DEVELOPMENT OF PROGNOSTICS AND HEALTH MANAGEMENT DESIGN TECHNOLOGY

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Graduation Year: 2012

16/04/2012 – 19/10/2012

PHM'T' & MADe content

1. What is *Prognostics and Health Management* (PHM)?
2. From the **J**oint **S**trike **F**ighter project to PHM Technology
3. Presentation of MADe software

What is Prognostics and Health Management?

PHM‘T’ & MADe

What is PHM?

PHM Technology

The MADe suite

BACKGROUND

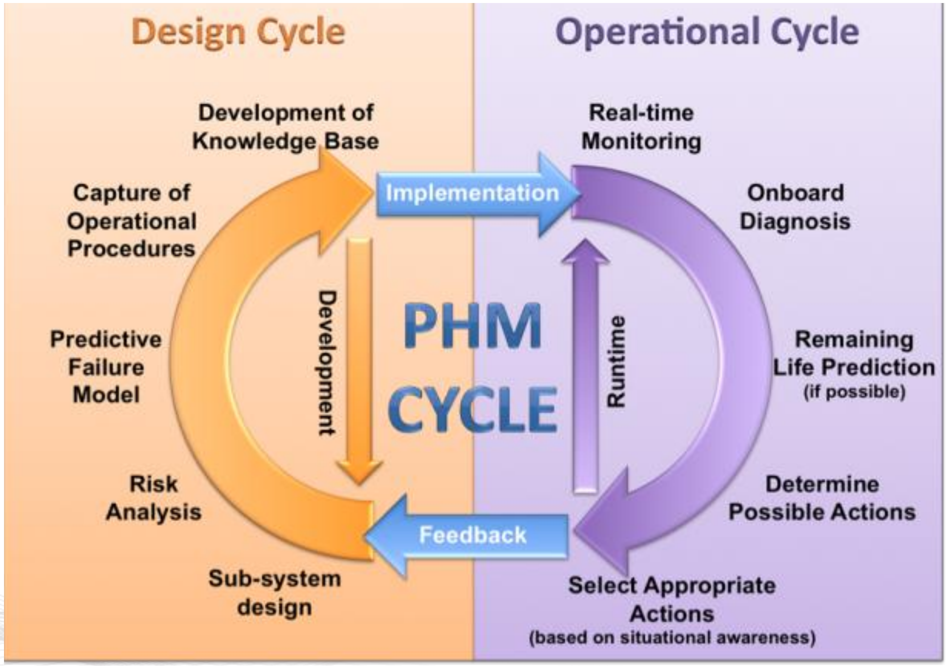
WORK

FURTHER WORK

THE PROJECT

WHAT WE GAIN?

- ***Routine maintenance***: replacing components to a schedule, whether or not they needed replacing.
- ***Condition Based-Maintenance (CBM)***: regular inspections and replacing components as they wear out.



Stecki, J. & C. and Andrew, L. and Cross J. and Glover, W.
The Use of Prognostic Health Management for Autonomous Unmanned Air Systems

The beginning of PHM Technology

PHM'T' & MADe

What is PHM?

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WHAT WE GAIN?

Dr J. Stecki

1980-1996: Head of the Machine Condition Monitoring center of Monash University (Melbourne)

✧ *Implement PHM:* ***What sensors? Where to put them?***

PHM Technology's birthday:

2004: Joint Strike Fighter (JSF) project

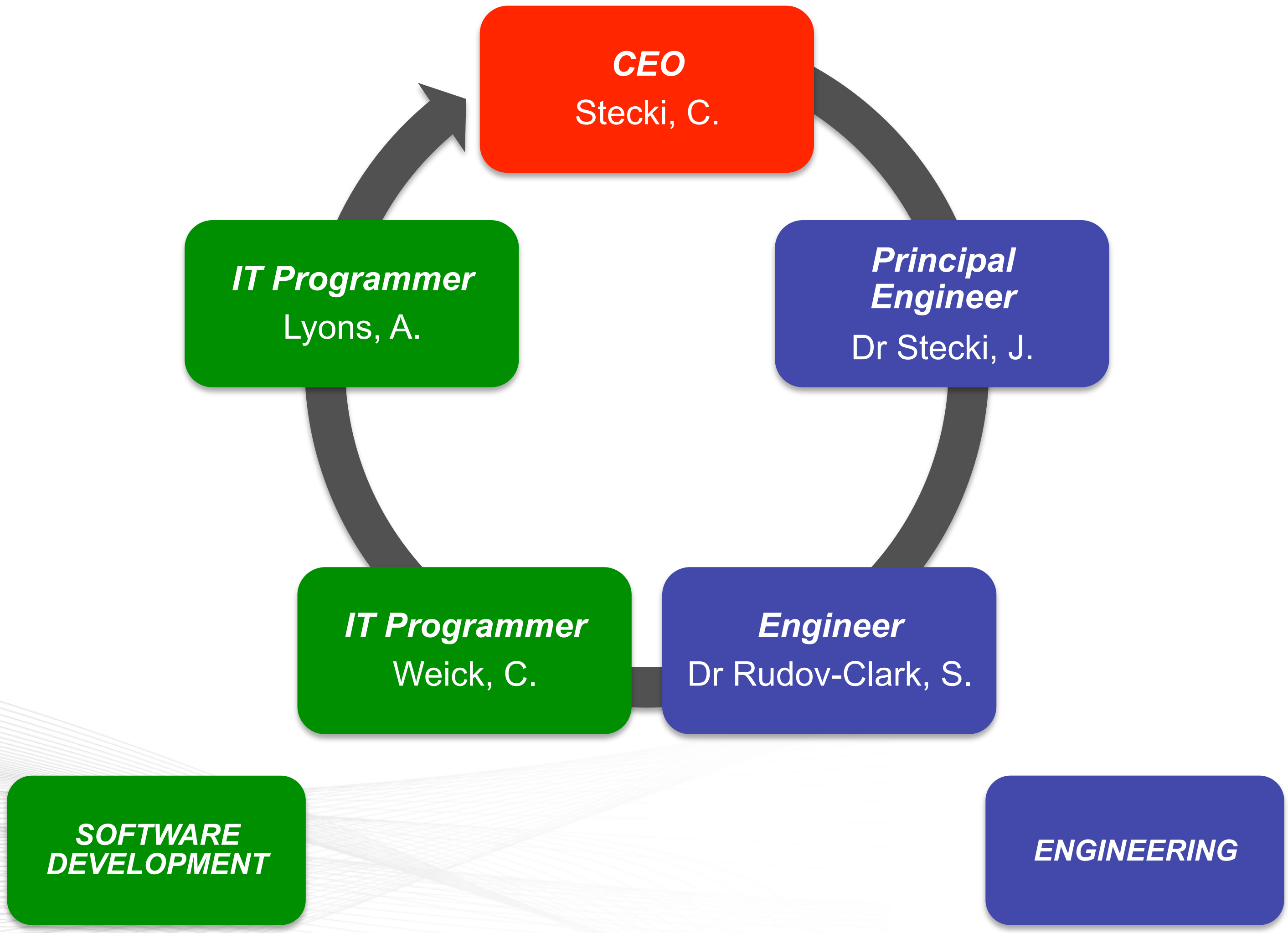
➢ A ***M****aintenance* ***A****ware* ***D****esign* ***e****nvironment* for 1.75m US$!

