APQP & GEOMETRICAL MANAGEMENT SUPPORTING ENTRY INTO SERVICE

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ABSTRACT

How to reach a good Product maturity level during Entry Into Service?

Geometrical Management of Key Characteristics (KC) starts with System Engineering and continues with functional analysis of the vehicle during the development phase. As next APQP (Advanced Product Quality Planning), focusing on industrial maturity and repeatability during the industrialization phase is performed and finally, the process ends with a control plan, which is deployed after entry into service for the serial life of the product.

This is a top-down approach leading to systems specification during the three main phases of the Helicopter lifecycle:

• Design development,

• Industrialization (MAP – Industrial Process Improvement)

• Serial life

During *Industrialization*, we focus on the demonstration of process robustness considering system requirements and program specifications. It includes process definition and requires product/process optimization (MAP) a Specification Verification phase.

During Serial life, we shall provide optimized methods and tools matching with quality and production objectives (OTD, OQM, ramp-up) and viewing results format.

Since the tolerances are represented by a network, we have defined a format for injecting the results at a given level as input data to the next level.

Due to the nature and interconnections of this network, the volume of data to be processed can be significant. So we have implemented an appropriate numerical technique to deal with a continuous influx of measurement data.

The objective was to propose a comprehensible representation of the re-evaluated risks at each stage of the process, i.e.:

- Initial risks related to the current helicopter definition
- Re-evaluated risks related to an aircraft serial number completed with each new measurement of characteristics for this aircraft.
- Re-evaluated risks related to the observed variability of the product/process.

The aim of this paper is to present the geometrical risk evaluation at each step of the development for preparation to H/C EIS (Entry Into Service) phase, which is also called "Ramp-up" phase, based on one system example: A cockpit door integration.

Conclusions & drawbacks:

Using the collection of measurement data on the first batch of H/C combined with a criticality of the associated function and detectability we were able to reduce measurement without changing non-conformity risk level. For the cockpit door function, we get 55 CTI. Finally, after risk analysis we kept only 15 CTI to be measured. Meaning from 100% of measured requirements we are able to reach the same level of risk with only 27% of requirements measured.

1. NOTATION

A/C: Aircraft
CTI: Critical items

EIS: Entry Into Service

FMEA: failure mode and effect analysis
KC: Key Characteristic

MAP: product & process improvement (also Mise au point)

OQM: On Quality Milestone

OTD: On Time Delivery

WP: Work Package

2. INTRODUCTION

2.1. Airbus Strategy

Today, Airbus ambition is very clear: we want to transform our management of quality from reactive fire fighting and corrective to proactive and preventive. A benchmark study showed that top performing companies having achieved this transformation spend 70% on prevention costs, 20% on detection (or inspection) and 10% on failure. In a manufacturing industry, like us today, it is just the opposite: 10, 25 and 65% for the failure costs. We just want to reverse this data at Airbus. How is it possible? Thanks to more upfront planning and well-rounded processes all along the production cycle. We, now, plan quality from the design phase and put in place all means so that we can get it right first time. By getting rid of our repetitive issues and tackling the true root cause, we will reach our aim to achieve quality excellence in our products and processes. On new H/C development, we will strongly focus on our processes to improve our preventive approach and automatize control so we can gradually reduce the number of corrective actions. This is the objective of the CNQ (Cost of Non-Quality), SPC (Statistical Process Control) and **APQP (Advanced Product Quality Planning)** initiatives.

2.2. Geometrical Tolerance management

The Geometrical Tolerancing management process defines how to handle geometrical specifications concerning the aircraft during its complete lifecycle. Indeed, geometry is one of the key parameters to achieve aircraft performance gathering a set of generic and specific functions such as Aerodynamic performance, Aesthetic aspects, Handling capacity, Modularity, and Maintenance capacity (Interchangeability), Tightness, Etc.
The main stakes of strengthening our mastery of geometrical specification are:

- Ensure customer satisfaction (On Target Quality/Parts interchangeability);
- Master product integrity with a focus on contractual commitments with suppliers;
- Manage interactions between product design and assembly process;
- Reduce tailoring/rework rate and assembly lead time;
- Ease production offsets.

The Geometrical Tolerance management process is currently deployed in Airbus Helicopters.

