of integration but tend to operate more like sovereign states." (Spear, The High-Velocity Edge How Market Leaders Leverage Operational Excellence to Beat the Competition, 2009).

Spear highlights that high velocity organizations possess the following capabilities:

(1) Specifying Design to Capture Existing Knowledge and Building in Tests to Reveal Problems
(2) Swarming and Solving Problems to Build New Knowledge
(3) Sharing New Knowledge throughout the Organization
(4) Leading by Developing Capabilities 1, 2, and 3

These capabilities are shared by front runners in their respective industries. For example, Toyota is a commonly referenced high-velocity company within the automotive industry. These capabilities can and should also be exercised by individual efforts within a company. Assembly A efforts should implement these capabilities to be successful, as this design team bears the responsibility of being the lead assembly for NPM implementation in Aircraft ABC.

In his scholarly article *Designing Products and Processes: Aligning Hierarchical Problem Levels with Problem-Solving Team Forms* Spear discusses the granular details involved in building a high-velocity learning organization.

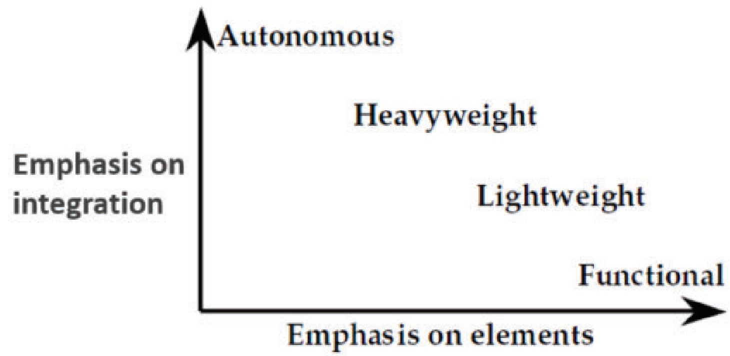


*FIGURE 4: TRADE-OFFS AMONG TEAM TYPES (Spear, Designing Products and Processes: Aligning Hierarchical Problem Levels with Problem-Solving Team Forms, 2005)*

High functioning teams are generally formed into either autonomous, heavyweight, lightweight, or functional teams as shown in FIGURE 4. Some organizations progress into multiple stages with combinations of these team structures. Autonomous teams are the least issue-specific of the four. They are largely cross functional and focus on bringing people and ideas together in on and off-site locations to facilitate idea exchange. For the introduction of a new product, autonomous teams are best positioned early in the development stages. Functional teams live at the other end of the spectrum focusing on more esoteric ideas using specialists from within a technical discipline. As autonomous teams operate in a broad sense, functional teams operate deep within the technical details. As specific problems surface in need of complex testing, functional teams are best assigned with the resolution of these tasks.

Heavyweight teams share the co-located and collaborative qualities that exist in autonomous teams. However heavyweight teams are better suited for a slightly more mature product development stage. At the point in time when heavyweight teams make sense, the broad functionality and core areas of development have been established and team members are ready to think in terms of more architectural detail. When it is time to introduce additional granularity, lightweight team structures then allow team members to segment into smaller, more technically focused groups. The primary role of a lightweight team is to ensure that interfaces and boundaries between project areas are considered, be they physical interfaces or the interface of ideas. The usefulness of these four teams during progressive design stages in product development are categorized below in FIGURE 5.

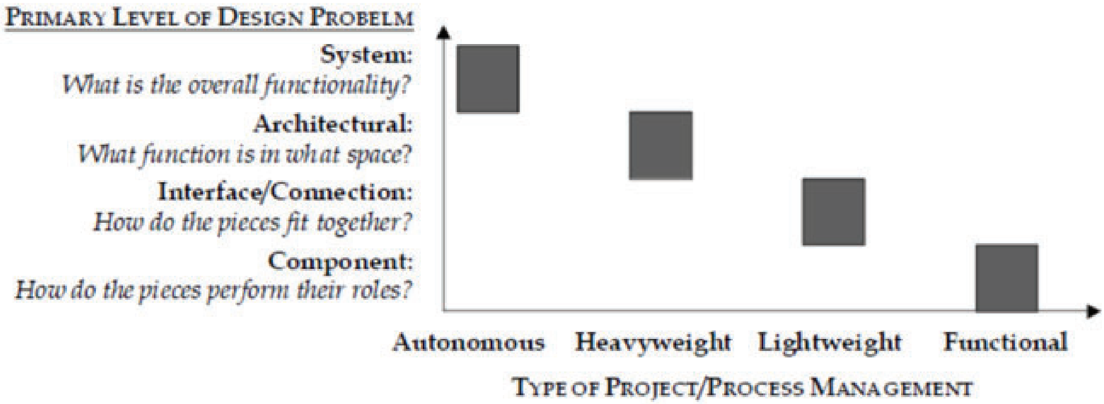


*FIGURE 5: MATCHING TEAM STRUCTURE TO DESIGN-LEVEL PROBLEM (Spear, Designing Products and Processes: Aligning Hierarchical Problem Levels with Problem-Solving Team Forms, 2005)*

High velocity strategies are especially important when applied to an organization implementing a change in product or process. In their academic journal entry *Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms*, Rebecca M. Henderson of the Massachusetts Institute of Technology and Kim B. Clark of Harvard University study innovations resulting from improving existing designs and introducing new concepts in an organization. They argue that product development requires two types of knowledge to be successful: one in which the product is viewed as a system and another where a product is viewed as a set of components.

These knowledge bases can be applied to four types of innovation shown in FIGURE 6: Radical, Incremental, Modular, and Architectural. The boundaries between these quadrants are not intended to be clear cut in their definitions. Henderson and Clark write, “Radical innovation establishes a new dominant design and, hence, a new set of core design concepts embodied in components that are linked together in a new architecture. Incremental innovation refines and extends an established design” (Henderson & Clark, 2007). Modular innovations will change core design concepts but leave architecture intact. The development of Aircraft ABC itself is an example of a modular change, where a new aircraft design is being developed but is using design principles from Company Z’s deep aerospace knowledge base.

Architectural Innovation, however, is the most disruptive type of innovation. It is also the most pertinent concept to this project as it reflects the specific changes occurring in Assembly A. In Assembly A, changes to the overall subcomponent functionality largely remain the same however the implementation of NPM changes in components creates new interactions and linkages with other components. This type of change is the most likely to handicap a firm because it engenders a need for teams to recognize which historical information is useful and which must be abandoned in favor of new developments. Success is dependent on the way organizations such as Company Z store and manage knowledge across and within business units (Henderson & Clark, 2007).

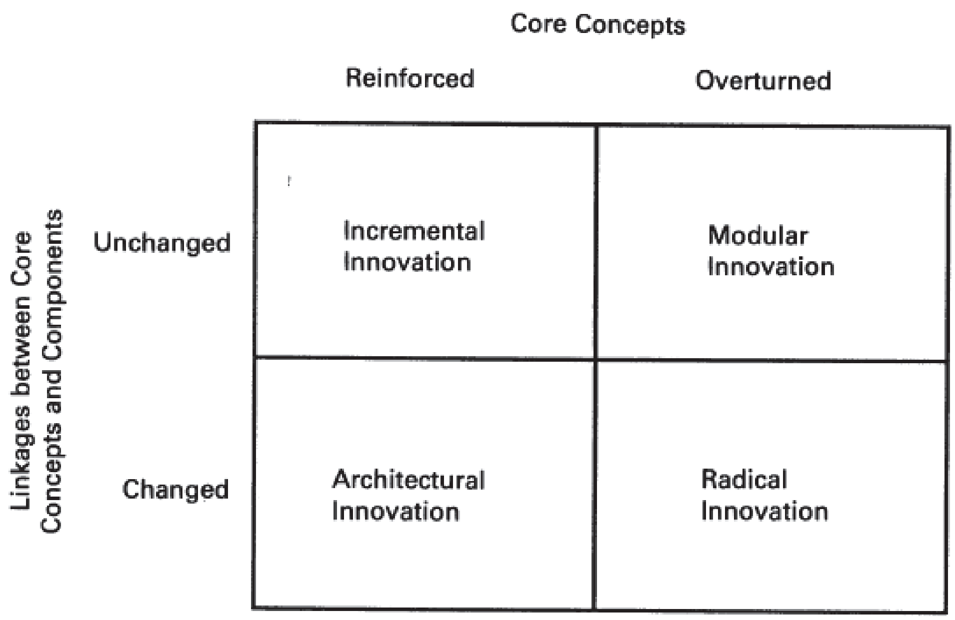


*FIGURE 6: A FRAMEWORK FOR DEFINING INNOVATION (Henderson & Clark, 2007)*

# 3. ASSEMBLY A ENGINEERING REQUIREMENTS

## 3.1 Company Z AIRCRAFT XYZ NPM RESULTS

Assembly A and its equivalents on other airplanes were previously manufactured externally to Company Z. Due proprietary information associated with external development, there is no internal history on manufacturing and assembly processes. There is an absence of any baseline for the manufacturing and assembly processes of Assembly A. Detailed part designs and tolerance schemes used for previous models of Assembly A remain unknown. It is possible to reverse engineer Assembly A part design through the use of CMMs and laser scanners to determine tolerances used and exact part geometry, though this process is time consuming. The external assembly process for Assembly A is much more difficult to reverse engineer. Engineers must determine how an internal assembly line will correspond to the finished product at the same cost, time, and quality as delivered by the external supplier.

Adding to the complexities of an unfamiliar Assembly A assembly process is the incorporation of NPM into Aircraft ABC assembly designs. Company Z has mandated that NPM shall be implemented wherever it is feasible on Aircraft ABC, which includes Assembly A. As NPM is novel to the Aircraft ABC group as an organization, there are many unanswered technical questions regarding feasibility and implementation. When looking to implement NPM in Assembly A the team must therefore look to NPM applications on other assemblies used on other aircraft models in the company. These assemblies can provide valuable data on part manufacturing accuracy using NPM tolerances, assembly process control and success rates, and assembly line issues.

Problematically, many programs within Company Z who report NPM success have data that is only anecdotal. This anecdotal evidence is promising, communicating an NPM assembly success rate of 99.997% but does not provide adequate piece part data to guide a new team in their development efforts. Fortuitously, two aircraft programs were found to have gathered substantial data on their piece part development.

The technical focus of this project is to use data uncovered from these two programs as a platform for comparison to predict NPM success on Assembly A. These programs and assemblies will be referred to in this document as Assembly B on Aircraft XYZ and Assembly C on Aircraft

UVW. Leadership, engineers, and assembly operators alike report that NPM use in Assembly B and Assembly C works well during assembly. The data collected from these programs can be used to plan testing and project expectations for NPM success in Assembly A development. This data in combination with the positive NPM reviews will help to manage expectations for NPM implementation in Assembly A before any demonstrations are carried out.

## 3.2 NPM HOLE INTRODUCTION

NPM holes can be manufactured in both simple parts and complex parts. In this document, a simple part is defined as a piece part with a single plane or with multiple simply angled planes. Simple parts have non-complex geometry which means that tools can easily navigate surfaces to drill holes without a major tool adjustment or setup change. Complex parts are defined as parts in which there are multiple planes at varying angles to one another that create complexity in how a Computer Numerated Control machine (CNC) is able to drill holes.

A general illustration of this can be viewed in TABLE 3, below.

*TABLE 3: HOLE CLASS QUALITIATIVE TOLERANCE COMPARISON*

| **Hole Type** | **Corresponding Hole Diameter and Positional Tolerance** |
|---|---|
| Close Ream | Very Tight fit. Top end of industry capabilities |
| Class 1 | Tight fit |
| Class 2A | Class 1 Equivalent. Tight fit |
| Class 3 | Loose fit |

Aircraft XYZ non-complex parts are typically assigned Class 1 tolerances, while similar non-complex parts on Aircraft UVW commonly use Class 2A tolerances. Class 2A tolerances are considered the Aircraft UVW equivalent of Class 1, though with slightly looser tolerances.

