



Computational Methodology for the Prediction of Functional Requirement Variations Across the Product Life-Cycle

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Problem

- Parts within mechanisms are generally specified for the assembly stage of their life cycle
- Useful values of Functional Requirements are usually defined under operating conditions (at higher temperature and strains...)
- These 2 occurrences will be referred to as product configurations in this work



Problem

- Currently, the study of the functional requirement (FR) is done on an ideal model of the mechanism
- Challenge : How to study FR evolution during the product life cycle ?
- This work investigates the definition of multiple configurations to integrate part deformation in the FR calculation process

Illustration of the problem

At Assembly



Low Temperature ($\approx 20^{\circ}\text{C}$)
No Centrifugal Force on the blades

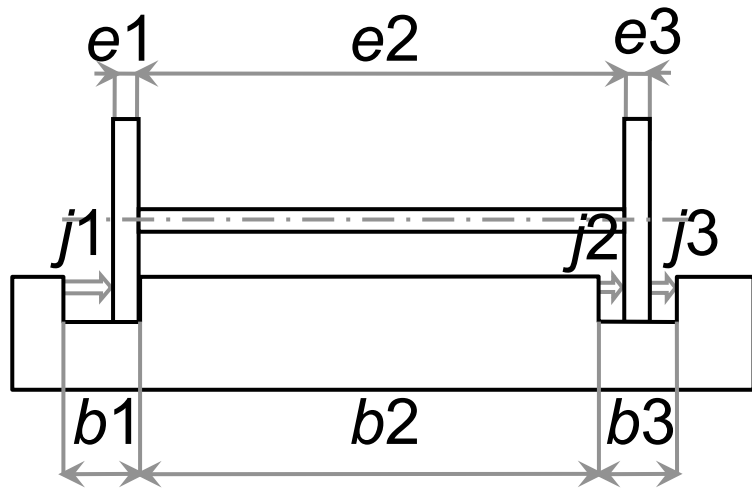
In Operation



High temperature
Important centrifugal force on the blades

How maintain the proper gap between the blades and the frame in these 2 physical states ?

Simple application case : Geometry



- Wheel shaft made of Aluminium ($\alpha=1,2 \text{ E-5}$)
- Frame made of steel ($\alpha=2,38 \text{ E-5}$)
- Dimensions defined at 20°C
- Parts deformations due to thermal expansion only
- Design variables : dimensions of the frame



Sources of functional requirement variations

- Uncertainties due to Tolerances stack-up : analysis of tolerance zones made thanks to existing techniques
- Changing environment (variation of mechanical load or temperature) : Elastic strain on parts.

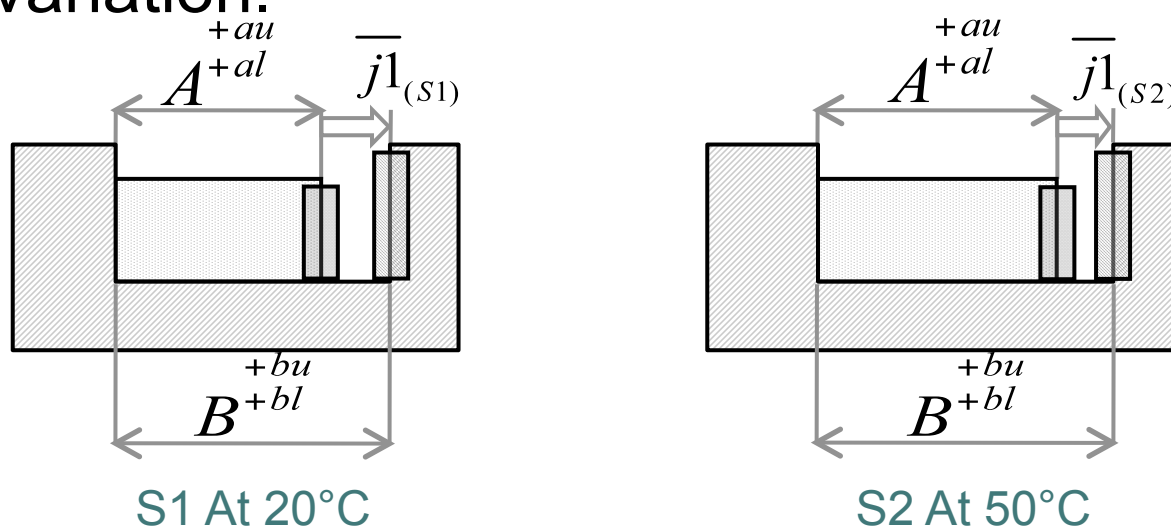
Functional requirements variations across the life-cycle

