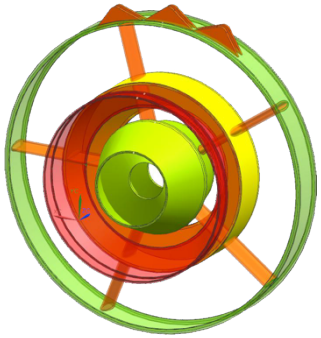

Value-oriented concept selection in aero-engine sub-systems design: the EVOKE approach

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EU FP7 **CRESCENDO** *(Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation)* project - http://www.crescendo-fp7.eu/

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Exceptional Value for Airlines

Product Development is about successfully maintaining focus on **Value Generation** throughout the development process.

EVOKE is about improving practices to enable a Value-Driven Design development at sub-system level (engine components)

Why Value Driven Design?

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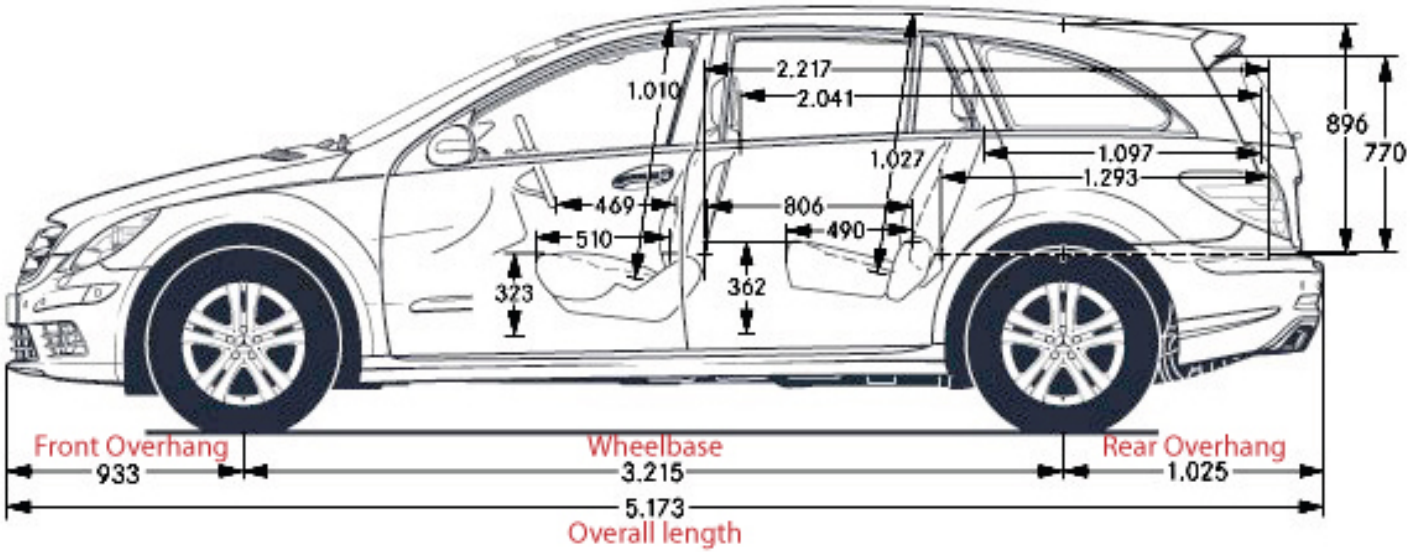
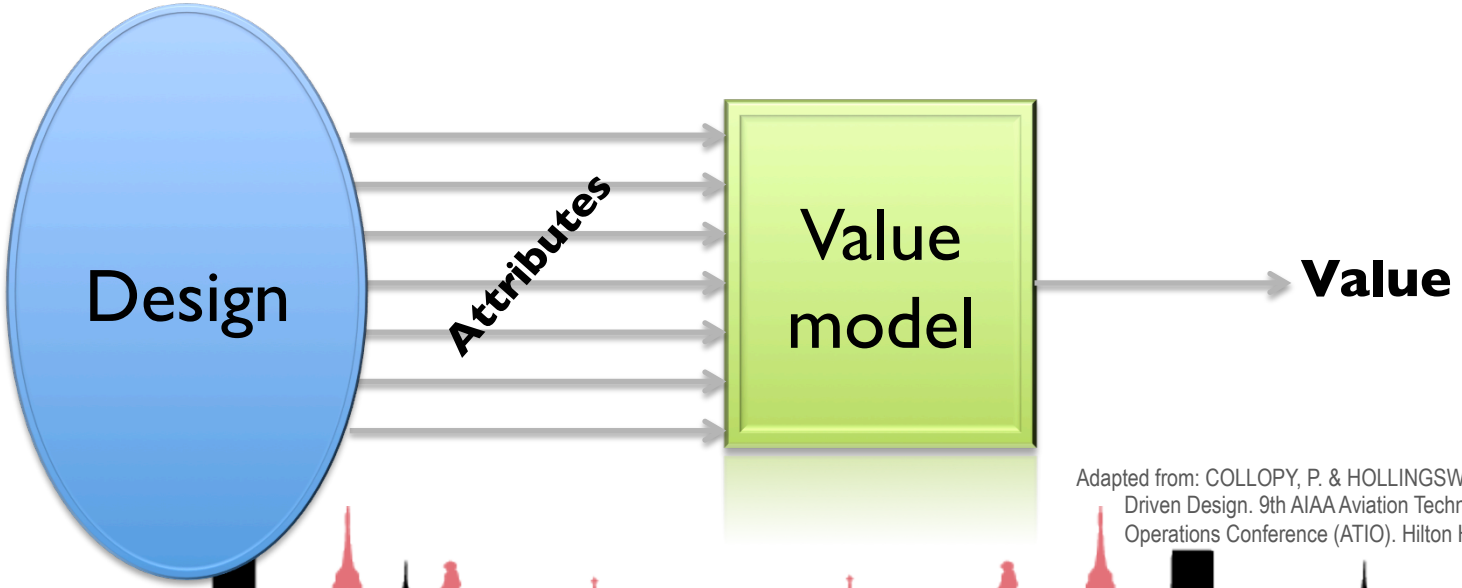
- Ideally, engineered systems should be optimized according to an **objective function**[1].
- Realistically this is often too hard, so it is necessary to set **performance requirements** to be satisfied[1].
- Hence, **design choices** are made to meet performance requirements rather than to maximize system value.



[1]HERBERT S.A. 1969. The Sciences of the Artificial, The Science of Design – 3rd edition. The MIT Press, Cambridge MA. Retrieved 2009-05-25.

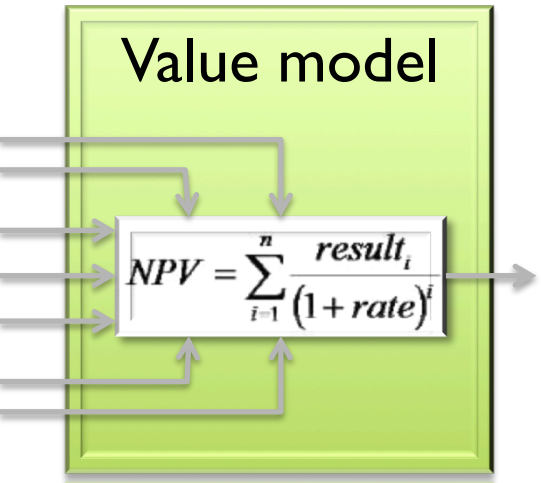
What is Value Driven Design?

- VDD is a **Systems Engineering** strategy that enables multidisciplinary design optimization.
- VDD wants to compare design alternatives using **value,** rather than requirements.
- VDD is **controversial** because performance requirements are a central element in the design of complex systems.



Adapted from: COLLOPY, P. & HOLLINGSWORTH, P. 2009. Value Driven Design. 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO). Hilton Head, SC.

How does Value Driven Design work?



- The **objective function** that is used to optimize the design is called **"value model".**
- A value model is traditionally expression of profit for a business (e.g., **Net Present Value**).
- The **higher** is the NPV, the better is the design.

Value Driven Design - European research teams

Manchester U.
Coordinating AIAA VDD Program Committee

Queen's University
Aircraft fuselage panels design

RR UK
Aero-engine design, several components

U. Southampton
Unmanned aerial vehicles design.

AIRBUS
Laminar wing design.

Delft
Aero engine design, mainly maintenance models.

GKN Aero Sweden
Aero-engine compressor case design.

Blekinge Institute of Technology
Value Driven Design and PSS

Lulea University Of Technology
Value assessment in preliminary Design

Value Driven Design: main issues today

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HOW TO MEASURE VALUE?

- Lack of agreement on what should be the measure of design "goodness", and how they can be measured[1,2,3].

Be aware that what is measured is a surrogate of imagination[2].

Compare apples to apples[1].

- Monetization might have no sense in many cases[3].

HOW TO INCORPORATE INTANGIBLES?

- Current value approaches are strongly product centered and consider only physical or functional architectures, not relationship-based aspects[2,3,4].