For complex parts, a common configuration for both Aircraft XYZ and Aircraft UVW is to use Class 1/Class 2A tolerances on one plane and Class 3 tolerances on mating planes.

This project aims to do improve production methods using the machine and assembly capability results from Aircraft XYZ and Aircraft UVW programs. Hole manufacture data for simple and complex parts will be manipulated to mimic Close Ream tolerances to predict Assembly A success rates.

Three types of tolerances are considered in the following sections: hole diameter, hole positional tolerance, and hole pattern tolerance. Hole position and pattern are annotated together in the Geometric Dimensioning and Tolerancing (GD&T) scheme as composite tolerances.

A hole diameter tolerance is simply the amount a hole diameter is allowed to vary from nominal. An example of this is displayed in FIGURE 7 below, where the black circle indicates the nominal hole diameter of 0.3755”. The blue dotted lines, each concentric to the nominal hole, display a bilateral tolerance. This means that the nominal hole diameter can vary according to the amount specified in both directions. In this example, a 0.3755” hole is allowed to increase or decrease by 0.001” to provide an allowable range between Ø 0.3745” – 0.3765”. This bilateral hole tolerance would be annotated on a part drawing as 0.3755 +/-0.001”.

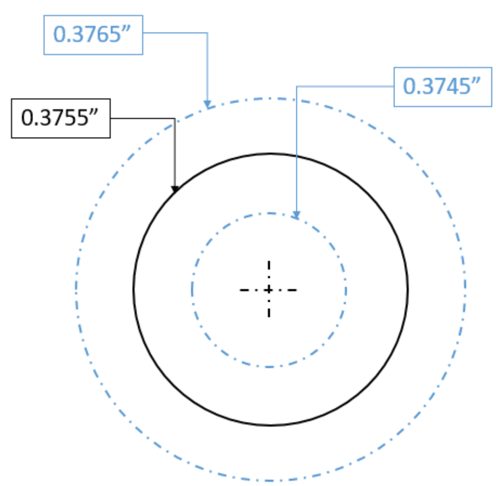


*FIGURE 7: HOLE DIAMETER BILATERAL TOLERANCE EXAMPLE*

A hole positional tolerance refers to where a hole is positioned in reference to a pre-defined set of datums. Common datum selections are holes and flat surfaces. An example of a simple part with specified datums is found below in FIGURE 8. The boxed letters A, B, C represent three datums used to locate part features. In this case, the datums are three planes. Part tolerances commonly contain boxed numbers called basic or theoretical exact dimensions.

As specified by the drawing source article “The M with a circle around it that appears after the geometric tolerance in the geometric frame prescribes that the positioning tolerance of Ø0.005 is to be applied when the hole is at its maximum material condition (MMC), which for our holes is Ø0.515. The geometric callout frame in [FIGURE 8] necessitates that the position of each hole should be within a cylindrical tolerance zone of Ø0.005 when the hole is at its MMC of Ø0.515, located by the basic dimensions as shown with respect to the primary datum A, secondary datum B and tertiary datum C” (Mehta, 2018).

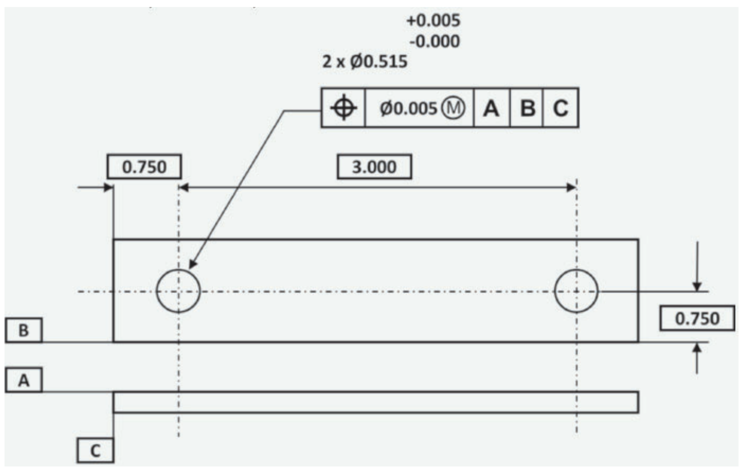


*FIGURE 8: HOLE POSITIONAL TOLERANCE EXAMPLE (Mehta, 2018)*

A hole pattern tolerance dictates the tolerance zone in which a pattern of holes can be located when in reference to specified datums. Hole pattern and positional tolerances are combined in one tolerance block to form a composite tolerance, where the positional tolerance is the top boxed specification and the pattern tolerance is the bottom boxed specification as shown in FIGURE 9 below. This example indicates that holes axes cannot vary in relation to one another or the datum structure by more than 0.2”.

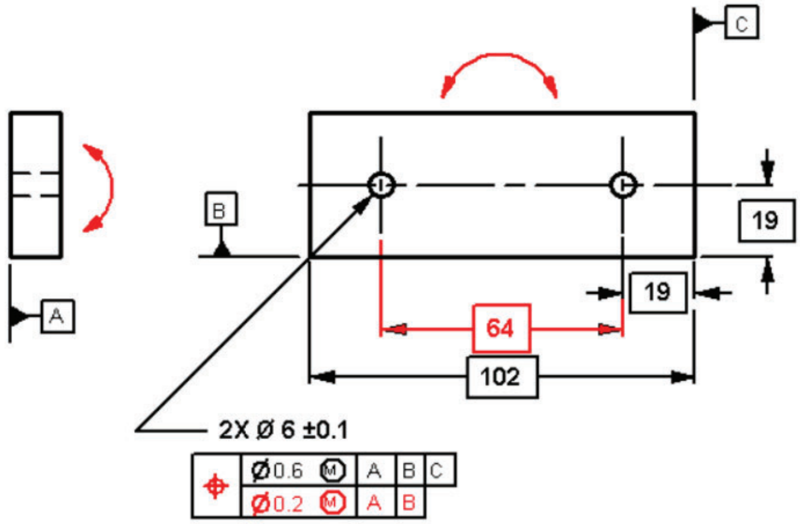


*FIGURE 9: HOLE PATTERN TOLERANCE EXAMPLE (Composite Tolerancing, 2019)*

## 3.3 MANUFACTURING CAPABILITIES FOR NON-COMPLEX PARTS

### 3.3.1 NON-COMPLEX HOLE DIAMETER ANALYSIS

The Aircraft XYZ primary structure team performed machine capability testing. The program reported measurement results in Company Z documents stored in an internal document repository. Two distinct 5-axis CNC machines were used to drill holes for the plated samples to simulate variability and reliability between multiple machines.

This testing is valuable to the Assembly A NPM effort because it demonstrates machine capability on a single plane. This data can be extrapolated to the Assembly A pieces that are machined on single planes to determine the likelihood of hole matchup for an NPM application with reasonable certainty. Assembly A single plane parts are primarily used as fairing structures encapsulating the assembly.

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As shown in FIGURE 12 and FIGURE 13, data for Machine 1 (Mach 1) and Machine 2 (Mach 2) do not have normal distributions. When testing an alternative hypothesis of a non-normal distribution among each machine scenario, we see a P-Value of less than 0.005. This indicates substantial evidence to reject the null hypothesis that the distributions are normal under the Anderson-Darling normality test.