- Elastic strain

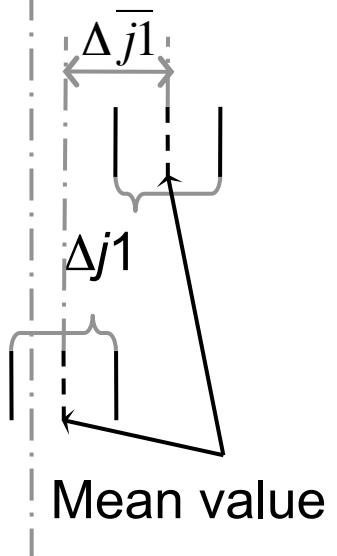
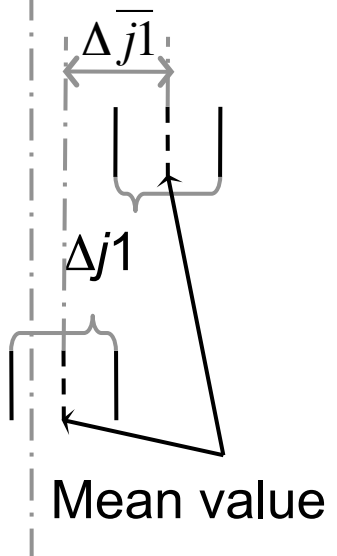
$$au - al \ll \bar{A} \quad \Delta(au - al) \ll \Delta\bar{A} \ll \bar{A}$$

au, al : upper and lower tolerance zone boundaries

- Variation of tolerance zone width is insignificant relatively to mean dimension variation.

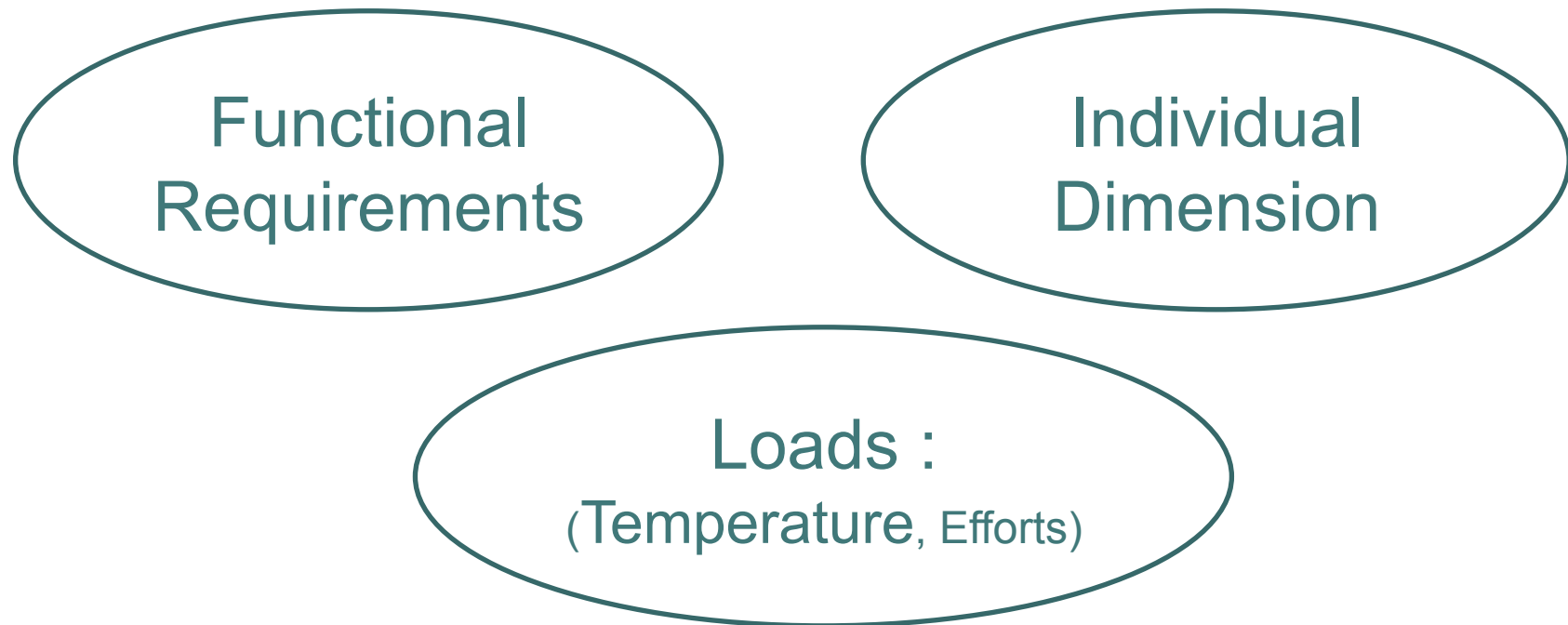


Functional requirements variation across life-cycle

Life-cycle stage	Value of Functional Requirement - 0 + Interference possible motion
Initial State (S1)	
Final State (S2)	



