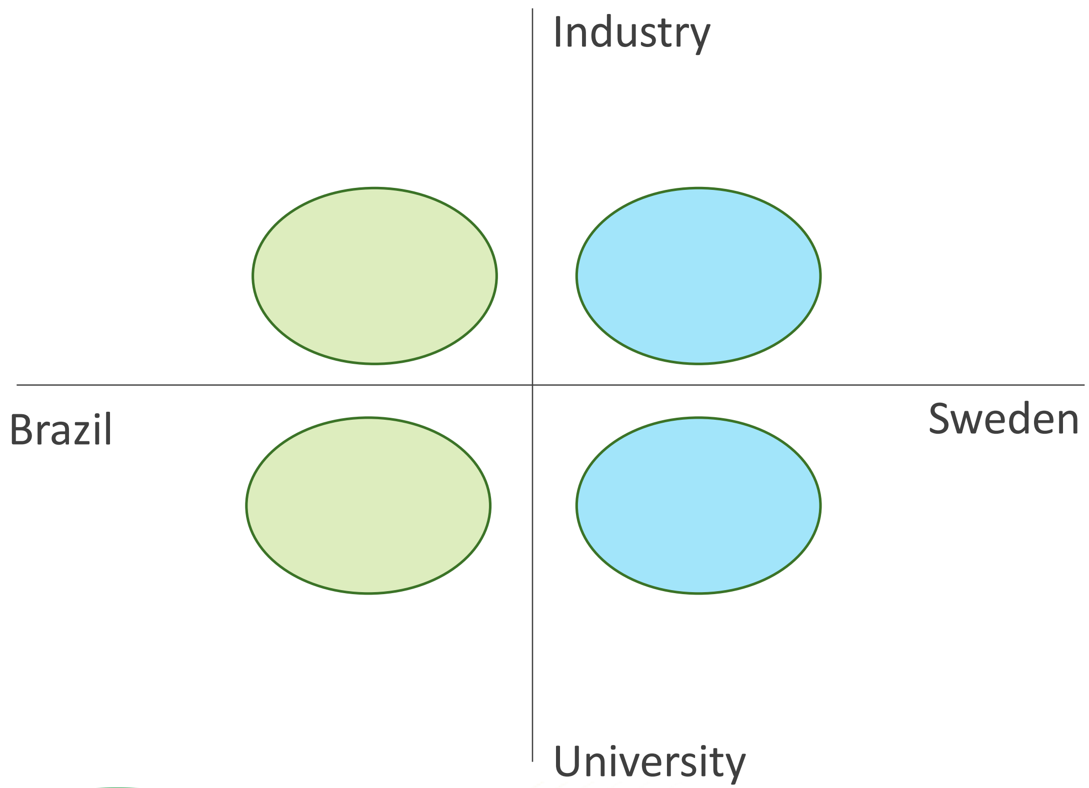
Swedish Endowed Professors Chair at ITA in the Honor of Peter Wallenberg Sr

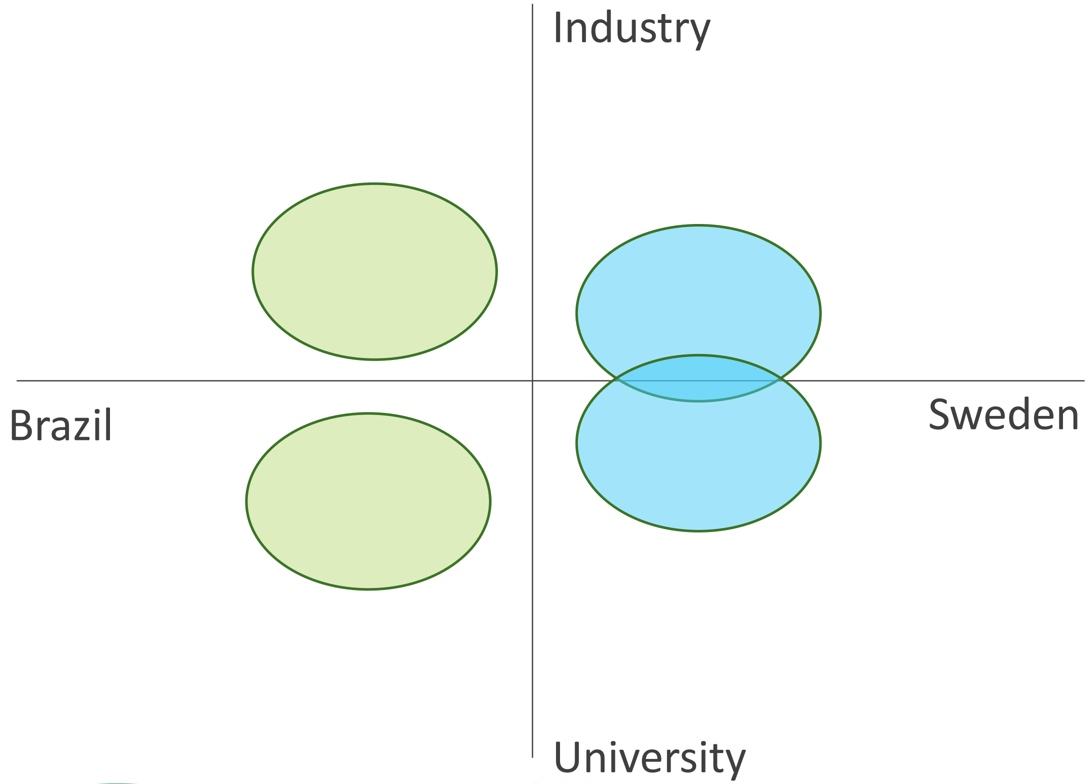
Petter Krus

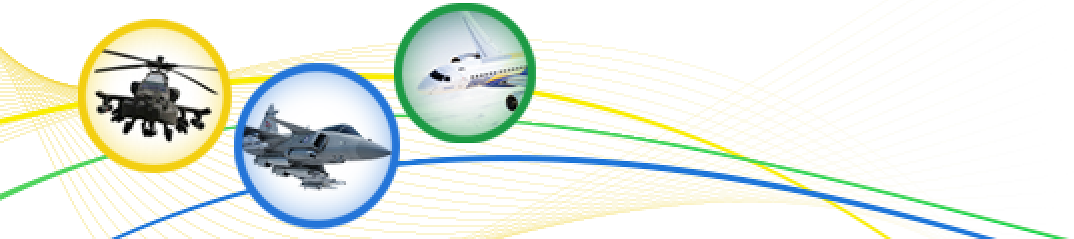
CISB CENTRO DE PESQUISA E INOVAÇÃO SUECO-BRASILEIRO | KTH VETENSKAP OCH KONST | SAAB TECHNOLOGIES | INNOVAIR Strategic Innovation Program | Linköping University | VINNOVA | CHALMERS UNIVERSITY OF TECHNOLOGY

