KC/CTI GEOMETRICAL MANAGEMENT DURING INDUSTRIALIZATION (MAP)

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Abstract

This process, based on end to end philosophy defines the way of managing geometrical specifications concerning the aircraft during its complete lifecycle. Final geometry of an aircraft is the result of many manufacturing operations performed by many stakeholders. As a result, geometrical management is centered on Frontier and Interface management, following the sharing of responsibilities of vehicle systems and integrators. System geometrical Management is based on functional analysis of the Helicopter vehicle.

This is a top-down approach leading to systems specification at each level of the Aircraft assembly, and following the 3 main phases of the Helicopter lifecycle:

- *Design development,*
- *Industrialization (MAP)*
- *and Serial life.*

During *Design development*, this approach leads to a cascade of specification in line with the product cascade, where Frontier specification becomes an input data for system design and manufacturing. This process guaranties the transversal robustness of design and industrial process against H/C performance criteria.

During *Industrialization*, we focus on demonstration of process robustness considering system requirements and program specification. It includes process definition and requires product/process optimization (MAP) → Specification Verification phase. At this stage we are facing majors' challenges:

- Models validation with prototype manufacturing
- Measurement analysis
- Design & manufacturing change management
- Preparation to serial life

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.

Indeed, due to the number of data, the problem linked to the representation of the results of the studies was addressed.

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 focus on our process deployment based on the last A/C development in Airbus Helicopters, presenting the first results, the advantages and drawback for Industrialization phase based on a sliding door integration.

1. NOTATION

A/C: Aircraft
CTI: Critical items
KC: Key Characteristic

IT: Tolerance Interval

OTD: On Time Delivery

OQM: On Quality Milestone

WP: Work Package

2. INTRODUCTION

KC/CTI geometrical management is based on a System Engineering philosophy, and inspired from Airbus way of managing interfaces between systems such as airframe work-packages, electrical, mechanical, air conditioning systems of the aircraft, etc.

KC/CTI geometrical management is leaded by a process, based on end to end philosophy. This process defines the way of managing geometrical specifications concerning the aircraft during its complete lifecycle. Indeed, geometry is one of the key parameter 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 geometry of an aircraft is the result of many manufacturing operations performed by many stakeholders, each one being responsible for distinct tasks. As a result, geometrical management is centered on Frontier and Interface management, following the sharing of responsibilities of vehicle systems and integrators.

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

Phase 2: Industrialization: demonstration of process robustness considering system requirements and program specification. It includes process definition and requires product/process optimization (MAP) → Specification Verification phase,

Phase 3: Serial life: Monitoring strategy deployed through the appropriate quality plan to demonstrate continuous conformity of the products: → Conformity to Specification phase

This approach leads to a cascade of specification in line with the product cascade, where Frontier specification becomes an input data for system design and manufacturing. Insofar as geometry management requires a transversal approach with the contributions of many stakeholders and skills, there is a need of a process assuring the robustness of design against A/C performance criteria.

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.

This KC geometrical management process is currently deployed in Airbus Helicopters.

3. SCOPE AND STAKES

The KC/CTI geometrical management approach consists in 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 physical interfaces of the A/C. Logical interfaces, such as electrical, hydraulic or data interfaces no not make 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 defined product cascade of the A/C and according to functional analysis of each installation. Some examples of geometrical functions are presented in figure 1