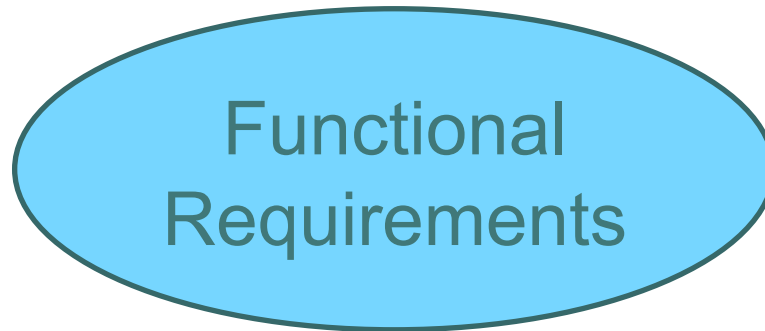
Design variables and constraints



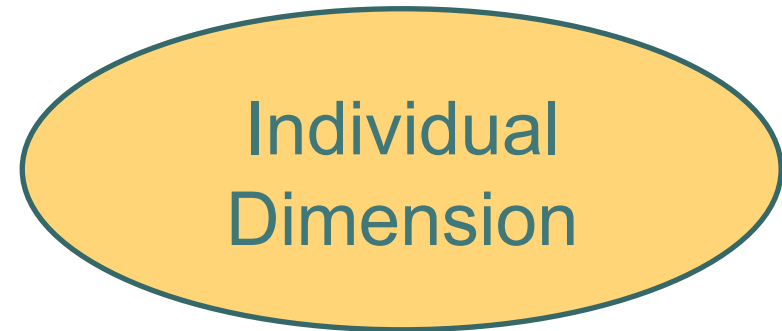
Design paradigm : 2 out of 3 of the above elements must be chosen for a design to be fully constrained.

Three approaches (1)

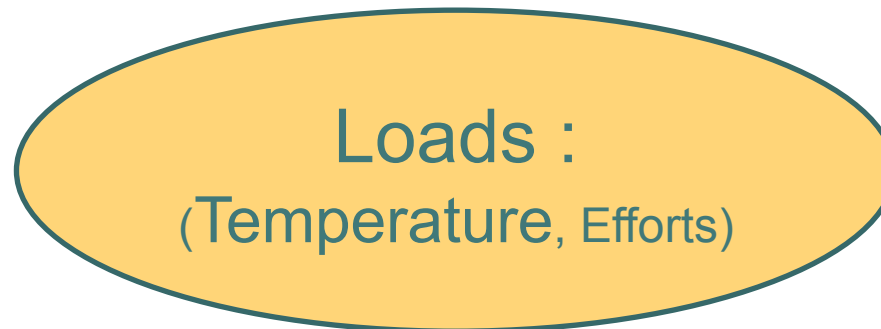
Dimension driven



At final stage



At initial stage



At initial and
final stages



Three approaches (1)

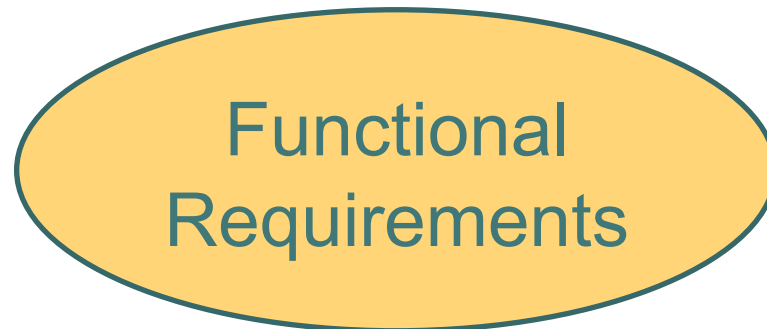
Dimension Driven

- Known variables
 - Temperature at initial and final stages
 - Individual dimensions at initial stage
- Resulting variable
 - Functional requirements at initial and final stages
 - Individual dimensions at final stage
- Typical Issue

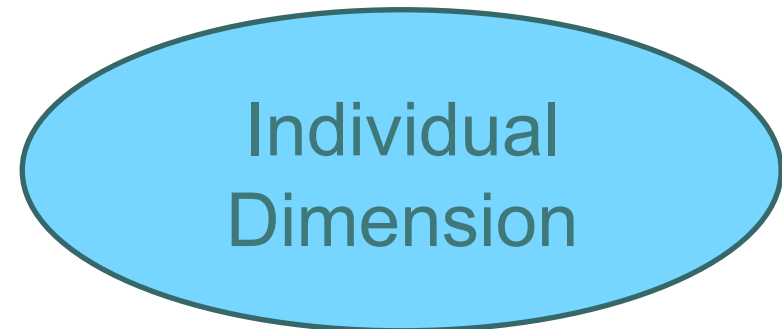
What will be the value of a given functional requirement after the thermal expansion of the parts?