Research Collaboration

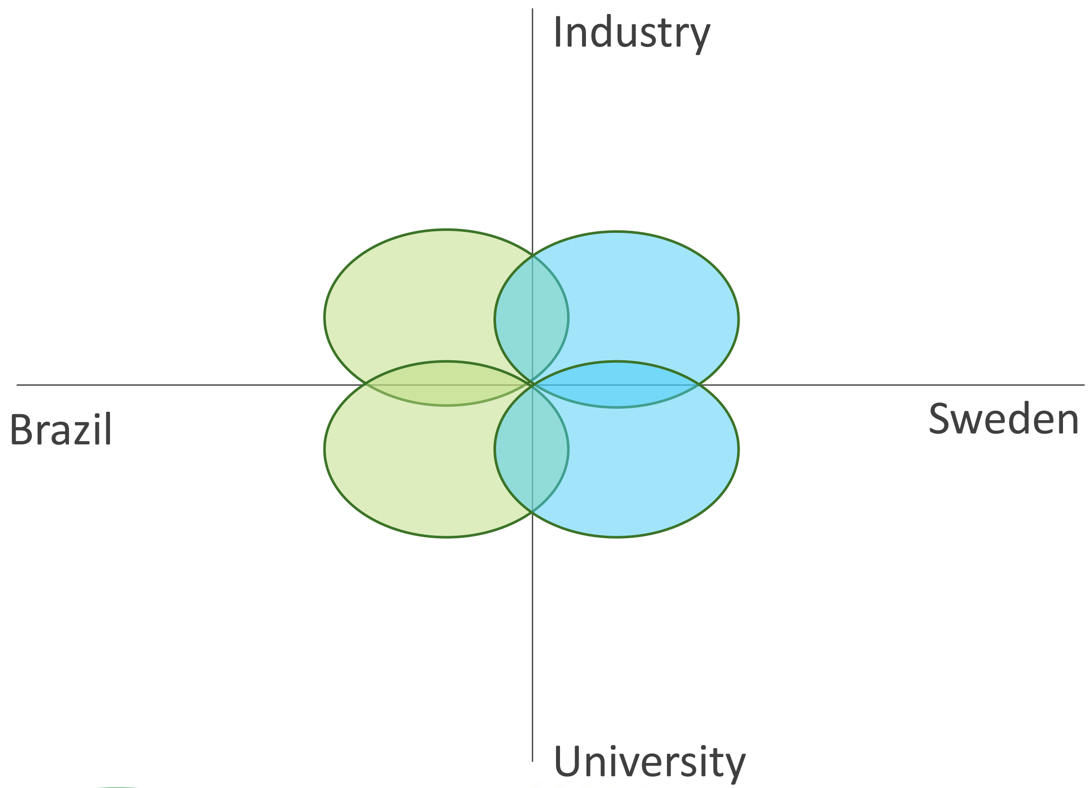


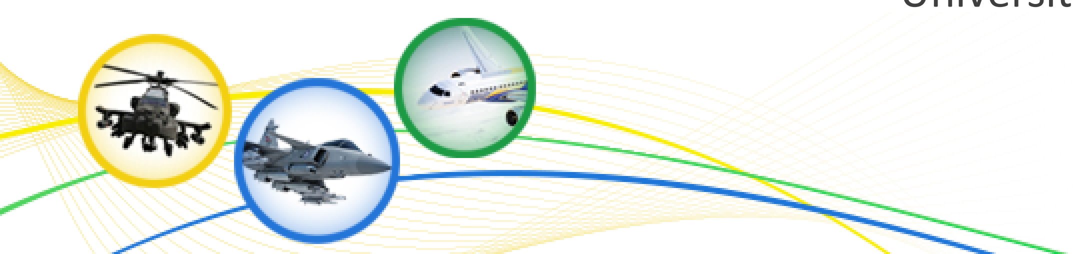
Research Collaboration



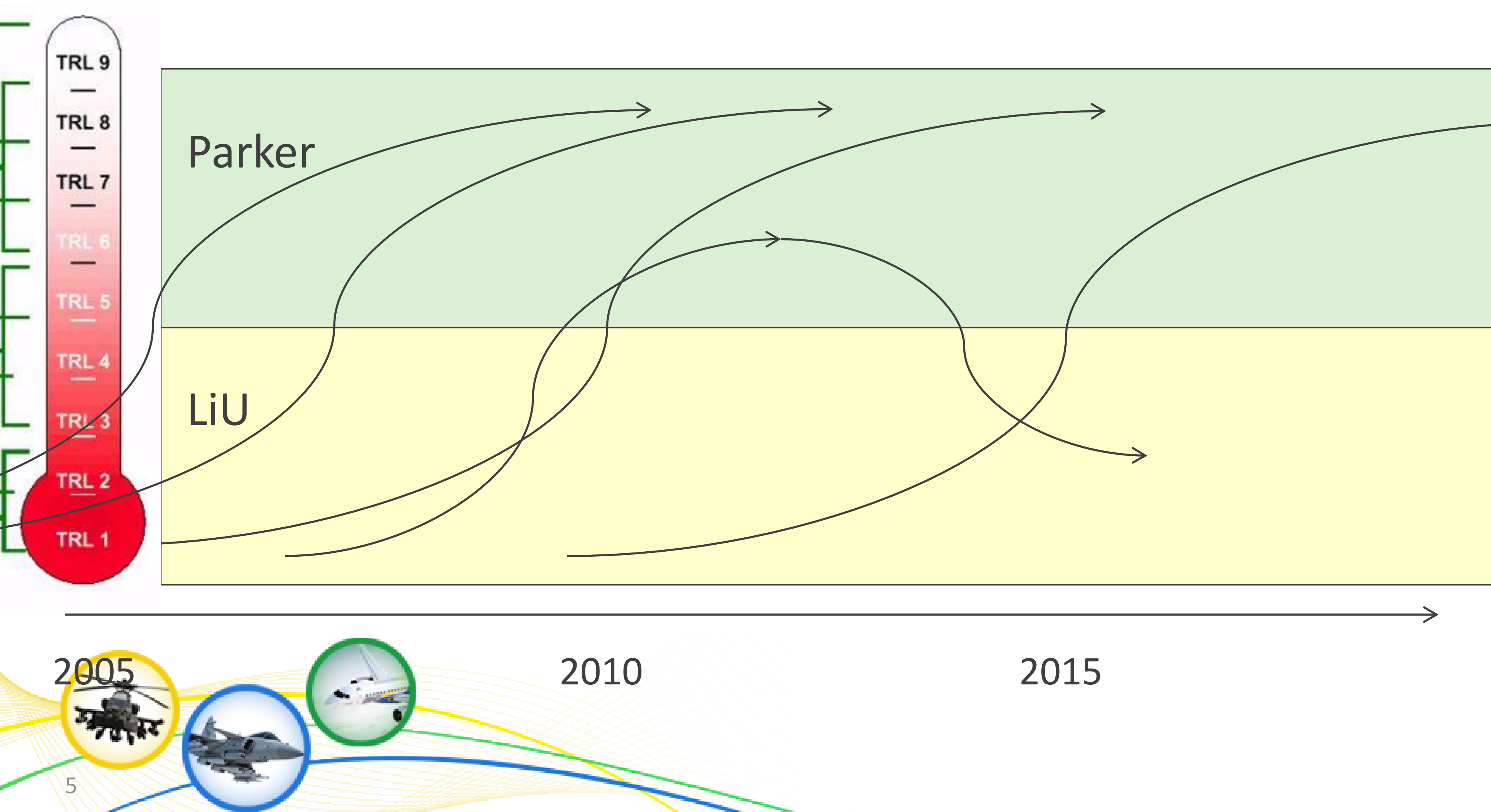


Research Collaboration

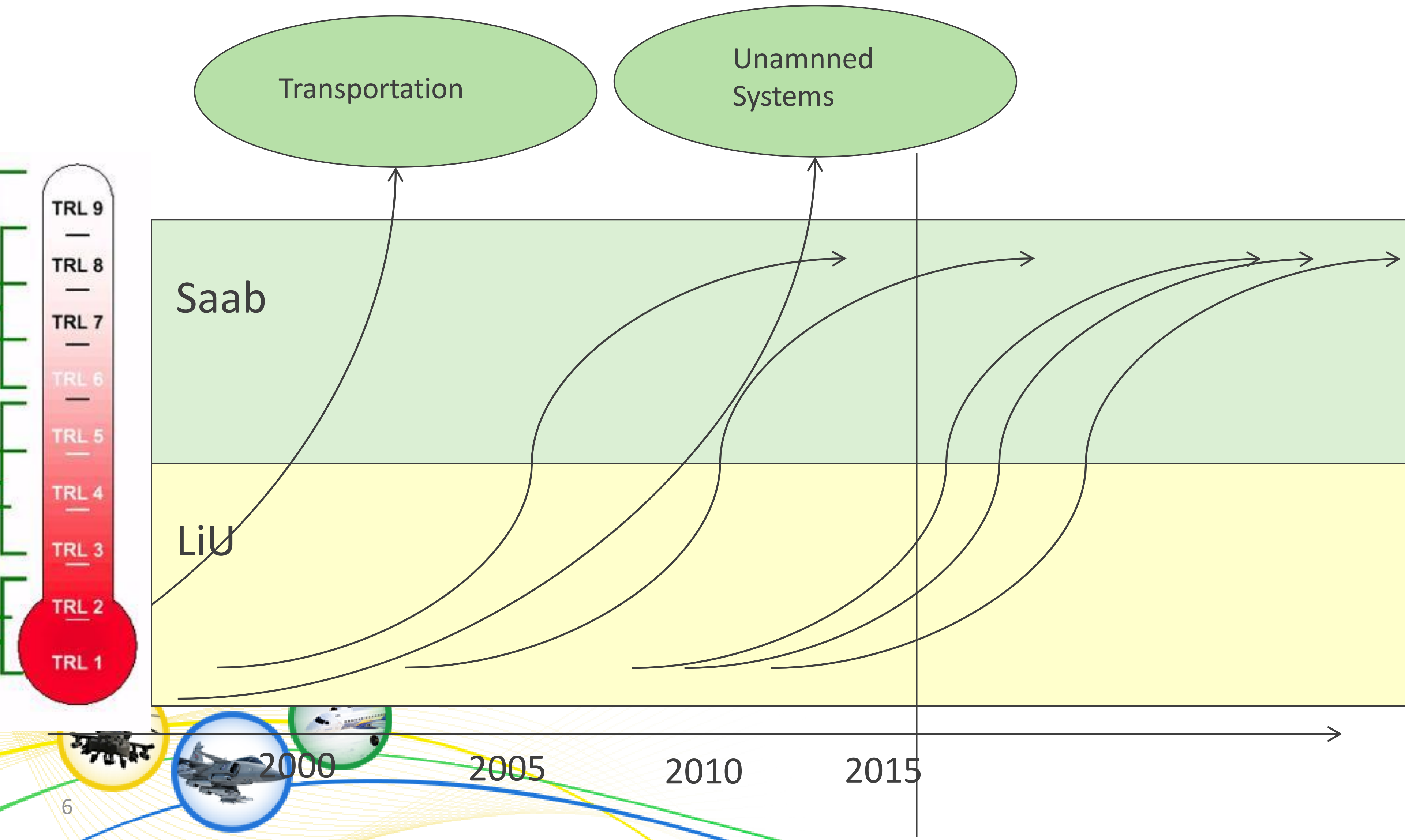




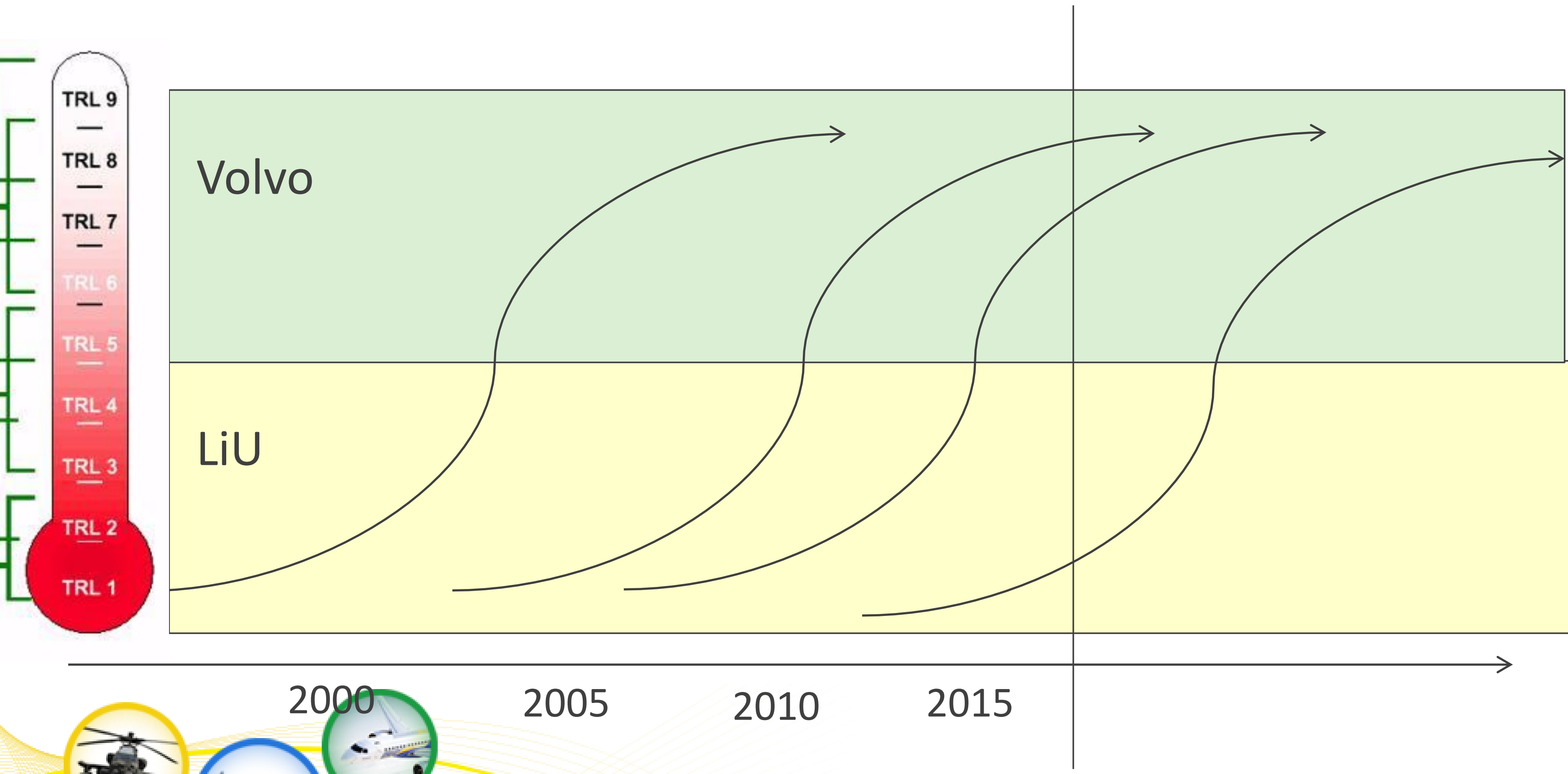
Mobile Systems

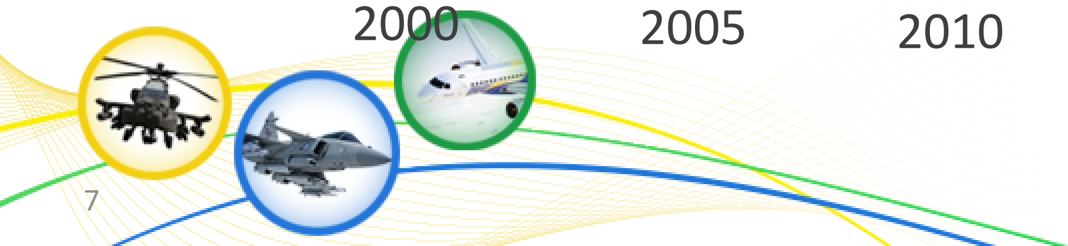


Aircraft Conceptual design
(Design tool development)



Volvo CE projects



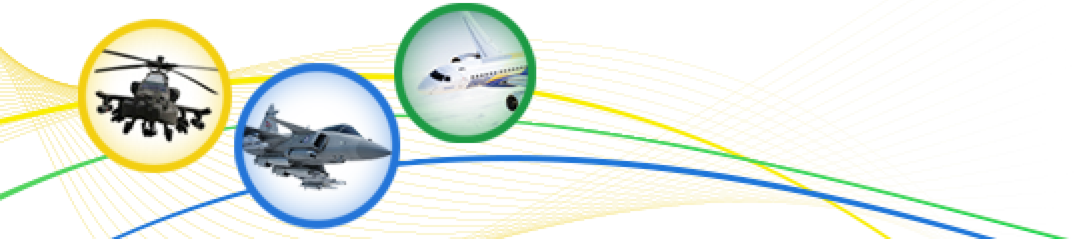


Petter Krus

- 1988 PhD in Fluid Power at Linköping University
- 1988 Assistant Prof at Division of Fluid Power at LiU.
- 1991 Associate Prof at Division of Fluid Power at LiU.
- 2001 Full Professor and head of division of Machine Design (LiU)
- 2010 Full Professor and head of division of Fluid and Mechatronic Systems (LiU)
- 2010 Dec. First visit to Brazil…..

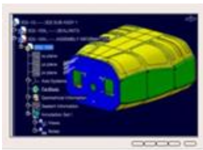
Tasks for the professor

- Bilateral Research Project
- Joint Education and faculty participation at ITA
- Promote long term research collaboration

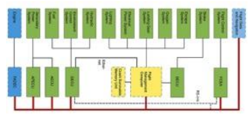


WHAT DOES AERONAUTICS CONTAIN ?