Be aware that supplier and customer centered approaches only consider a relationship value[4].

Proactivity, trust, shared norms and shared mind-sets are important[4].

HOW TO HANDLE UNCERTAINTY?

- Value figures in preliminary design phase are built on knowledge with low degree of maturity which is they are not trustworthy[2,5].

Be able to distinguish design errors from unintended consequences from another[2].

Measure the maturity of the knowledge behind the value models[5].

HOW TO COMMUNICATE VALUE?

- Visual ways of displaying and rationally analyze value information are yet to be explored[2,5].

Explore the potentials of graphic analysis and sensemaking[2].

Embed value visualization tools in the the engineering environment[5].

[1] COLLOPY, P. & HOLLINGSWORTH, P. 2009. Value Driven Design. 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO). Hilton Head, SC.

[2] COLLOPY, P. 2012. A Research Agenda for the Coming Renaissance in Systems Engineering. 50th AIAA Aerospace Sciences Meeting, 10p.

[3] SOBAN, D.S., HOLLINGSWORTH, P., PRICE, M.E. 2011. Defining a Research Agenda in Value Driven Design: Questions That Need to be Asked, Air Transport and Operations Symposium 2011, 11p.

[4] KOWALKOVSKY, C. and KINDSTRÖM, D., 2009. Value Visualization Strategies for PSS Development. In: Sakao, T., Lindahl, M., Introduction to Product/Service-System Design, Springer London, London, 159-181.

[5] KOSSMAN, M. 2012. Validation Of The System To Link Expectations To Technical Requirements. CRESCENDO project official deliverable.

Value Driven Design: hints for solutions

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HOW TO MEASURE VALUE?

- Be aware that what is measured is a structure of imagination[2].
- Compare apples to apples[1].
- Monetization might have no sense in many cases[3].

HOW TO INCORPORATE INTANGIBLES?

- Be aware that supplier and customer maintain a relationship over time[4].
- Proactivity, trust, shared norms and shared mind-sets are important[4].

HOW TO HANDLE UNCERTAINTY?

- Be able to distinguish a design prone to unintended consequences from another[2].
- Measure the maturity of the knowledge behind the value models[5].

HOW TO COMMUNICATE VALUE?

- Explore the phenomena of group dynamics and sensemaking[2].
- Embed value visualization tools in the the engineering environment[5].

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CRESCENDO

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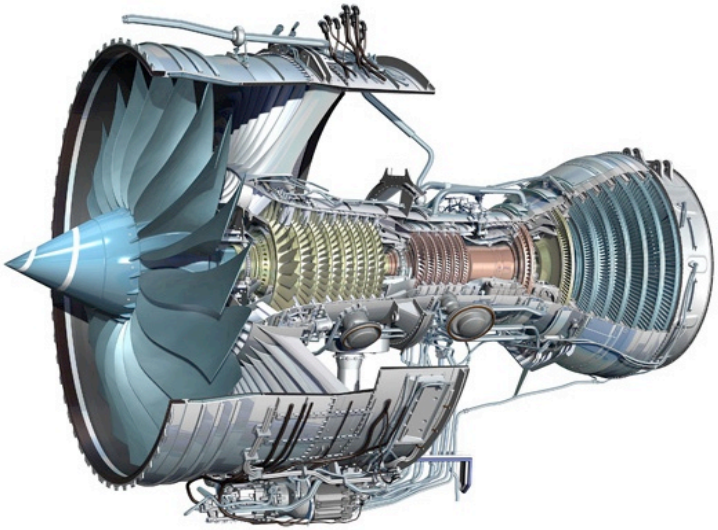

EVOKE

(Early Value Oriented Design Exploration with Knowledge Maturity)

Experience from an aero-engine development project.

VDD in aero-engine components design

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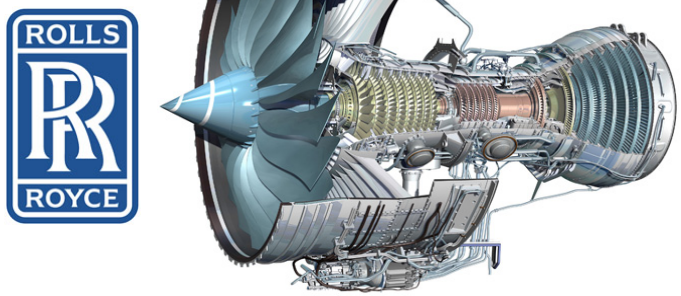
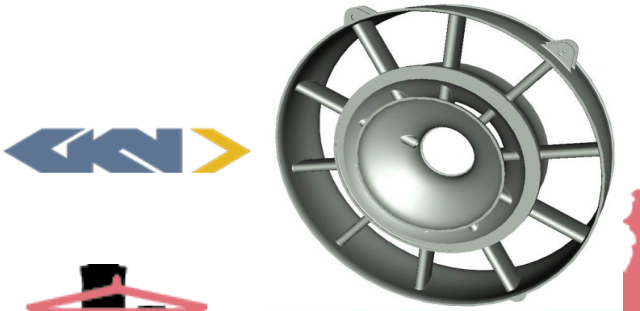




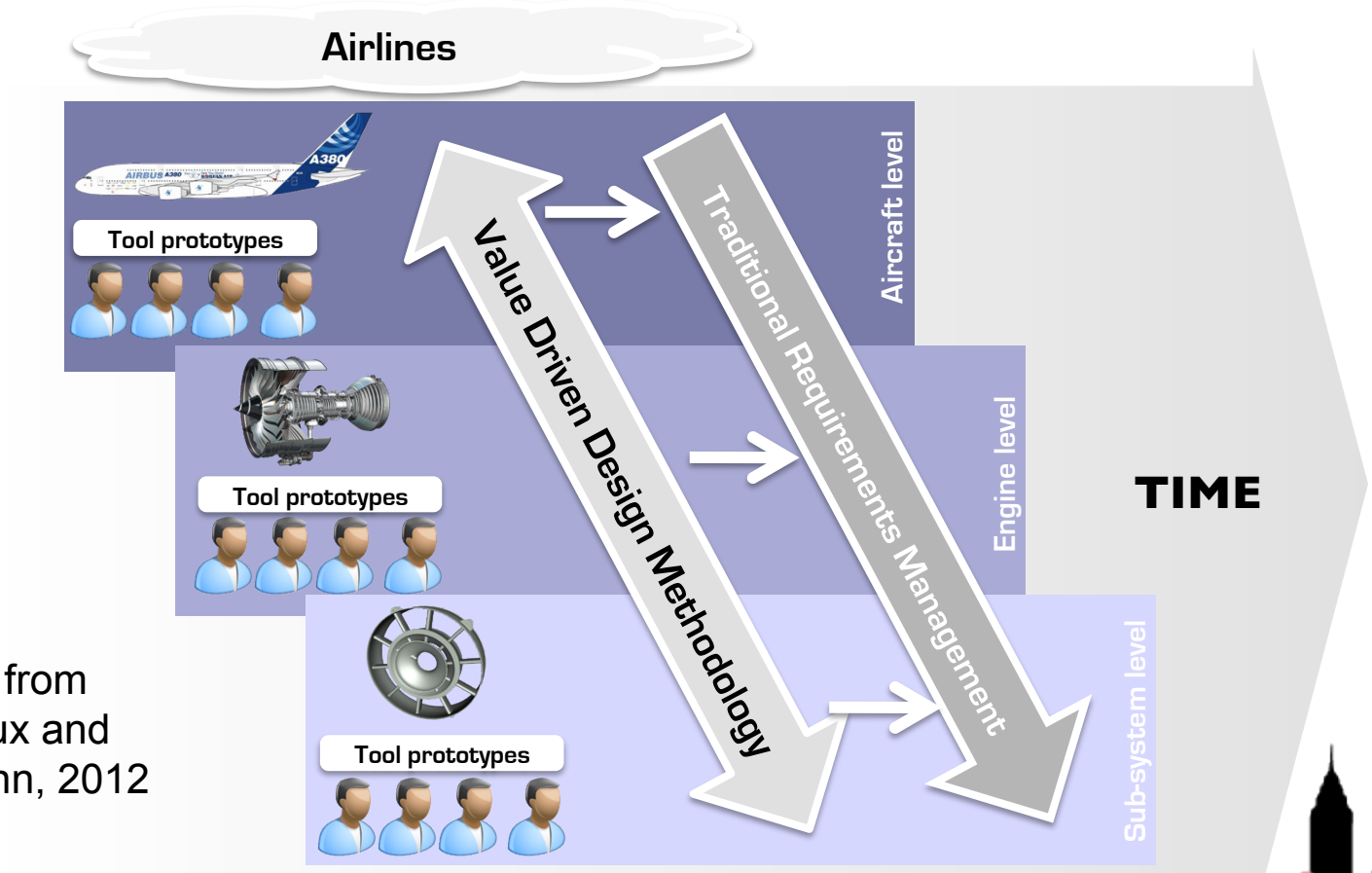
Development programs are often initiated **many years** before detailed A/C requirements are made available to the engine and component manufacturers.