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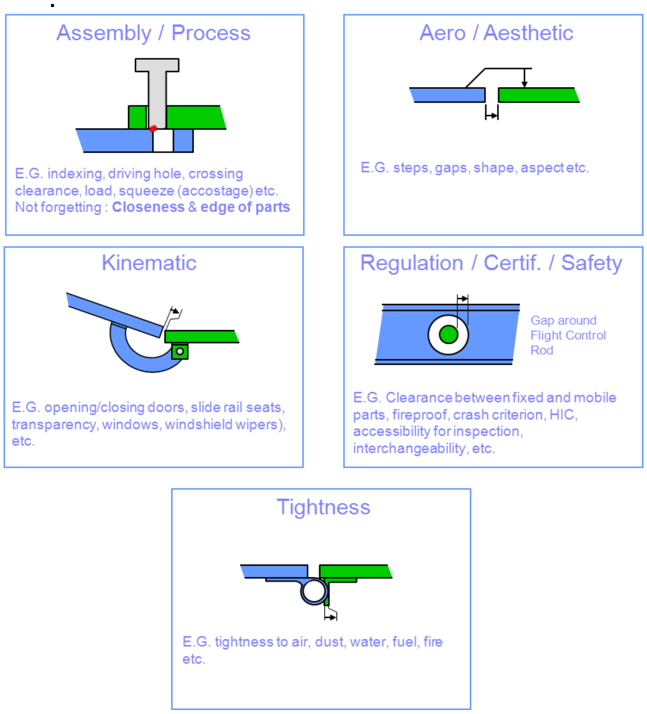


Figure 2: Types of functional geometrical requirements

All along the development, this approach brings to influence 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 **Erreur ! Source du renvoi introuvable.**). 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.

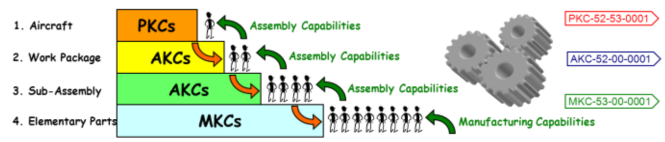


Figure 2: Tolerance Specification Cascade

Each level of specification is officialised to guaranty the robustness and tractability 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:

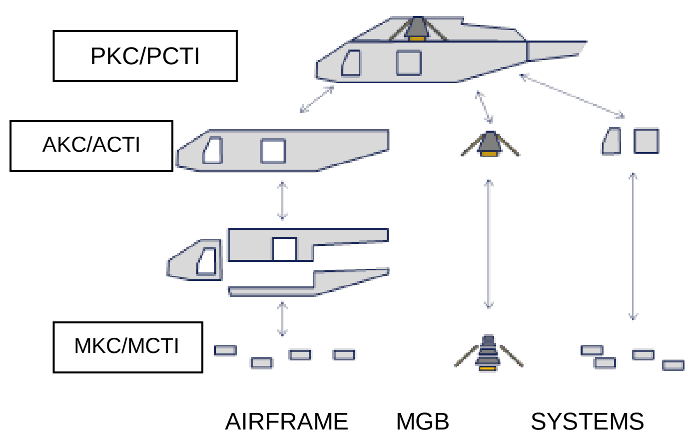


Figure 3 : workpackage cascading

In the following paragraph we will develop this approach with the sliding door example during industrialization phase

4. TOLERANCING SPECIFICATION OF THE SLIDING DOOR

4.1. Description

The cabin doors, which are fully hand operated, can be locked and unlocked from inside and outside the cabin. For opening, the sliding doors slide rearward outside the fuselage along rails mounted on the airframe fuselage. Accordingly, they slide forward for closing.

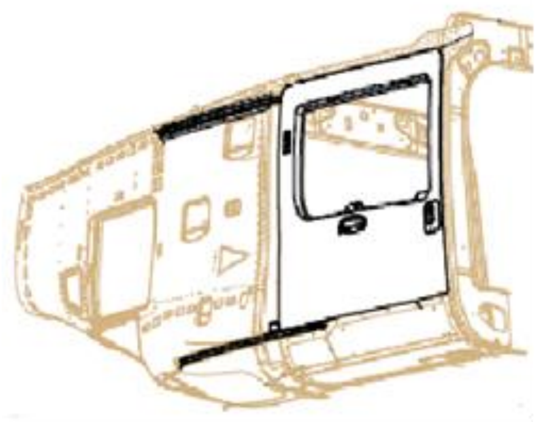


Figure 4:Isometric vue of the right sliding door

In the fully open position the sliding doors can be maintained and locked thanks to the specific device described below.