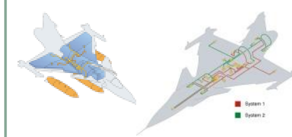
Aeronautical Engineering



Computer Systems



Vehicle Systems



Human-Machine Interaction

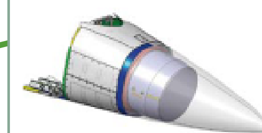
Autonomy & Decision Support

Maintenance Systems

Systems Integration

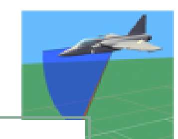
- Systems of Systems Integration
- Decision support
- Operational Analysis
- Concept Design
- Overall Design and Architecture
- Survivability
- Safety & Reliability
- ILS, Availability and Maintainability

Tactical System



Weapons Integration

Flight Test and Verification

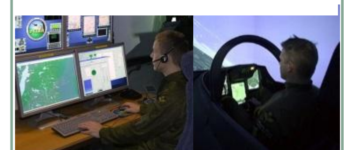


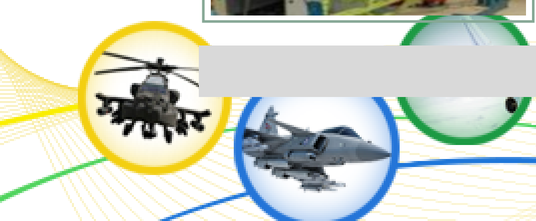
Structural Technology

Airframe Design

Production Systems

Support Systems and Simulators



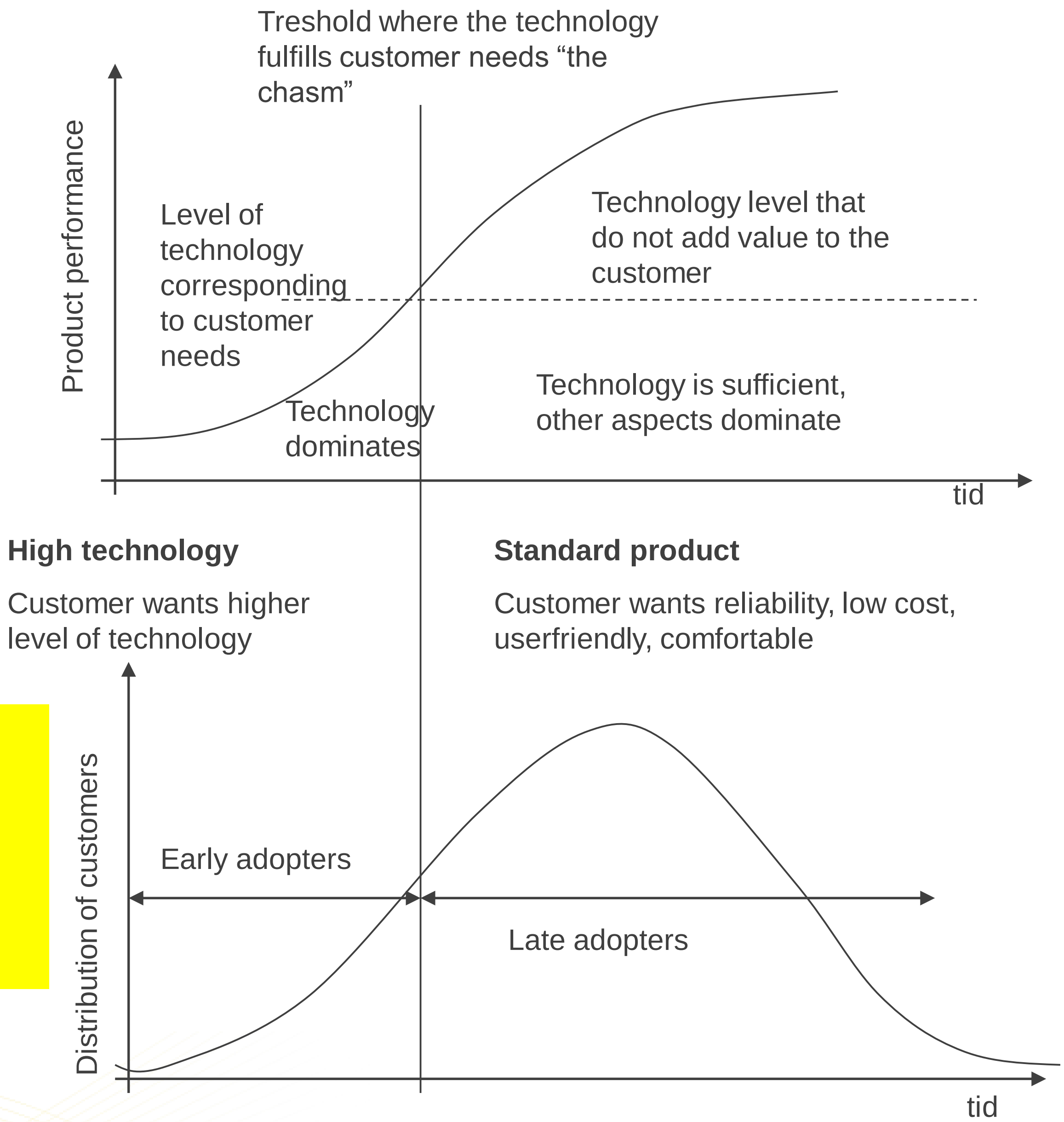


Engineering Methods & Tools

LiU Flumes Technologies

- Systems that are characterized by a close coupling between:
  - Mechanical system
  - Power transmission/Actuation system
  - Sensors
  - Control System
- This requires, *Multidisciplinary co-design,* i.e. Mechanical design and control system co-design where modelling and simulation are central

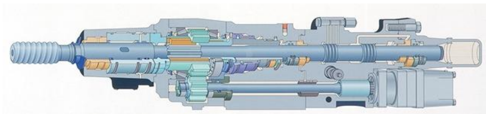
Development phases



- *A car costs ca 10 $/kg*
  - *(Like a hamburger)*
- *A military aircrat costs 1000 times more*

Cross Fertilisation

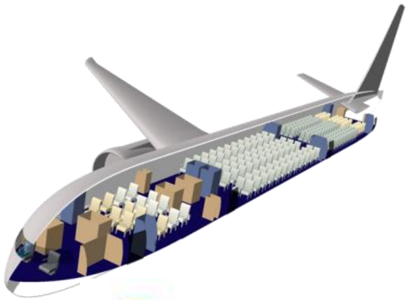
Simulation based System Optimization



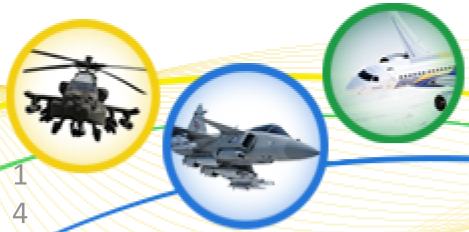
- With a good network, methods developed in one area can be transferred to other application areas.
- Simulation based optimization was implemented for aircraft hydraulic system optimization in 1991 at LiU Flumes.
- Simulation based optimization in Hopsan is heavily used by Atlas Copco for Rock drill development.
- Simulation based optimization was introduced for pump design with Parker.
- Simulation based System optimization was introduced at ABB for design of industrial robots.

Cross Fertilisation and Spill Over

Knowledge based Engineering, KBE

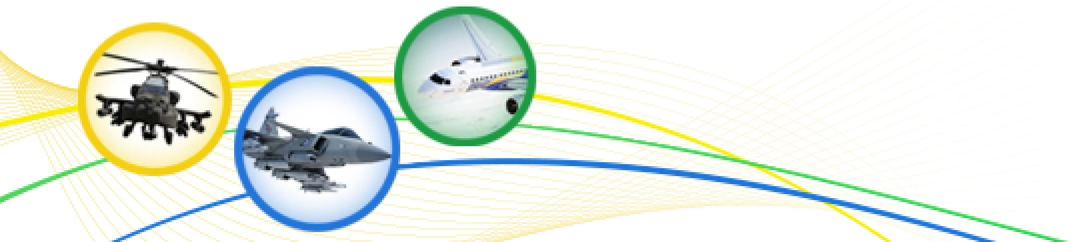


- Needs in aircraft design project led to involvement in this area starting 2003.
- The methodology become interesting also to ABB for industrial robot design and is now part of their process.
- Same methodology has subsequently has also made Bombardier a partner with the Machine Design Division at LIU.



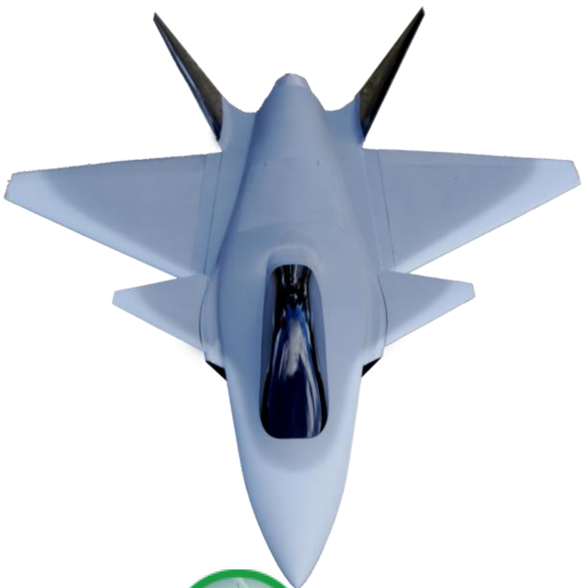
Bilateral Research Project

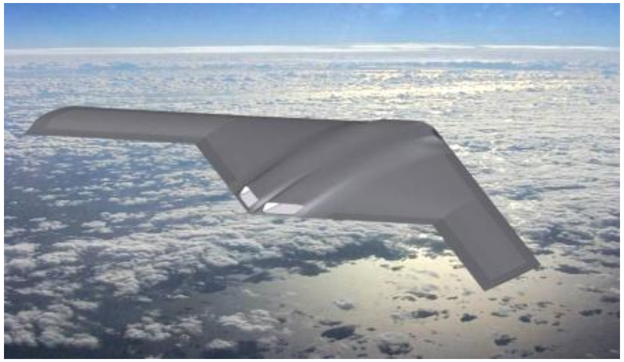
- FADEMO - Future Combat Aircraft Design Study and Demonstration
  - MSDEMO- Methods for Scaled Demonstrator Development
    - Swedish subset (Innovair)

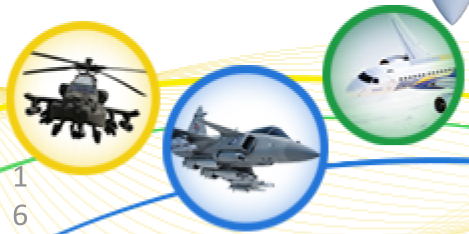


New Project: Future Combat Aircraft Design Study and Demonstration, FADEMO

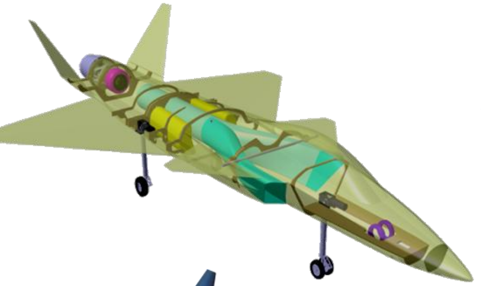
- Subscale flight testing for early evaluation of new concepts