Even if requirements exist, the overall **design intent gets lost** as far as requirements are decomposed into sub-systems and components.

At sub-system level, engineers are **not fully aware** of the detailed system-level consequences produced by their early design decisions.

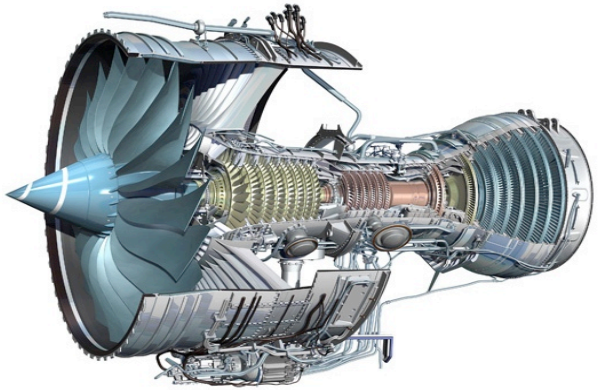
The VDD in the aero-engine supply chain

- Relevant value dimensions/drivers are **exchanged** across the supply chain before system requirements are made public.



Adapted from Monceaux and Kossmann, 2012

Case study: designing an intermediate compressor case (IMC)



Baseline

Fully casted IMC, bleed-air offtake function implemented.

Option #1

Similar to the baseline, featuring fabricated Outlet Guide Vanes.

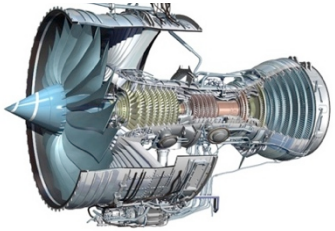
Option #2

Mostly made in composite, without bleed-air offtake.

The EVOKE process for VDD

ENGINE LEVEL

#1 Define system-level value dimensions.



#1: Define system-level value dimensions

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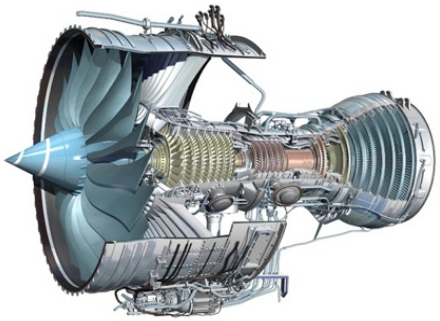
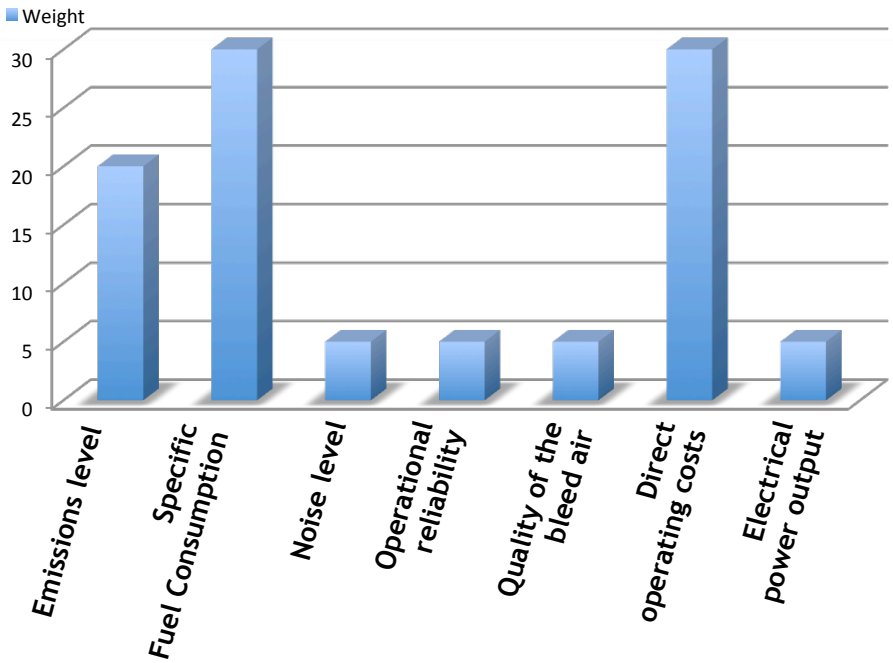
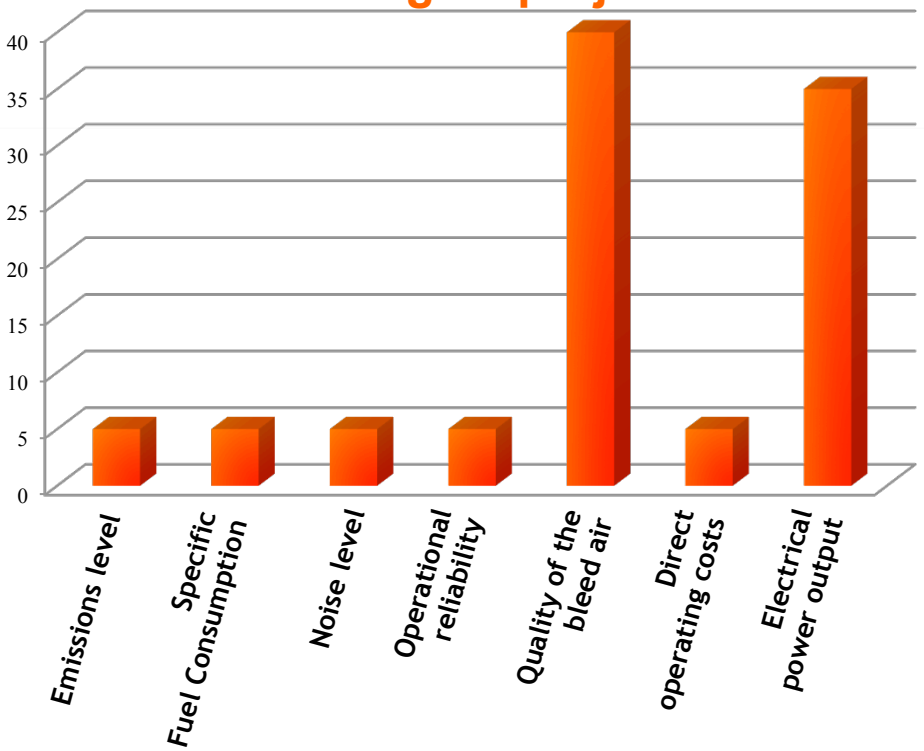


- Engine expectations and needs are interpreted in terms of **value dimensions**.
- Different projects address different needs, which **emphasize** different dimensions.

Aero-engine project #1



Aero-engine project #2



The EVOKE process for VDD

ENGINE LEVEL

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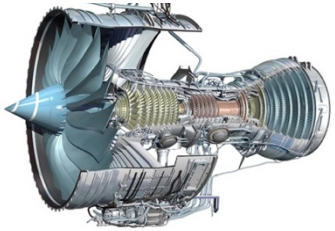


#2 Define local value drivers.

#2: Define local value drivers

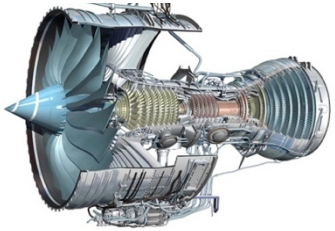
- Reflect engineering characteristics of the sub-system that are important to **ensure value provision** along the system lifecycle.
- They are derived from system-level value dimensions and are **linearly independent**.

Temperature
Pressure
Weight
Drag
Reliability
Maintainability
Adaptability
Knowledge Reuse
Weldability
Manufacturability

The EVOKE process for VDD

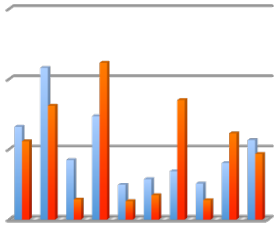
ENGINE LEVEL

#1 Define system-level value dimensions.