Three approaches (2)

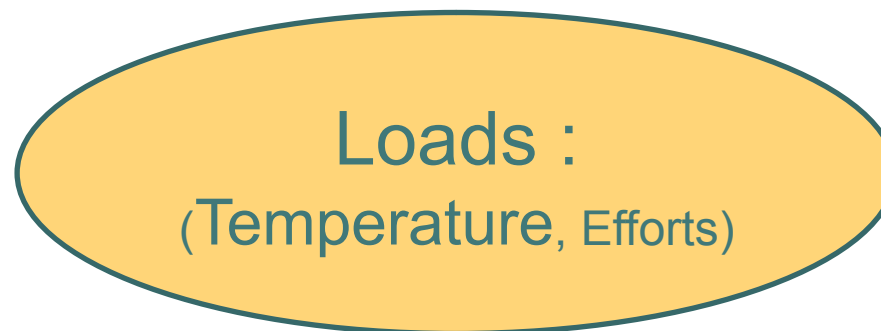
Functional requirement driven



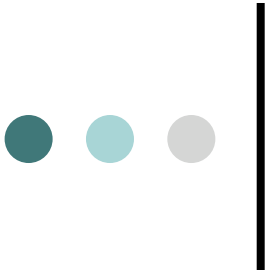
At initial stage



At final stage



At initial and
final stages



Three approaches (2) Functional Requirement Driven

- Known variables
 - Temperature at initial and final stages
 - Functional requirement at initial stage
- Resulting variable
 - Individual dimension at initial and final stages
 - Functional requirement at final stage
- Typical Issue

Which dimensions have to be chosen in order to obtain a given value for a functional requirement after thermal expansion ?