⇒ **2009:** PHMT delivered MADe to the Joint Project Office

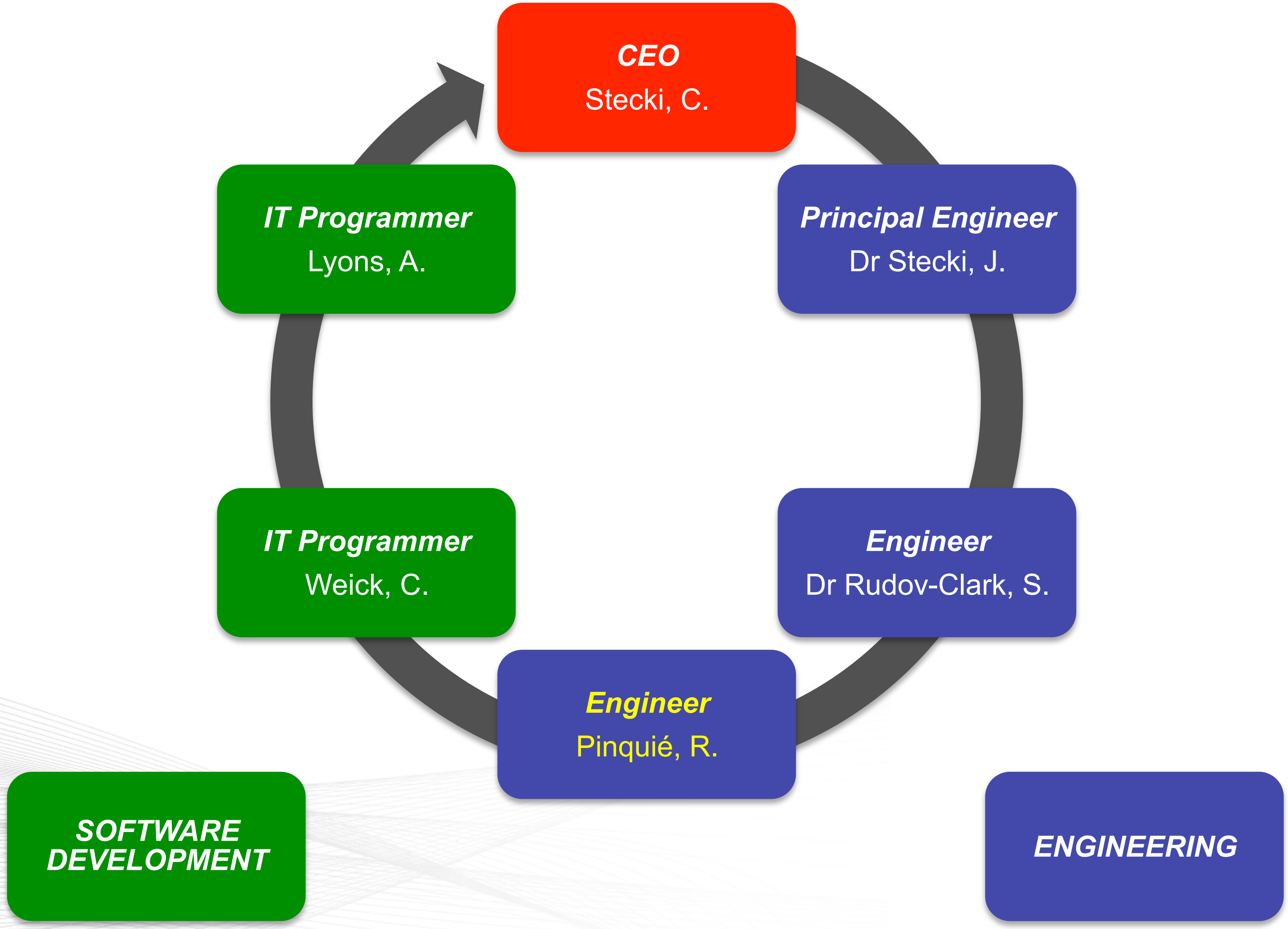
made

MAINTENANCE AWARE DESIGN

PHM Technology personnel



Where am I?



CEO
Stecki, C.
Principal Engineer
Dr Stecki, J.
Engineer
Dr Rudov-Clark, S.
Engineer
Pinquié, R.
IT Programmer
Weick, C.
IT Programmer
Lyons, A.
SOFTWARE DEVELOPMENT
ENGINEERING

Customers and Pipeline

« STILL UNDER R&D… »

Customers:

✧ NASA / Sikorsky / Boeing / US Army: AMRDEC & AMSAA

Pipeline:

✓ Finland: Department of Intelligent Hydraulics and Automation, Tampere University of Technology

✓ UK: Centre for Integrated Vehicle Health Management, Cranfield University *(BAE & Boeing & Rolls-Royce)*

✓ US: Centre for Life Cycle Engineering (CALCE), University of Maryland, Maryland *(EADS & Lockheed Martin & US DoD)*

✓ US: Palo Alto Research Centre (PARC), Palo Alto, California

Maintenance Aware Design environment

PHM'T' & MADe

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WHAT WE GAIN?