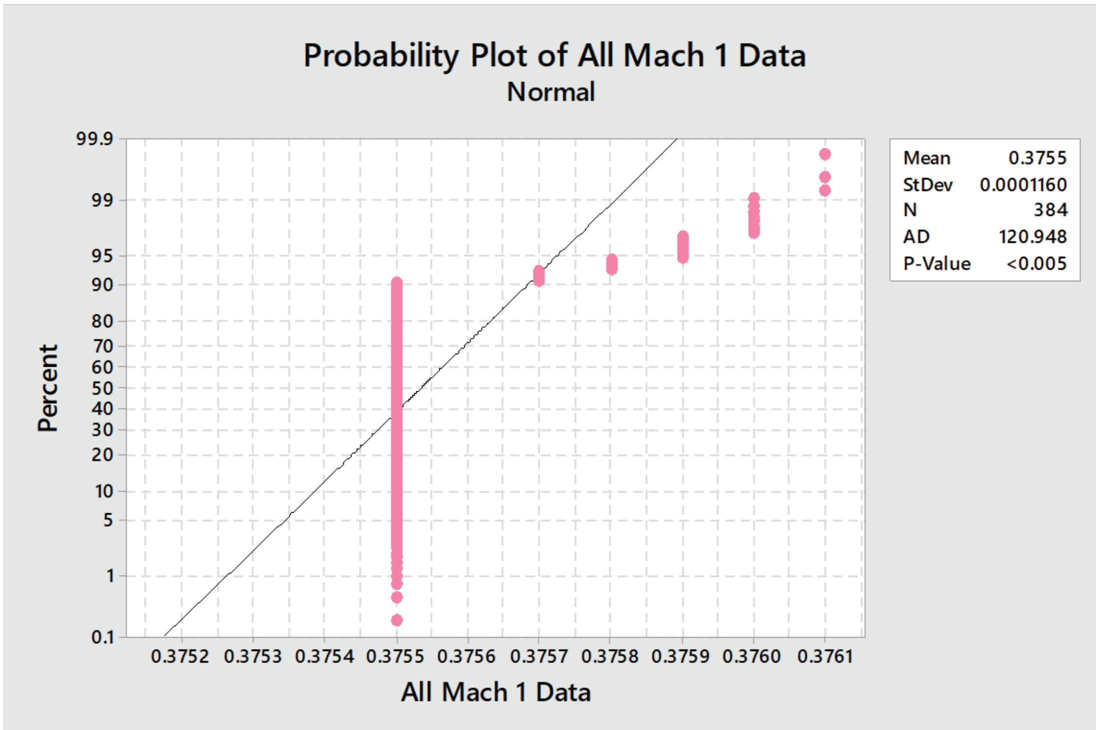


*FIGURE 12: MACHINE 1 ANDERSON-DARLING NORMALITY TEST*

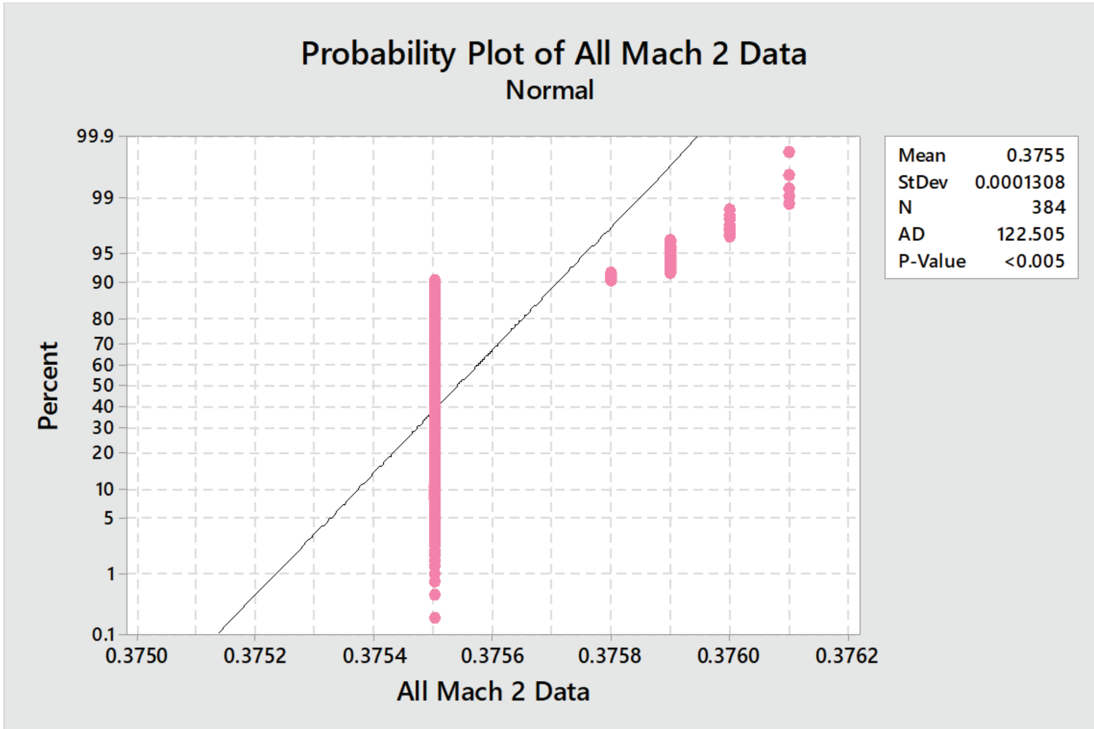


*FIGURE 13: MACHINE 2 ANDERSON-DARLING NORMALITY TEST*

Additionally, the histograms for Machine 1, Machine 2, and both machines combined in FIGURE 14 provide a visual indicator that the trends are not normally distributed. Means for all three data sets are higher than their medians suggesting a right skew. This affects the ability to determine the statistical significance of the process mean variation between Machine 1 and Machine 2 as well as the variation between test setups in tech machine. However, by using the central limit theorem we can assume that in repeated sampling the mean distribution will converge to a normal distribution. Therefore, this study will be treating the data for both Machine 1 and Machine 2 as normally distributed.

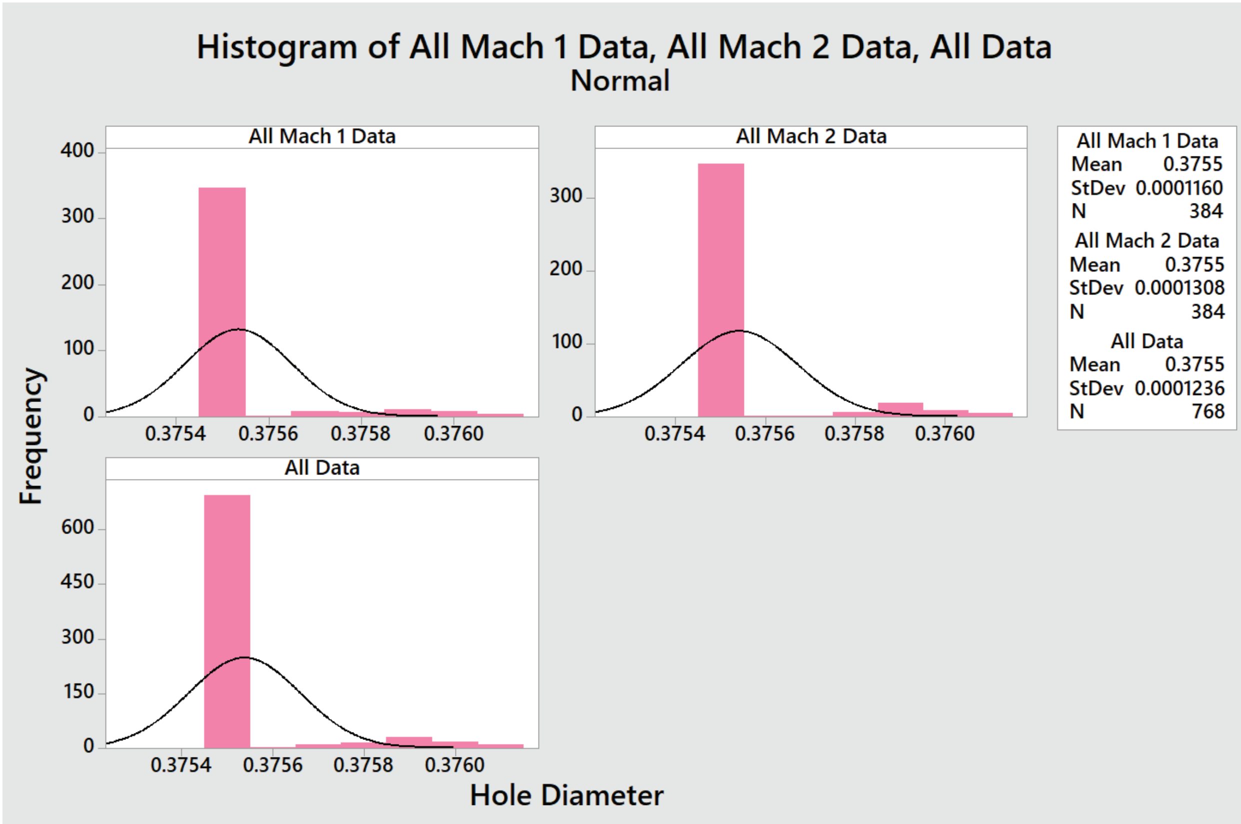


*FIGURE 14: MACHINE 1, MACHINE 2, ALL MACHINE HISTOGRAM DATA*

We will treat all the eight plates used per machine as one sample set to determine if the population means of Machine 1 and Machine 2 are equal to one another. With a null hypothesis equal to $Ho: \mu_1 - \mu_2 = 0$ Equation 1 and an alternative hypothesis equal to $H1: \mu_1 - \mu_2 \neq 0$ Equation 2 there is a calculated P-Value of 0.466. As this value is far greater than a significance level of 0.05, we have enough evidence to fail to reject the null hypothesis. Meaning, the population means between Machine 1 and Machine 2 are not statistically significant. In terms of NPM applications, this means that the Assembly A team can rely not only on hole size accuracy, but can rely on this accuracy across different CNC machines.

$$H_o: \mu_1 - \mu_2 = 0 \qquad \textit{Equation 1}$$

$$H_1: \mu_1 - \mu_2 \neq 0 \qquad \textit{Equation 2}$$

### 3.3.2 PROCESS QUALITY CAPABILITY ANALYSIS FOR AIRCRAFT NON-COMPLEX PART HOLE DIAMETERS

Process quality capability is a chief concern in the manufacturing industry. $C_p$, $C_{pk}$, $P_p$, and $P_{pk}$ are four metrics that are traditionally used in the industry to determine if a process is under control and therefore safe and predictable to a high degree of certainty. $C_p$ and $C_{pk}$ indicate process capability while $P_p$ and $P_{pk}$ indicate process performance.

As Daniela Marzagão so aptly summarizes in her article from the popular ISIXSIGMA online resource "The difference between capability rates ($C_p$ and $C_{pk}$) and performance rates ($P_p$ and $P_{pk}$) is the method of estimating the statistical population standard deviation. The difference between the centralized rates ($C_p$ and $P_p$) and unilateral rates ($C_{pk}$ and $P_{pk}$) is the impact of the mean decentralization over process performance estimates" (Marzagao, 2019).

If the example displayed previously in FIGURE 7 is considered, a hole diameter of 0.3755 +/-0.001" indicates the range for acceptable dimensions is 0.3745 – 0.3765". In essence, $C_p$ and $P_p$ do not consider where the mean averages fall in this range, only that the majority of the data points (4 sigma) remain in the range. $C_p$ and $P_p$ values communicate that the process is accurate within the boundaries of the tolerance. $C_{pk}$ and $P_{pk}$ communicate whether these processes are centered i.e. if the mean values of the data points are close to the nominal value and tails (4 sigma) are contained within the tolerance range.

Process capability metrics ($C_p$ and $C_{pk}$) determine if a process is capable over time. Data points over many different tool passes, setups, and batches are used to form a complete picture of how capable a process is. Process performance metrics ($P_p$ and $P_{pk}$) are more focused on a specific set of samples. Process performance is generally used for small batches, or in situations where multiple tools, setups, and batches are not possible. They will not be used as a metric for this project.

We will focus on the values attained for $C_{pk}$ in for Aircrafts ABC, XYZ, and UVW. A $C_{pk}$ value of 1.33 or more is the general industry standard for confidence in a controlled manufacturing process as it indicates a four sigma compliance. This compliance value means that for every one million parts that are manufactured, sixty-three of them will be out of tolerance. This equates to 99.9937% parts within specification limits. In more regulated industries such as biomedical instruments and aerospace manufacturing a $C_{pk}$ value of two is used for a six sigma compliance.

Statistically, six sigma compliance indicates that for every one million parts manufactured .002 of them will be outside of specification. This translates to 99.999% of parts being within specification. Cpk is determined using $C_{pk} = min\left(\frac{USL-\ \mu}{3\ x\ \sigma}, \frac{\mu - LSL}{3\ x\ \sigma}\right)$

Equation 3 below.

$$C_{pk} = min\left(\frac{USL-\ \mu}{3\ x\ \sigma}, \frac{\mu - LSL}{3\ x\ \sigma}\right) \qquad \textit{Equation 3}$$

Where, USL = Upper Specification Limit

LSL = Lower Specification Limit

μ = Mean value

σ = Standard deviation

Incremental $C_{pk}$ values and their associated sigma compliance values as well as defects per million can be found in TABLE 4 below.

*TABLE 4: CPK VALUE CONVERSION TABLE (Marzagao, 2019)*

| $C_{pk}$ | Sigma Limits | PPM Defective | % Population within Limits |
|---|---|---|---|
| **.33** | 1 Sigma | 317,300 | 68.27% |
| **.67** | 2 Sigma | 45,500 | 95.45% |
| **1.00** | 3 Sigma | 2,700 | 99.73% |
| **1.33** | 4 Sigma | 63 | 99.9937% |
| **1.5** | 4.5 Sigma | 3.4 | 99.99966% |
| **1.67** | 5 Sigma | 0.6 | 99.99994% |
| **2.00** | 6 Sigma | 0.002 | 99.99999 |

The $C_{pk}$ values for Aircraft ABC, Aircraft XYZ, and Aircraft UVW can be found listed in TABLE 5TABLE 5. Each aircraft was analyzed separately. A single piece part type was chosen for each aircraft and a specific hole type and diameter on this piece was chosen for analysis. Multiple measurements of this hole type for each aircraft were analyzed to determine $C_{pk}$ levels for that aircraft. Each hole was treated as a separate data point. This data was translated into a bell curve for each aircraft type in which the $C_{pk}$ can be determined for that hole diameter.

*TABLE 5: AIRCRAFT HOLE PROCESS ANALYSIS RESULTS*

| Aircraft Model | Tolerance Scheme | $C_{pk}$ | $C_p$ | $P_{pk}$ | $P_p$ |
|---|---|---|---|---|---|
| Aircraft ABC | Close Ream | 4.80 | 4.99 | 2.59 | 2.70 |
| Aircraft XYZ | Class 1 | 0.19 | 7.48 | 0.10 | 4.05 |
| Aircraft UVW | Class 2A | 4.80 | 4.99 | 2.59 | 2.70 |

As shown in FIGURE 15, a $C_{pk}$ value of 4.80 for both Aircraft ABC and Aircraft UVW indicates drilled holes for these aircraft are well within the specified tolerance boundaries and the hole drilling process is in control with a near-perfect level of certainty for hole diameters. These values surpass the general industry standard of $C_{pk}$ 1.33 by a large margin. This is graphically displayed in FIGURE 15 using again the example of a 0.3755" diameter hole with a tolerance of +/-0.001". The dotted red vertical lines indicate the specified tolerance boundaries. The bell curve peaks displaying mean measurement value lie very closely to the 0.3755" nominal diameter specification. Bell curve tails remain within the tolerance range in this graphic, signaling a high level of $C_{pk}$ compliance.