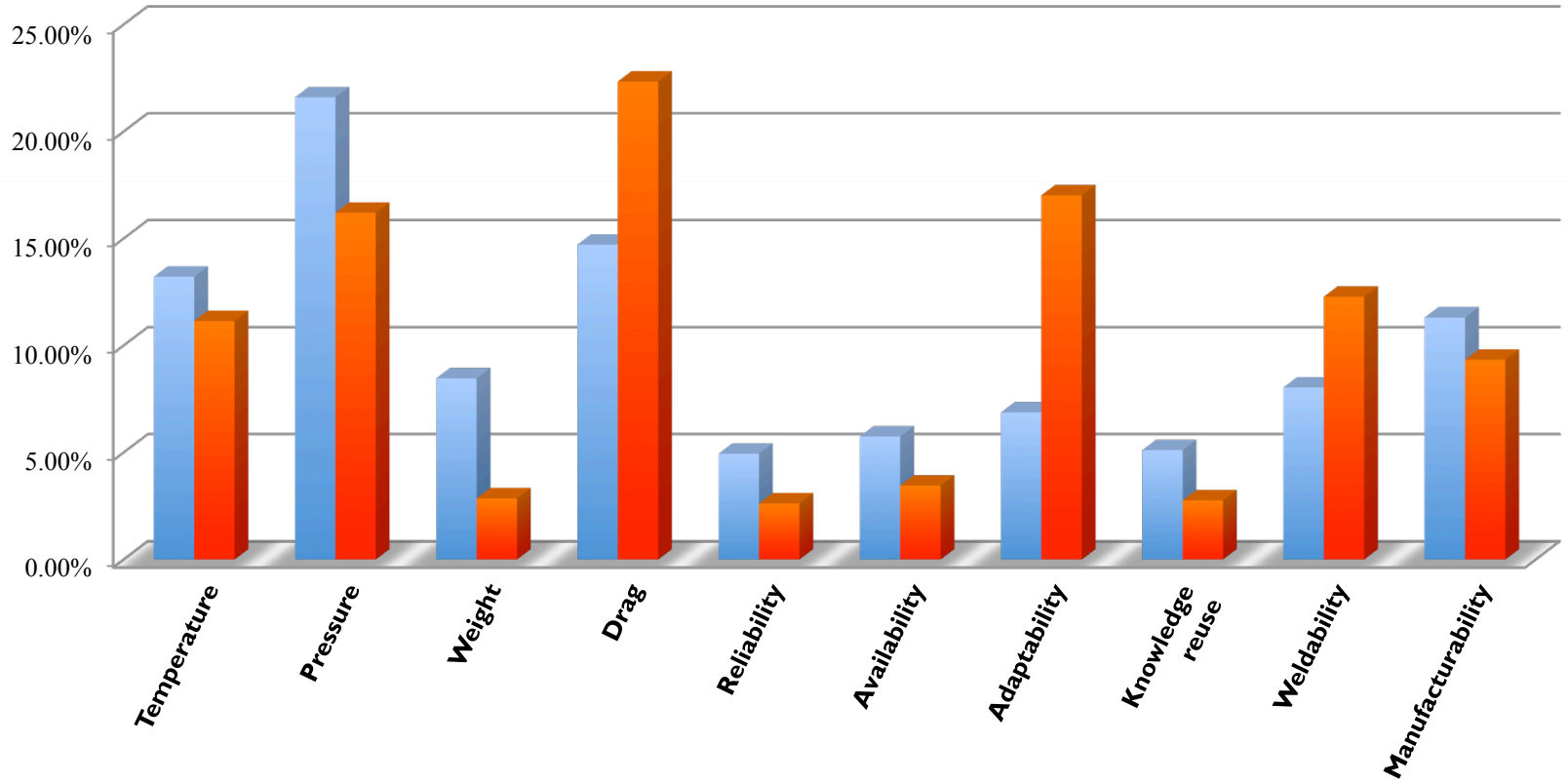
#2 Define local value drivers.

#3 Map value dimensions with local value drivers.



#3: Map dimensions with local drivers

- Different strategies at system level **emphasize** certain dimensions, and in turn a few local value drivers.
- The mapping activity renders **different weights** for the local value drivers, which are then used in the value model.



The EVOKE process for VDD

ENGINE LEVEL

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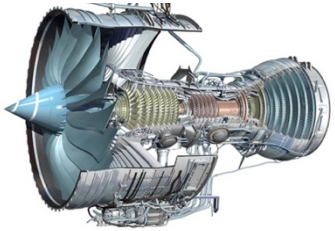

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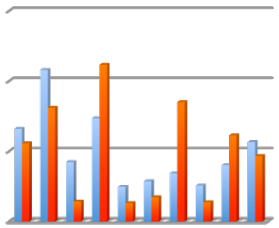

#4 Define the engineering characteristics of alternative designs.

#4: Define the engineering characteristics of alternative component designs

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- New design concepts are evolutions of an existing **technology platform.**
- They are defined in terms of their expected **high level engineering characteristics** (e.g., shape, dimensions, materials, lifecycle properties), using the platform as a reference.

	Engineering characteristics		
Option #1 	**10%** use of composite material	**5mm** case thickness	**6m^3/s** discharge of cooling fluid
Option #2 	**80%** use of composite material	**7mm** case thickness	**8m^3/s** discharge of cooling fluid

The EVOKE process for VDD

ENGINE LEVEL

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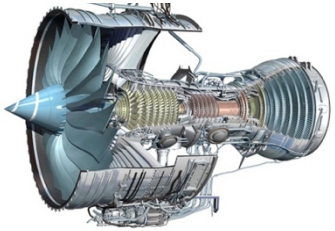

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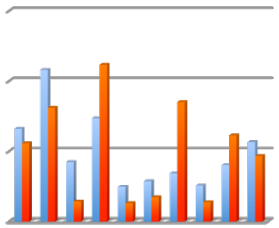
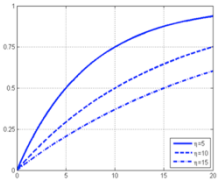


#4 Define the engineering characteristics of alternative designs.

#5 Map value drivers against engineering characteristics.



#5: Map value drivers against engineering characteristics

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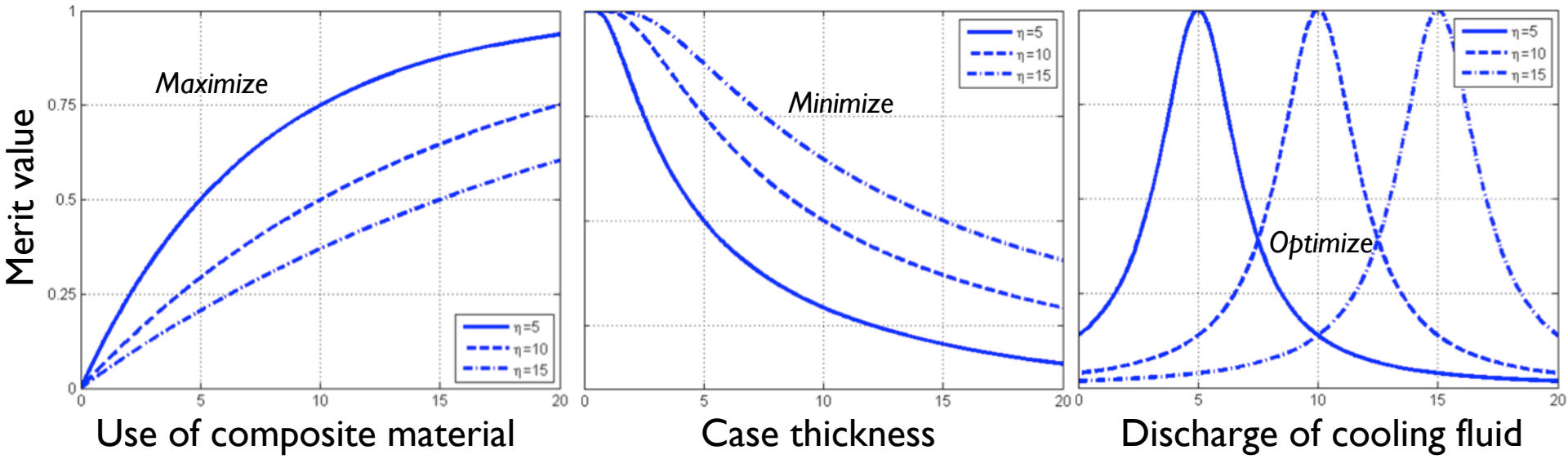
- **Non linear merit functions** are used to measure the "goodness" of a design for a given value driver.
- They approximate well the behavior of **utility curves**.
- The shape of a "Merit curve" is **controlled** by a "neutral" ("optimum") point and by a Tolerance value.

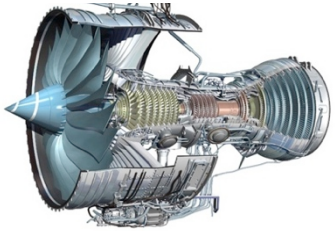
WEIGHT



The EVOKE process for VDD

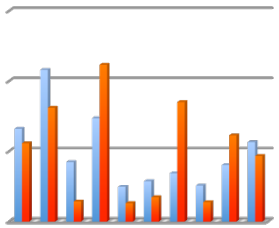
ENGINE LEVEL

#1 Define system-level value dimensions.



#2 Define local value drivers.

#3 Map value dimensions with local value drivers.



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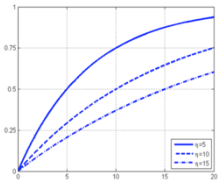

#6 Calculate the merit score (value) of each design.