For maintenance reasons the sliding doors can be dismantled by removing rearward, after disassembly of the two stoppers.

As for operation on the ground, the sliding doors are able to be opened during flight up to a forward speed of 60kts. Furthermore, it is possible to fly with opened cabin doors up to 150kts, in cruise condition, with the doors parked and locked fully open, as defined in the flight manual.

Each door is equipped with 2 locks on the front and 3 centering pins on the front door body frame and corresponding brackets are integrated on the structure door frame.

The cabin doors include 6 major components:

- Primary structure

- Jettisonable window (Not part of the scope of this document)

- Handles

- Sliding door system (incl. brackets, rollers carriages, rails …)

- Mechanism for opening/ closing/ locking

- Door seals

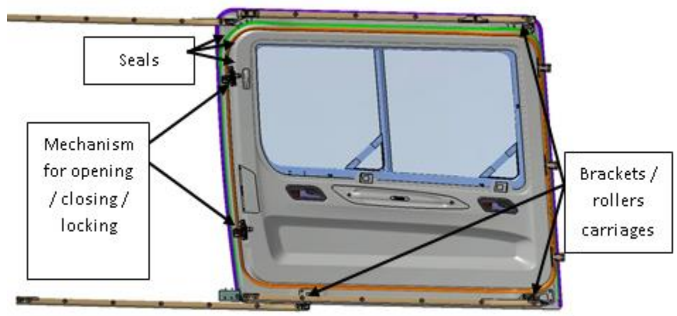


Figure 5 :Cabin door overview

4.2. The main functions of the cabin doors

- Provide access in the cabin
- Provide PAX access (on board/outboard)
- Locking and opening the access to the cabin
- Ensuring air and water tightness

The designer use dimensions and ISO annotation and dimensions i.e. symbol to translate functional requirement into the drawings with respect to Tolerancing rules.

4.3. Tolerancing Rules

Rule 0: Hyperstatism

Hyperstatism is not a crime,
Hyperstatism = Isostatism position + Physical support condition

Rule1: Integration datum, Degree of Freedom

6DOF locked (3T + 3R)
ex : [Plane + Line + Point] ≠ [3X,2Y,1Z]

Rule 2: Kelvin Rule

Always locks 1DOF ⊥ to movement (Kelvin rule)

Rule 3: Datum size

Take contacts as soon as possible with biggest space between, and not aligned

Rule 4: IT hierarchy

IT rule: IT form < IT orientation < IT localization

Rule 5: Tolerance Offset

Suppression possible of offset tolerances,
if:
Keep centered tolerance as soon as possible by Nominal = Middle
If not
For application of this rule, (Form, Orientation, and Position), it is necessary to respect:
Same medium value* of element offset with respect to Rule 4
* Exception: Orientation & flatness for plane or strait line.