● ● ● | Three approaches (3)
Geometry driven

Functional
Requirements

At initial and
final stages

Individual
Dimension

At initial stage

Loads :
(Temperature, Efforts)/

At final stage

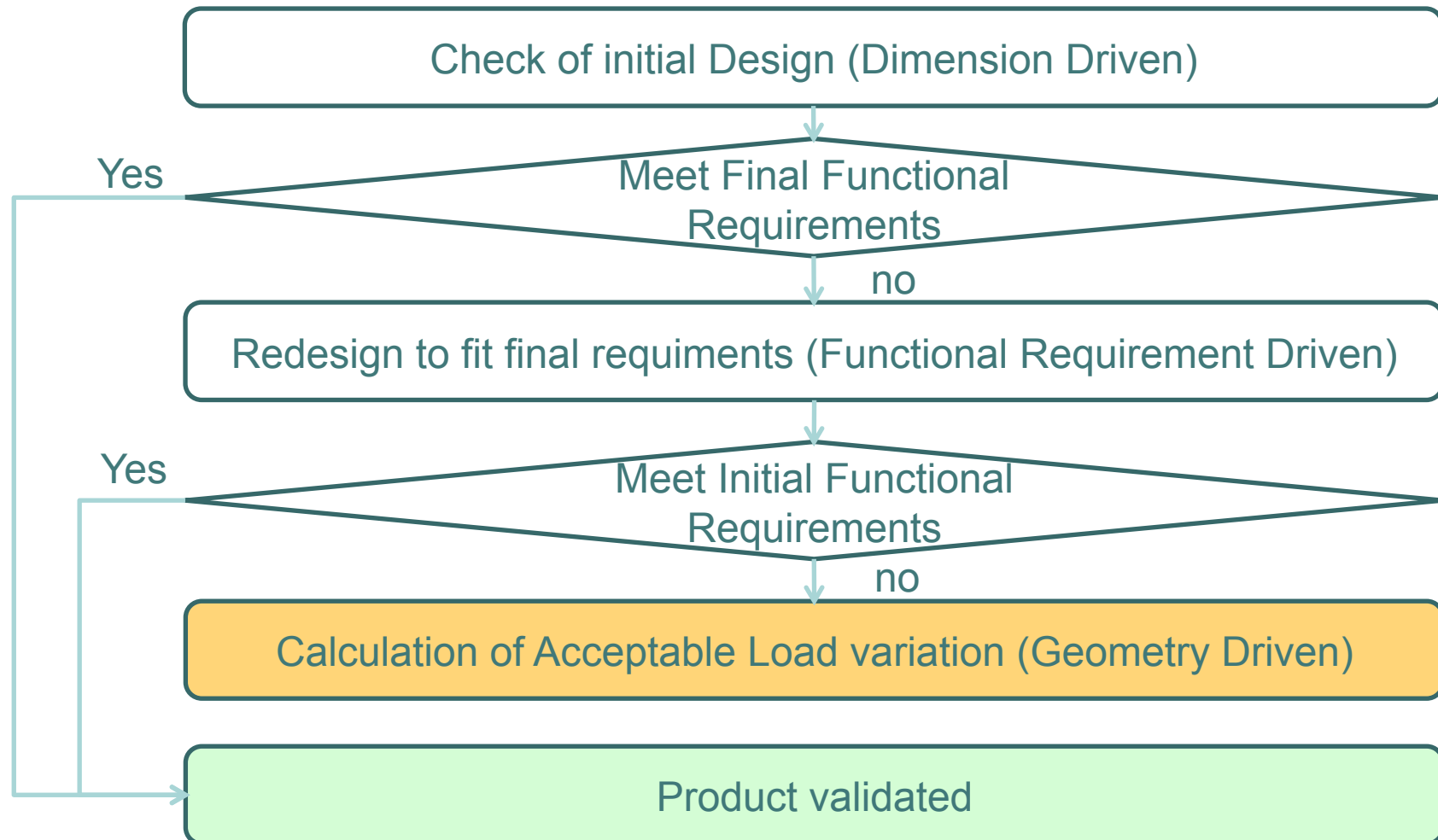


Three approaches (3) Geometry driven

- Known variables
 - Functional requirement at initial and final stages
 - Temperature at initial stage
- Resulting variable
 - Temperature at final stage
- Typical Issue

Which loads are acceptable in order to ensure the respect of a common functional requirement at 2 different stages of the product life cycle.

Example of FR management along the product life cycle



Calculation 1

Dimension driven

Life-cycle stage	Value of j_1 - 0 + Interference Motion Possible	Value of j_2 - 0 + Interference Motion Possible	Value of j_3 - 0 + Interference Motion Possible
Stage "Si" @ 20°C Stage "Sf" @ 50°C			

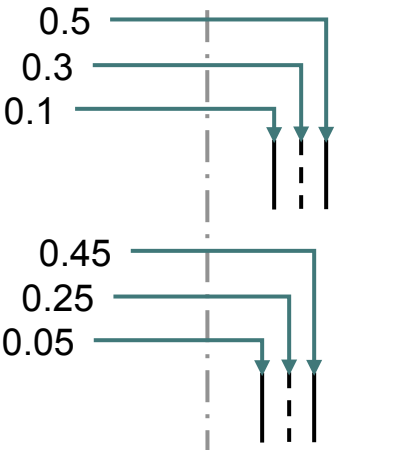
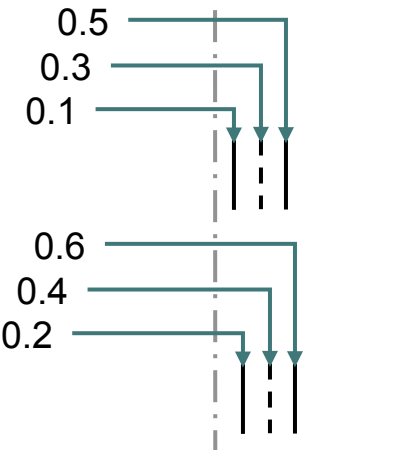
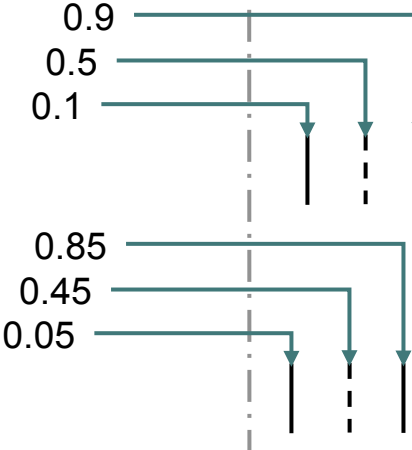
Calculation 2

Functional Requirement driven

Life-cycle stage	Value of j_1 - 0 + Interference Motion Possible	Value of j_2 - 0 + Interference Motion Possible	Value of j_3 - 0 + Interference Motion Possible
Stage "Si" @ 50°C			
Stage "Sf" @ 20°C			

Calculation 3

Geometry driven

Life-cycle stage	Value of j_1 - 0 + Interference Motion Possible	Value of j_2 - 0 + Interference Motion Possible	Value of j_3 - 0 + Interference Motion Possible
Stage "Si" @ 20°C Stage "Sf"			
Allowable final temperature	91.0°C	25.9°C	22.8°C



Conclusion

- High-level management of Functional Requirement along the product life-cycle.
- Investigation of typical design scenarios involving loads and functional requirements variations.
- Use of multiple configurations of the mechanism for studying product evolution along life cycle.