Data is not always as straightforward as this set. The calculated $C_{pk}$ level of 0.19 for Aircraft XYZ is graphically displayed in FIGURE 16. This could indicate this process is not in control, however the high $C_p$ level of 7.48 displayed in TABLE 5 indicates that the process is well within tolerance boundaries but is not centered within the tolerance range. Aircraft XYZ uses a unilateral tolerance scheme for the 0.3755 hole, with a specification of +0.003 and -0.000. As shown, the bell curve means are centered on the low end of the tolerance range which in this case is the nominal measurement. In this case, $C_{pk}$ does not tell the whole story and is not the best statistic to relay manufacturing information.

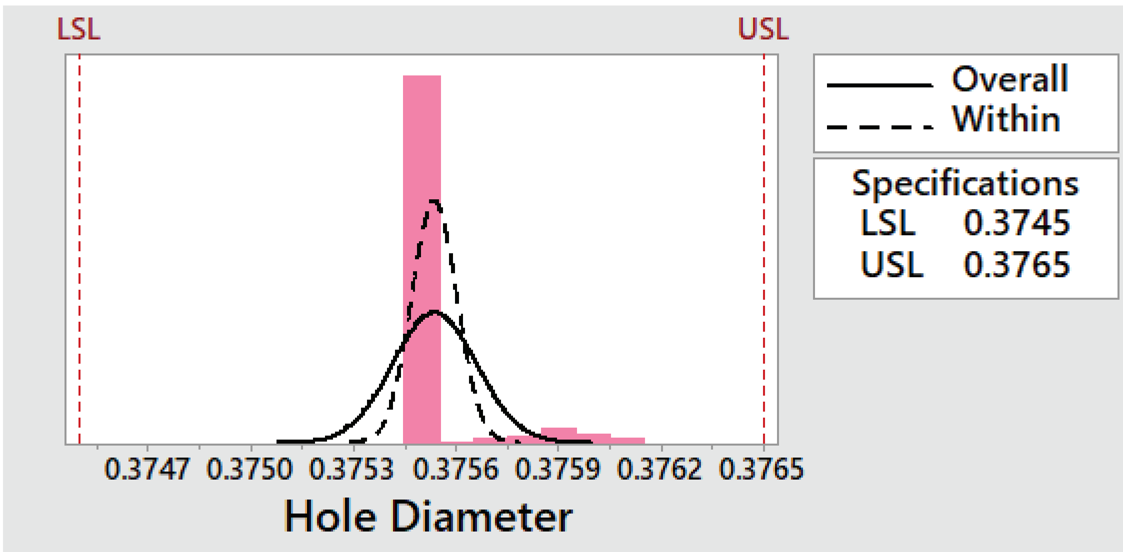


*FIGURE 15: AIRCRAFT ABC/ UVW CPK ANALYSIS*

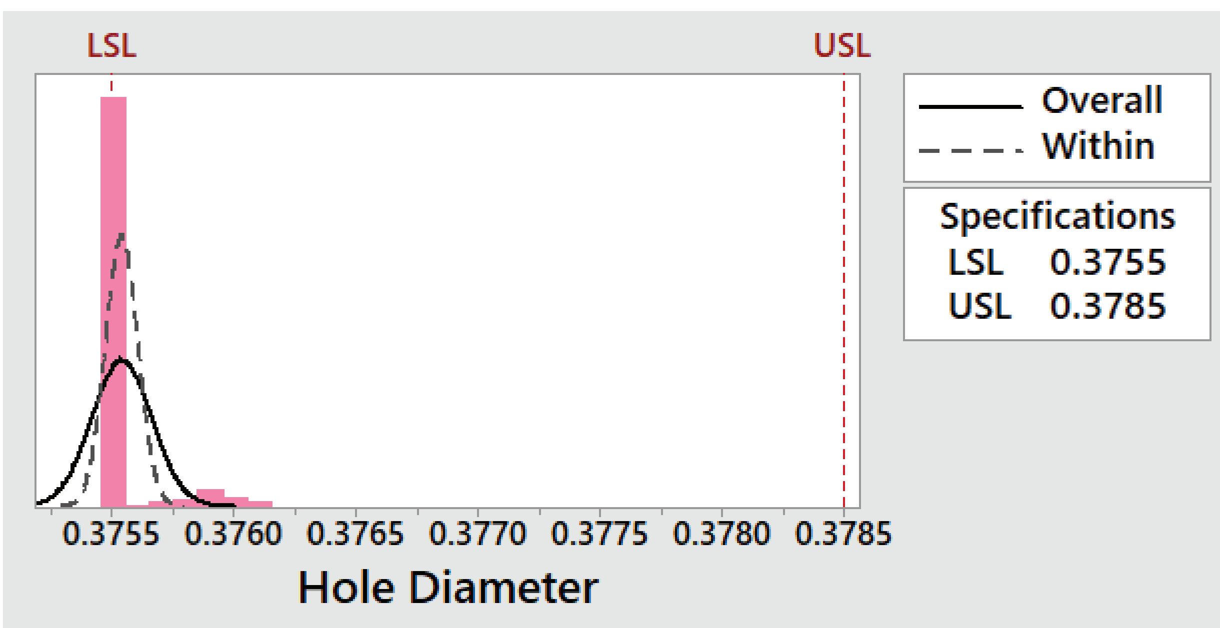


*FIGURE 16: AIRCRAFT XYZ CPK ANALYSIS*

### 3.3.3 NON-COMPLEX HOLE POSITION AND PATTERN ANALYSIS

With the data pointing towards a controlled CNC machining capability for Close Ream hole diameters, the next analysis is to determine if the process is able to hold hole position and hole pattern locations within tolerance. Assembly A piece parts are defined using a Global Dimensioning and Tolerancing (GD&T) method. This means that hole features are not only controlled for their diameter (size), but their form, orientation, and location as well. GD&T uses composite tolerances to control for the latter three features. The nominal position for each feature, in this case a hole, is defined by a 3D Computer Aided Design (CAD) model. A positional tolerance specifies a boundary which the hole can occupy and still be considered within specifications. This tolerance references a datum scheme defined by the part design and manufacturing team.

Because raw measurement data exists for piece parts used by Aircraft XYZ and Aircraft UVW programs, these data points can be analyzed using Aircraft ABC tolerance schemes to simulate future Aircraft ABC measurements and NPM assembly results.

To begin this process, a simple non-complex v-shaped part used in Aircraft XYZ was measured on a CMM and used to build the data shown in TABLE 7. This table summarizes the pass rate averages for each feature in the part, displaying the results in the highlighted column 3. Because the part is v-shaped, two surfaces are measured distinctly from one another and identified as the “Top” surface and the “Angle” surface. These names correspond to the position of the flanges when the part is viewed in an isometric orientation. The data was then re-run using the tolerance schemes from Aircraft ABC (column 2) and Aircraft UVW (column 4) to understand how the tolerance changes across programs affect feature pass rates.

Tolerances are generally tightest for the Aircraft ABC program and loosest for the Aircraft UVW program, with Aircraft XYZ in the middle. This is due to the requirements in the Aircraft ABC program where Close Ream is needed due to stress and fatigue considerations for Assembly A. Aircraft XYZ and UVW have less stress and fatigue mandates for the subassemblies chosen for analysis and are therefore able to allow more variance in their dimensioning schemes.

*TABLE 7: AIRCRAFT XYZ NON-COMPLEX NPM HOLE PART CMM PROFILE AND POSITION PASS PERCENTAGES RECONSTRUCTED FOR AIRCRAFT ABC AND AIRCRAFT UVW*

| | **Aircraft ABC Simulated Tolerances** | **Aircraft XYZ Tolerances** | **Aircraft UVW Simulated Tolerances** |
|---|---|---|---|
| | Close Ream | Class 1 | Class 2A |
| **Top Surface: Profile** | 97.87% | 100.00% | 100.00% |
| **Top Surface: Hole Position** | 29.16% | 100.00% | 100.00% |
| **Top Surface: Hole Composite Position** | - | 100.00% | 100.00% |
| **Angle Surface: Profile** | 100.00% | 100.00% | 100.00% |
| **Angle Surface: Hole Position** | 41.66% | 100.00% | 100.00% |
| **Angle Surface: Hole Composite Position** | - | 97.67% | 100.00% |
| **Inner Radii** | 12.50% | 100.00% | 100.00% |
| **Part Periphery** | 67.64% | 100.00% | 100.00% |

TABLE 7 shows us that for both the Top and Angle surfaces, 5-axis CNC machines are capable of maintaining profiles within specified tolerances for each program. Percentages show that almost 98% of all parts are within specification for all three programs. Similarly, the machines are capable of maintaining pass rates of ~98% part acceptance and higher for hole position and hole pattern position for Aircraft XYZ and Aircraft UVW tolerances. Hole pattern tolerances were not specified for Aircraft ABC.

However, hole position pass rates of only 29.16% and 41.66% for the Top and Angle surfaces respectively show that current 5-axis CNC machining is not able to maintain Close Ream tolerances needed by the Aircraft ABC program for hole position. The CNC machines are statistically able to maintain only Class 1 tolerance schemes for this feature type.

## 3.4 MANUFACTURING CAPABILITIES FOR MULTI PLANE PARTS

When analyzing complex piece part data sets we see similar, more pronounced trends as compared to the non-complex data analysis. Piece parts containing more complex geometry spanning over multiple planes present challenges to the CNC machining process. Often, piece parts cannot be manufactured with a simple setup due to the complexity of feature locations. Parts must be reoriented for part of the manufacturing process. It was proven earlier in this chapter that machines are consistent across multiple machines and setups for single plane and non-complex parts. In the case of more complex parts, we are adding another variable by adding at least one more setup per piece part.

Aircraft UVW provided hole positional measurement data for a piece part that can be classified as "complex," with many planes, complex features, and holes that are difficult for a machine head to reach. Only hole positional tolerance was considered for complex parts as it was previously demonstrated that it is a fairly simple manufacturing feat to maintain statistical consistency across hole diameters.

Similar to the non-complex case in the last section, the positional measurement data was averaged to produce a final pass/fail percentage for Aircraft UVW, displayed in the highlighted row 4 of TABLE 8. Statistics were run on this data a second and third time, manipulating tolerances to mimic those found in Aircraft XYZ and Aircraft ABC programs. This data summary can be found in row 2 and row 3.

*TABLE 8: NPM HOLE POSITION MEASUREMENTS FOR COMPLEX PART PASS/FAIL PERCENTAGE*

| Aircraft Model | Tolerance Scheme Desired | Percentage Pass | Percentage Fail |
|---|---|---|---|
| Aircraft ABC | Close Ream | 54% | 46% |
| Aircraft XYZ | Class 1 | 74% | 26% |
| Aircraft UVW | Class 2A | 100% | 0% |

The analysis results show that the CNC manufacturing process is unable to consistently produce complex piece parts using the Close Ream tolerances desired by the Aircraft ABC team. Additionally with a fail rate of 26%, the process appears to be unable to hold hole positional tolerance requirements for Class 1 holes consistently. Based on this data it is expected that the Assembly A demonstration will fail when attempting to assemble complex parts in the majority of instances if it specifies anything tighter than a Class 2A tolerance scheme.