Her after some examples of requirement specifications transferred into drawings

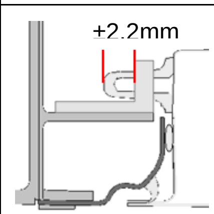
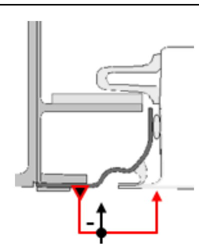
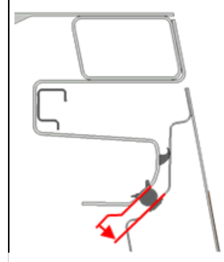
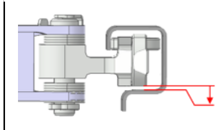
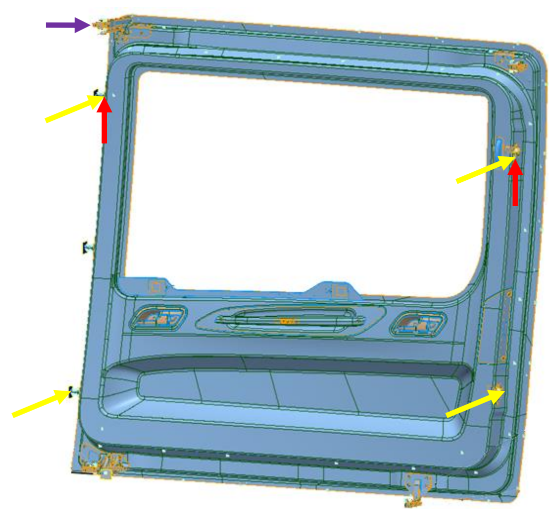
Function	Description	KC/CTI	Annotation
FIT	Front sliding door upper pin pitching	PCTI-52-53-0300	
Aesthetic/ Aero	Step between Door and Airframe	PCTI-52-56-0305	
Tightness	Seal compression	PCTI-52-53-031X (X= 1 to 5)	
FIT/stress	Z gap on sliding door reels (max deformation)	PCTI-52-53-0316	

Figure 6: From Function to tolerances: a few sliding door functions

4.4. Inputs for Tolerancing study & cascading

To ensure Function justification Tolerancing specialist will collect inputs as :

4.4.1 Design principles from Interface drawings and Datum



4x Ty,Rx,Rz, in y direction on hinges and lockers

Tz, Ry in z direction on hinges

Tx, in x direction, stop on upper roller

Figure 7: Degrees of freedom immobilization datum

4.4.2 Assembly process

Sliding door assembly constitution is based on the manufacturing process flow hereafter:

Step 1: Door structure obtained by blow-molding

Step 2 Door structure machined (cutting and holes) with datum following outer shape holding feature.

Step 3: Installation of brackets and hinges by hole to hole process.

Step 4: installation on the airframe

4.4.3 Manufacturing capabilities

Linked to process and materials, Tolerancing analysis is based on ISO 2768m for elementary part, in first loop. After stack chain analysis negotiations can appear to optimize stack chain result by minimizing tolerances taking into account design optimization if possible.

4.5. Tightness Function specification cascading

Example of Front seal compression between sliding door and airframe: PCTI-52-53-0310 liked to ACTI from sliding door, ACTI from Airframe and MCTI from locking device

In the following table you will find contributors to the stack chain and influence:

CTI	Description	Tol.	Parts	Infl.	Contrib
ACTI-53-52-3333	position of interface with locks	0,8	airframe	1,36	1,09
ACTI-53-52-3318	door frame sealing contact surface	0,8	airframe	1,00	0,80
ACTI-53-52-3331	position of holes for lock assembly	0,8	airframe	0,62	0,50
ACTI-52-00-3318	sealing joint area shape	0,5	door	1,00	0,50
MCTI-52-00-3325	radial position of locking device axis (lock in nominal)	0,15	low lock catch	1,00	0,15
				WC result	3,03
				Stat RSS	1,53

Figure 8: table summarizing stackchain linked to tightness function

Each functional requirement will be cascaded in single stack chain taking into account relationship and interdependencies between them, thanks to CTI naming and database consolidation.

5. MAP PROCESS

5.1. Rules and pre-requisites

The most critical component of tolerance management in manufacturing is a well-established set of standards for tolerance notation and specification. These standards have associated rules for accumulation and principles to help minimize accumulation.

5.1.1 MAP principles

These principles are integrally tied to all the basic work-structuring decisions previously discussed, with the exception of when a chunk is done and how it is released. Tolerance maps, vector models and tolerance analysis support work-structuring decisions and the application of the principles.

Principles 1 and 2 deal with the clarity in the communication of tolerances (requirements of the product)

Principle 1: A feature or part should be completely specified with tolerance system.