2.3. APQP

Advanced Product Quality Planning is:
- Structured framework to deliver right first time and just in time while satisfying cost target,
- Customer(s) satisfaction focused approach,
- Specific key business deliverables continuously monitored and tracked up to closure.
APQP comes from the automotive industry. It is now recognized by most industries and has been adapted to fit the specificities of Aerospace.
Airbus joined the International Aerospace Quality Group (IAQG) in 2012 to define the EN9145, the first APQP International

Aerospace Standard that has been released in 2017.

APQP is a structured approach that:

- Supports the development of a new or modified product (new or up-grade Program, Major Modification, and new contracts or amendments) to ensure its Right 1st Time delivery (anticipating risks, reducing costs of non-quality, reducing process variation, etc.);
- Applies for Physical Products only (no software) but can be deployed even if the product itself is not directly modified
- Drives a quality-focused approach through Key Activities / Elements (including Quality Standards such as FMEA, CTI / KC, Control Plan, MSA, SPC…) and related Key Business Deliverables.

2.4. Geometrical Management & APQP

This is a top-down approach applied at each level of the H/C assembly and follows the 3 main phases of the Product development: Design development, Industrialization and Serial life.

Step 1: **Design development:** convergence to program requirements at the Helicopter level about systems constraints. Practically, maturation loops lead to quote geometrical targets achievable as program specification in coherence with systems specification to Specification Validation phase,

With respect to System Engineering cascading process, this is the top-down approach

Step 2: **Industrialization:** demonstration of process robustness (repeatability) considering system requirements and program specification. It includes process definition and requires MAP to Specification Verification phase,

In line with APQP process & tools. It is a "Horizontal process "leading to determine reproducibility on parts and process robustness

Step 3: **Serial life:** Monitoring strategy deployed through the appropriate quality plan to demonstrate continuous conformity of the products ***following Aerospace quality standards based on EN9100 "Standards for Quality Management Systems".***

3. SCOPE AND STAKES

3.1. Methodology

The KC/CTI geometrical management approach consists of cascading A/C requirements through design and manufacturing breakdown in order to validate technical and industrial choices done at each step of the development.

This process only concerns the physical interfaces of the A/C. Logical interfaces, such as electrical, hydraulic, or data interfaces are not part of this process.

The starting point of KC/CTI geometrical management activity is the list of general performance requirements of the A/C (General Aesthetic/Aeronautic Tolerances; Interchangeability and Servicing Requirements, etc.) combined with a macro work sharing of the A/C, in respect to the FAL assembly sequence i.e. lead Frontier Drawing.

KC/CTI geometrical management is a transversal activity concerning design, production, and quality people. It deals with tolerance requirements to fulfill at each step of assembly of the aircraft. These requirements are identified in accordance with the defined product cascade of the A/C and according to the functional analysis of each installation. Some examples of geometrical functions are presented in figure 1

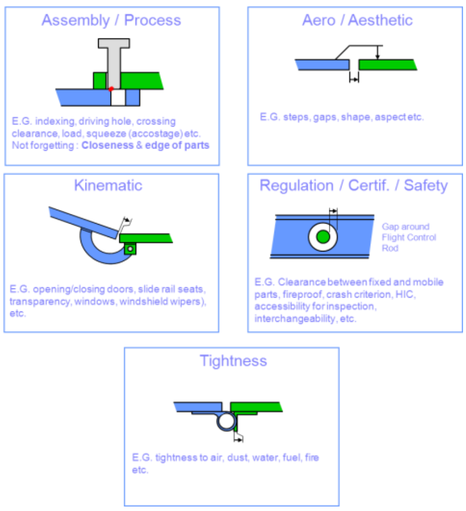


Figure 1: Types of functional geometrical requirements

All along the development, this approach influences manufacturing technologies and assembly sequences.

This is a top-down approach leading to systems specification at each level of the Aircraft assembly (vehicle, airframe & systems, sub-systems, parts) and following the 3 main phases of the Helicopter lifecycle: Design development, Industrialization (MAP) and Serial life.

This process leads to the complete tolerance cascade on the A/C according to product cascade (See Figure 2: Tolerance Specification Cascade). Performance KCs (PKC) defined at Aircraft level are cascaded into Assembly KCs (AKC) at Work-Package and assembly levels. AKCs are then cascaded into Elementary parts as Manufacturing KC (MKC). KCs are always compared to assembly and manufacturing capabilities to verify the robustness of the specification.