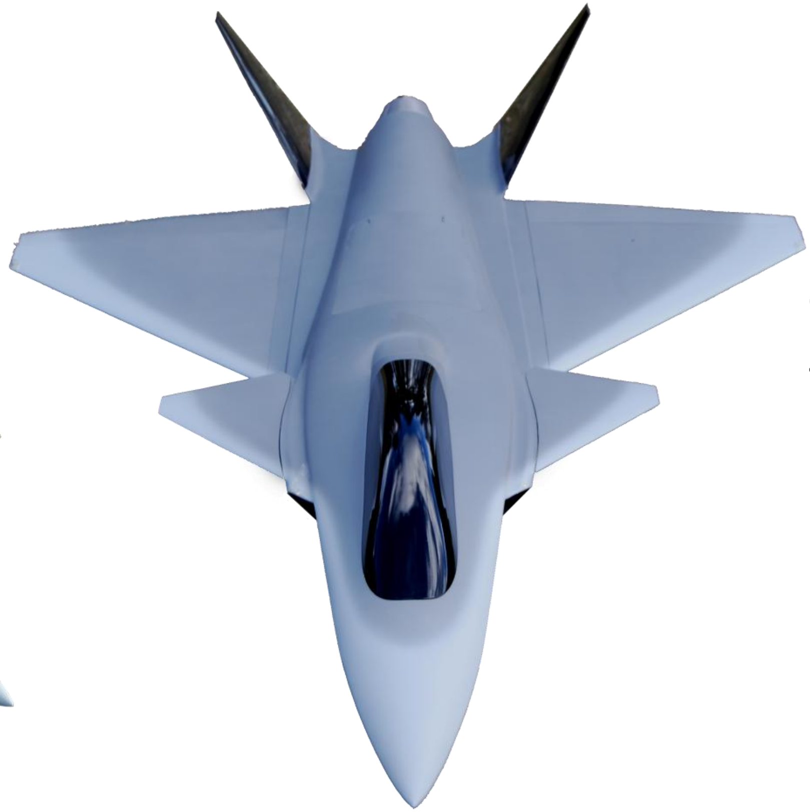






Generic Future Fighter (GFF) Subscale Demonstrator

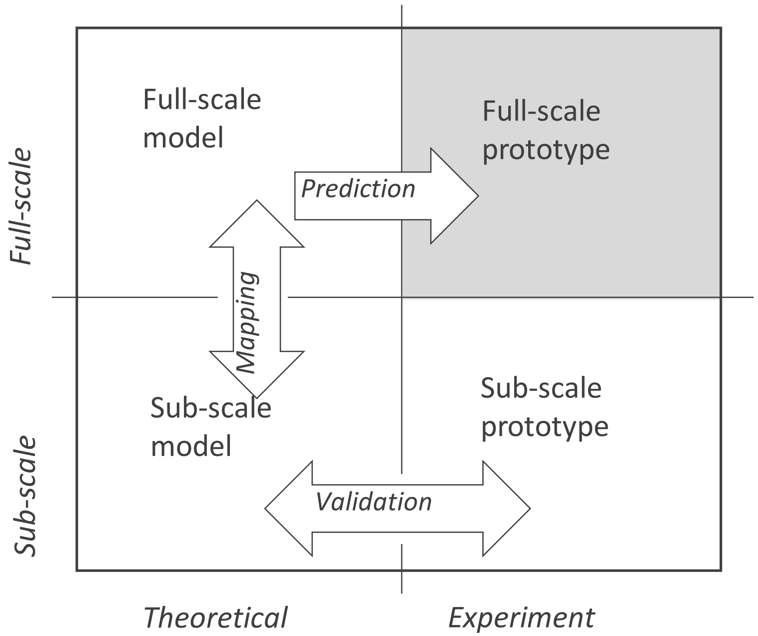




Concept developed by Saab
Subscale demonstrator build on request from FMV and Saab at Linköping University

Real Jet Engine with 170 N thrust a
Length 2.4 m
Span 1.5 m
Weight 15 kg
13% scale

Subscale Flight Testing



Subscale Flight Test Model of Hypothetical Next Generation Fighter Aircraft

Real Jet Engine with
170 N thrust a
Length 2.4 m
Span 1.5 m
Weight 15 kg

Promote long term research collaboration

- In order to build a strong capability in aeronautics related areas, the university network in Brazil with ITA as the focal point, should be consolidated to bring together all expertise at a national level. Research collaboration will in addition to ITA also be in collaboration with these named universities:
  - Aircraft Actuation Systems and System Simulation with UFSC.
  - Product Development and Innovation Management with UFABC.
  - Aircraft Design and Design Automation with USP.
- With these universities, collaboration has already been initiated, and good contacts with ITA have also been established. However, collaboration is likely to be extended to more universities.

UFABC. Programa de Pós-Graduação em Engenharia & Gestão da Inovação
Master program in Engineering and Innovation Managment

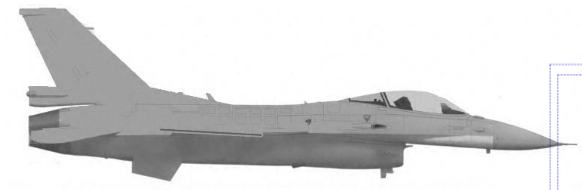
- A new Master program that combines engineering, incl systems engineering, economics and other disciplines to promote innovation
- This is a new kind of program with an integrative aproach to adress the challanges faced by industry to produce innovation.
- It aims at producing professionals with a genuine understanding of the different elemets, skills and competences needed in a team to produce innovation.

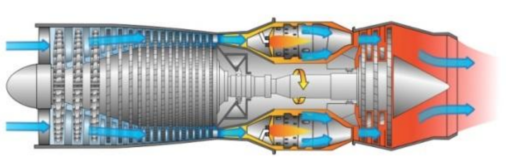
Collaboration through CISB

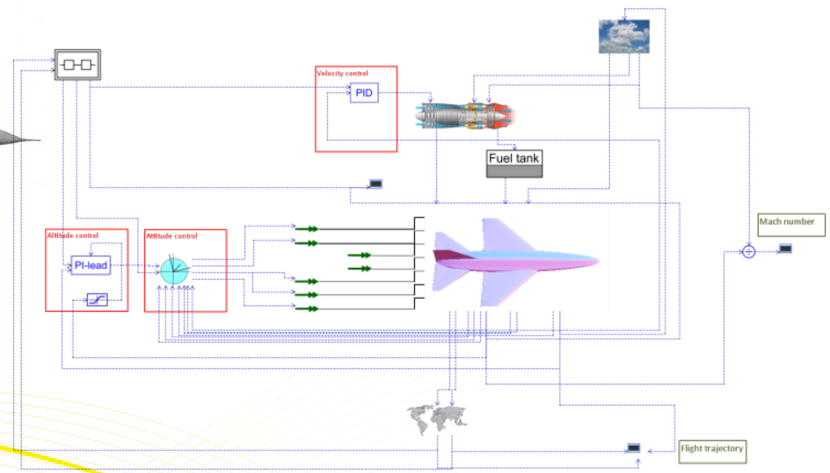
- 2013. Aircraft Conceptual Design, Alvaro Abdalla, USP
- 2014. Aircraft Hydraulic Systems, Cristiano Locatelli, UFSC.
- 2014-15. Aircraft Hydraulic Systems, Henri Belan, UFSC.

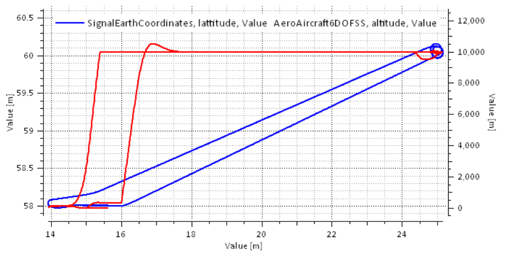
Existing Research Collaboration:
The Effect of Engine Dimensions on Supersonic Aircraft Performance
A. Abdalla, USP, H. Gazetta. ITA, T. Grönstedt, CTH, P. Krus, LiU

- In this study conceptual engine-airframe co-design is demonstrated, using models of comparable fidelity for both the engine design and the aircraft design.



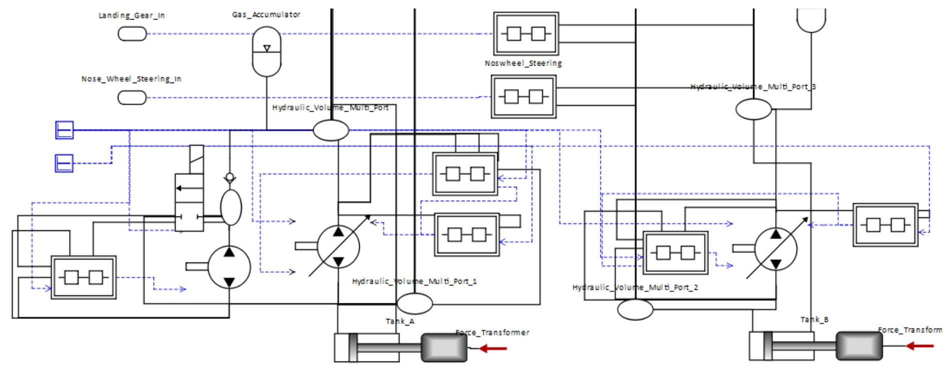






Novel Architectures for Hydraulic Supply System . UFSC

- CISB project with PhD student from UFSC



Researcher: Cristiano Cardoso Locateli
Advisor (LiU): Prof. Petter Krus
Advisor (UFSC): Prof. Victor J. De Negri
Co-Advisor (UFSC): Prof. Edson R. De Pieri

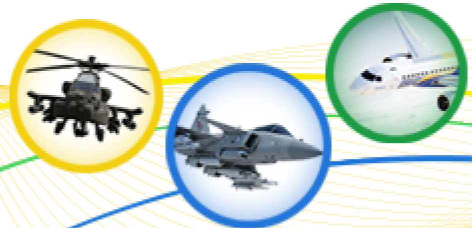
Fluida och Mekatroniska System
FluMeS
Fluid and Mechatronic Systems

LASHIP
HYDRAULICS & PNEUMATICS

UFSC

Novel Architectures for Hydraulic Supply System . UFSC

- **Keeping the current hydraulic system and allowing the operation of the electric hydraulic pump** with few modifications in the variable displacement pump system **there are significant efficiency gains** in steady state without losing performance.
- It is possible **to safe around 32 %** of the energy spent in the hydraulic system in steady state operation. This proposal allow the same weight than current system, easy controllability, good performance and operation in the region of maximum efficiency of the electric pump.