46%

58%

#6: Calculate the Merit Score of each design

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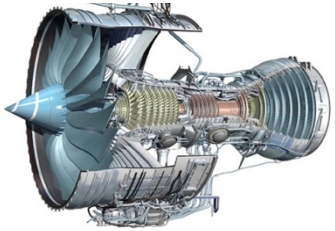
- Aggregating the Design Merit scores obtained by each value driver for each engineering characteristics, it is possible to obtain **the overall "value"** of a design.
- The method used for value calculation is named Customer Oriented Design Analysis (**CODA**) and it is derived from QFD.

		Surface finishing					Young modulus	Discharge of cooling fluid	Heat transfer coefficient	Bleed air offtake	Reuse of technology	Access to experts	Production lead time	Line commonality	
		Design parameter	0.11	Constraints (Upper and Lower)	0.15	0.01	10.00	5.00	5.00	0.01	0.25	0.25	25.00	0.10	
Value drivers	Normalised weights	Correlation	Neutral point or optimum point	Relationship Type (Min, Max, Opt)	Tolerance (for type Opt)	Design Merit	Design Merit	Design Merit	Design Merit	Design Merit	Design Merit	Design Merit	Design Merit	Design Merit	**Overall Design Merit**
Temperature	12.76%					0.00%	64.64%	42.57%	42.57%	40.39%	57.47%	53.99%	0.00%	0.00%	**6.99%**
Pressure	14.71%					0.00%	50.00%	42.57%	42.57%	40.39%	40.13%	55.46%	0.00%	0.00%	**7.27%**
Weight	5.55%					0.00%	0.00%	57.96%	0.00%	40.39%	44.92%	62.11%	0.00%	0.00%	**2.38%**
Drag	17.54%	0.90	0.08	Min		39.60%	0.00%	0.00%	0.00%	33.89%	40.13%	53.99%	0.00%	0.00%	**7.21%**
Reliability	3.57%					0.00%	56.47%	42.57%	42.57%	40.39%	37.27%	63.99%	0.00%	0.00%	**1.68%**
Maintainability	4.00%					0.00%	0.00%	0.00%	0.00%	30.38%	40.13%	53.99%	0.00%	0.00%	**1.34%**
Adaptability	12.78%					0.00%	0.00%	42.57%	0.00%	90.19%	0.00%	0.00%	0.00%	0.00%	**10.01%**
Knowledge reuse	3.89%	0.10	0.03	Max		92.13%	43.88%	100.00%	0.00%	40.39%	40.13%	53.99%	0.00%	0.00%	**2.23%**
Weldability	11.98%					0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Manufacturability	13.22%	0.30	0.08	Max		61.44%	43.88%	100.00%	0.00%	18.69%	40.13%	53.99%	61.81%	35.83%	**6.05%**

The EVOKE process for VDD

ENGINE LEVEL

#1 Define system-level value dimensions.



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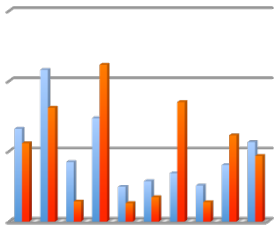
#3 Map value dimensions with local value drivers.



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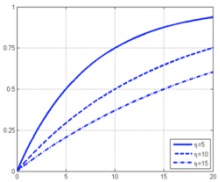
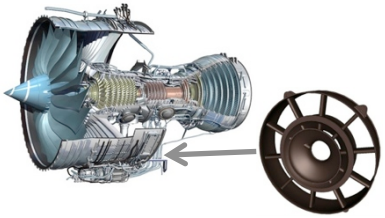


#6 Calculate the merit score (value) of each design.

46%

58%

#7 Assess engine value and update dimensions



Knowledge Maturity assessment

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- A Knowledge Maturity model is used to evaluate the maturity/fidelity of the knowledge on which the value model is built.
- Knowledge maturity is assessed over three dimensions - input, method, expertise - on a scale from 1 to 5.

Input

Confidence on the engineering chatacteristics

Quantified objectives	*Units*	*Option #1*
Hub Outer Wall		The HOW is polished to reduce drag in the component.
•Surface finishing	R_a	0.05
•Young modulus	M lbf/in²	18
•Discharge of cooling fluid	m³/s	8
•Heat transfer coefficient	W/m²K	19
•Bleed air offtake	m³/s	7.1
•Reuse of technology	%	35.00%
•Access to experts	%	50.00%
•Production lead time	h	80
•Line commonality	%	30.00%

Method #1

Confidence on the engine/ sub-system correlation

Stakeholders needs (Engine)	Value drivers/ dimensions (Engine)	Temperature
The engine emission levels need to lower than those of competitors	CO2 emissions	0.9
	CO emissions	0.9
	NOx emissions	0.9
	SOx emissions	0.9
	Volatile Organic Compounds	0.3
	Particulates	0.3

Method #2

Confidence on the value assessment matrix

		Surface finishing				
		Design parameter	0.11	Constraints (Upper and Lower)	0.15	0.01
Value drivers	Normalised weights	Correlation	Neutral point or optimum point	Relationship Type (Min, Max, Opt)	Tolerance (for type Opt)	Design Merit
Temperature	12.21%					0.00%
Pressure	14.87%					0.00%
Weight	5.39%					0.00%
Drag	17.16%	0.90	0.08	Min		39.60%
Reliability	3.66%					0.00%
Maintainability	4.11%					0.00%
Adaptability	13.20%					0.00%
Knowledge reuse	4.00%	0.10	0.03	Max		92.13%
Weldability	12.21%					0.00%
Manufacturability	13.20%	0.30	0.08	Max		61.44%

Expertise

Confidence on the value assessment team

Overall Knowledge maturity

THE EVOKE VALUE MODEL

Simulating alternative value creation strategies

Communicating the value model results

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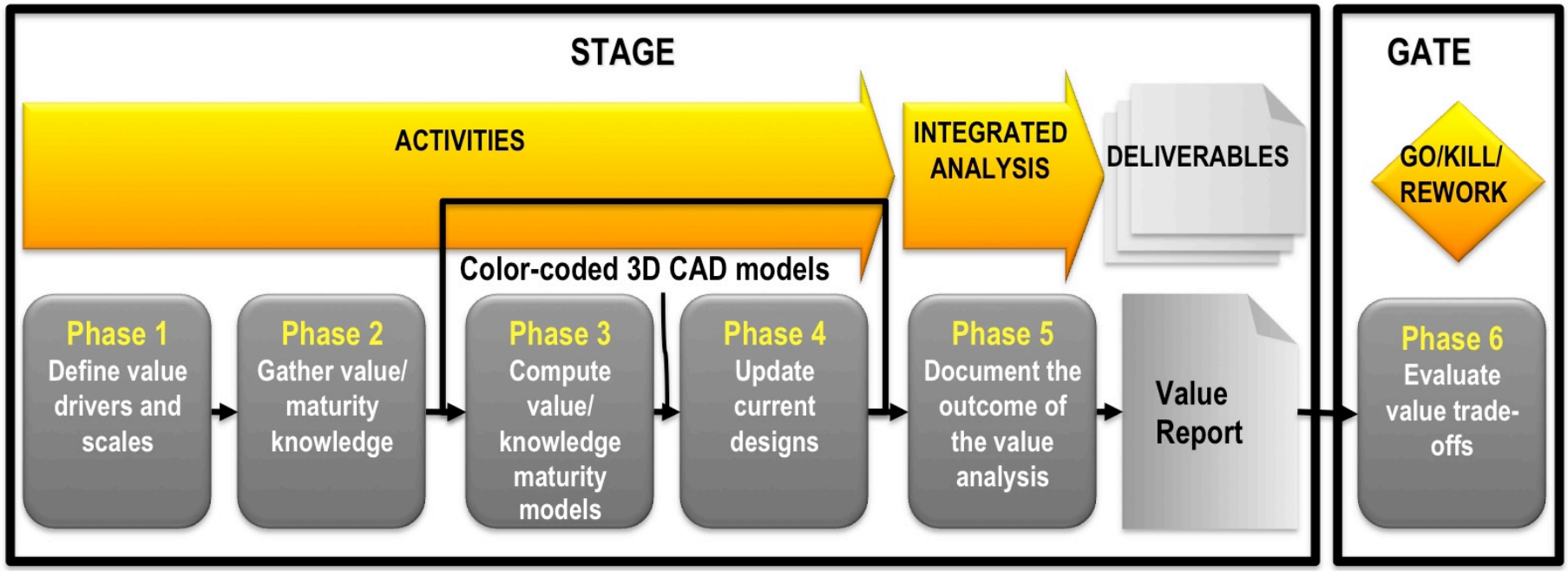
- VDD takes place in a **Stage-Gate** process.
  - It is highly collaborative and **cross-disciplinary**.
- To be effective, VDD requires means to:
  - Communicate "value" to the **designers in the Stage**, linking it to the product requirements.
  - Show "value contribution" to design **stakeholders at the Gate**.



Color-coding 3D CAD models

Want details?