MADe

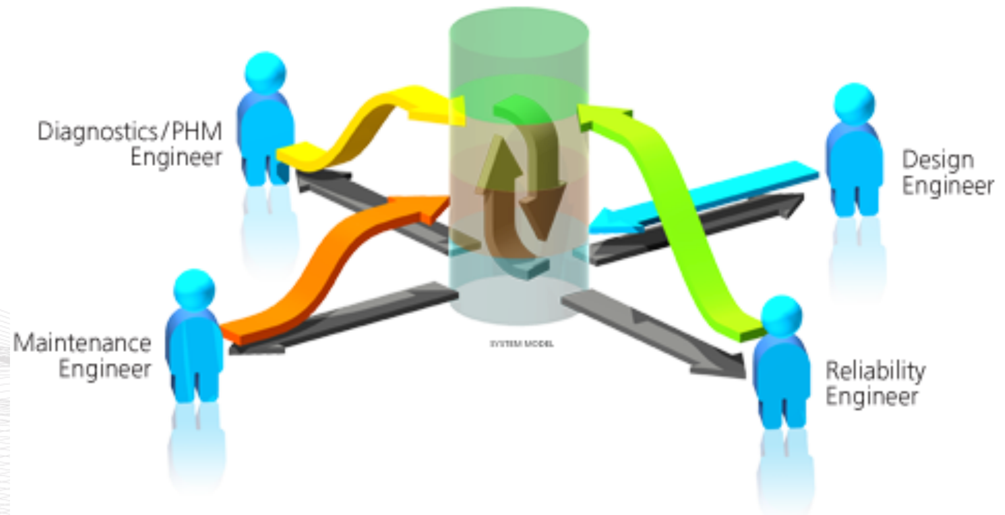
- Functional Design
- Failure Database
- Failure analysis

MADe RAM

- Reliability
- Availability
- Maintenability

MADe PHM

- Sensor set design
- Sensors allocation
- Sensor set optimisation



Background contents

PHM'T' & MADe

BACKGROUND

What is FMECA?

What is RBD?

Objectives

WORK

FURTHER WORK

THE PROJECT

WHAT WE GAIN?

1. What is a ***F**ailure **M**odes, **E**ffects and **C**riticality **A**nalysis*?
2. What is a ***R**eliability **B**lock **D**iagram?*
3. What were the objectives of the last four months?

Failure Modes, Effects and Criticality Analysis

Functional Approach

1949: US Military Procedure - *MIL-P-1629*

1960s: NASA Apollo programme

Spreadsheets:

Item	Function	Functional Failure Mode	Functional Failure Cause	Failure Effect on:		
				Functional Assembly	Next Higher Assembly	System
Switch	Initiates Motor Power Function	Fails to Open	Release Spring Failure	None	Maintains Energy to Circuit Relay	Maintains Energy to Pwr Circuit Through Relay
ETC…						

✧ **Unconstrained** use of **natural language**

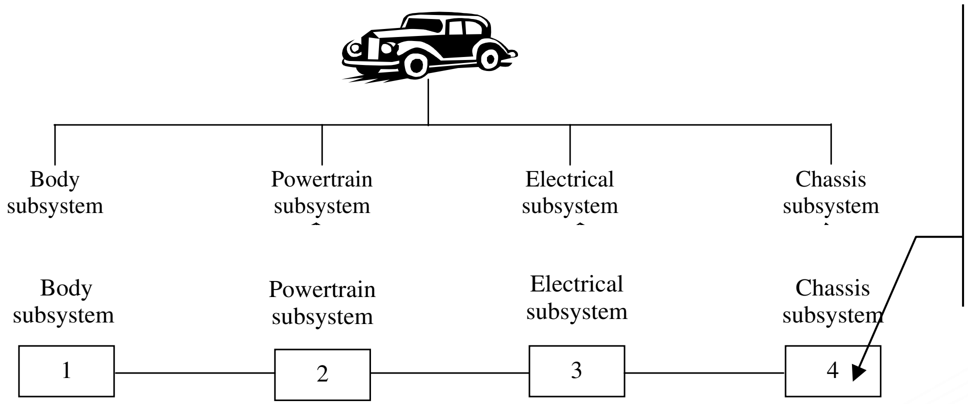
→ **Inconsistent Function & Failure descriptions**

✧ **Unfriendly** updates throughout the system / product's lifecycle

Reliability Block Diagram

Probabilistic Reliability Engineering

RBD: shows by concise visual short hand the various block combinations that result in item success.



- ***Failure rate***
- ***Mission Time***
- *Reliability*
- *Availability*
- *Time To Failure*