## 3.5 MANUFACTURING CAPABILITIES IN SHOT PEENING

Shot peening is a commonly used manufacturing technique for metals requiring additional strength for particular use cases where the part must undergo cyclic and repetitive loads. It is commonly used on primary structure parts in the aerospace industry. Generally Airblast technology is used in equipment which shoot small spherical shot peen media (usually metal, glass, or ceramic) at a metal component. This process works by creating many small dimples which in combination plastically deform the material surface (What is Shot Peening?, 2019). This induces residual compression stress as the surface below each dimple is under compression. Because the compressive environment is resistant to crack propagation, this process is very effective.

A common material choice for Company Z structural parts is Titanium alloy Ti-6Al-4V, with high strength, low weight, and excellent corrosion resistance. This alloy has a yield strength of 850 MPa prior to shot peening, with an increased yield strength of up to 1080 MPa after undergoing the shot peening process, or about a 27% increase (Xie, Wen, Wang, Jiang, & Ji, 2016). This process and material have been selected for structural members in Assembly A and for Assembly A equivalents in other Company Z aircraft. The piece parts analyzed in this section are manufactured using Ti6Al4V and have been selected to represent similarly processed Assembly A parts as applied to an NPM application.

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# 4. ORGANIZATIONAL ARCHITECTURE

## 4.1 EXISTING ARCHITECTURE

Company Z is developing Aircraft ABC using the Agile philosophy. The Agile strategy pulls together team members from various traditional job functions to support a common goal. This allows them to manage teams and work in an organized fashion that is traceable and easily aligned to program gates which dictate major program milestones. Agile has been implemented successfully in other Company Z development teams. Aircraft ABC aims to adopt this strategy to improve overall development. It is currently being used to aid in the NPM development efforts for Assembly A. The challenges with implementing this Agile strategy in Aircraft ABC lies in Company Z's inexperience with Agile implementation at such a large scale. Aircraft ABC will be implementing Agile program-wide and incorporating the strategy into process gating which has and will continue to result in a learning curve for Company Z.

### 4.1.1 Company Z AGILE METHODOLOGY

Agile is an umbrella term for many frameworks which aim to develop large scale projects using iterative means and continuous feedback loops. Agile projects break large efforts down in to small increments and allow for testing of each increment before moving to the next. This inherently builds quality into the process and creates quick learning cycles, enabling the mantra of continuous improvement (An Introduction to Agile Frameworks, 2019). Agile provides businesses the opportunity to use feedback cycles to produce learnings. The fast thinking derived from this process flow ideally becomes a cost saver, as each sequential task is completed with more and more knowledge.

Specifically we will review the Scaled Agile Framework (SAFe) under the Agile umbrella to develop Assembly A. FIGURE 17: SIMPLIFIED Company Z AGILE FRAMEWORK displays a simplified map of the SAFe configuration as it is implemented within the Company Z Assembly A team. This framework begins with the vision for the Assembly A end product. Based on this vision, the team is divided in to three distinct roles: product owners, scrum masters, and team members. Product owners create a product backlog which includes a list of items that must be completed to accomplish the vision based off of business goals. They interact with high level decision makers to prioritize these goals. These goals are presented to teams during iteration planning to determine which can be completed during an iteration given available resources. Each iteration is no longer than three weeks and thus a finite amount of items in the backlog can be accomplished. Any impediments encountered during each iteration period are immediately addressed and solved by the scrum master. An iteration demo is completed at the end of every iteration period as an opportunity for all stakeholders to understand the finished product and provide feedback. Each iteration concludes with a retrospective, which serves as a lessons learned to be applied to the next iteration.

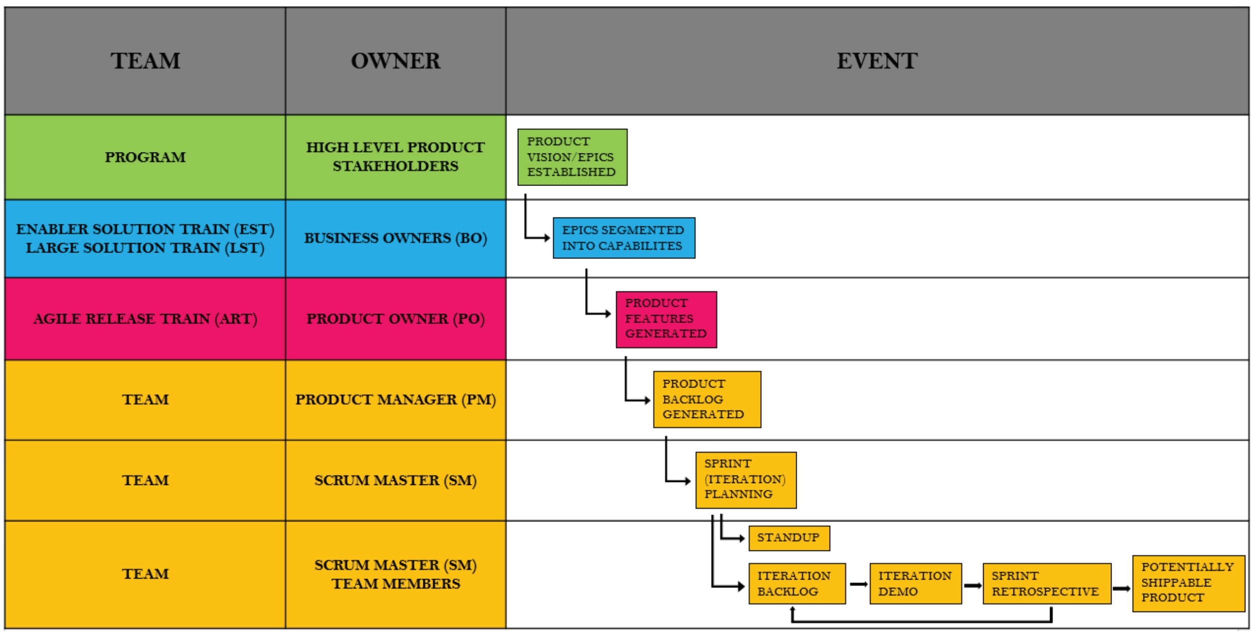


*FIGURE 17: SIMPLIFIED Company Z AGILE FRAMEWORK*

### 4.1.2 TRADITIONAL TEAM FUNCTIONS

The Assembly A development effort spans over thirteen functional teams. These teams are either solely dedicated to Assembly A or contribute as part of their overall job functions, which may include other Aircraft ABC efforts. Examples of functional teams at most companies include stress and design engineering, manufacturing, supply chain, and finance. These teams work together to learn from each other's expertise in their specific functional areas to build a product.

Four Agile teams have been assembled for Assembly A development and participate in NPM implementation: the Build Enablers team focusing on affordability targets, the Design Build Research Team (DBRT) focusing on NPM implementation, design, stress, and other engineering aspects, the Productivity Demo team working on the design and implementation of the NPM test demonstration, and the Design Build Team (DBT) focusing on Assembly A builds. Within these teams only four functional teams (teams reporting to the same manager) are included in the official team roster. This is a huge improvement opportunity for the Assembly A NPM effort. More cross functional interactions will foster a better result. The process to categorizing the current state and proposal for improvements is detailed in the following section.

## 4.2 NPM COLLABORATION STUDY

With the knowledge of limited team participation in the four Agile groups, a study was performed to test the hypothesis that there is limited cross-team collaboration between Assembly A functional groups as part of the NPM development effort. Though the existing Agile team list helps to support this hypothesis, it cannot account for informal meetings and "hallway conversations" between team members. These can manifest as meetings, phone calls, emails, instant message, and physical conversations. Interactions between team members external to the Agile teams and those listed on the teams create added value that has not been accounted for.

### 4.2.1 COLLABORATION STUDY PHASE ONE: SURVEY INTRODUCTION AND COMPILATION

The first phase of the collaboration study was to deploy a survey to functional groups with a stake in Assembly A development. Survey questions asked various Assembly A team members to state their own functional team and rate the level of interaction they have with other teams also working on Assembly A. After asking participants to identify their functional group the survey progresses through a series of thirteen questions, each asking a version of the question "How often do you interact (emails, phone calls, meetings, in person) with Team X for Assembly A NPM Activities?" for varying X teams.

The response rate for this survey was 80% within the first 24 hours of release. This may indicate that many of those surveyed also hypothesized that there were communication issues needing to be addressed and were thus motivated to participate. Because of this response rate, the survey was able to gather a statistically significant data set across the Assembly A organization in a short period of time.

For each question, survey participants were asked to select one answer as shown below in the "Multiple Choice Option" column in TABLE 9*: WEIGHTED COLLABORATION RATINGS* . Each individual response was weighted according to the stated amount in the "Points Assigned" column of TABLE 9. Weight values were assigned in non-linear increments for each successive collaboration level. This is due to the exponential increases between collaboration cadence options (i.e. “Once” is only slightly more often than “Never”, but “Daily or more” is significantly more often than “Weekly”).

*TABLE 9: WEIGHTED COLLABORATION RATINGS*

| **Multiple Choice Option** | **Points Assigned** |
|---|---|
| I do not know who this team is | 0 |
| Never | 1 |
| Once | 2 |
| Monthly | 5 |
| Weekly | 10 |
| Daily or more | 25 |

Within each functional team, individual points assigned from survey participants were averaged for each question. Based on this average, team match-ups were each assigned a collaboration level with score values from “Low” to “Very High” as shown in TABLE 10.

*TABLE 10: COLLABORATION RESULTS CATEGORIZATION*

| **Collaboration Level** | **Average Score Range** |
|---|---|
| Low | 0 - 5 |
| Medium | 6 – 10 |
| High | 11 - 20 |
| Very High | 21 - 25 |

### 4.2.2 COLLABORATION STUDY PHASE TWO: NPM COLLABORATION RESULTS ANALYSIS

During phase two of the collaboration study, the collaboration scores were mapped across all thirteen functional teams surveyed to identify trends and gaps in the data. This functional group data can be compared to the Agile group data to determine opportunities for improvement.

TABLE 11 details the raw survey results from all participant averages for all teams surveyed. All "Low" results are coded as light red, "Medium" as light yellow, "High" as light green, and "Very High" as darker green. Additionally, the four blue squares shown outline the functional teams involved with each of the four Agile teams referenced previously. The raw survey results display a visual representation of the number of functional groups involved with the Agile structure versus the number of total possible teams who are not.