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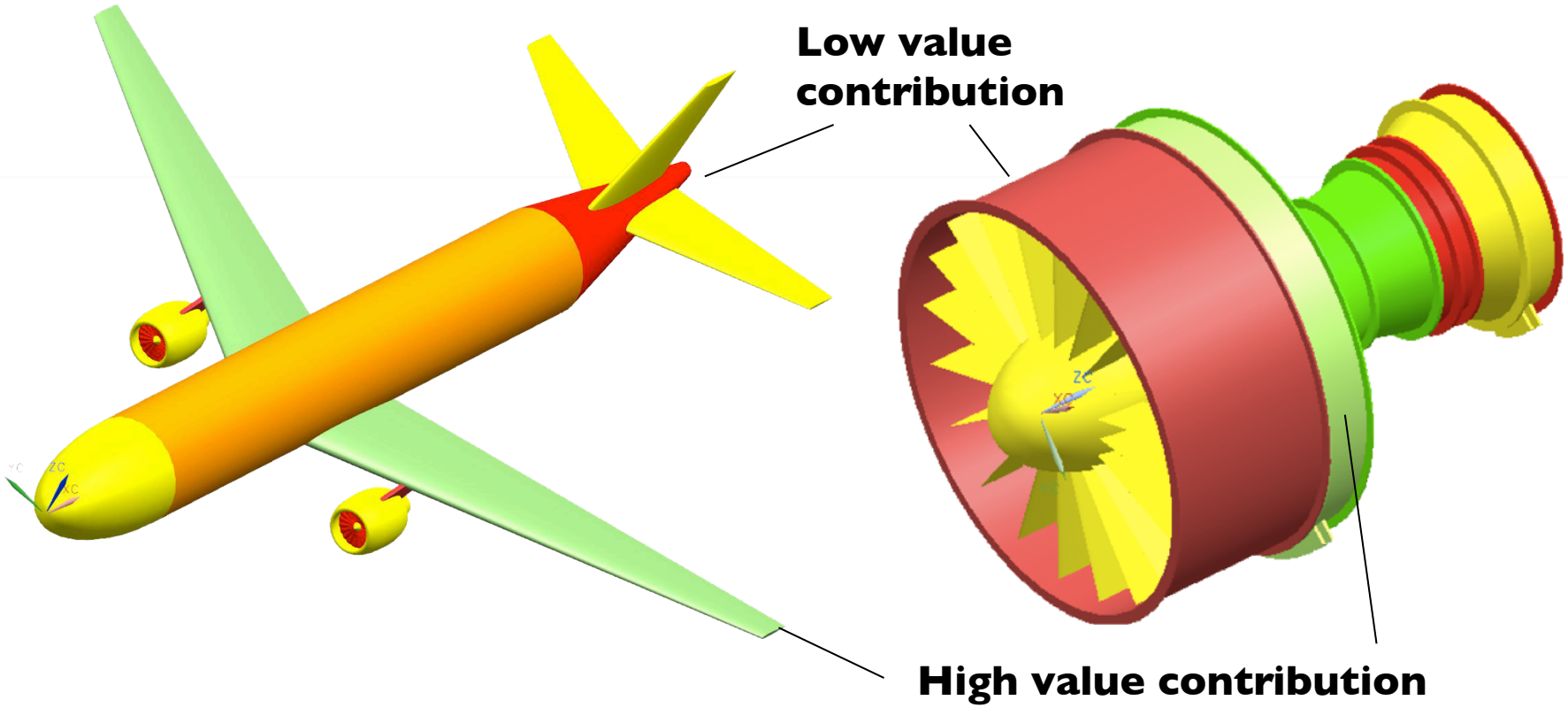
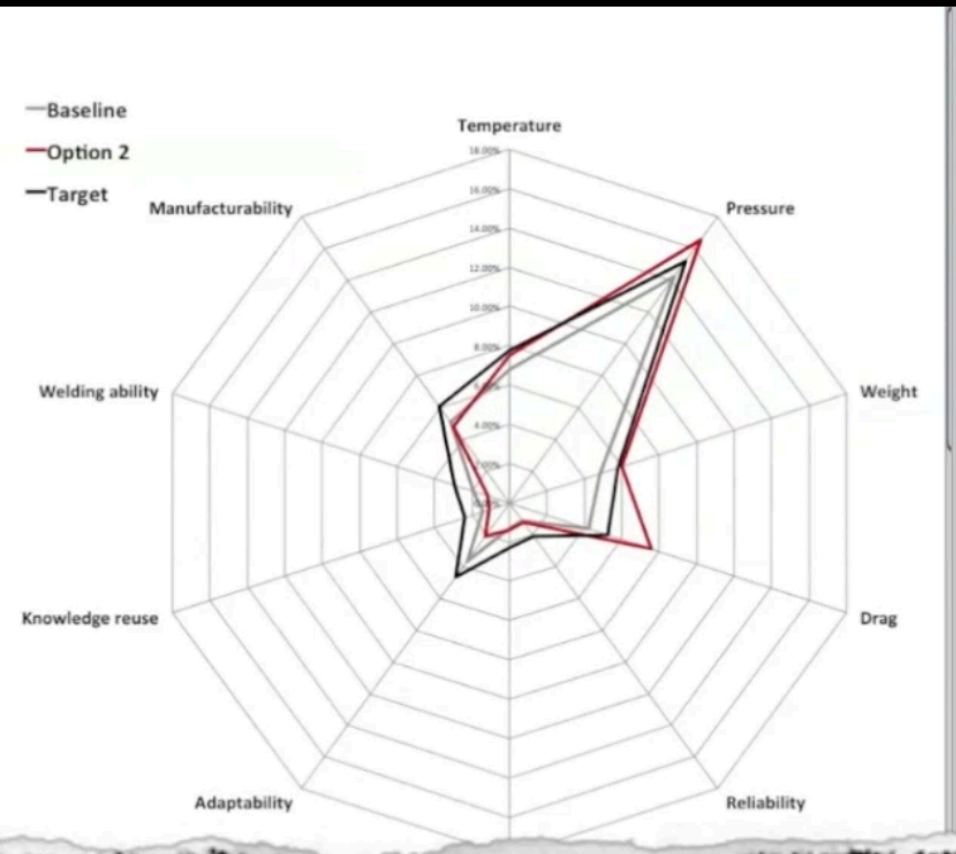
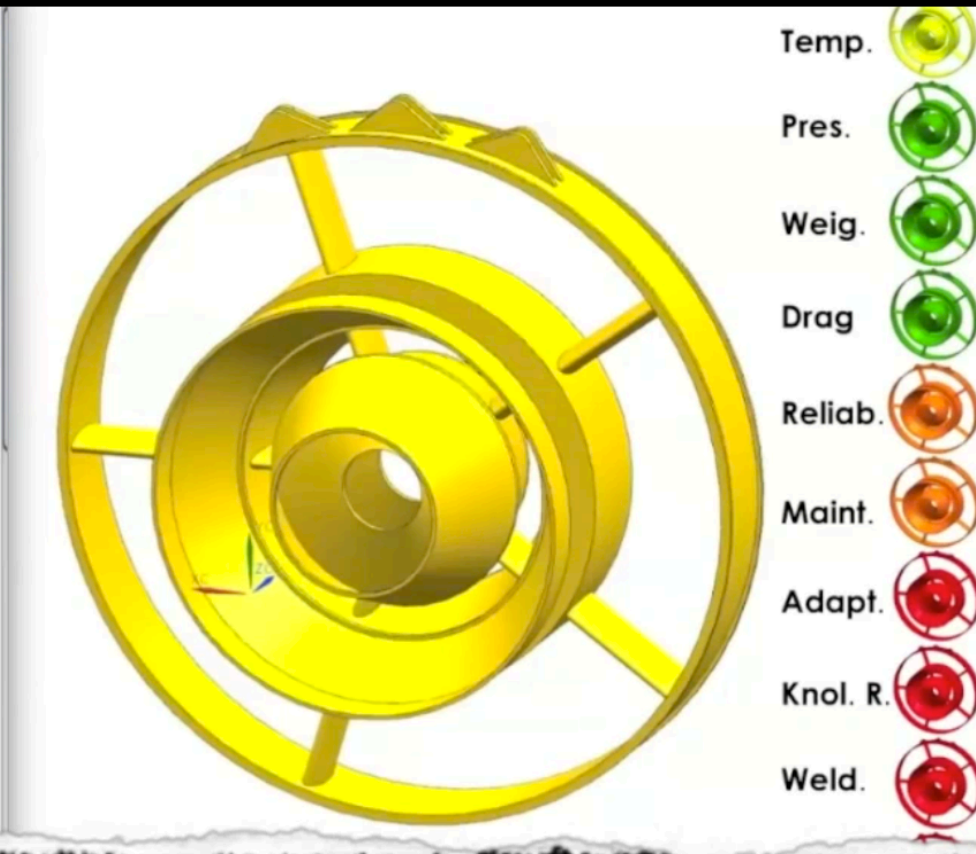
- The colored visualization can characterize **a part, a component, an assembly or a whole product**, based on the focus of the analysis that the design team is targeting.
- The component or sub-assembly value depends on its higher up assembly or product (**assembly context**).