Principle 2: Every specified tolerance must be met independently unless one of the envelope relationships is specified

Principles 3, 4 and 5 all strive to reduce tolerance accumulation through datum selection

Principle 4: Datum features with less variability (higher quality) should be selected where function permits

Principle 5: Select more robust datum for a given critical where function permits

Principle 6: Select connection types that eliminate large variations contributing to the critical dimension in the assembly equation

Principle 7: Tolerance analysis should be done to ensure variations in dependent critical variables are acceptable. If they are not, design should be modified

Principle 8: Functional tolerances should be specified such that the implied sequence of fabrication, fabrication methods, and inspection methods are achievable and reasonable where possible. Similarly, every specified tolerance should preferably be directly controlled or inspected using reasonable fabrication and inspection processes

5.1.2 Measurement System Analysis

Measurement means accuracy will be assessed using prototype parts, measuring equipment and calibration data. In order to capture and analyzed data, the key variables will be assessed regarding measurement error i.e. precision and Accuracy.

We will define sources of process variation, to be able to conclude on KC/CTI values deviation and short term solutions (repair, scrap…).

5.1.3 Model validation

The objective is to adapt the 3Dstackchain calculation model to a useable model in the shop floor taking into account data quantity, quality and signing the direction of tolerance. It's lead to the idea that the measurement can be represented as a highly eccentric distribution with an average value equal to the measured value and its variance depending on the accuracy of the measurement means.

5.2. MAP Process

This process leads to First time right and/or predictive analysis. MAP is based on evidences/facts validated

After measurement system analysis, MAP will use measurement report as the basis for touch-up and modifications.

Touch-up / Modification will focus on Process with most predictive outcome, focus on easiest, quicker and least expensive modification.

MAP will always minimize work regarding number of part and aftereffect.

MAP team will deal with "Metier" constraints.

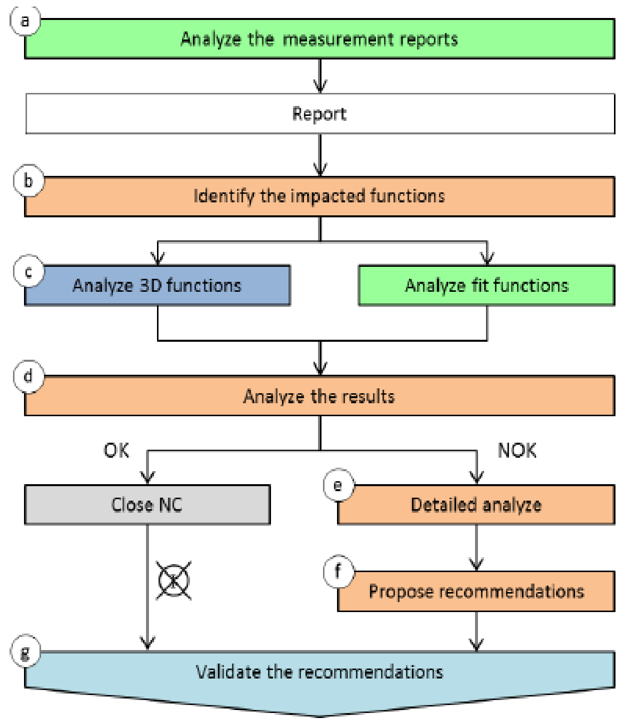


Figure 9: synoptic of MAP process

Following this process the question is :

How to prioritize the validation process of system's functions?

Regarding geometrical aspect, it leads to Tolerancing breakdown studies and database.

5.3. Design and manufacturing change management priorization

With a measurement system able to produce "good" reports and a stack chain model useful for measurement analysis some manufacturing information are mandatory before starting investigations on system MAP.

5.3.1 Principles

1/ Parts are industrialized from serial & validated means

2/ About repeatability: Parameter reflecting the process repeatability & link between function are evaluated in the stack chain database.