↗ **Reliability & Availability**

↘ **Costs of maintenance & Ensure Mission Time**

Objectives

1 – Enhance the Functional Modelling (FMECA) module

- Functional Taxonomy for structures
- Failure Concept Taxonomy for structures

2 – Probabilistic Reliability Engineering

- Validation of the RBD tool
- Research on *Standby* redundant systems

Functional Modelling of structures

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BACKGROUND

WORK

FMEA of structures

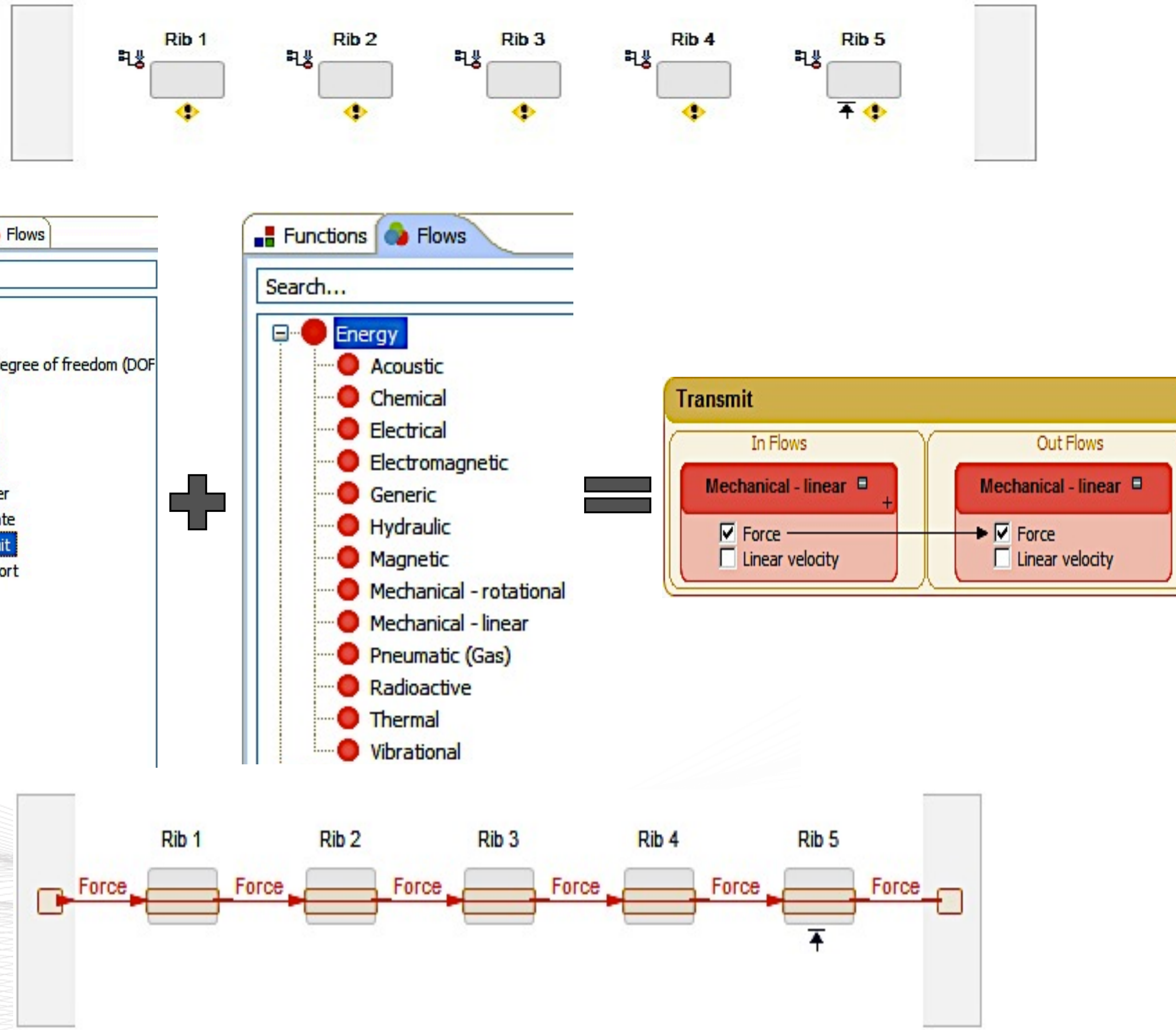
RBD validation

Standby redundancy

FURTHER WORK

THE PROJECT

WHAT WE GAIN?



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WHAT WE GAIN?

Functional Taxonomy for structures

Function Verb	Flow noun		Flow property
Resist	*Energy*	*Structural – Static Stresses*	*Tensile stress* *Compressive stress* *Shear stress* *Bending stress* *Torsion stress* *Combined bending and direct stress* *Hydrostatic (volumetric) stress* *Combined bending and twisting stress*
	Energy	*Structural – Dynamic Stresses*	*Impact stress*
	Energy	*Structural – Fatigue Stresses*	*Alternating/Reversing stress* *Repeated stress* *Combined steady and alternating stress* *Random stress*
	Energy	*Structural – Thermal stress*	*Thermal stress*
Limit	*Energy*	*Structural – Strains*	*Normal Strain* *Shear Strain* *Volumetric Strain*
	Energy	*Structural – Displacements*	*Displacement* *Deflection* *Angle of torsion*
Transmit	*Energy*	*Structural – Static Concentrated Loads*	*Tensile force* *Compressive force* *Shear force* *Bending moment* *Torsional moment*
	Energy	*Structural –Static Distributed Loads*	*Uniform load* *Triangular load* *Parabolic load* *Exponential load* *Sine load* *Cosine load*
	Energy	*Structural – Inertia loads*	*Gravity load* *Spinning load*
	Energy	*Structural – Dynamic Periodic Loads*	*Harmonic High cyclic load* *Harmonic Low cyclic load* *Non-Harmonic High cyclic load* *Non-Harmonic Low cyclic load*
	Energy	*Structural – Dynamic Aperiodic Loads*	*Transient load*
	Energy	*Structural – Impact Loads*	*Impact load*
	Energy	*Structural – Pressure*	*Pressure*

Failure Concept: '*Failure Diagram*'

- PHM'T' & MADe
- BACKGROUND
- **WORK**
  - FMEA of structures
  - RBD validation
  - Standby redundancy
- FURTHER WORK
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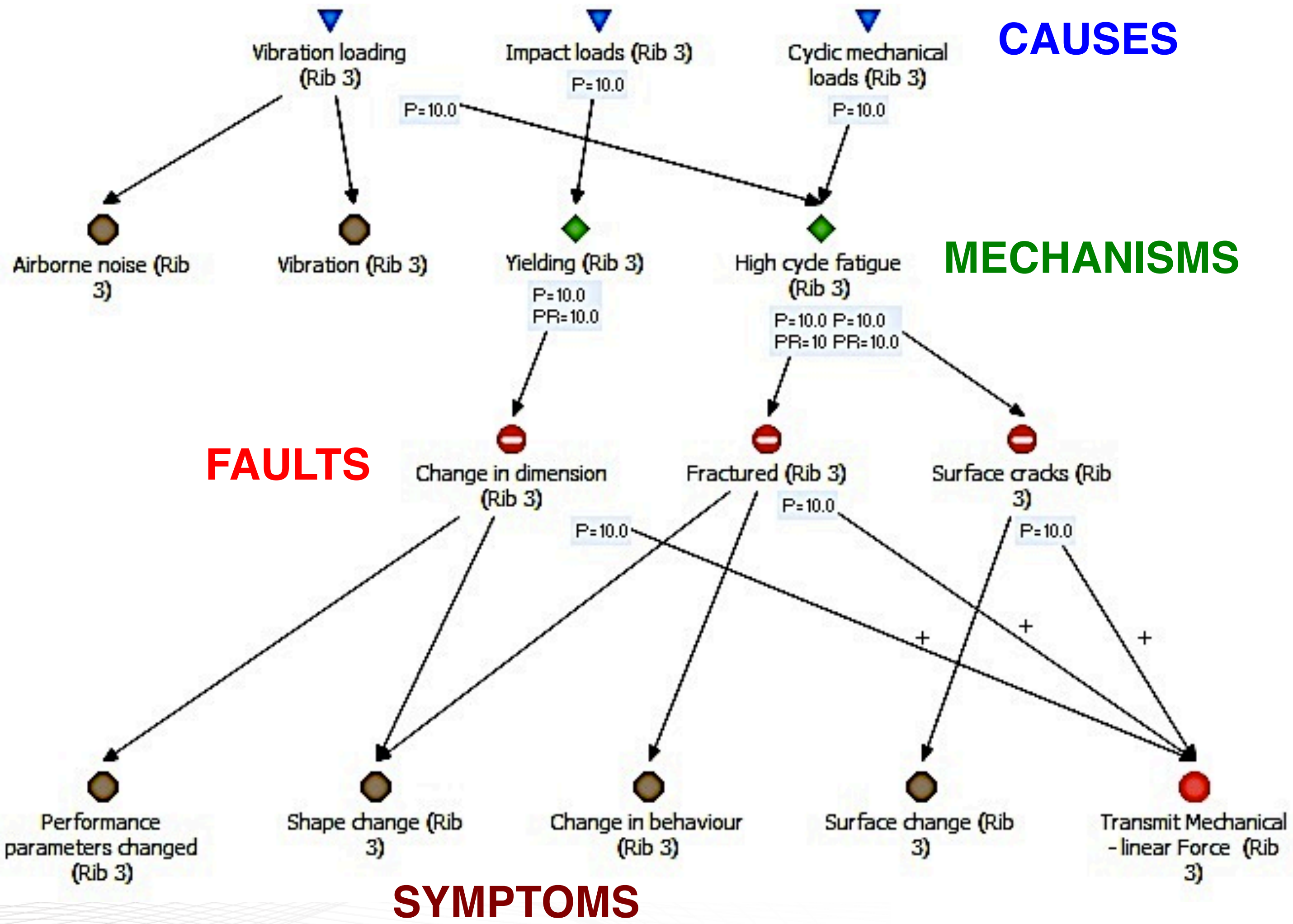
- WHAT WE GAIN?