*TABLE 11: RAW SURVEY RESULTS*

| Team | Q1 | Q2 | Q3 | Q11 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Description of job for Program for Assembly A related work | Collaboration Frequency with ***Team A*** for Assembly A Activities? | Collaboration Frequency with ***Team B*** for Assembly A Activities? | Collaboration Frequency with ***Team C*** for Assembly A Activities? | Collaboration Frequency with ***Team D*** for Assembly A Activities? | Collaboration Frequency with ***Team E*** for Assembly A Activities? | Collaboration Frequency with ***Team F*** for Assembly A Activities? | Collaboration Frequency with ***Team G*** for Assembly A Activities? | Collaboration Frequency with the ***Team H*** team for Assembly A Activities? | Collaboration Frequency with ***Team I*** for Assembly A Activities? | Collaboration Frequency with ***Team J*** for Assembly A Activities? | Collaboration Frequency with ***Team K*** for Assembly A Activities? | Collaboration Frequency with ***Team L*** for Assembly A Activities? |
| Team A | - | - | - | - | - | - | - | - | - | - | - | - |
| Team B | 7.50 | 25.00 | 25.00 | 5.00 | 17.50 | 0.50 | 2.50 | 0.50 | 5.00 | 5.00 | 10.00 | 1.00 |
| Team C | 17.50 | 25.00 | 25.00 | 7.50 | 17.50 | 5.00 | 5.50 | 5.00 | 10.00 | 5.00 | 5.00 | 6.00 |
| Team D | 8.33 | 15.00 | 25.00 | 25.00 | 20.00 | 1.67 | 2.33 | 7.33 | 5.00 | 5.00 | 13.33 | 1.00 |
| Team E | 8.75 | 11.25 | 17.50 | 8.75 | 25.00 | 4.50 | 7.75 | 4.00 | 8.00 | 6.25 | 6.25 | 15.25 |
| Team F | 1.75 | 7.00 | 11.25 | 7.00 | 11.25 | 21.25 | 16.25 | 0.75 | 2.75 | 1.75 | 7.00 | 4.25 |
| Team G | - | - | - | - | - | - | - | - | - | - | - | - |
| Team H | 0.67 | 0.67 | 4.33 | 7.00 | 6.67 | 0.67 | 4.00 | 25.00 | 2.67 | 0.67 | 1.00 | 1.00 |
| Team I | - | - | - | - | - | - | - | - | - | - | - | - |
| Team J | 1.00 | 2.00 | 10.00 | 1.00 | 10.00 | 10.00 | 10.00 | 1.00 | 10.00 | 25.00 | 1.00 | 10.00 |
| Team K | 1.00 | 10.00 | 10.00 | 0.00 | 25.00 | 25.00 | 25.00 | 0.00 | 2.00 | 10.00 | 25.00 | 10.00 |
| Not Listed | 2.00 | 5.00 | 5.00 | 5.00 | 5.00 | 1.00 | 1.00 | 10.00 | 5.00 | 5.00 | 10.00 | 1.00 |

FIGURE 18 displays the percentages of team match ups within each collaboration level category. A notable trend is that the highest concentration of "High" and "Very High" interactions occur clustered in areas where teams are physically close together. Teams farthest from one another, whether in separate states or working on separate aircrafts entirely displayed the highest number of "Low" scoring team interactions.

On the surface, this survey data suggests that there are lost opportunities resulting from almost 50% of team pairs having low or no interaction at best, and complete unfamiliarity with each other at worst. In fact, of the functional team matches in the "Low" collaboration category, 20% of these team responses indicated that they did not know of another team listed. Only 25% of team pairs scored a "High" or "Very High" level of collaboration. Though this data paints a picture of very low collaboration, there are complex interaction factors at play that influence the interpretation of the results. An additional phase in this study is needed to interpret these results in a way that fairly represents team interactions as value and non-value added, which is dissected in the following section. Not all team pairs in the "Low" category have a value add when communicating with one another. Conversely, there are some team pairs in which there will be considerable value added from early and continuous engagement.

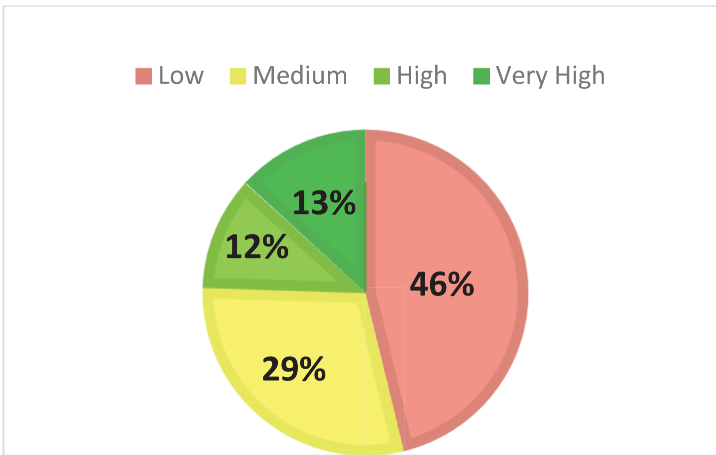


*FIGURE 18: COLLABORATION LEVEL PERCENTAGES*

### 4.2.3 COLLABORATION STUDY PHASE THREE: IDENTIFICATION OF SPECIFIC IMPROVEMENT OPPORTUNITIES IN NPM COLLABORATION

This study provides a look at the general picture of the ground level Assembly A development. Further exploration is required to determine a path forward. Not all teams need to interact with one another at all stages in the development cycle. Therefore, the collaboration level percentages shown in FIGURE 18 are a good tool to show trends but do not provide the granular details necessary to make actionable changes. Phase three of the analysis was spent interviewing key stakeholders in each functional group to provide the additional information necessary to make recommendations. Interviewees were asked the following questions:

(1) What areas does your group contribute to overall Assembly A development effort?

(2) What areas of development could your team be of benefit that you are not included in?

(3) Do you see any holes with the current state of interaction between all groups invested in the Assembly A development?

A common trend reported by interviewees was the necessity for Design and Stress Engineering (Teams B and C in TABLE 11) to pull in more teams earlier on in their process. Teams also expressed their willingness to collaborate more with Manufacturing (Team K), Supply Chain (Team A), and Quality (Team J) but did not know who to contact or how to do so. The Variation Risk Management (VRM) team specializing in NPM and tolerance analysis felt their value was providing input to all Assembly A development groups and coordinating to disperse information amongst the teams. Based on evidence from VRM (Team F) interactions in TABLE 11*: RAW SURVEY RESULTS*this was not the case being perceived by other teams.

A top observation of the team members interviewed was regarding the Agile process implementation and the ineffectiveness of the collaboration it is introducing. Though the Agile philosophy is designed to be inclusive, it is not manifesting in the Assembly A NPM teams. This is cause for concern because poor communication creates an environment where creativity is stifled and solutions are not optimized. The reported current condition is that work is happening in silos and valuable input from other groups is not being heard. The root cause for this issue lies in the way the Company Z Aircraft ABC program has defined Agile teams.

Agile teams are inadvertently non-inclusive because the stated cross functional job roles in these teams were originally determined by job type code and not group. For example, the DBRT team contains nineteen engineers, however these nineteen engineers report up through only four different managers. This is the most diverse Agile group, with Build Enablers and Productivity Demo teams containing employees reporting up through only two managers, and the DBT team with all members reporting to the same manager. An additional root cause for the siloed work efforts is the nature of the quick cycles in the Agile framework. The three week increments require workers to focus solely on impending deadlines rather than collaboration. Anecdotally, interviews indicated that there is no time left for dedicated collaboration efforts. This is an indication that the incremental workloads are too large for the current staff to handle effectively.

### 4.3 THREE LENS ANALYSIS

In parallel with an Assembly A Agile framework analysis, it is helpful to view an organization through strategic, cultural, and political lenses prior to suggesting any organizational changes. The following three lens analysis helps to frame the potential upsides and pitfalls of introducing a new process to a group of seasoned employees well-versed in a more traditional approach. The approached is modeled after John S. Carroll's Introduction to Organizational Analysis: The Three Lenses (Carroll, 2006).

### 4.3.1 STRATEGIC ANALYSIS

By developing Aircraft ABC using the Agile strategy, Company Z is able to manage teams and work in an organized fashion that is traceable and easily aligned to program gates. Assembly A development is tasked to follow this strategy but as shown in the organizational analysis in the previous section, the Agile process is not currently working as intended. At a micro level this creates a problem with cross functional related creativity and information flow. It also affects the broader development framework for Aircraft ABC because Assembly A is intended to be used as a pilot for NPM implementation for later development efforts. Without cross functional collaboration, key conclusions regarding technical feasibility may be missed. Strategy must therefore be adapted to remedy the communication holes identified by the organizational analysis.

### 4.3.2 CULTURAL ANALYSIS

Viewing Aircraft ABC through a cultural lens reveals a deviation from the traditional project development mindset existing at Company Z. The push for NPM is symbolic in that the company is looking to weave more innovation into their cultural foundation, particularly regarding the airplane production system. This is received differently by different groups. Dissenters include those who believe NPM is not technically feasible or those who have been with the company for many years and are used to the status quo. Supporters are generally transplants from other groups who have been through an NPM conversion process before and believe it will work for Aircraft ABC. This division of opinions is common when introducing a big change to a business. The low level of cross functional collaboration within Assembly A teams has resulted in a slower development of new norms. The group is stagnant in the storming phase.

A perhaps big contributor to the number of dissenters is the compartmentalized nature of the NPM implementation communication. Transplants from external groups have been tasked to implement NPM in Aircraft ABC and are working with leadership to do so. However, their communication with many of the technical experts is limited. This framing is creating an “us vs. them” mentality which is slowing down the process of gaining acceptance among dissenters. The primary cultural lever to improve this situation is the sharing of data. Data provides a strong basis for collaboration success in that it can be tested, refuted, or proven. NPM implementation perception can then shift from a package delivered as an imposition to an exploration of possibilities.

### 4.3.3 POLITICAL ANALYSIS

FIGURE 19 below highlights challenges in the Assembly A team by mapping the political differences between those associated with the NPM project. As illustrated, the primary dissenters are the technical design team who have interests in designing a safe, reproducible product. This group holds a high powered position because it is the technical driving force for NPM design and testing. However, they answer to their leadership. Leadership is politically linked to the NPM supporters such as the Production, Preparation, Process (3P), lean, tooling, and process teams, thus giving the NPM supporters power. Relations between leadership and the individual contributors at Company Z are generally more top down than bottom up. Though direction at Company Z primarily comes from leadership interest, this system can be harnessed so that it is advantageous to all parties. It is clear that supporters and dissenters are in conflict, but leadership can work to meet with Agile teams regularly. Giving engineers a platform to voice concerns with leadership will empower the group.

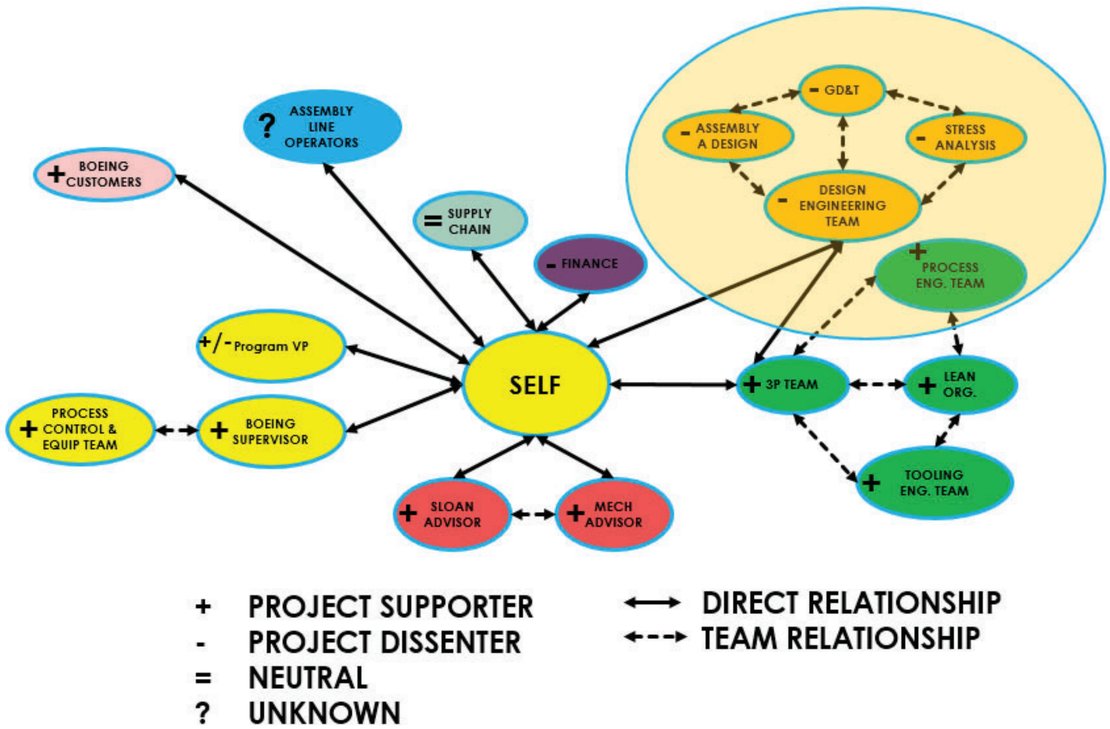


*FIGURE 19: STAKEHOLDER ANALYSIS MAP*

There is a notable relationship between the map displayed in FIGURE 19 and the collaboration survey results displayed in TABLE 11. The primary dissenters enveloped in the yellow circle are the same design and stress engineers that make up survey teams B and C. These teams are clustered together geographically, have similar functions and managers, and have similar opinions. Because of this, they are a force that proves difficult to persuade especially considering they are the primary members of the Agile teams tasked with exploring NPM implementation. However, these teams are closely linked with Process (Team E) and Tooling/Mechanic (Team K) teams who are all supporters of the NPM implementation. This is evidence that increased collaboration will in fact help supporters to persuade dissenters to change their mindset to the acceptance of an NPM implementation in Assembly A.