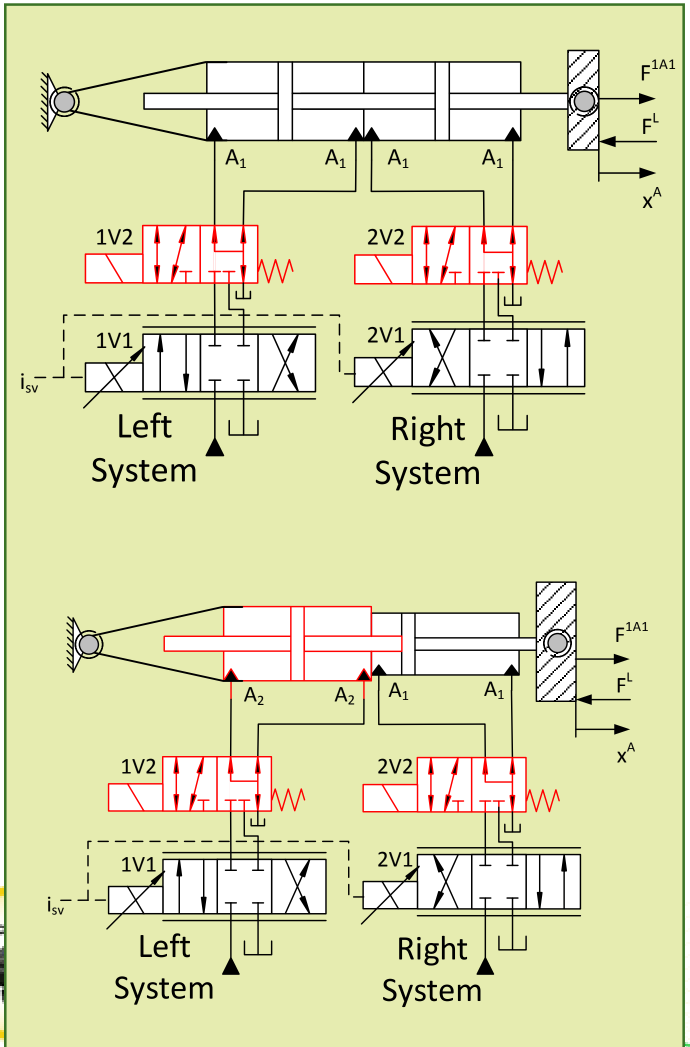


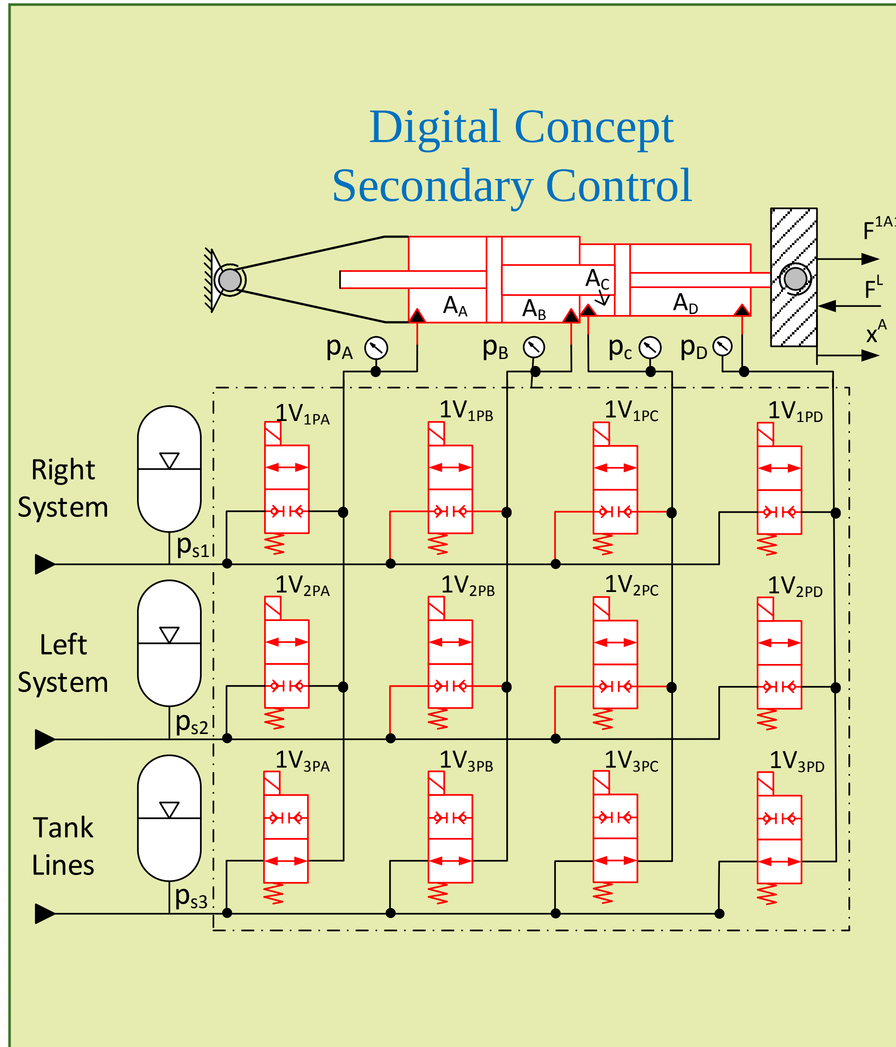
Fluida och Mekatroniska System
FluMeS
Fluid and Mechatronic Systems

LASHIP
HYDRAULICS & PNEUMATICS

Novel Actuation System Using Digital Valves

(Henri Belan UFSC)

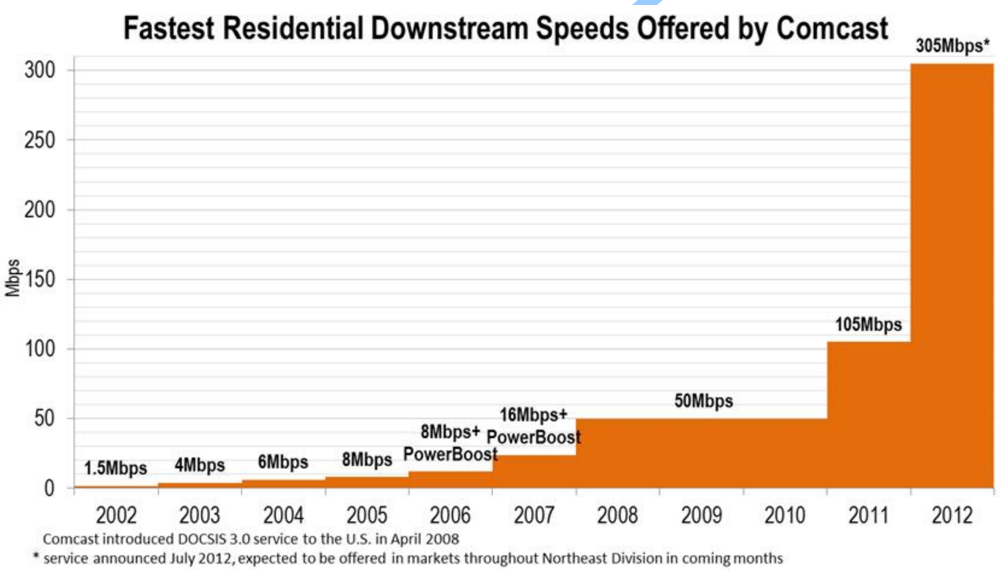




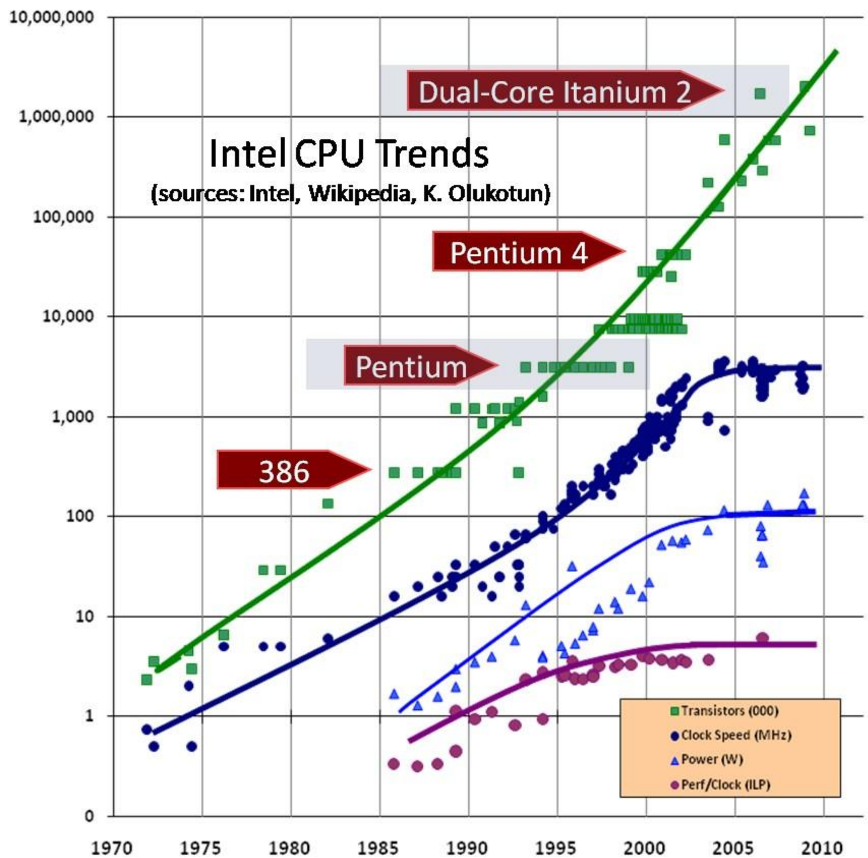
Related Areas: Construction and Forest Machines

Future Trends of Design Tools
Computational capabilities

- In ten years time computational cost will be reduced with a factor of 1000.
- Internet backbone speed will be increased with a factor of 100.
- There is an increasing performance gap between the physical possibilities in hardware, and the actual design capability.



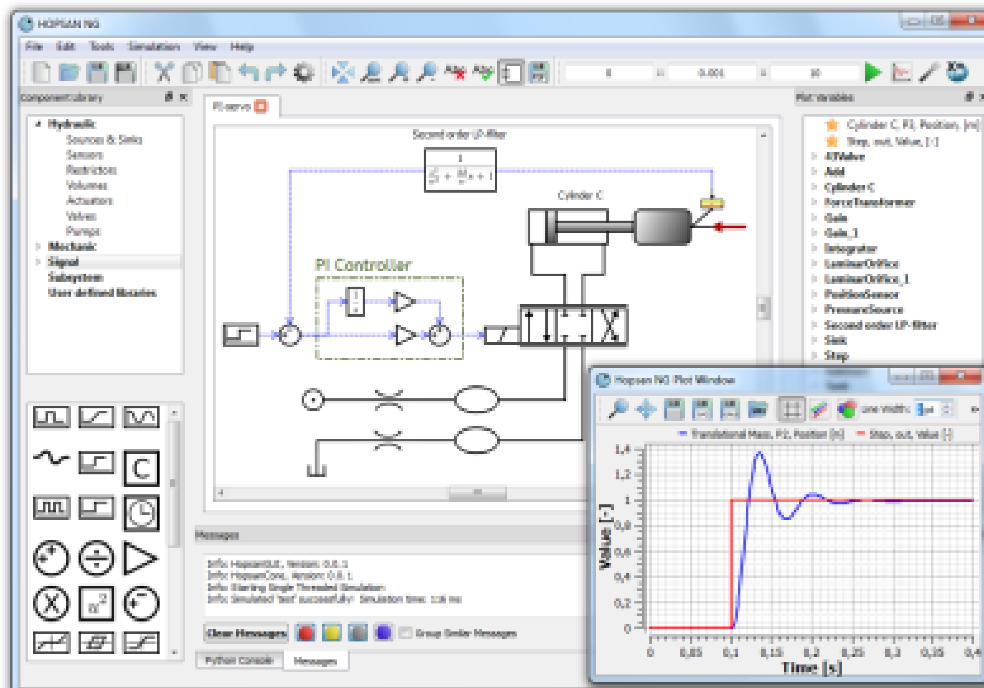
Computer hardware speed up



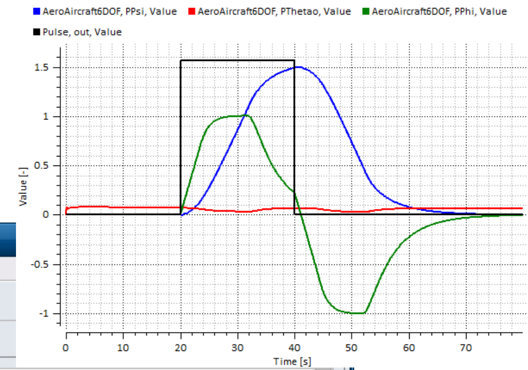
- **The Free Lunch Is Over**
  A Fundamental Turn Toward Concurrency in Software. By Herb Sutter (2005)
- *“We have left the golden era of scaling of the nineties.*
- *Concurrency is the only way to take advantage of computer development.”*
- Engineering problems in general are well suited for parallelization.
- Will there be jumps into a new technologies, e.g. Quantum computing?