Failure *Mechanisms* for structures

PHM'T' & MADe

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FMEA of structures

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Standby redundancy

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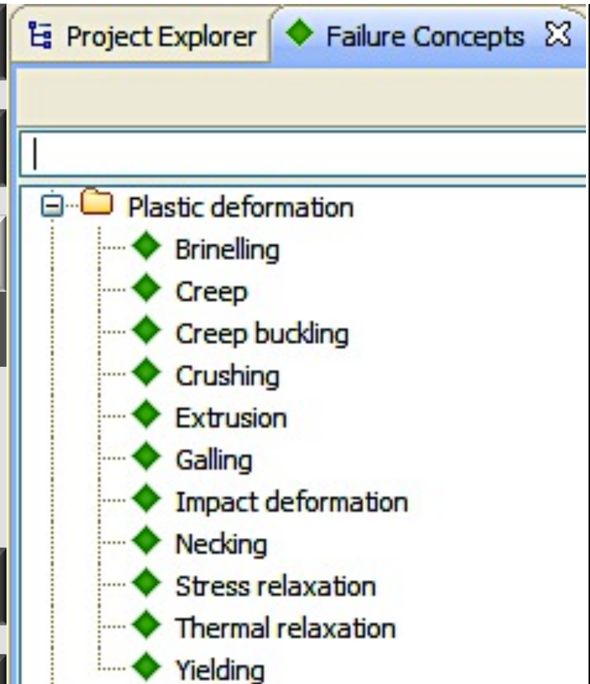
WHAT WE GAIN?

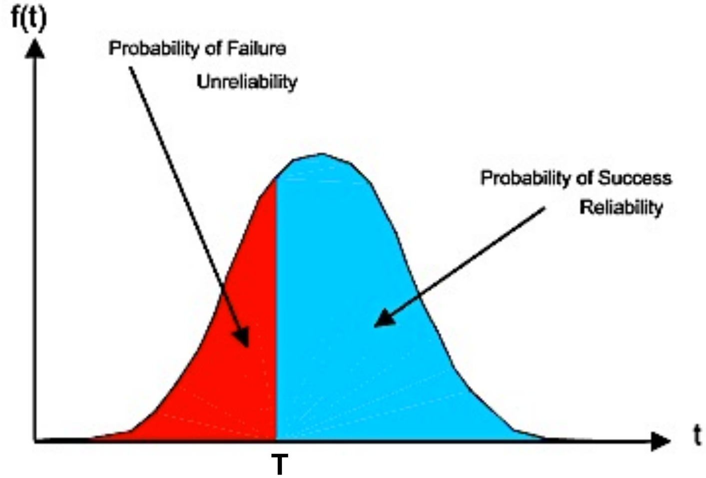


Mechanism Group	Mechanism of failure
Fracture	*Tensile fracture*
	Compressive fracture
	Shear fracture
	Bending fracture
	Torsion fracture
	Combined bending and tensile fracture
	Combined bending and compression fracture
	Combined torsion and tensile fracture
	Combined torsion and compression fracture
	Combined bending and torsion fracture
	Resonance fracture
Elastic deformation	*Tensile deformation*
	Compressive deformation
	Shear deformation
	Bending deformation
	Torsion deformation
	Combined bending and tensile deformation
	Combined bending and compression deformation
	Combined torsion and tensile deformation
	Combined torsion and compression deformation
	Combined bending and torsion deformation
Plastic deformation	*Tensile yielding*
	Compressive yielding
	Shear yielding
	Bending yielding
	Torsion yielding
	Combined bending and tensile yielding
	Combined bending and compression yielding
	Combined torsion and tensile yielding
	Combined torsion and compression yielding
	Combined bending and torsion yielding

Failure *Causes* for structures

Cause Group	Cause of failure
Static Concentrated Loads	***Tensile force*** ***Compressive force*** ***Shear force*** ***Bending moment*** ***Torsional moment***
Static Distributed Loads	***Uniform load*** ***Triangular load*** ***Parabolic load*** ***Exponential load*** ***Sine load*** ***Cosine load***
Inertia loads	***Gravity load*** ***Spinning load***
Dynamic Periodic Loads	***Harmonic High cyclic load*** ***Harmonic Low cyclic load*** ***Non-Harmonic High cyclic load*** ***Non-Harmonic Low cyclic load***
Dynamic Aperiodic Loads	***Transient load***
Impact Loads	***Impact load***
Pressure	***Pressure***

The gist of Probabilistic Reliability Engineering

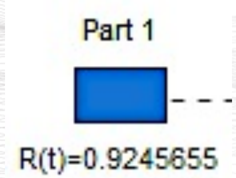


EXPONENTIAL DISTRIBUTION :

Exponential failure distribution : $f(t) = \lambda.e^{-\lambda.t}$

Failure rate : $\lambda(t) = cte$

Reliability, i.e population fraction surviving time 'T' : $R(t) = \int_T^{+\infty} f(t)\,dt = \underline{\underline{1 - F(t) = e^{-\lambda.T}}}$



$$R_1(t) = e^{-\lambda_1.T_1} = e^{-\left(\frac{7843.14}{10^6}\right).10} = 0.9245655$$