3/ Geometrical quality analysis: from prototype to serial phase.

First step: analysis based on MCTI measurement then ACTI measurement

Second step: PCTI analysis based on part assembly and final result

4/ Touch-up: deal with uphill function following mandatory rule IT shape < IT localization

5/ About failing function type

1/ Isolated function: possible interaction with shape = action local touch-up

2/most of functions linked to a common datum = touch up by simulation + impacted function analysis

3/final function linked to functions with a common datum = touch up by simulation + impacted function analysis

5.4. Application to sliding door

Following MAP process for "long term" solution first activity will be to validate stack chain model with MCTI, ACTI measurement and in comparison to PCTI results

5.4.1 Validation model

The following figure represents the resulting gap between door and airframe.

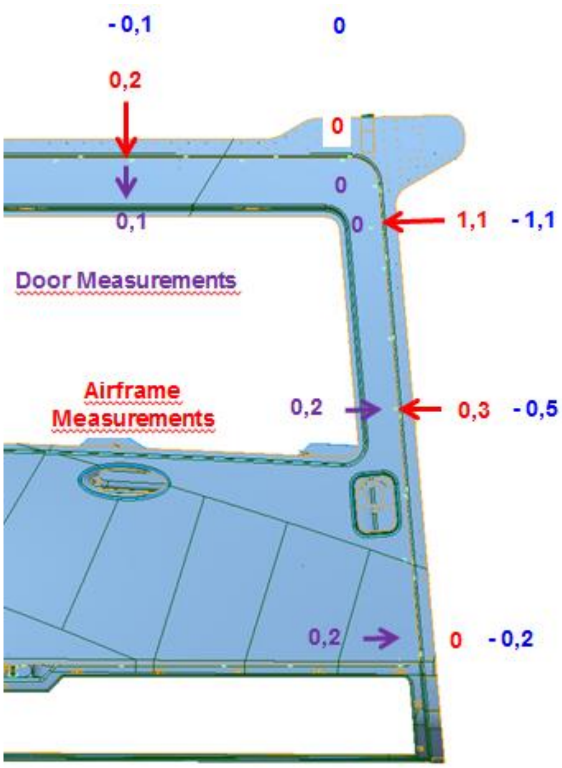


Figure 10: resulting gap between door and Airframe

5.4.2 Tightness status: PCTI-52-53-0310

The following figure represents the resulting seal compression between door and airframe

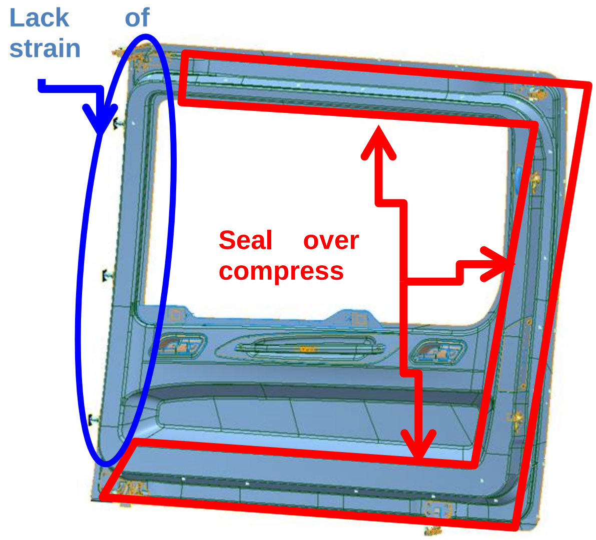


Figure 11: resulting seal analysis between door and Airframe

64% of PCTI measured on the door installation are compliant with the tolerances requirements.

To tackle these poor results touch-up method is applied.

Seal compression stack chain is a function directly linked to the installation datum of the door.

By analyzing the door datum measurement report and door frame datum measurement on airframe we note slight deviation for datum's door and a door frame twisted.