Radar plot vs colour-coded 3D model

Implementation in SIEMENS NX HD3D VR

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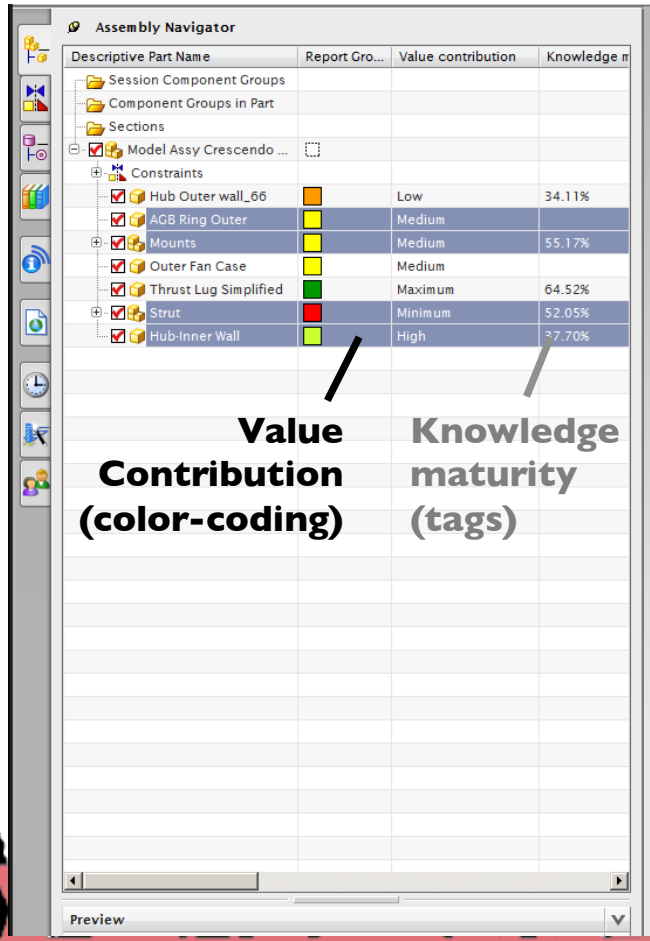
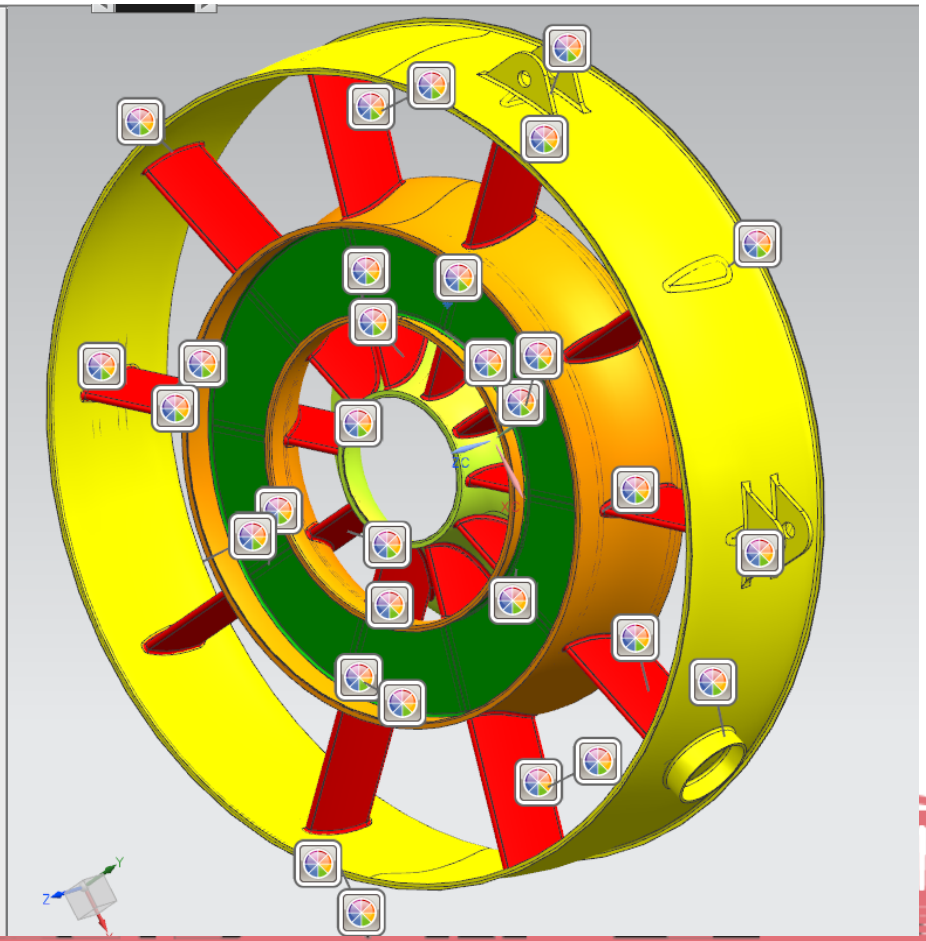
Users **navigate** the value model results within the product structure.

No limitation (in theory) to the **level of granularity** of the color-coded visualization, as far as the underlying value scores are present.

Jump to validation





Conclusions

- EVOKE is an approach for preliminary concept selection that uses value as a basis for decision
- It enables qualitative value analyses to be executed early on, before detailed requirements are made available,
- Takes as input the value dimensions and drivers communicated by the system integrators.

Aknowledgement

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 234344 (www.crescendo-fp7.eu/).

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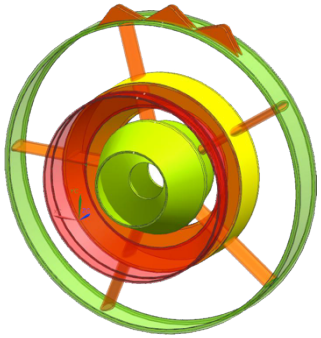

Thank you!

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Verification and testing

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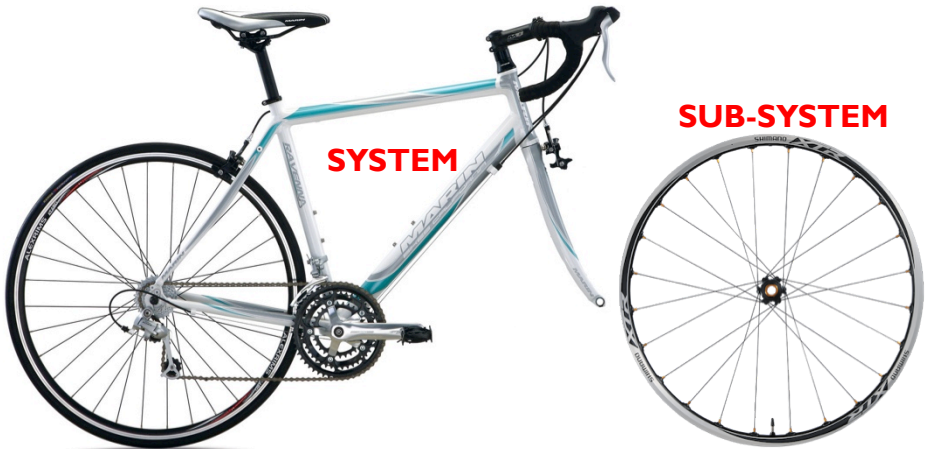
EVOKE

- 3 training sessions at GKN Aerospace Sweden.
  - 45 participants.
- Design of a bike wheel.
- Questionnaire + value model exercise.



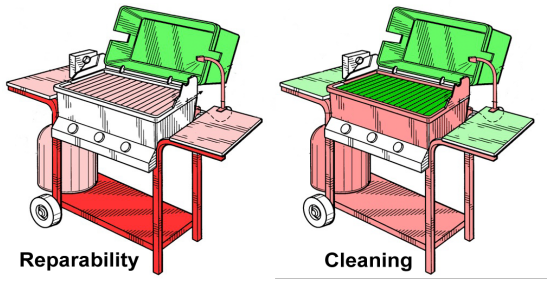
Color coding

- 8 design sessions with students in the Master Program in product development.
  - 26 participants
- Design of a PSS solution for BBQ grilling.
- Observations with protocol analysis.