ESTIA ECOLE D'INGENIEURS CCI BAYONNE PAYS BASQUE

PHMTechnology

Classic RBD configurations

PHM'T' & MADe

BACKGROUND

WORK

FMEA of structures

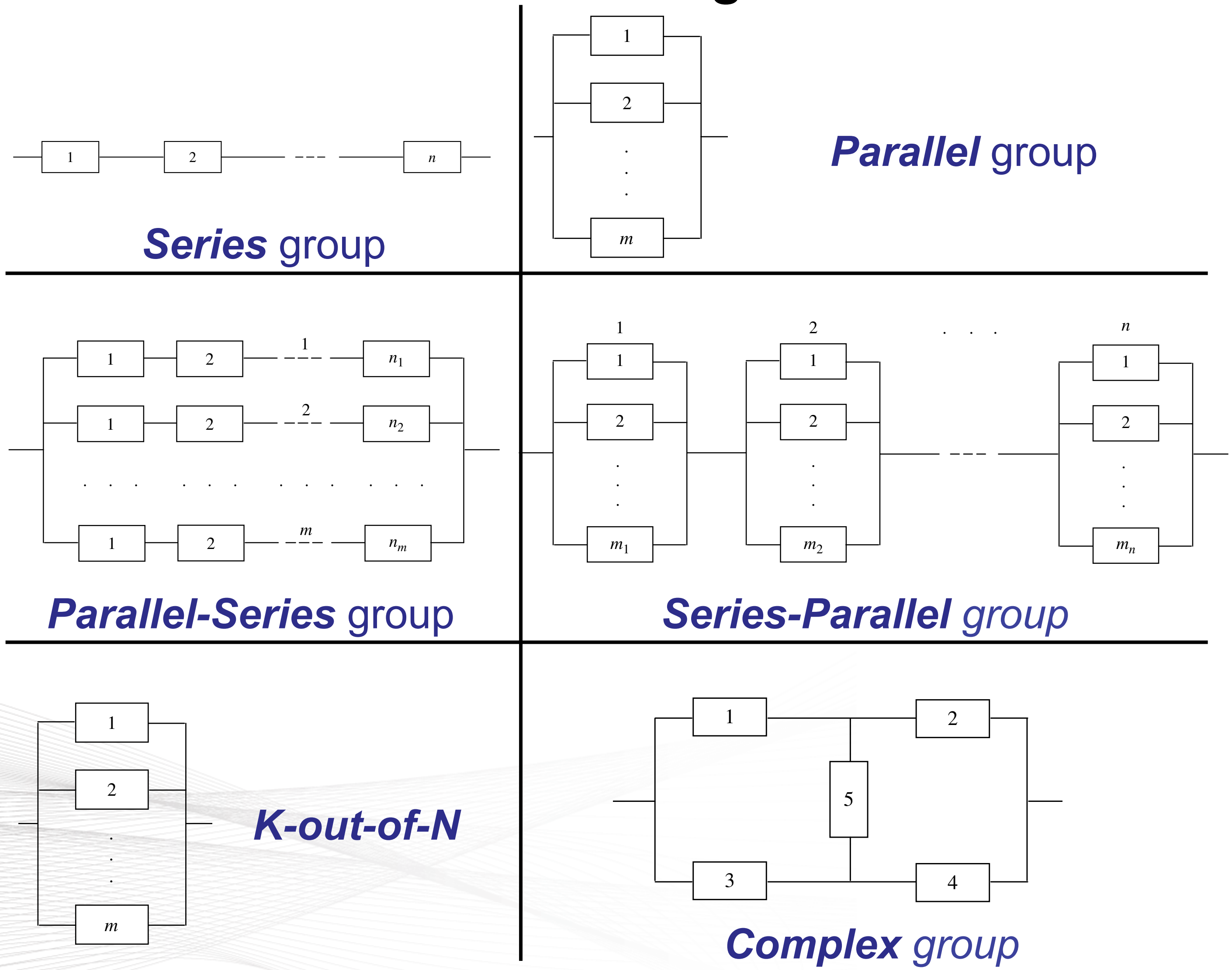
RBD validation

Standby redundancy

FURTHER WORK

THE PROJECT

WHAT WE GAIN?



Example with a *Series* group

- PHM'T' & MADe
- BACKGROUND
- WORK
  - FMEA of structures
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- FURTHER WORK
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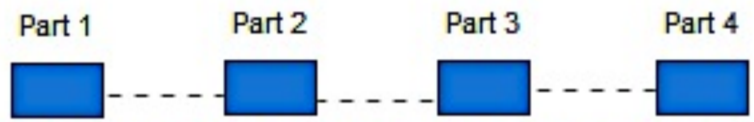
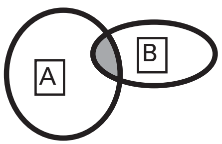
- WHAT WE GAIN?



Series group:

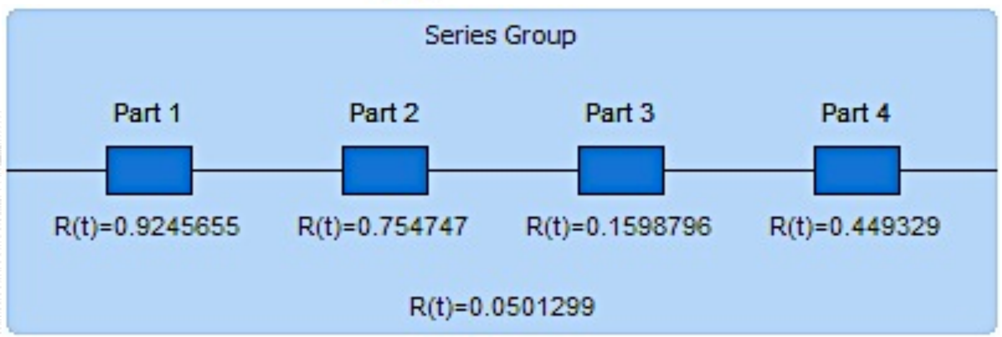
$A \cap B$:



$$\mathrm{Rs}\ (t) = P(\cap_{i=1}^{n} A_i)$$
$$= P(A_1).P(A_2).P(A_3). \dots .P(A_n)$$
$$= R_1.R_2.R_3. \dots .R_n$$
$$= \prod_{i=1}^{n} R_i$$

4 components:

$$\mathrm{Rs}\ (t) = \prod_{i=1}^{4} R_i = R_1.R_2.R_3.R_4 \cong \mathbf{0.0501299}$$



Results of RBD validation

- PHM'T' & MADe
- BACKGROUND
- WORK
  - FMEA of structures
  - RBD validation
  - Standby redundancy
- FURTHER WORK
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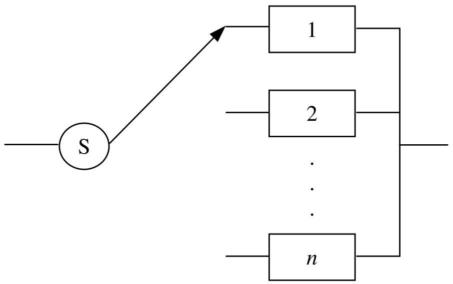
- WHAT WE GAIN?