HOPSAN-NG (Next Generation)

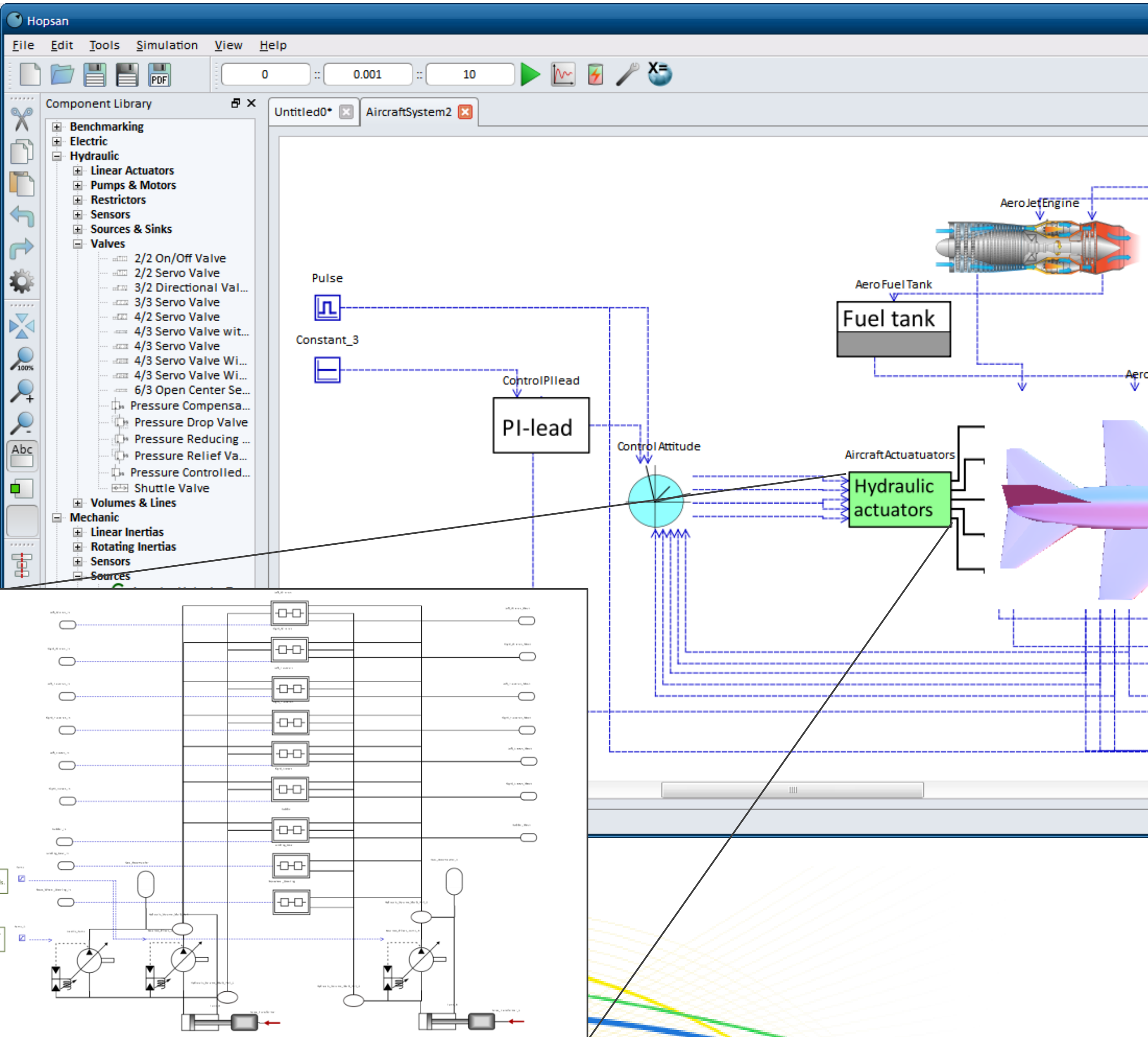
- Bidirectional delay-lines
- First system simulation software to have build in support for multi-core simulation
- Hopsan has FMU export/import for model exchange.
- Models can be exported to Simulink.
- Freeware that can be downloaded from http://www.iei.liu.se/flumes/system-simulation/hopsanng

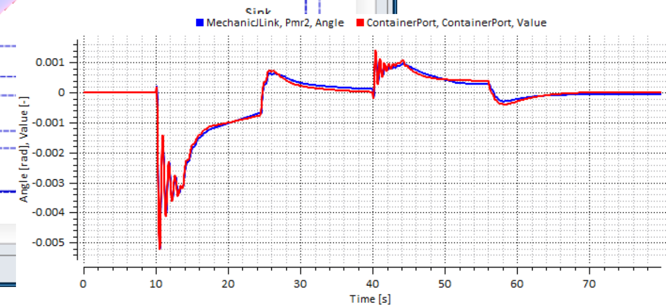


System Modelling and Simulation



The aircraft attitudes during an S-maneuver.