On function, point of view, seal compression default is excepted on lower area and Y and Z over constraint in the reels.

Hereafter the resulting measures on main functions

	PCTI	Description	Target	Min	Max	status
Intgration Datum	PCTI-52-53-0300	Front sliding door upper pin piching	2,2	0,0	0,0	OK
	PCTI-52-53-0301	Front sliding door upper pin alignement	0,5	0,0	0,0	OK
	PCTI-52-53-0302	Front sliding door lower pins pitching	2,2	0,0	0,3	OK
	PCTI-52-53-0303	Y gap between sliding door lower pins & airframe	0,2	0,0	0,2	OK
Step&Gap	PCTI-52-53-0304	Front seal covering between sliding door & airframe	2	0,0	1,9	OK
	PCTI-52-53-0305	Front step between sliding door & airframe	3	-1,9	0,0	OK
	PCTI-52-53-0306	Upper seal covering between sliding door & airframe	2	-1,2	0,0	OK
	PCTI-52-53-0307	Upper step between sliding door & airframe	3	-1,5	0,3	OK
	PCTI-52-53-0308	Rear seal covering between sliding door & airframe	2	-1,5	0,0	OK
	PCTI-52-53-0309	Rear step between sliding door & airframe	3	0,0	0,9	OK
Tightness	PCTI-52-53-0310	Front seal compression between sliding door & airframe	1,5	-0,2	1,6	KO
	PCTI-52-53-0311	Upper seal compression between sliding door & airframe	2	-1,8	0,0	OK
	PCTI-52-53-0312	Lower seal compression between sliding door & airframe	1,6	-0,2	1,2	OK
	PCTI-52-53-0313	Rear seal compression between sliding door & airframe	1,9	-1,5	0,0	OK
reels interface	PCTI-52-53-0315	Y gap on lower sliding door reels (max deformation)	0,4	-1,8	0,0	KO
	PCTI-52-53-0316	Z gap on sliding door reels (max deformation)	2,5	-4,1	5,2	KO

Figure 12: few PCTI measurement results

At this stage touch-up methodology is deployed

5.4.3 Optimized door datum

The choice is based on key function with respect to minimizing rework on tooling for composite part. In this example that mean the blow molding composite door.

Taking into account a new optimized datum localized with the seal track surface and cutout points we verify touch-up rightness on the datum with respect to rule 4 (IT hierarchy) : : IT form < IT localization with these new parameter.

Touch-up assessment focus on holes on composite door for bracket and hinges installation. By simulation we quantify holes localization modification and provide a new simulated measurement report based on this new datum.

	PCTI	Description	Target	Min	Max	status
Intgration Datum	PCTI-52-53-0300	Front sliding door upper pin piching	2,2	0,0	0,0	OK
	PCTI-52-53-0301	Front sliding door upper pin alignement	0,5	0,0	0,0	OK
	PCTI-52-53-0302	Front sliding door lower pins pitching	2,2	0,0	0,0	OK
	PCTI-52-53-0303	Y gap between sliding door lower pins & airframe	0,2	0,0	0,0	OK
Step&Gap	PCTI-52-53-0304	Front seal covering between sliding door & airframe	2	0,0	2,3	KO
	PCTI-52-53-0305	Front step between sliding door & airframe	3	-0,7	0,0	OK
	PCTI-52-53-0306	Upper seal covering between sliding door & airframe	2	-1,0	0,0	OK
	PCTI-52-53-0307	Upper step between sliding door & airframe	3	-0,7	1,0	OK
	PCTI-52-53-0308	Rear seal covering between sliding door & airframe	2	-2,0	0,0	OK
	PCTI-52-53-0309	Rear step between sliding door & airframe	3	0,0	2,1	OK
Tightness	PCTI-52-53-0310	Front seal compression between sliding door & airframe	1,5	0,0	1,2	OK
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	PCTI-52-53-0312	Lower seal compression between sliding door & airframe	1,6	-1,6	0,0	OK
	PCTI-52-53-0313	Rear seal compression between sliding door & airframe	1,9	0,0	2,5	KO
reels interface	PCTI-52-53-0315	Y gap on lower sliding door reels (max deformation)	0,4	-0,6	0,0	KO
	PCTI-52-53-0316	Z gap on sliding door reels (max deformation)	2,5	-2,8	2,8	KO