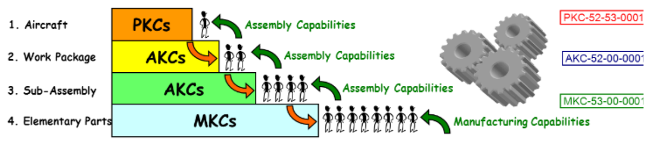
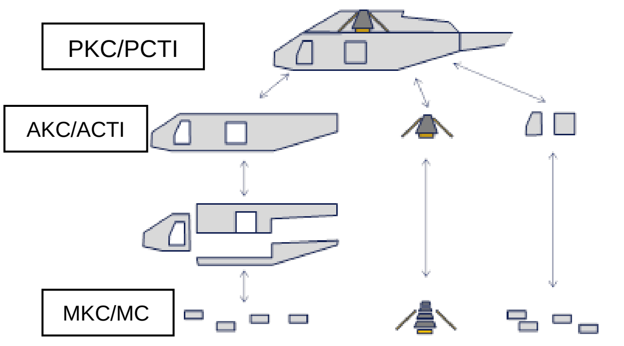


Figure 2: Tolerance Specification Cascade

Each level of specification is officialised to guarantee the robustness and traceability of requirement break-down through A/C specification. Moreover, if a Work Package is under responsibility of a partner, AH do not finish the cascade of requirement inside work-package perimeter. The partner is in charge of justifying the way the specification of the work package is respected as presented in figure 3:



AIRFRAME **MGB** **SYSTEMS**

Figure 3 : workpackage cascading

In the following paragraph we will develop this approach with the cockpit door example in preparation to EIS

The method described in this paper proposes a comprehensible representation of the re-evaluated risks at each stage of the H/C life cycle as described in this chapter.

3.2. SPECIFY

Initial risks related to the current helicopter definition justification at each component level is based on first bottom-up chain of dimension calculation considering also the tolerances. This leads to the definition of the geometrical requirements at each process level as presented in the figure 4.

Figure 4: Main steps on V&V process vs APQP

Tolerancing specification of the cockpit door

3.2.1 Short System Description

The H160-B is equipped with two hinged doors, one on each side of the helicopter. Excepting the symmetry effects LH doors are identical to the RH in size, function, and handling.

The cockpit doors, which are fully hand operated, can be locked and unlocked from the inside and from the outside.

For maintenance reasons the cockpit doors can be removed. A disconnection of the Door Opening Assistance is required in this case.

Each door is equipped with two locks and one anti-burst on the door body frame and 3 corresponding brackets on the structure door frame. Two locks are located on the rear of doors; the anti-burst is installed on the upper-front of the frame. Anti burst Pins are used for safety system to keep the door close if missing locks function. Locks are released from outside and inside by mono-stable handles.

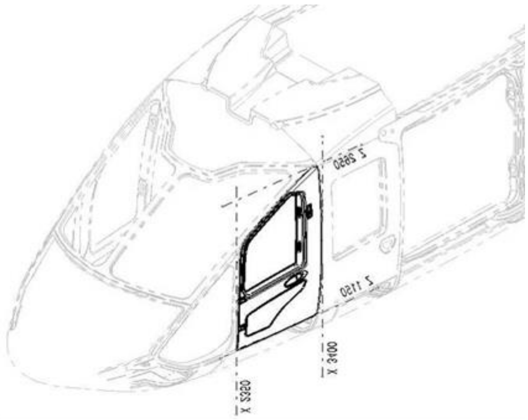


Figure 5: Isometric view of the right cockpit door

3.2.2 Functions of the cockpit door

The main functions of the cockpit doors are:

- Provide a locking and opening access to the cockpit
- Ensuring air and water tightness
- Provide crew access in the cockpit
- Ensuring visibility through the windows

The Secondary functions are:

- Provide operation of the door from the cockpit
- Provide operation with only one hand
- Simple and obvious handling

The cockpit door include 6 major components:

- Primary structure

- Windows with bad weather windows or not.

- Hinge system

- Door Opening Assistance

- Mechanism for opening/ closing/ locking

- Door seals

- Sensors

3.2.3 Requirements

- **Cockpit door is in interface with :**
  - **Door frame**
  - **Windshield & window**
  - **Fairing**
- Here after one example of requirement specifications transferred into drawings

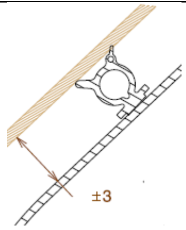
Function	Description	KC/CTI	Annotation
TIGHTNESS	Seal compression all around the door	PCTI-52-53-0115	

Figure 6: Final Requirement (example)

Integration Datum definition

The datum is composed by a plane defined by hinges location holes and locks, a line following upper and lower hinges hole, a contact point defined by one hinge hole interface.