Perspectives & Further Work

- Use of a parametric representation for 3D extension.
 - Dimension chains viewed as vector loops
 - Deformations viewed as variations on vectors' lengths and orientations
- Results from Finite Elements calculation used to quantify dimension variations
- Integration within a PLM based framework representation

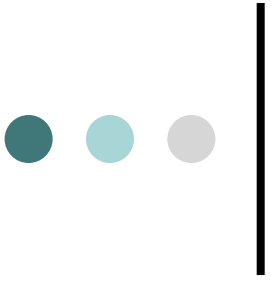


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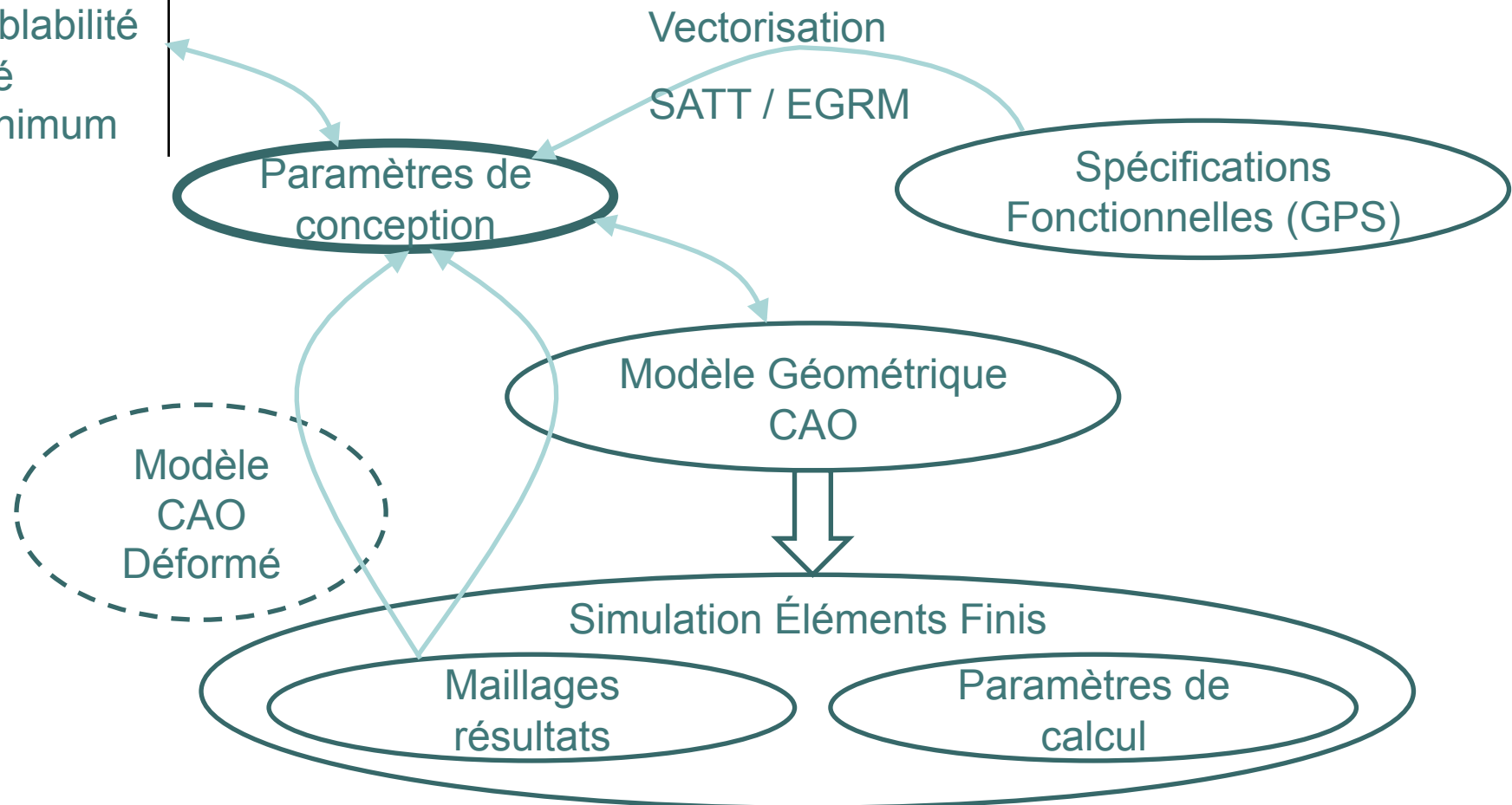
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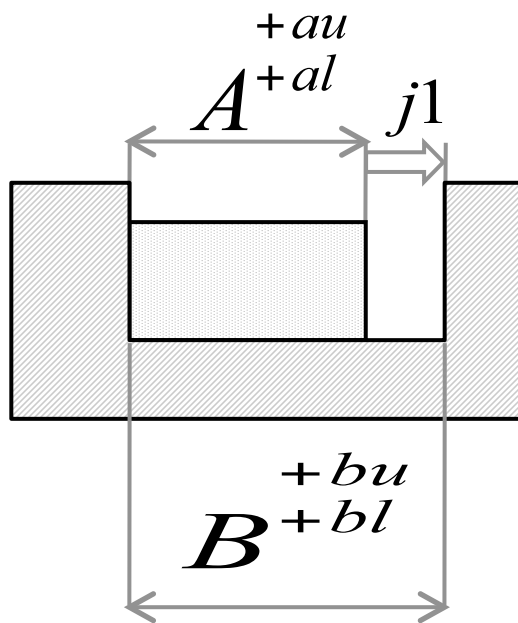