Figure 13: few PCTI simulation in door optimized datum

In this simulated report 89% of PCTI on the door installation are compliant with the tolerances requirements. But we notice that a new gap default on front and rear area, seal compression default and Y and Z over constraint in the reels improved but not yet at the target.

Root cause of seal compression out of tolerance is a consequence of the twisted door frame surface. Indeed, after investigations on door frame measurement report, we note an IT form > IT localization, meaning an issue on manufacturing assembly process or tooling.

After investigation, with tooling department we conclude about Industrial Process improvement on door frame positioning together with door datum optimization.

This new simulation report with tooling modification on door frame installation is provide thereafter

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	PCTI-52-53-0316	Z gap on sliding door reels (max deformation)	2,5	-0,8	0,9	OK

Figure 14: few PCTI simulation in door optimized datum

For last tolerances out of target we use mean shift solution after evaluation of repeatable process. The variation due to mean shifts is a one-time affair. Once the part processes are set, with whatever random mean shifts they experienced, it is assumed that they will stay at those mean shifts. The part to part variations around these set means will happen anew for each part produced.

In conclusion, during measurement analysis, designer will take care about system itself, but counterpart too, at the same stage.

Use of global geometrical database, meaning inter-dependencies identification is a powerful tool for investigations during MAP phase.

6. PREPARATION TO SERIAL LIFE

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.

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

6.1. 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. Two type of variation are due to different root causes:

Common cause is random, stable, and consistent over time. It is an inherent part of the process itself and can only be changed by fundamentally changing the process itself. Since management owns and creates the process, it is up to management to change the process if this variation needs to be substantially reduced. When only common causes are present the process is said to be in control or stable.

Special cause is assignable to extraordinary causes that we can identify. It is usually caused by an external factor acting upon the process. This variation can be eliminated by eliminating / controlling the external factor acting on the process. When special causes are present the process is said to be out of control.

According to Edward Deming, of all variation, 85% to 95% is common cause; 5% to 15% is special cause.

6.2. Key Process Indicator

Coherence and robustness of System Geometrical Management is guaranteed by four main pillars of the process: Traceability of geometrical items, Coherence in data convergence, Transversal management of geometrical specification and Impact on A/C weight and cost management.

KC/CTI management is the answer to this first pillar

Traceability of geometrical items

This first pillar is linked to EN 9100 “Quality Management Systems - Requirements for Aviation, Space and Defense Organizations”: According to this standard, Tolerancing items contributing to functional or industrial performance of the aircraft are identified, quantified and monitored through System geometrical management process.

During concept and design phases, all contributing tolerance items are identified, classified and stored. The classification takes into account EN 9100 criteria to flag Tolerancing items as Key Characteristics, Critical Items or Specific Tolerance Requirements. Theoretical simulations of tolerance bring the links between tolerance items and theoretical contributions.

During industrialization phase, all tolerance items are compared to practical industrial data. KC and CTI items are included in Quality Management of the Aircraft to monitor A/C quality in accordance with expected geometrical vehicle requirements. These tolerances items are the key geometrical parameters to perform serialization of the A/C and demonstrate industrial robustness. This serialization process can lead to optimization loops into tolerance specification.

During serial phase, according to classification and risk analysis on each tolerance item, a dedicated monitoring plan is performed. Non-compliance of parts or work-packages regarding geometrical specification can be analyzed to identify potential impacts on next steps of assembly and upper-level requirements. Then specific action plan is defined.