# 5. CONCLUSIONS

## 5.1 TECHNICAL CONCLUSIONS

Data sets for non-complex and complex parts were provided from Aircraft XYZ and Aircraft UVW teams. The data sets provided from these programs used datum structures and tolerances defined by their associated aircraft development teams, and this information is clearly indicated on part drawings. These information sets were manipulated to simulate Aircraft ABC's datum setup, measurements, part fixturing, machining order of operations, and process methodology in the absence of any physical Aircraft ABC piece parts to study. Because the parts analyzed were designed and sourced by other programs, they provide only a statistical estimate of expected results for the Assembly A project. Actual results for Assembly A cannot be fully proven or disproven until a full demonstration is performed to mimic production manufacturing and assembly process as designed for that specific subassembly. The data provided from Aircraft XYZ and Aircraft UVW is used to provide a baseline for which the Aircraft ABC Assembly A demonstration can be compared against.

Assumptions used for the data collected are as follows:

(1) 5-axis CNC was used to manufacture all parts that provided data to this analysis
(2) Machining tolerances do not vary across differing materials
(3) Proper thermal regulating best practices were used for part manufacture (i.e. coolant, temperature controlled environment)
(4) Data was captured from a high resolution CMM that can accurately detect variation and out of specification conditions
(5) Parts were unconstrained when measured on CMM
(6) Part flexibility has no effect on assembly

### 5.1.1 HOLE DIAMETER CNC CAPABILITY ON NON-COMPLEX AND COMPLEX PARTS

When attempting to assess the feasibility of NPM implementation, the Assembly A team interviewed a few key players who were involved in NPM implementation on other programs. The Assembly A team received abundant anecdotal evidence indicating that NPM was a success on the other programs. Data provided by the Aircraft XYZ and Aircraft UVW teams shows evidence to support these positive claims.

Revisiting TABLE 5 we see that hole diameter $C_p$ values for Close Ream, Class 1, and Class 2A are very high. Though this does not translate to a high $C_{pk}$ value for Aircraft XYZ due to the one sided tolerance band, we see very high values for the other two programs including the simulation performed for Close Ream tolerances. This 4.80 $C_{pk}$ indicates NPM manufactured parts for Assembly A will be compliant to a 99.999% assembly first pass yield in Close Ream applications for hole diameter tolerances. Due to a > 4 sigma level of process control for hole diameter tolerances for Close Ream diameters across setups and machines, it can be concluded that the NPM manufacturing process will accommodate tool and setup changes needed when producing complex parts.

### 5.1.2 HOLE POSITION CAPABILITY ON NON-COMPLEX AND COMPLEX PARTS

It can be seen however that Close Ream holes are not able to be maintained in position or in reference to one another and the part datum structure. The data summary provided in TABLE 7 indicates that a Close Ream tolerance scheme will yield a low pass rate of sub-50% for non-complex part hole position. The conclusion is the same for complex piece parts, where TABLE 8 shows that selected analyzed piece parts only yield a pass rate of 54% for Close Ream tolerances. From this it must be concluded that **for hole position, Close Ream tolerances cannot be implemented in both non-complex and complex piece parts in an NPM application successfully over time.** In fact, TABLE 8 additionally shows that for complex piece parts, Class 1 is not likely to be successful either. Assembly A includes a significant portion of complex parts in its design.

TABLE 7 indicates a near 100% success rate for Class 1 hole position in non-complex parts. If 100% of non-complex parts pass inspection, this means that multiple non-complex parts will be able to fit together easily, as both will be within specification. It is concluded from this data that **for hole position, non-complex parts will yield assembly success if assembled together with only other Class 1 non-complex parts in an NPM application.**

A 100% pass rate in complex parts for hole positions is only achieved when Class 2A tolerance schemes are used. From this it can be concluded that **all complex parts manufactured with Class 2A tolerances for hole position will fit together in an NPM assembly with high certainty.** It can also be concluded that **non-complex parts using Class 1 tolerances for hole position will fit together with complex parts using Class 2A tolerances for hole position with high certainty.**

Assembly A is attempting to implement Close Ream hole tolerances due to stress and fatigue conditions. An decrease in hole quality to either Class 1 or Class 2A requires a significant increase in Assembly A weight due to the resulting increase in part thickness to add strength to the assembly. The push to implement Close Ream hole quality is in direct conflict with the results from both non-complex and complex part studies in this document. A combination of Class 1, Class 2A, and perhaps Close Ream in very limited applications for non-complex and complex parts may provide an acceptable compromise for the program, to be discussed in the upcoming Recommendations section of this document.

## 5.2 CONCLUSIONS ON CURRENT STATE ORGANIZATIONAL ARCHITECTURE

When the Company Z Aircraft ABC organization set out to create Assembly A using NPM, it began with a team possessing a broad range of experience ranging from novice to expert. Employees new to the aerospace industry and longtime subject matter experts alike came together to assist in the development of the aircraft subassembly. Of these varying experience levels there were also a plethora of job functions, some reaching broadly across subject fields and others with depth in a specific area.

There are four hierarchical levels of product design that can be used as a framework for the Assembly A development effort. System, Architecture, Interface/Connection, and Component design levels should be used to outline critical questions associated with the design effort. This builds the skeletal structure for which a detailed process can be designed (Spear, Designing Products and Processes: Aligning Hierarchical Problem Levels with Problem-Solving Team Forms, 2005). See TABLE 12 below for the application of this philosophy as defined for Assembly A NPM development specifically. Assembly A NPM implementation is largely an Architectural change, where connection points in a pre-existing system are changing to accommodate this new design strategy.

*TABLE 12: HIERARCHICHAL LEVELS OF PRODUCT DESIGN AS APPLIED TO ASSEMBLY A NPM DEVELOPMENT*

| Design Level | Critical Question | Assembly A NPM Implementation |
|---|---|---|
| System | What overall functionality does the system provide for whom? | What system requirements must Assembly A meet?<br>What internal requirements must it meet? |
| | What objectives have to be met in the design? | What are the costs, weights, and form factors that must be met? |
| Architecture | What individual functions are assigned to what elements, components, or pieces of the system? | How will connection points be established? |
| | What elements, components, or pieces are connected to each other? | How will individual piece parts match up to one another?<br>What fasteners will be used?<br>How tightly do we want fasteners to fit? |
| Interface/ Connection | How are the elements, components, or pieces connected? | How will the assembly tie in to Assembly B and Assembly C groups?<br>What are the tolerances allowed for these primary assembly joints? |
| Component | What are the designs of the individual elements, components, or pieces of the system, given the functions assigned to them and the interfaces they have with the system? | How is each piece part configured?<br>How are mating interfaces designed?<br>What materials are needed for each part? |

A system requirement for Assembly A NPM implementation is that the design must meet all FAA regulations for primary structures. Design tolerances must be defined such that they can be met by CMM equipment, weight must meet Aircraft ABC constraints, materials must be selected based on cost and availability, and quality must maintain the highest standards. The design must be Designed for Manufacture (DFM) and Designed for Assembly (DFA).

Architecture decisions made for Assembly A must consider the design of the piece parts used to assemble Assembly A as this relates to NPM. In plain terms, this means that each part must go together with the other parts given the tight close ream tolerances being specified by the design.

Interface decisions are especially important on Assembly A, because this subassembly is interfacing with other primary structures. Connection points must be strong and strategically placed such that each primary assembly is stable on its own and jointly with the other assemblies. Additionally there must be a plan for important features such as wiring, fuel, and hydraulic lines to span between the sub-assemblies.

Finally, component design parameters require each piece part to nest with others such that the structure fits together as per the assembly specification. Multi-part stack ups must come together easily. Each individual piece part has a function including stability ribbing, fairing structure, framing, access holes, and bracketing.

With this understanding we are able optimize the way people and teams work together to maximize learning as the NPM design process develops. Each stage in the design cycle teaches the team new strategies to use in the next stage. As such, the succession of team formations in each stage must change and adapt to improve upon existing conditions. Physical location of work must adapt to suit the needs of the program. Additional interactions must be triggered with local subject matter experts. And, perhaps most importantly, data must be collected and distributed among stakeholders across the Company Z community to enable a high velocity organization.

Ultimately to create this high velocity environment the Assembly A team must strive to remove waste from their organizational architecture system. The end goal is to create a defect free system where requirements are mandated correctly the first time by a diverse group of team members, lessons are learned quickly, and are applied to shorten future learning cycles. In the case of the Assembly A organizational structure, there are many improvements needed before waste is eliminated from within the Agile processes. If teams are not built according to needs defined by diverse and co-located teams, requirements may be missing or incorrectly mandated. If functional teams are pursuing requirements that are incorrect or uncertain, this is a waste of cycles. Activities pursuing these inaccurate requirements are a waste of staff time, company money, and project schedule. Additionally, a failure of sync ups and proper collaboration can trickle down to the manufacturing line where mechanics may face wasted activity due to poor ergonomics and part design. Assembly A is currently facing all of these issues as a result of their current organizational architecture.

# 6. RECOMMENDATIONS

## 6.1 TECHNICAL RECOMMENDATIONS

As discussed in the previous 5.1 TECHNICAL CONCLUSIONS section, the following conditions must be met for consistent NPM assembly success:

(1) Non-complex parts may specify Class 1 or Class 2A tolerances for holes

(2) Complex parts may specify Class 2A tolerances for holes

(3) Close Ream holes may be used in limited, tested cases where single plane non-complex parts are assembled to one another

In a recent Assembly A demonstration, a model was manufactured using simplified aluminum piece parts to represent those in Assembly A. Class 1 tolerances were specified for all parts, and Close Ream conditions were simulated using tighter pins. This demonstration has yielded less than desirable results for Class 1 and Close Ream use cases. It is a strong indication that tolerances must be loosened for the next demonstration. It is recommended that the next demonstration strategy implement the three recommendations stated above for tolerance assignments.

The demonstration team must first define each part as either non-complex or complex based on factors including part setup during the CNC machining process, clearance for machines to drill holes, number of planes and datum sets, and part length. Parts with an unclear assignment should be defaulted to complex with Class 2A tolerances. These parts may undergo a Class 1 pinning simulation to be performed by increasing the fastener size during an assembly trial, mimicking Class 1 tolerance conditions. All parts with a clear non-complex or complex delineation must specify tolerances according to the concluded tolerance schemes shown above.

Some non-complex defined parts may be able to accommodate Close Ream tolerances during the next demonstration. Primarily, small single plane parts. For those parts where Close Ream may be possible, Class 1 tolerances should be used during part manufacture and Close Ream conditions can be simulated during assembly via increasing the fastener size to allow for less overall tolerance.