Discussion

Calculs de :
Tolérancement
Assemblabilité
Mobilité
Jeu minimum



Definitions and concepts

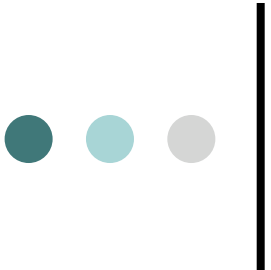


- Nominal dimension : A
- Tolerance : $[al; au]$
- Mean dimension : $\bar{A} = A + \frac{au + al}{2}$
- Dimension chain : $j1 = B - A$
- Calculation of functional requirement values



Uncertainties on Functional Requirements

- For all dimensions tolerance zones are 0.2mm width
- Uncertainties on Functional Requirements are deduced thanks to dimension chains relation
 - $j1$ has a 0.4mm width uncertainty zone
 - $j2$ has a 0.4mm width uncertainty zone
 - $j3$ has a 0.8mm width uncertainty zone



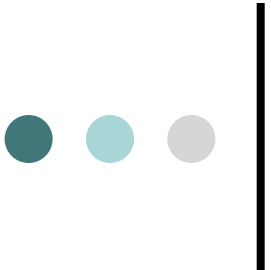
Functional requirements variation across life-cycle

- Width of uncertainty for Functional Requirement is not varying along life cycle
- Loads variations affect the mean value of the Functional Requirement
- Tolerance analysis/synthesis made once at the initial stage.
- Variations due to the changing environment are evaluated on the mean values



Further Work

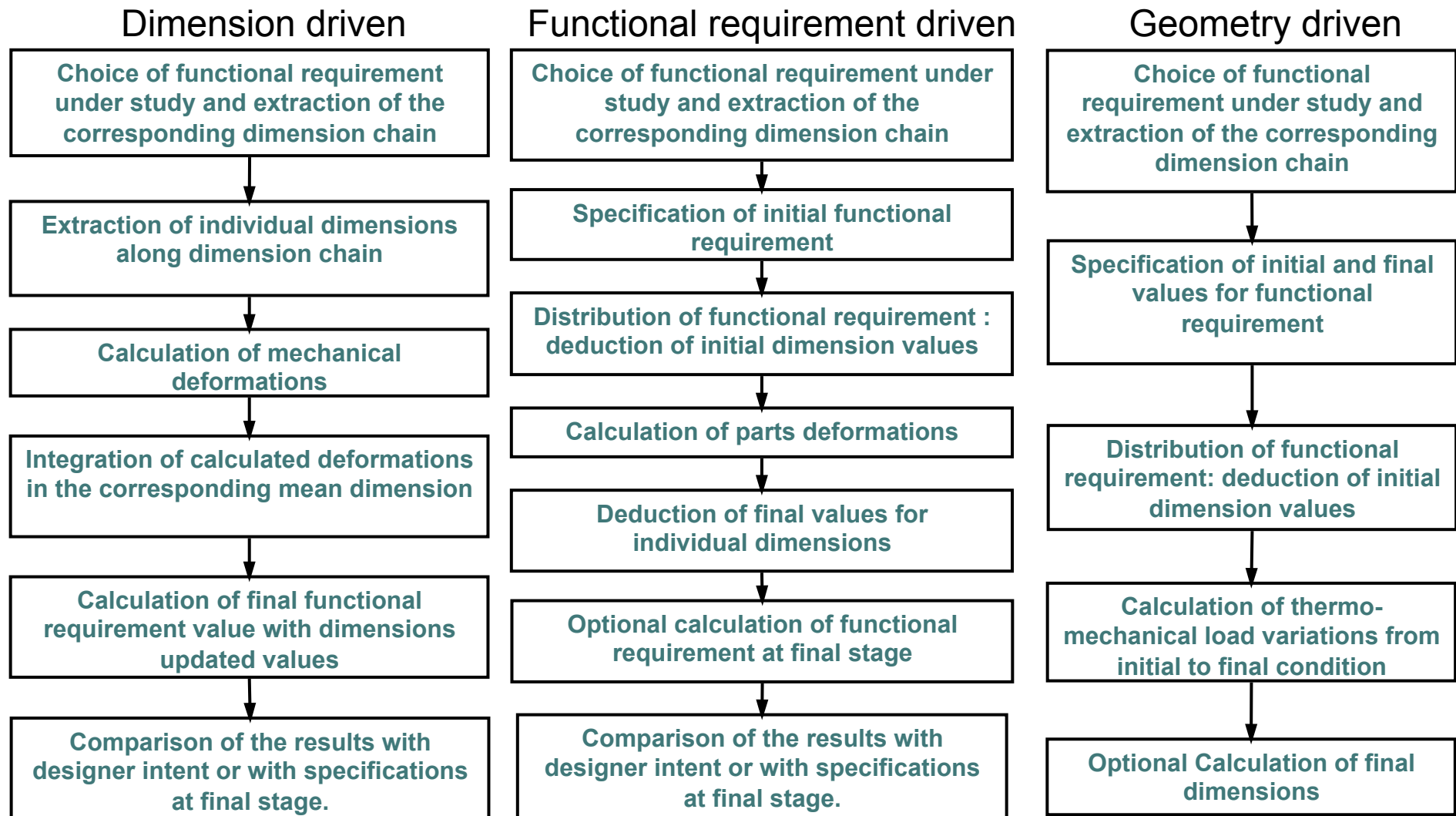
- Use of a deformed mesh to deformed BRep transfer. [Louhichi]
- Association of the deformed mechanism to an ideal and FR compatible “neighbour”.
- Calculation of the distance between deformed and associated parameterisation vectors
- deduction of minimal functional requirement [Serré]