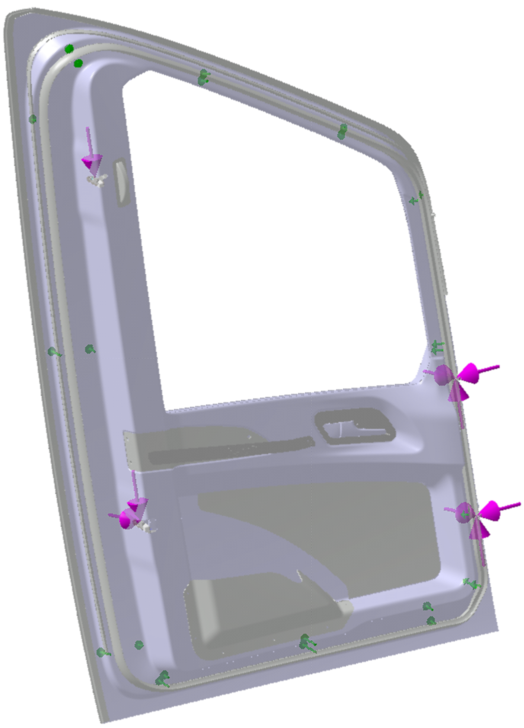


Figure 7: Cockpit door Integration Datum

After contribution evaluation to PCTI-52-53-0115

We determined the main contributors to this requirement

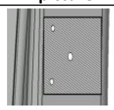
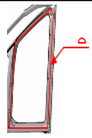
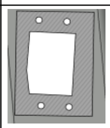
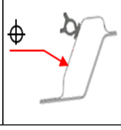
KC/CTI	Description	System	picture	Contribution
ACTI-53-52-3139	Position of shape of Door Frame on Hinge contact	Canopy		32,00%
ACTI-53-52-3113	Position of shape of Door Frame on Lip Seal Contact Area In Door	Canopy		31,40%
ACTI-53-52-3140	Position shape of Door Frame on door catches contact	Canopy		5,20%
ACTI-52-00-3112	Position of internal shape in local datum	Door		31,40%

Figure 8: Requirement at sub-system level (example)

Then we are able to start production and measurement activity

3.3. MEASURE

3.3.1 Strategy

Helicopter is "a complex system"

Helicopter is complex regarding integration of systems.

On our last H/C development, we deployed our management process to 44 major systems integration in parallel and managing 2871 KC/CTI.

During Industrialization: From pre-serial to serial H/C, we decided to measure 100% of CTI requirements in 3 batches of H/C. It leads to validate first the stack chain justification and the process capability.

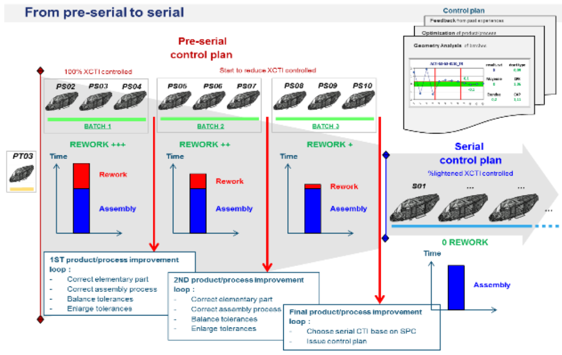


Figure 9: Ring methodology deployment

We fine-tune our industrial tool, verify and validate its robustness by building nine pre-production aircraft. During this run, we implemented the Ring methodology and a process to verify our approach: the geometrical stability of our interfaces, time management, and reduction in non-quality, verification and validation of our tools, documents, bill of materials, tests, operator training, and so on. This, help us to bring our performance in line with the industrial objectives before the ramp-up and achieve a good level of industrial maturity for the aircraft.

3.3.2 Tools

A comparison between measurement report and drawing requirements (for door frame tolerances) leads to reassessment of the risks (link to Installation function). This step is schematically illustrated in Figure 10. By this way, sources of process variation are identified in order to conclude on manufacturing deviations and short term solutions (e.g. rework, scrap…) for each pre-serial H/C.