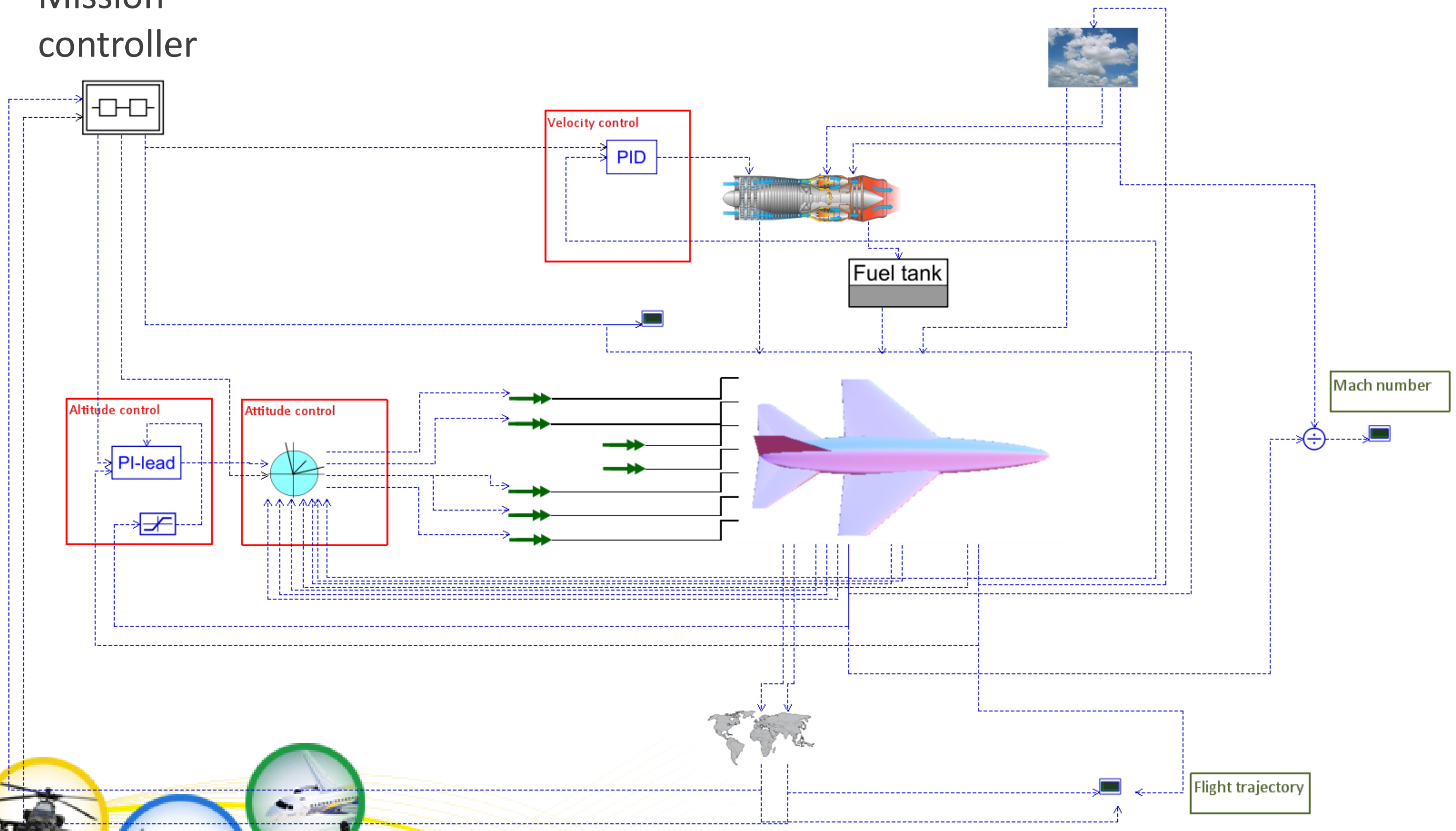


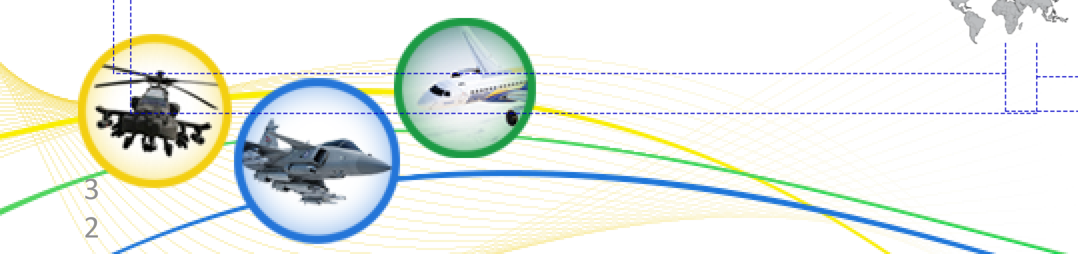


Angular position and reference position of the rudder actuator

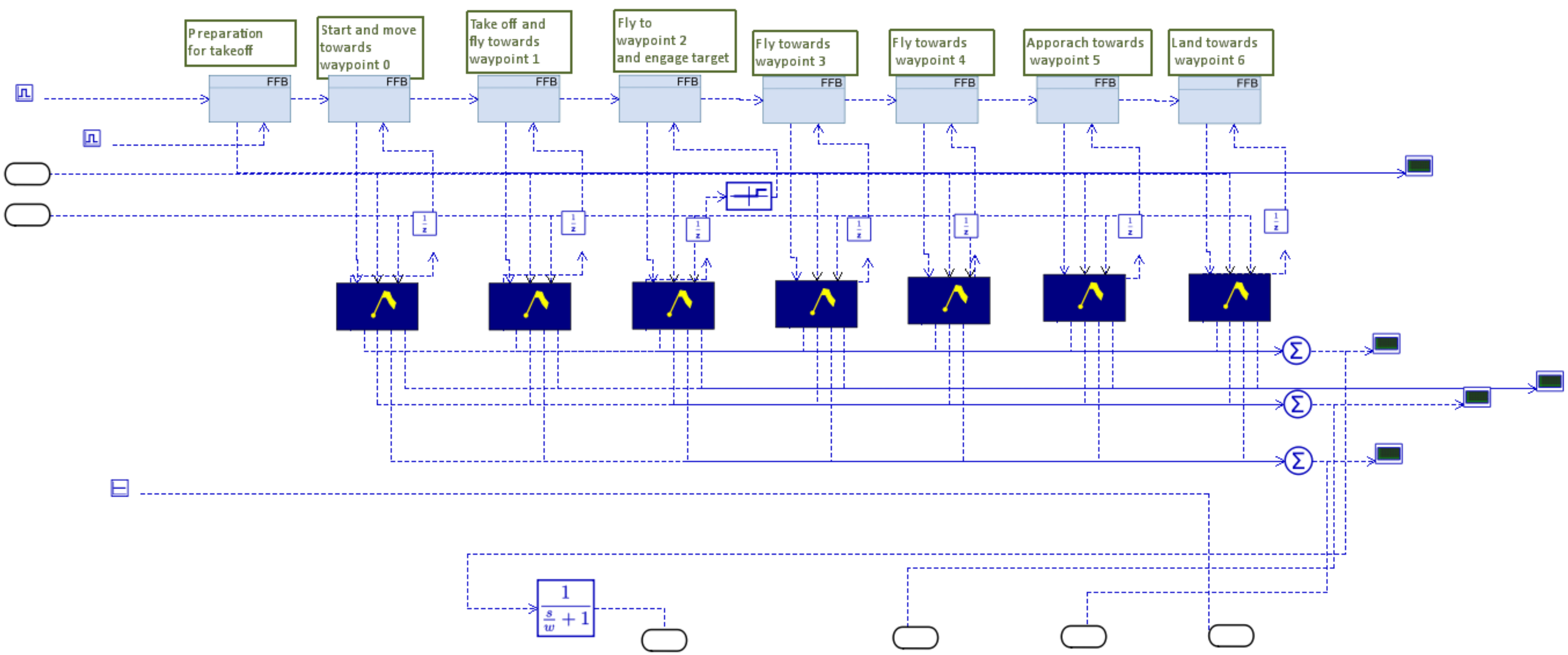
System model for mission simulation

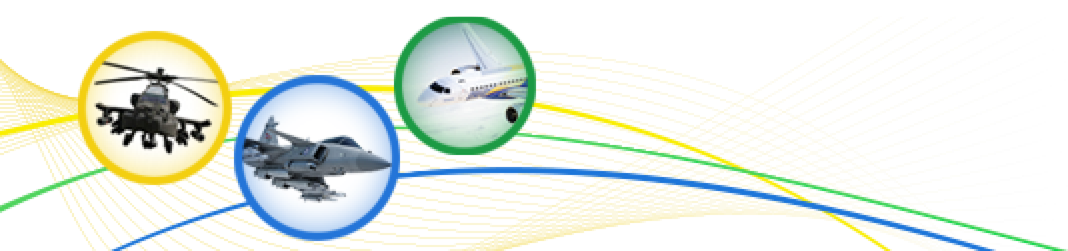
Mission controller



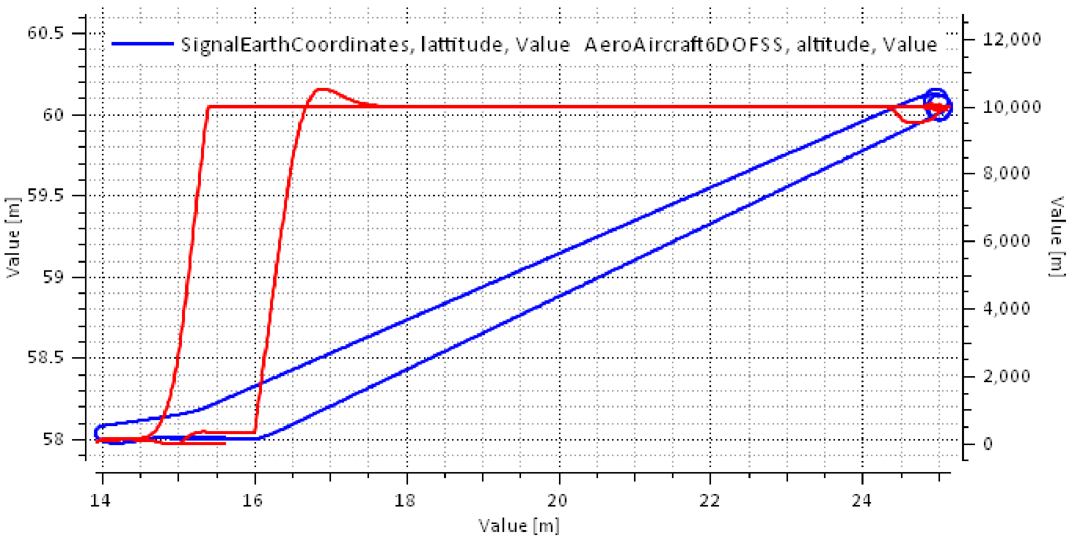


Mission Controller



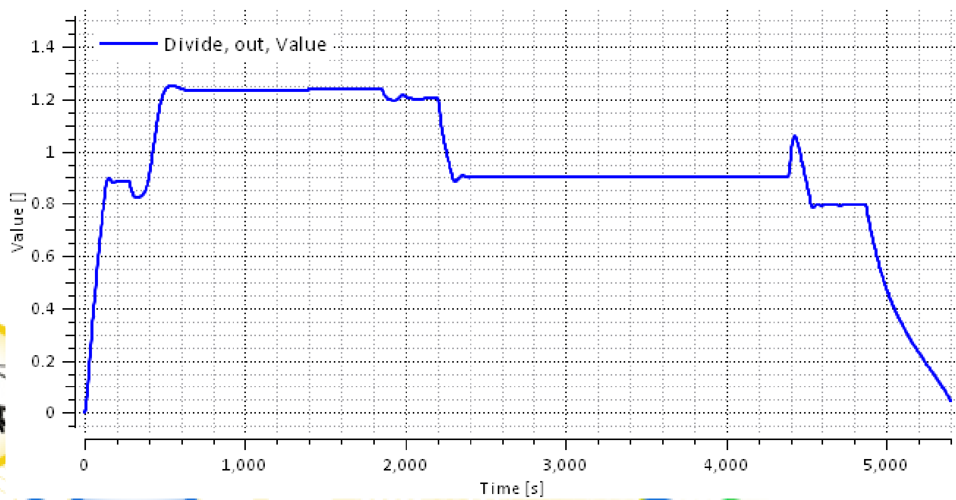


Mission Simulation Results



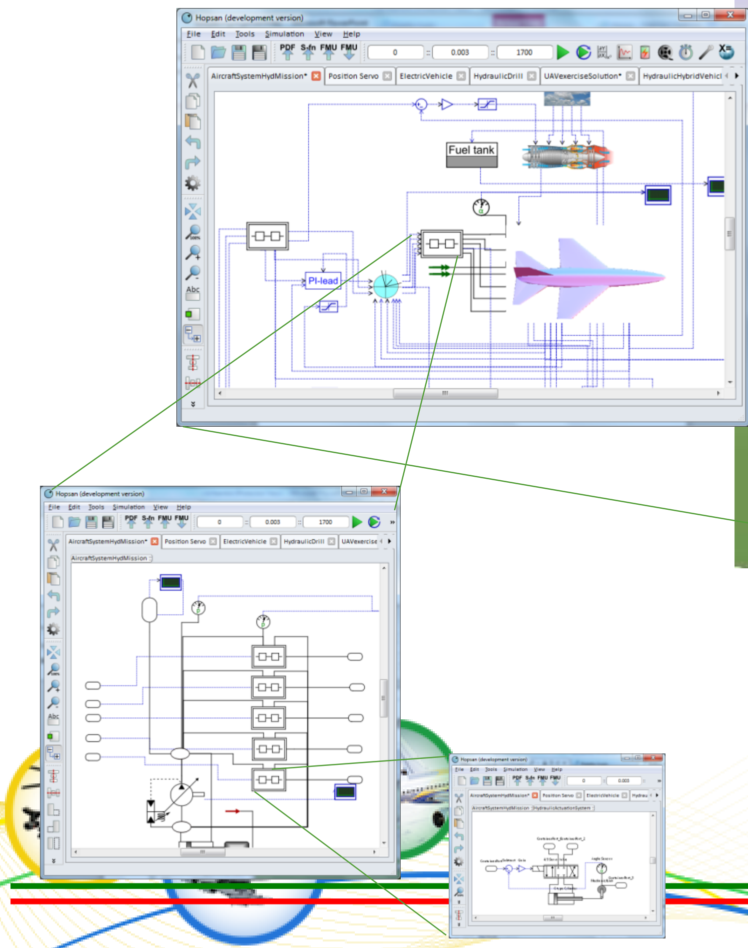
Flight trajectory

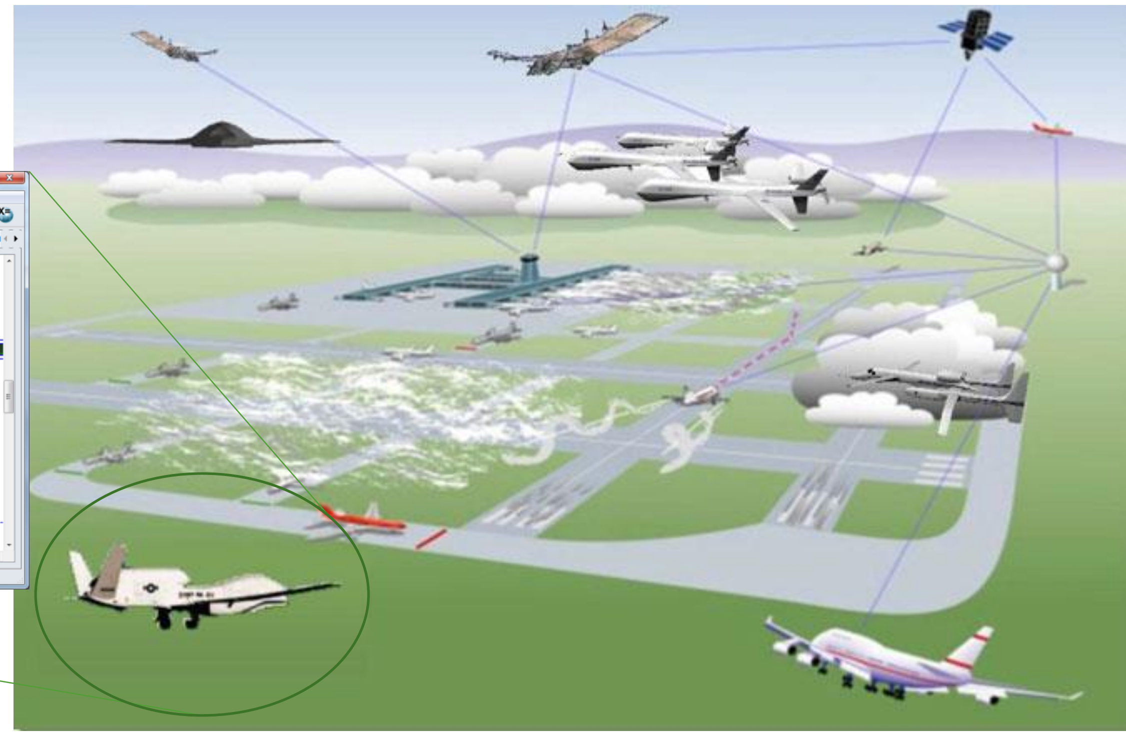
Simulation time 5400 sec in 24 seconds 216 times real time (73 times real time including actuation system)



Velocity profile

System of systems simulation





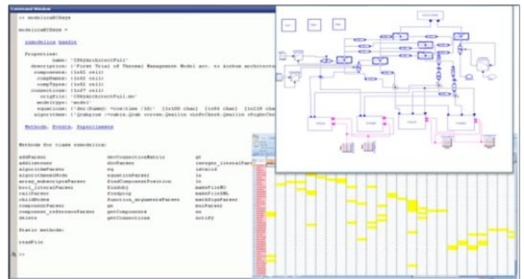
Simulation for operational analysis
and subsystem verification

Conceptual Aircraft Design (LiU/Saab)

SIZING AND AERODYNAMICS

Matlab

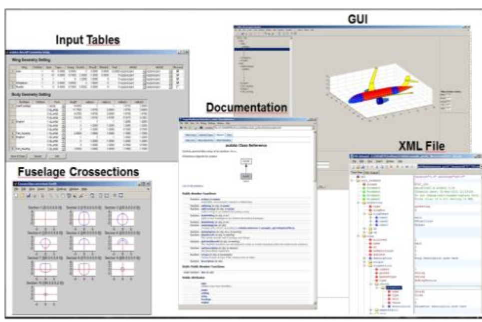
- **Tango -** Aircraft sizing
- **Tornado**- Aerodynamics



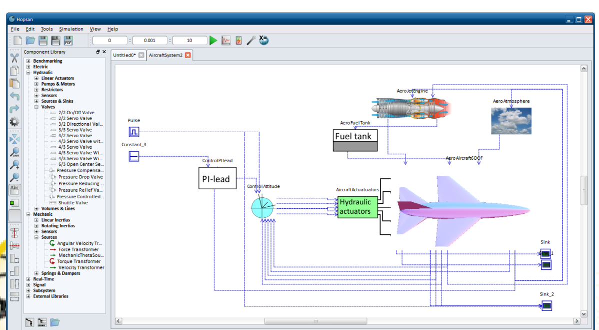
Modelica (Dymola)