Based on produced data from Aircraft XYZ and Aircraft UVW teams, there exists a high degree of certainty that this strategy will yield a successful assembly attempt for a second demonstration of Assembly A. Further work should be completed to investigate other factors influencing part performance in an assembly part stack up. Factors such as material selection, thickness, assembly order, fastener choice, use of lubricant, and temperature of the assembly environment may provide key information that will allow for further refinement of hole class recommendations. These actions will continue efforts to move forward the successful implementation of NPM for the Assembly A team and the Aircraft ABC group as a whole.

## 6.2 RECOMMENDATIONS FOR ORGANIZATIONAL IMPROVEMENTS

The focus of the recommendations made for Company Z in this section is the challenge of forming a strategy for Assembly A NPM development and implementation. Assembly A development is a large change to the Company Z development structure. As Assembly A was previously externally manufactured, Company Z does not have a complete history on the processes used as it would with other aircraft assemblies. The implementation of NPM further adds to the complexity because it is also a major architectural change in the way the Assembly A team will design the subassembly components. There are five recommendations which will improve the way the Assembly A team progresses with NPM implementation. These changes will also be beneficial to future primary assembly NPM implementation in Aircraft ABC:

(1) Agile team formation based on organization and job functions instead of job titles
(2) Integrations with Aircraft XYZ manufacturing engineers and operators
(3) Supplier visits with Aircraft XYZ and Aircraft UVW suppliers who specialize in the manufacture of complex NPM parts and post processing
(4) Data gathering and distribution to other groups throughout Boeing
(5) Strategic partner suppliers

### 6.2.1 RECOMMENDATION 1: AGILE TEAM FORMATION

Company Z reports show a high level of cross functionality in the existing four Agile teams associated with Assembly A. These metrics are based on the job function of each individual in the Company Z internal system. In reality, these job functions may differ only in name but not in day to day tasks. Team members often perform similar work and report to the same manager though they have different job titles. These team members generally sit near one another and collaborate on a daily basis. As a team, they develop a group think that engenders problem solving in very specific areas but hinders diversity of thought overall. As displayed in TABLE 11, only four cross functional teams are involved in the Agile team structure.

To improve upon the current state, each functional team working on Assembly A must be identified and their contributions to the NPM effort clearly defined. At the beginning stages of development for Assembly A and the subsequent Aircraft ABC primary assembly teams, representatives from these teams should function as an autonomous group. Meaning, limited guidelines should be imposed on the content of brainstorming and development at this stage (Spear, Designing Products and Processes: Aligning Hierarchical Problem Levels with Problem-Solving Team Forms, 2005). As stated in Steven Spear's *Designing Products and Processes: Aligning Problem Levels with Problem-Solving Team Forms*, "An autonomous team is most desirable when a team is still sorting out design-objectives and needs a high degree of integration, breadth of perspective, and opportunity to try new things." As shown in FIGURE 20, this begins at the Agile Release Train (ART) level. At this stage, product features are generated. These high level mandates must be decided by a cross functional, autonomous team including all teams A-K (displayed in TABLE 11) for Aircraft ABC in addition to select groups from Aircraft XYZ and Aircraft UVW. These teams must be co-located and travel between both office and manufacturing environments. Efforts should be made to video conference and fly team members to a main location for collaboration.

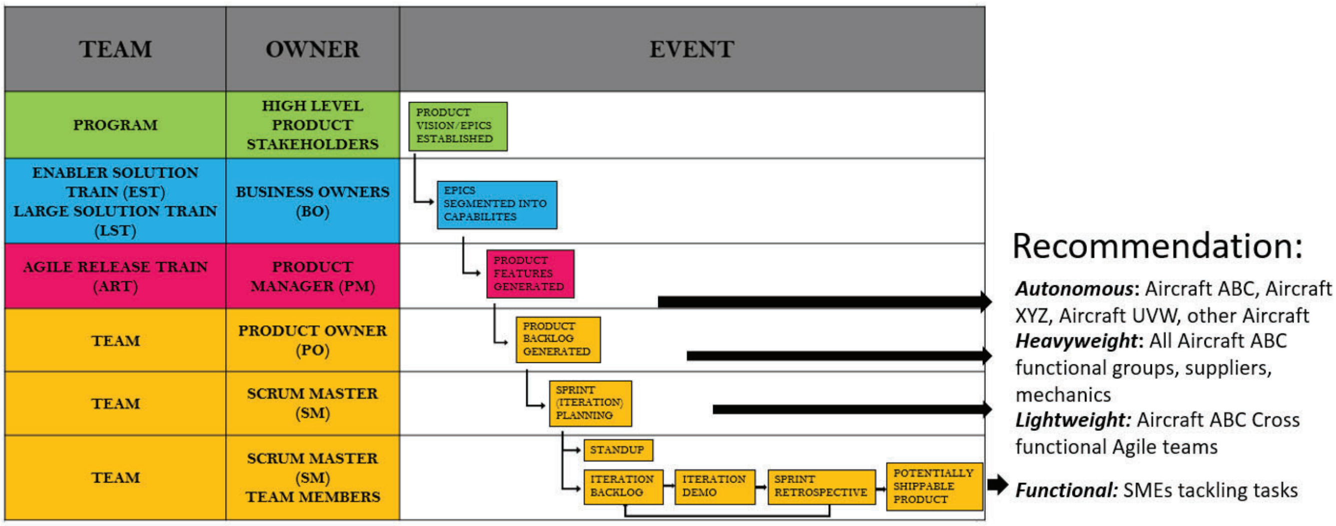


*FIGURE 20: PROPOSED ORGANIZATIONAL ARCHITECTURE FOR ASSEMBLY A NPM DESIGN*

The autonomous Assembly A team can contain representatives from each functional team rather than the full team to keep a reasonably sized group. If representatives are used, each representative is responsible to meet with their teams for bi-weekly report outs on progress, decisions, and road blocks. Each representative is also responsible for pulling in other members of their functional group as needed for development efforts.

After the autonomous team has completed an agreed upon feature list, the Agile scrum framework will task teams with developing product backlogs. This process is managed by the product manager (PM) but is a result of combined team efforts. Here is where Company Z could benefit from a Heavyweight team which includes Aircraft ABC functional groups but limits the amount of external input to "as needed." Suppliers and Mechanics are key teams who have not been previously included in this effort and should be brought in for future efforts. Aircraft ABC is the customer of the supplier, and mechanics are the customers of Aircraft ABC. Customer satisfaction determined at the early planning stages will save the system from waste during later design stages.

When Agile team structure progresses to Sprint (iteration) planning, heavyweight teams should slim down into more lightweight teams. These teams are what are referred to as the Agile teams. Though they do not need to be as collaborative as the autonomous and heavyweight teams before them, lightweight teams do need to be diverse in job function.

As Agile teams implement specific tasks, groups should become more functional. Subject Matter Experts (SMEs) should be tackling the tough technical problems aligned to their expertise. This information is fed back to the team through daily standups and the Sprint retrospective phase of the iteration cycle. The goal of this process is that, with every retrospective, Agile team task owners learn from one another and use this to eliminate learning cycle time in the next sprint.

### 6.2.2 RECOMMENDATION 2: AIRCRAFT XYZ INTEGRATION

Aircraft XYZ manufacturing and assembly is local to the Aircraft ABC development site. Aircraft XYZ has expert knowledge of NPM integration including manufacturing, post processing, assembly, and supplier relationships. Visits to this local facility are at no cost to Company Z but will contribute greatly to the NPM integration process for Assembly A. Though Aircraft UVW subject matter experts are on site at the Aircraft ABC team location, their own headquarters and manufacturing facilities are not nearby. Both teams should capitalize on the opportunity to meet with manufacturing engineers and operators at the Aircraft XYZ site to learn from their expertise and observe the NPM process firsthand at the gemba.

As stated by Marcie J. Tyre and Eric von Hipple in their academic journal entry *The Situated Nature of Adaptive Learning in Organizations*, "traditional, decontextualized theories of collaboration could be improved by taking into account that learning occurs not simply through human interaction, but through people interacting within one or more particular physical contexts." They argue that subject matter experts, although they may be value added contributors in an office setting, will often respond to stimuli differently depending on the context of their physical location (Tyre & von Hippel, 2003).

Company Z can capitalize on this free opportunity for learning acceleration and improved development. It is recommended that all teams with a stake in the Assembly A development effort visit the Aircraft XYZ facility for a tour. Additionally, team members should meet regularly on site with manufacturing engineers and operators to address concerns in the development process and brainstorm solutions. Where possible, these Aircraft XYZ team members should be pulled in as consultants on Assembly A Agile teams.

### 6.2.3 RECOMMENDATION 3: SUPPLIER INTEGRATION

Company Z currently manages the early stage supplier integration for Assembly A by consulting with Aircraft UVW suppliers on matters related to the manufacturing of the demonstration model. Though this provides some insight into supplier part manufacture for NPM parts, it does not allow for close scrutiny of their process. An improvement on current state would be to work with a local supplier who is familiar with NPM manufacturing and post-processing. Similarly to Aircraft XYZ on-site collaboration, local supplier collaboration would be at no cost to Company Z. It would allow Assembly A team members to see processes firsthand in a separate physical context that could help stimulate creative problem solving. Additionally, it allows subject matter experts with a history in the field to add value to the Assembly A team.

It is would also be largely beneficial for the Assembly A team to select a strategic supplier to partner with through the development and production process. In a similar way that visiting a local supplier will help with diversity of thought, a supplier partner can integrate and accelerate the learning process with ideas from the manufacturing floor. This may or may not be a common supplier to Aircraft XYZ and Aircraft UVW, though it is recommended. Rather than turning to the lowest bidder at the end of development, a strategic supplier will be a tangible cost saver to Company Z, reducing lost learning cycles during development.

### 6.2.4 DATA GATHERING AND DISTRIBUTION

Both Aircraft ABC and, more specifically, Assembly A could greatly benefit from access to data generated by other groups performing similar work. These groups do not have to be within the same business unit for their data to be valuable. Design process, manufacturing setup and validation, CMM data, final assembly results, and strategy derived from these factors are immensely important to expedite the learnings within the Assembly A team. Recommendations to best succeed regarding the dispersion of data begin with re-evaluating the definition of proprietary information. Most propriety data can be scrubbed to maintain anonymity which still provides value to other teams. Additionally, a central repository would be helpful to organize this data based on program and assembly. Though there is a repository for documents, most data gathering does not mature to the point where a formal document can be created and posted. Therefore, there needs to be an intermediate form between local desktop storage and centralized repository for data to be made available across the company.

In the absence of a centralized repository, Assembly A team can better access current data by following the below steps within Agile teams:

1. Identify list of internal Assembly A teams and contributions

2. Create team list with owner and function for all team members
3. Discover and highlight learning opportunities identified by the NPM Lightweight teams
4. Teams research and contact groups within Company Z who have designed to similar requirements
5. Each Agile team shall elect a representative to meet at a twice monthly cadence with other representatives to discuss data findings
6. Main Assembly A focal organizer to host a monthly Assembly A collaboration meeting for Agile teams to report back data findings to central cross functional (heavyweight) group. It is recommended that this effort is overseen by program management.

#### 6.2.5 SUPPLIER STRATEGIC PARTNERS

Aircraft ABC Agile teams are currently working on the assumption that suppliers are able to comply successfully with their demands. However, potential suppliers, and suppliers of other successfully run NPM programs have not been included in the team dynamic. Manufacturing capabilities, material readiness, scheduling, and reliability are all factors that are not currently proven due to the lack of supplier involvement and could create a significant amount of waste if the design of Assembly A piece parts warrants processes that do not meet current assumptions. Suppliers must be involved from design concept onset and treated as collaborative team members. It is recommended that they become embedded in Agile teams.

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