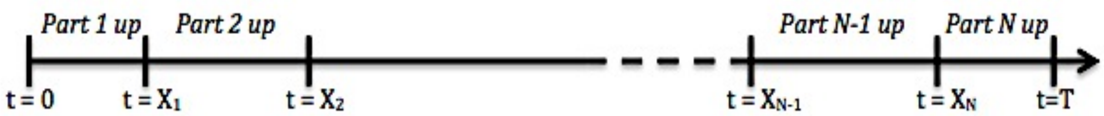
Configuration	Series	Parallel	Series-Parallel	Parallel-Series
Analytical	0.0501299	0.9914411	0.9745424	0.1429766
MADe	*0.0501299*	*0.9914411*	*0.9745424*	*0.1429766*
Configuration	**KooN (K=1)**	**KooN (K=2)**	**KooN (K=3)**	**Complex**
Analytical	0.44939329	0.3953634	0.0501299	0.7602351
MADe	*0.44939329*	*0.3953634*	*0.0501299*	*0.7602351*

VALIDATED!

Standby redundant systems



Cold Standby perfect switching:



$$Rs(t) = P\left(\sum_{i=1}^{N} X_i > T\right) = R_1(T) + \int_0^T f_1(X_1) R_2(T - X_1)\, dX_1$$

$$+ \int_0^T f_1(X_1) \int_0^{T-X_1} f_2(X_2) R_3(T - X_1 - X_2)\, dX_2\, dX_1$$

$$+ \int_0^T f_1(X_1) \int_0^{T-X_1} f_2(X_2) \int_0^{T-X_1-X_2} f_3(X_3) R_4(T - X_1 - X_2 - X_3) dX_3 dX_2 dX_1$$

$$+ \ldots$$

$$+ \int_0^T f_1(X_1) \int_0^{T-X_1} f_2(X_2) \ldots \int_0^{T-\sum_{i=1}^{N-2} X_i} f_{N-1}(X_{N-1}) R_N\left(T - \sum_{i=1}^{N-1} X_i\right) dX_{N-1} \ldots dX_2\, dX_1$$

Where $f_n(X_u)\, dX_u$ is the probability of the part n fails at an unknown time X_u.

Stochastic algorithm: *Monte-Carlo*

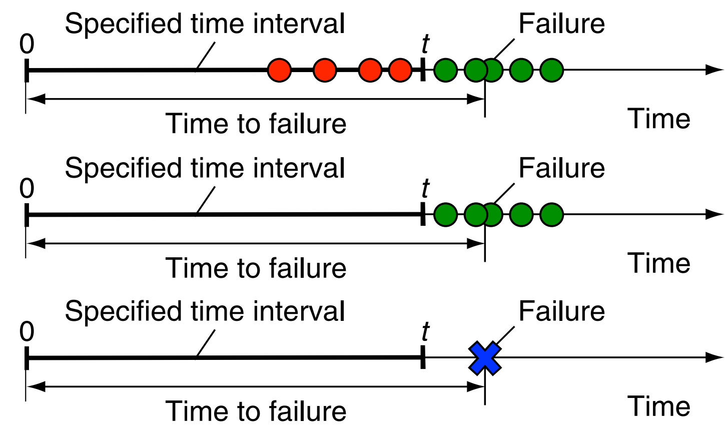
MONTE-CARLO ALGORITHM:

```
Nb_of_ success = 0;
For i = 1 to Number_of_trials do
{
        System_lifetime = 0;

        For i = 1 to Number_of_components
                System_lifetime = System_lifetime – TTF_i;

        If (System_lifetime > Mission_Time)
                then Nb_of_failure = Nb_of_success + 1;

}
Reliability = Nb_of_ success / Number_of_trials;
```



Component	Failure Rate
Active	0,05
Standby 1	0,04
Standby 2	0,03
Standby 3	0,08

Number of components =	4
Number of Iterations =	500
Mission Time =	75

Compute System Reliability

System Reliability = 0.556

$$> e^{-0.05\cdot 75} + \int_0^{75} 0.05\cdot e^{-0.05\cdot w}\cdot e^{-0.04\cdot(75-w)}\,dw + \int_0^{75} 0.05\cdot e^{-0.05\cdot w}\cdot \int_0^{75-w} 0.04\cdot e^{-0.04\cdot x}\cdot e^{-0.03\cdot(75-w-x)}\,dx\,dw + \int_0^{75} 0.05\cdot e^{-0.05\cdot w}\cdot \int_0^{75-w} 0.04\cdot e^{-0.04\cdot x}\cdot \int_0^{75-w-x} 0.03\cdot e^{-0.03\cdot y}\cdot e^{-0.08\cdot(75-w-x-y)}\,dy\,dx\,dw$$

0.5665807235

What can be improved in the future?

PHM'T' & MADe
BACKGROUND
WORK
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THE PROJECT
WHAT WE GAIN?

✧ Assess Risk & Improve Safety *(Currently in progress…)*

- **L**ayer **O**f **P**rotection **A**nalysis
- **S**afety **I**ntegrity **L**evel

✧ Reliability Engineering

- Cold Standby Imperfect switching
- Warm Standby (Load Sharing) Im/perfect switching