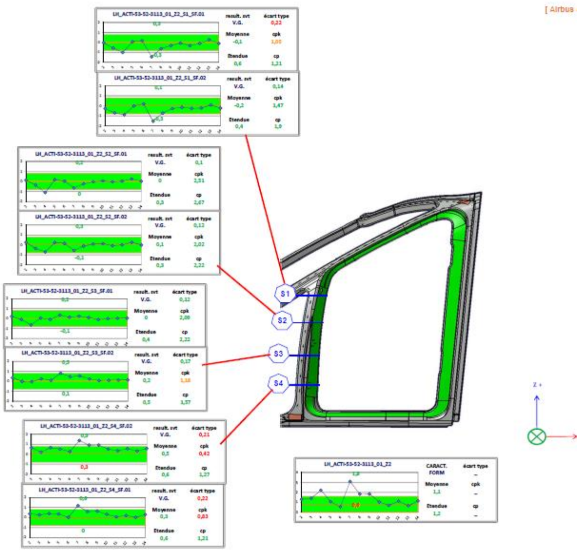


Figure 10: Log card for measurement analysis on ACTI-53-52-3113.

With this collection of measurement data, we can assess process repeatability and requirement target values.

3.3.3 Cockpit door application

Extract from the database, we can propose a detailed analysis of the requirement contributing to tightness requirement.

Main contributors are presented in the table below with Cp and Cpk calculation.

The **Cp and Cpk** indices are the primary production process capability indices. **Cp** shows whether the distribution can potentially fit inside the specification, while **Cpk** shows whether the overall average is centrally located. If the overall average is in the center of the specification, the **Cp and Cpk** values will be the same.

Considering our production rate Cp and cpk are considered good if result is higher than 1.

	Capability		PS02	PS03	PS04	PS05	PS06	PS07	PS08
Requirement	cpk	cp							
LH_ACTI-53-52-3139	1,035	1,14	0%	0%	0%	0%	0%	0%	0%
LH_ACTI-53-52-3140	0,34	0,685	0%	100%	75%	100%	100%	0%	0%
LH_ACTI-53-52-3113	0,34	0,71	0%	40%	80%	40%	100%	0%	0%
LH_ACTI-52-00-3112	0,92	1,39	0%	33%	0%	0%	0%	0%	0%

Figure 11: collection measurement data for Cp & Cpk determination

For ACTI-53-52-3139 and ACTI-52-00-3112 we can assume that manufacturing process is repeatable and on target requirement.

In comparison to final requirement results, i.e, tightness we can conclude that our tolerances values targets are in a good order of magnitude for early process warning about process deviation detection.

	Capability		PS02	PS03	PS04	PS05	PS06	PS07	PS08
Requirement	cpk	cp							
LH_PCTI-52-53-0115	0,37	0,45	0%	OK	OK	0%	OK	0%	0%

Figure 12: tightness status on cockpit door pre-serial A/C

3.4. ANALYSIS

3.4.1 Strategy

In next step, analysis is performed by re-evaluating the risks related to the observed variability of the product / process with model update.

3.4.2 Tools

Taking advantage of the measurement database, we are able to re-evaluate tolerances values and adapt our modelization to real production feedback.

Before delivery in FAL, we use Map Model to simulate door installation on canopy and produce report based on production data to assess functions linked to the system.

3.4.3 Cockpit door application

An example MAP model visualization is shown in Figure 13. In this figure, the measurement results and the comparison with target value are given for tightness requirement directly on the part with red and green arrow.

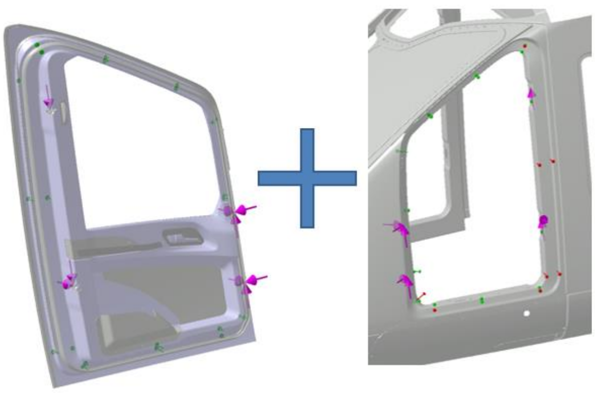


Figure 13: Door installed on Canopy

An other representation is presented herafter with a grey envelope defining the tolerances target and double arrow for measurement data amplitude.