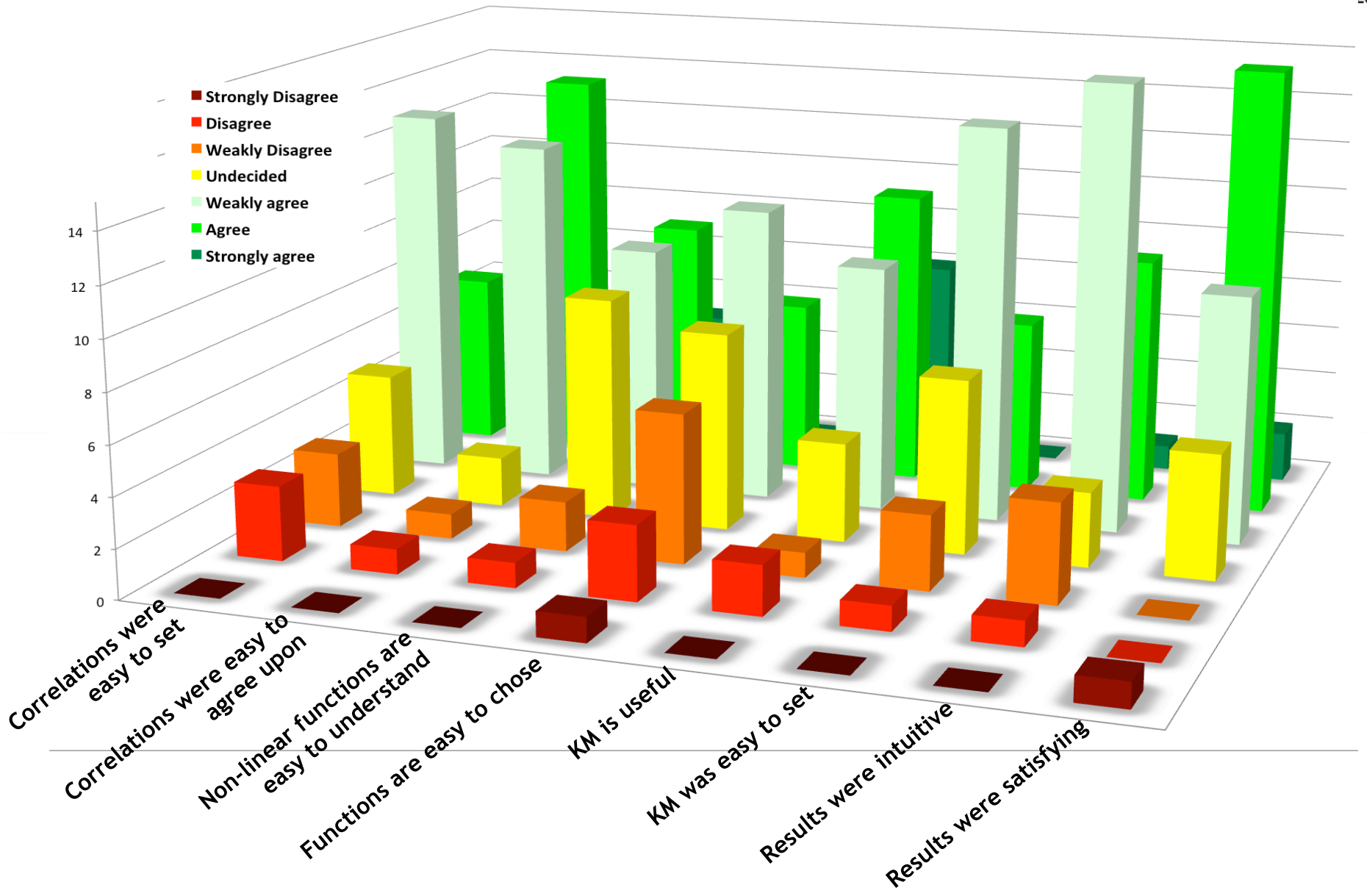
Color-coded tables

	Reparability	Cleaning
Cover	7	7
Case	5	3
Frame	2	3
Support	3	7
Grill	4	8
Air system	3	3
Gas Cylinder	4	3

Color-coded 3D models

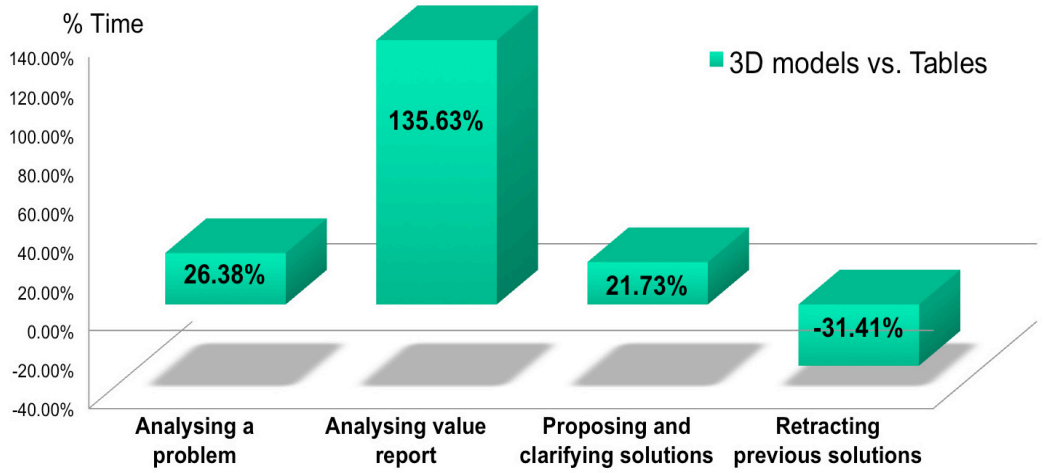


EVOKE– questionnaire results



Color-coding – results from observations

- Investing more time in analyzing the design problem helps reducing the knowledge gap related to the "**design process paradox**".
- Teams able to spend more time to **embed multidisciplinary aspects** in their analysis have been proven to be more successful in delivering a highly valuable solution.



Back to Conclusion

Preferences for value visualization

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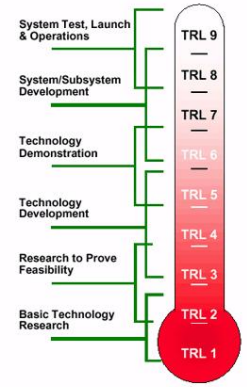
NON MONETARY VALUE

Monetizing in preliminary design is cumbersome and potentially meaningless.

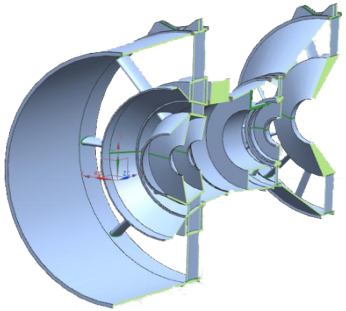
USE BENCHMARKS

Engineers want to understand if a solution is better or worse than reference options.



COMMUNICATE MATURITY

Engineers want to know the level of maturity of the knowledge upon which the value models are built.



LINK TO THE PRODUCT MODEL

Value information needs context, and has to be ralated to other design information.

USE MULTIPLE CUES

To take advantage of associative processing when linking to technical documentation.

USE A FEW CRITERIA

Inverted U-shaped relationship between decision making efficiency and the amount of value information provided.

Color-coding for value visualization

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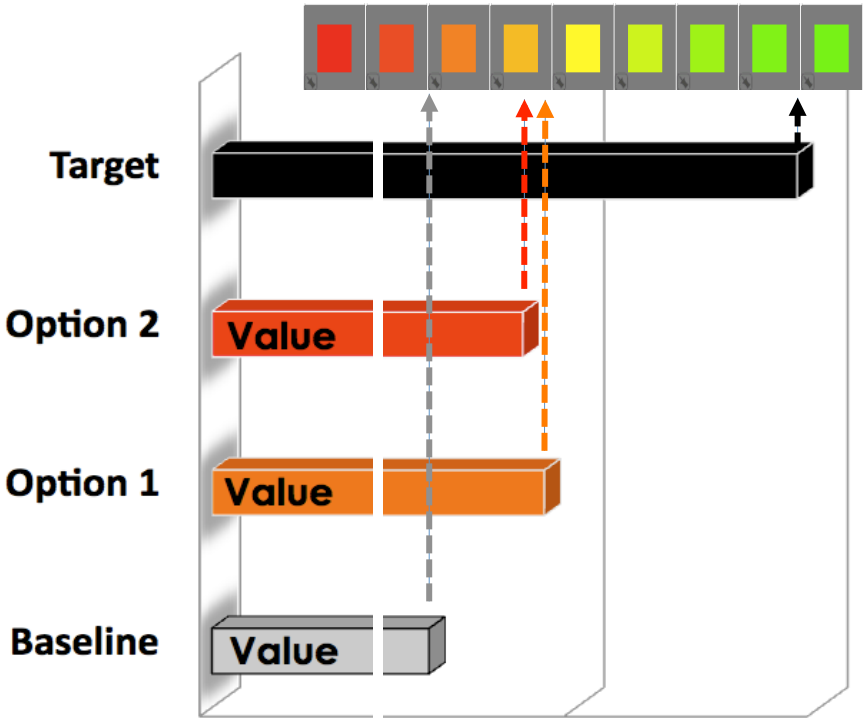

- The results of a value model are mapped against a **color scale**.
- A baseline and target value contribution are used as **benchmarks** to color-code the models.
- Results close to the baseline are displayed in **red**, close to the target in **green**.