Schedule

PHM'T' & MADe

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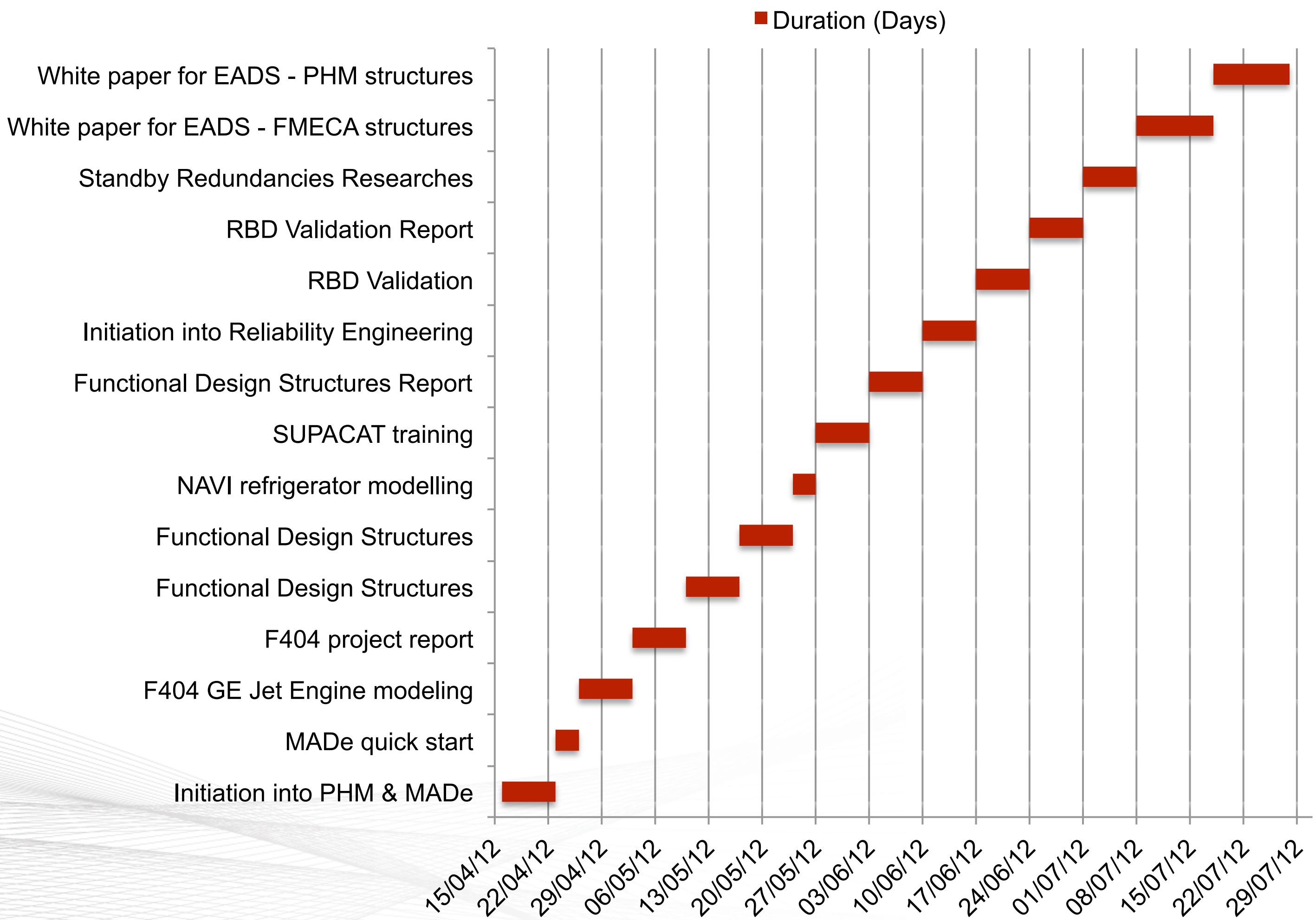
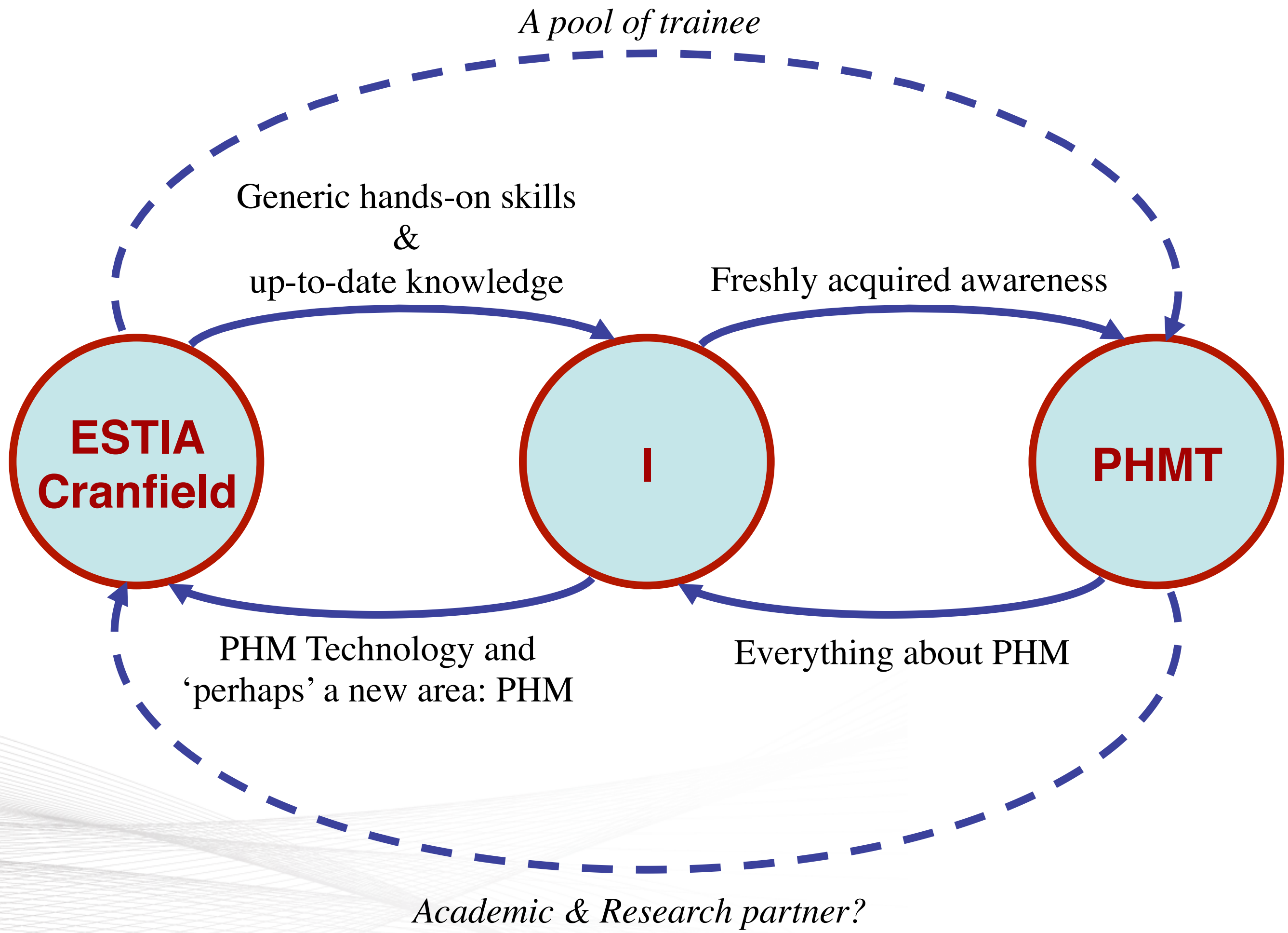


What we gain?

- PHM'T' & MADe
- BACKGROUND
- WORK
- FURTHER WORK
- THE PROJECT
- **WHAT WE GAIN?**



PHM'T' & MADe

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WHAT WE GAIN?

THANK YOU.

Any questions?