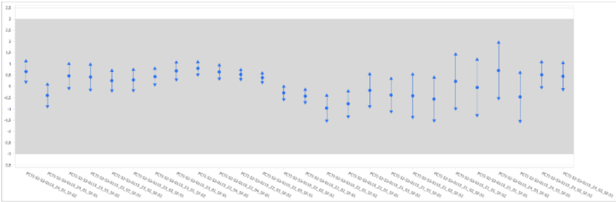


Figure 14: Tightness function results

3.5. IMPROVE

3.5.1 Strategy

During serial phase of the production, according to classification and risk analysis on each tolerance item, a dedicated monitoring plan is performed based on reduction strategy (as proposed in figure 15).

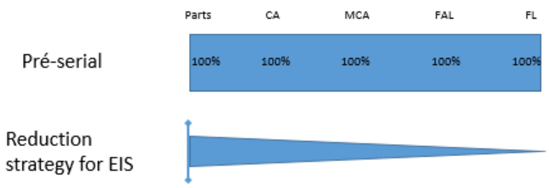


Figure 15: Measurement reduction ambition

3.5.2 Tools

Mastering a good MAP management with, production control plan will help us to manage design and process modification. The production control plan is prepared and applied from the production phase onwards, based upon the learnings of the MAP phase. Normally it gain from the experience of MAP and the development control plan resulting in a streamlined set of controls. Subsequently, it should be revised and updated throughout the life of the product in response to any quality issues evolution or changes (new controls, modified controls, eliminated controls).

Statistical process control are the activities related to implement a method of quality control which uses an statistical approach for monitoring and controlling the process inherent variability

Based on measurement database we performed a re-evaluation of Chain of dimensions, i.e., we adapted our model and tolerances workshare.

Then with a robust process capability and a 3Dstackchain model more realistic taking into account real parts tolerances and design adjustments we are able to provide a consistent risk analysis based on process cpk adjusted and CTI risk level into a FMEA

With FMEA table

Topic	AIRFRAME											
Requirement	Function	Part	Calc.	nb H/C	Cpk	Cp	Cpk Adj	Contributior	Occurrence	Severity	Detection	RPN
ACTI-53-52-3113	Tightness	Airframe	WC	14,00	0,12	0,62	-0,03	0,30	10	4,8	8	384,00
ACTI-53-52-3114	Aesthetics	Airframe	WC	14,00	0,11	0,32	-0,04	0,28	10	3,2	10	320,00
ACTI-53-52-3115	Aesthetics	Airframe	WC	14,00	0,5	0,83	0,28	0,41	10	3,2	10	320,00
ACTI-53-52-3133	Aesthetics	Airframe	WC	14,00			-0,15	0,20	10	3,2	10	320,00
ACTI-53-52-3135	Installation	Airframe	WC	14,00	0,57	0,77	0,33	0,16	9	0,8	4	28,80
ACTI-53-52-3139	Safety	Airframe	WC	14,00	1,66	1,67	1,10	0,34	5	8	6	240,00
ACTI-53-52-3140	Aesthetics	Airframe	WC	14,00	0,74	1,11	0,46	0,23	9	3,2	10	288,00
ACTI-53-52-3141	Installation	Airframe	WC	14,00	0	0,00	-0,15	0,26	10	2,4	4	96,00
ACTI-53-52-3142	Aesthetics	Airframe	WC	14,00	0,07	0,06	-0,08	0,03	10	0,8	10	80,00
ACTI-53-52-3143	Installation	Airframe	WC	14,00	0,11	0,12	-0,04	0,39	10	2,4	4	96,00
ACTI-53-52-3145	Safety	Airframe	WC	14,00	0,57	0,83	0,33	0,13	9	0,8	6	43,20
ACTI-53-52-3147	Aesthetics	Airframe	WC	14,00	0,02	0,17	-0,13	0,24	10	3,2	10	320,00
ACTI-53-52-3148	Aesthetics	Airframe	WC	14,00	0,48	0,50	0,27	0,00	10	0,8	10	80,00
ACTI-53-52-3149	Installation	Airframe	WC	13,00	0,06	0,10	-0,09	0,00	10	0,8	4	32,00
ACTI-53-52-3150	Installation	Airframe	WC	14,00	0	0,00	-0,15	0,00	10	0,8	4	32,00

Figure 16: FMEA Risk Priority Number

This table is based on RPN methodology

The Risk Priority Number (RPN) methodology is a technique for analyzing the risk associated with potential problems identified during a Failure Mode and Effects Analysis (FMEA). This first risk evaluation helps us to prepare our measurement reduction strategy.