Discussion : Contribution du LISMMA?

- Utilisation des relations de dépendance en 3D comme équation pour caractériser des conditions fonctionnelles.
- Pour les mécanismes iso-statiques ?

Three kind of calculations





Calculation 1

Dimension driven

What will be the value of a given functional requirement after thermal dilatation of the parts?

Hypothesis	Results
$t_i = 20^\circ\text{C}$	$\bar{e}_1 = 60.043$ at 50°C
$t_f = 50^\circ\text{C}$	$\bar{e}_2 = 1441.028$ at 50°C
$e_1 = 60^{\pm 0,1} \text{ mm}$ at 20°C	$\bar{e}_3 = 60.043$ at 50°C
$e_2 = 1440^{\pm 0,1} \text{ mm}$ at 20°C	$\bar{b}_1 = 60.322$ at 50°C
$e_3 = 60^{\pm 0,1} \text{ mm}$ at 20°C	$\bar{b}_2 = 1440.218$ at 50°C
$b_1 = 60.3^{\pm 0,1} \text{ mm}$ at 20°C	$\bar{b}_3 = 60.822$ at 50°C
$b_2 = 1439.7^{\pm 0,1} \text{ mm}$ at 20°C	$j_1 = [0.079 ; 0.479] \text{ mm}$ at 50°C
$b_3 = 60.8^{\pm 0,1} \text{ mm}$ at 20°C	$j_2 = [0.610 ; 1.010] \text{ mm}$ at 50°C
	$j_3 = [-0.431 ; 0.369] \text{ mm}$ at 50°C

Calculation 2

Functional requirement driven

Which dimension has to be chosen in order to obtain a given value of a functional requirement after thermal dilatation?

Hypothesis	Results
$t_i = 50^\circ\text{C}$	$\overline{e1} = 60$ at 20°C
$t_f = 20^\circ\text{C}$ $60.893^{\pm 0,1} \text{ mm}$	$\overline{e2} = 1440$ at 20°C
$j1 = [0.05 ; 0.45] \text{ mm}$ at 50°C	$\overline{e3} = 60$ at 20°C
$j2 = [0.2 ; 0.6] \text{ mm}$ at 50°C	$\overline{b1} = 60.27$ at 20°C
$j3 = [0.05 ; 0.85] \text{ mm}$ at 50°C	$\overline{b2} = 1440.109$ at 20°C
$e1 = 60.043^{\pm 0,1} \text{ mm}$ at 50°C	$\overline{b3} = 60.87$ at 20°C
$e2 = 1441.028^{\pm 0,1} \text{ mm}$ at 50°C	$j1 = [0.071 ; 0.471] \text{ mm}$ at 20°C
$e3 = 60.043^{\pm 0,1} \text{ mm}$ at 50°C	$j2 = [-0.310 ; 0.09] \text{ mm}$ at 20°C
$b1 = 60.293^{\pm 0,1} \text{ mm}$ at 50°C	$j3 = [0.581 ; 1.381] \text{ mm}$ at 20°C
$b2 = 1440.628^{\pm 0,1} \text{ mm}$ at 50°C	
$b3 = 60.893^{\pm 0,1} \text{ mm}$ at 50°C	



Simple application case : Hypothesis

- Wheel shaft made of Aluminium ($\alpha=1,2 \text{ E-5}$)
- Frame made of steel ($\alpha=2,38 \text{ E-5}$)
- Dimension known at 20°C
- Deformation of parts due to thermal dilatation only
- Design variables : dimensions of the

$$j1 = b1 - e1$$

frame

$$j2 = e2 - b2$$

$$j3 = b2 + b3 - e2 - e3$$