RPN number is from the number of key factors evaluated with a grid as detailled :

Occurrence: calculated from Cpk results

Severity: from function criticality and level of contribution to final requirement

Detection: based on step of control, early control is a must.

All key factor range are between 1 to 10

CTI with RPN lower than 100 are candidates for measurement reduction then we can adjust our detection strategy.

CTI with RPN higher than 100 are analyzed with all stakeholders (Quality, Design office & work preparation) taking into account process robustness, detection of non-conformities with other means than measurement.

Then we are able to establish Serial control plan by reducing number of measurement without changing level of Risk. In this way of managing requirements, we keep traceability of all geometrical requirement. In case of process deviation or design modification we can re-assess requirement and update our control plan.

That's why we develop tools and key process indicators.

4. CONCLUSION

The objective was to propose a comprehensible representation of the re-evaluated risks at each stage of the process, i.e.:

- Initial risks related to the current helicopter definition

- Re-evaluated risks related to an aircraft serial number completed with each new measurement of characteristics for this aircraft

- Re-evaluated risks related to the observed variability of the product / process.

With this method, a quality-focused approach through Key Elements (including Quality Standards Failure Mode Element Analysis, Control Plan, Measurement System Analysis, etc.) and related Key Business Deliverables is developed.

During industrialization phase (MAP), tolerance items are compared to real parts. KC and critical items are included in Quality Management system of the aircraft to monitor geometrical vehicle requirements. These tolerances items are the key geometrical parameters to perform serialization of the helicopter and demonstrate the industrial process robustness.

This serialization process will then lead to the optimization loops into tolerance specification. Geometrical management of key characteristics coordinate actions between Manufacturing and Engineering and gives arguments to take the right decision.

Four main pillars of the new process guarantee the coherence and robustness of the System Geometrical Management:

- Traceability of geometrical items,
- Coherence in data convergence,
- Transversal management of geometrical specification,
- Impact on H/C weight and cost management.

Three main achievements are demonstrated with this new methodology as shown in the figure 17 below.

As first it has been demonstrated that the assembly lead time in Final Assembly Line (FAL) is reduced by app. 60% for pre-serial aircrafts compared to the lead-time needed for a similar legacy aircraft. Similarly app. 30% improvement in lead-time between first prototypes and serial aircraft were achieved.

The second achievement demonstrated by this new methodology concerns the reduction of non conformity on perceived quality. Here with introduction of new approach, the number of non-conformities before touch-up will be reduced to less than 10 % for serial aircrafts compared to first prototypes.

Finally, the delays in helicopter deliveries due to customer satisfaction related to reworks resulting from assembly process will be reduced to zero compared to 4% on first prototype aircrafts

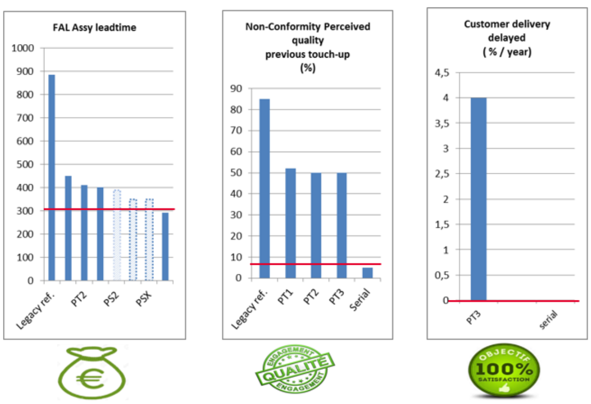


Figure 17: our KPI ambition

5. PRIOR PUBLICATION

This document is based on Geometrical management process steps. In this paper we presented the last step of this process called preparation to serial life. Previous paper AHS135_2019 was presenting the industrialization phase only.

Paper 135: Geometrical Management leading to merge System Engineering & APQP, proposed at the Vertical Flight Society's 75th Annual Forum & Technology Display, Philadelphia, PA, USA, May 13-16, 2019.