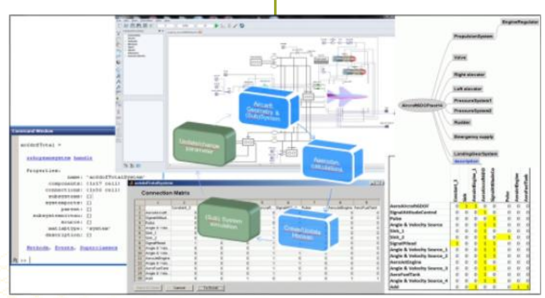
CATIA

RAPID



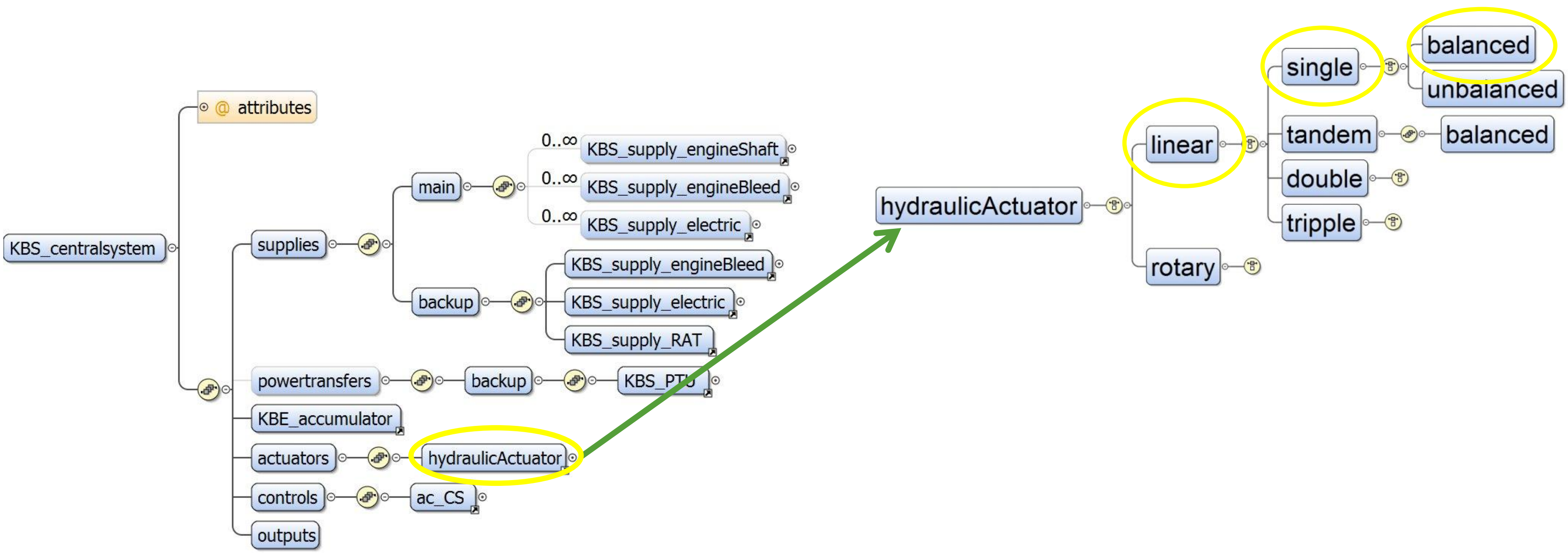
Hopsan



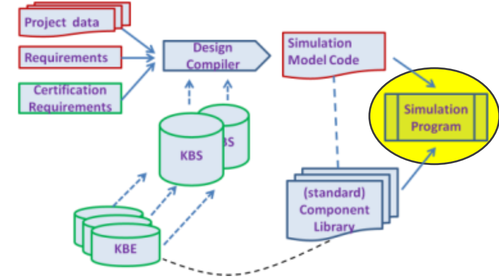


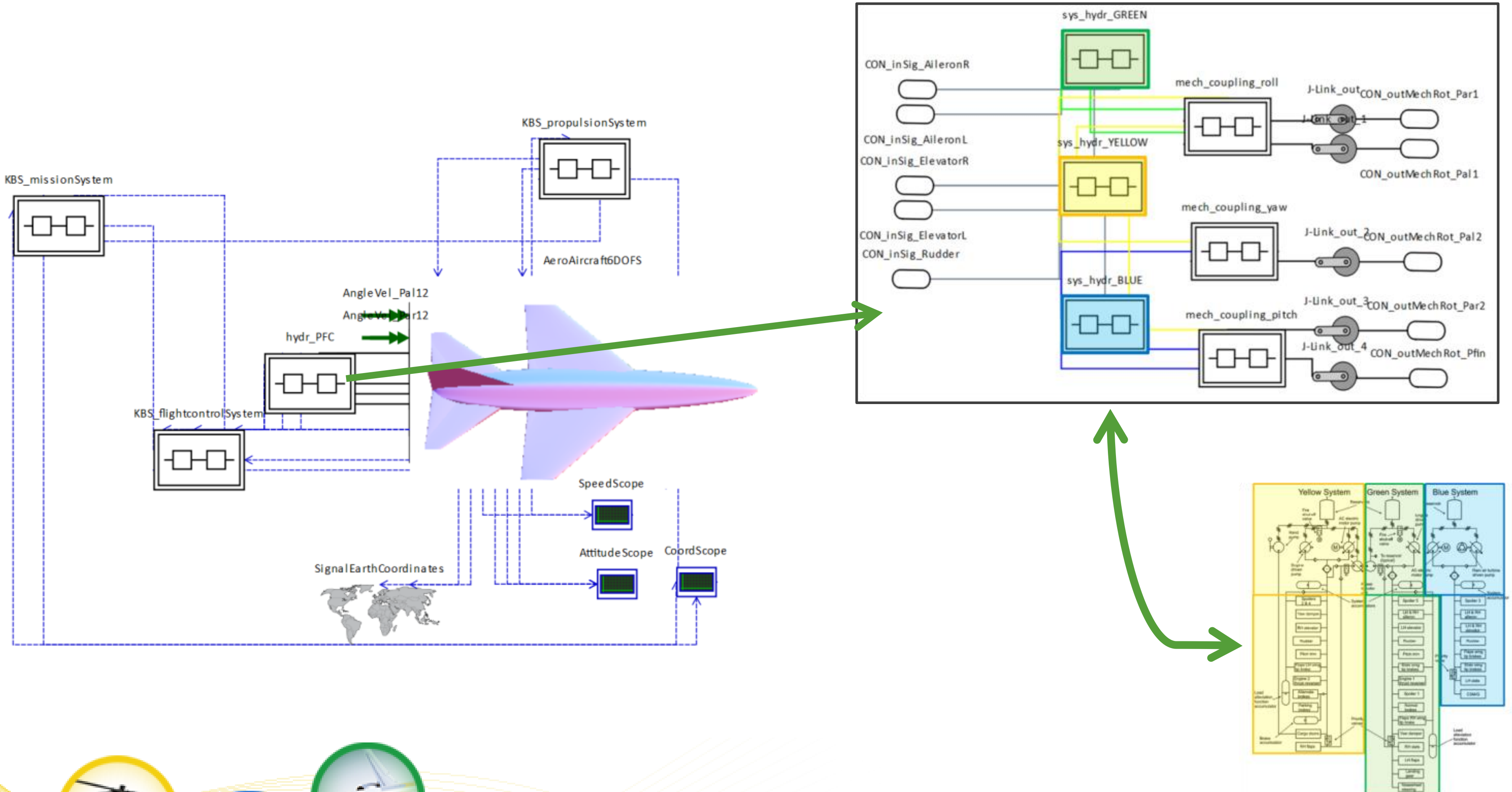
KBE for system

Knowledge modelling of aircraft hydraulic System



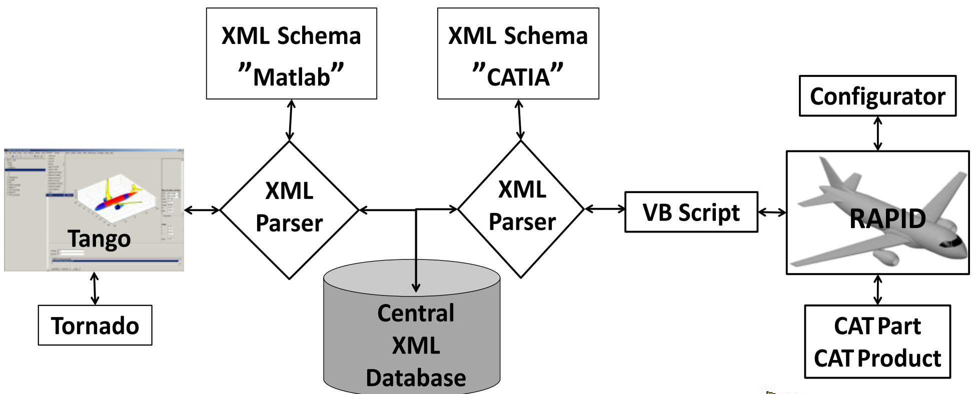
Example Result: Total aircraft Simulation Model

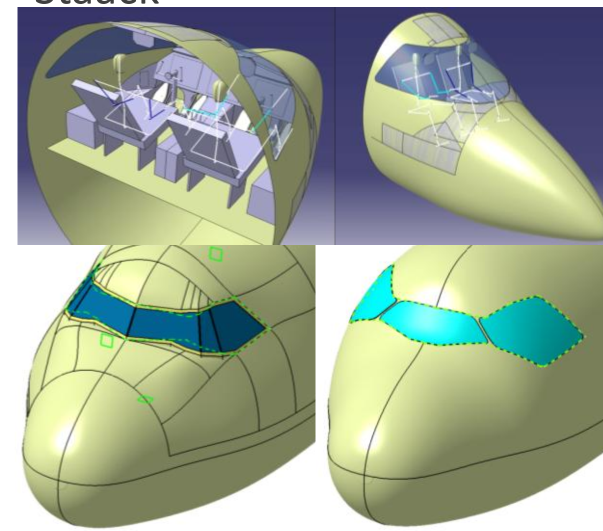


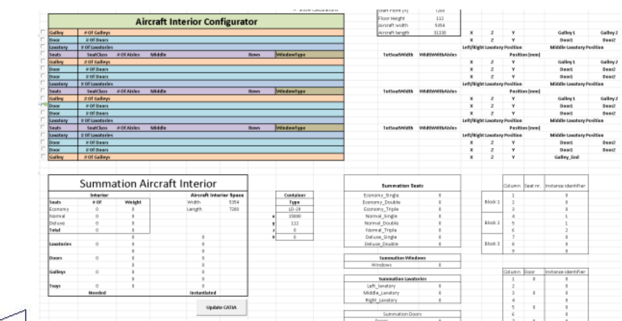


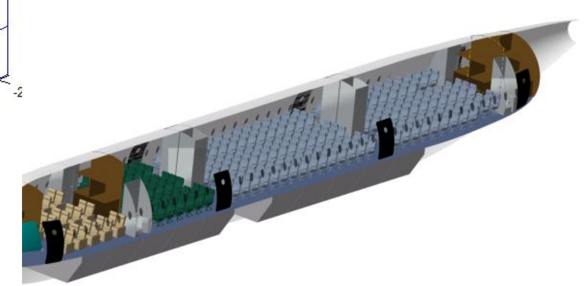
Raghu Chaitanya M.V. , Ingo Staack

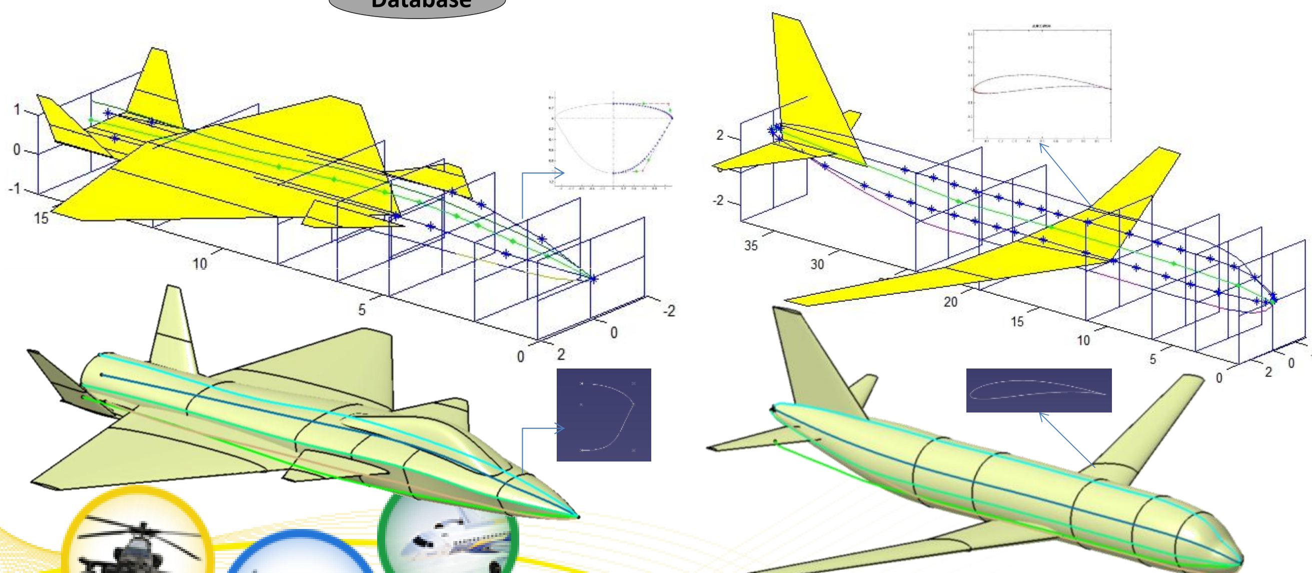
KBE for Aircraft Conceptual Design



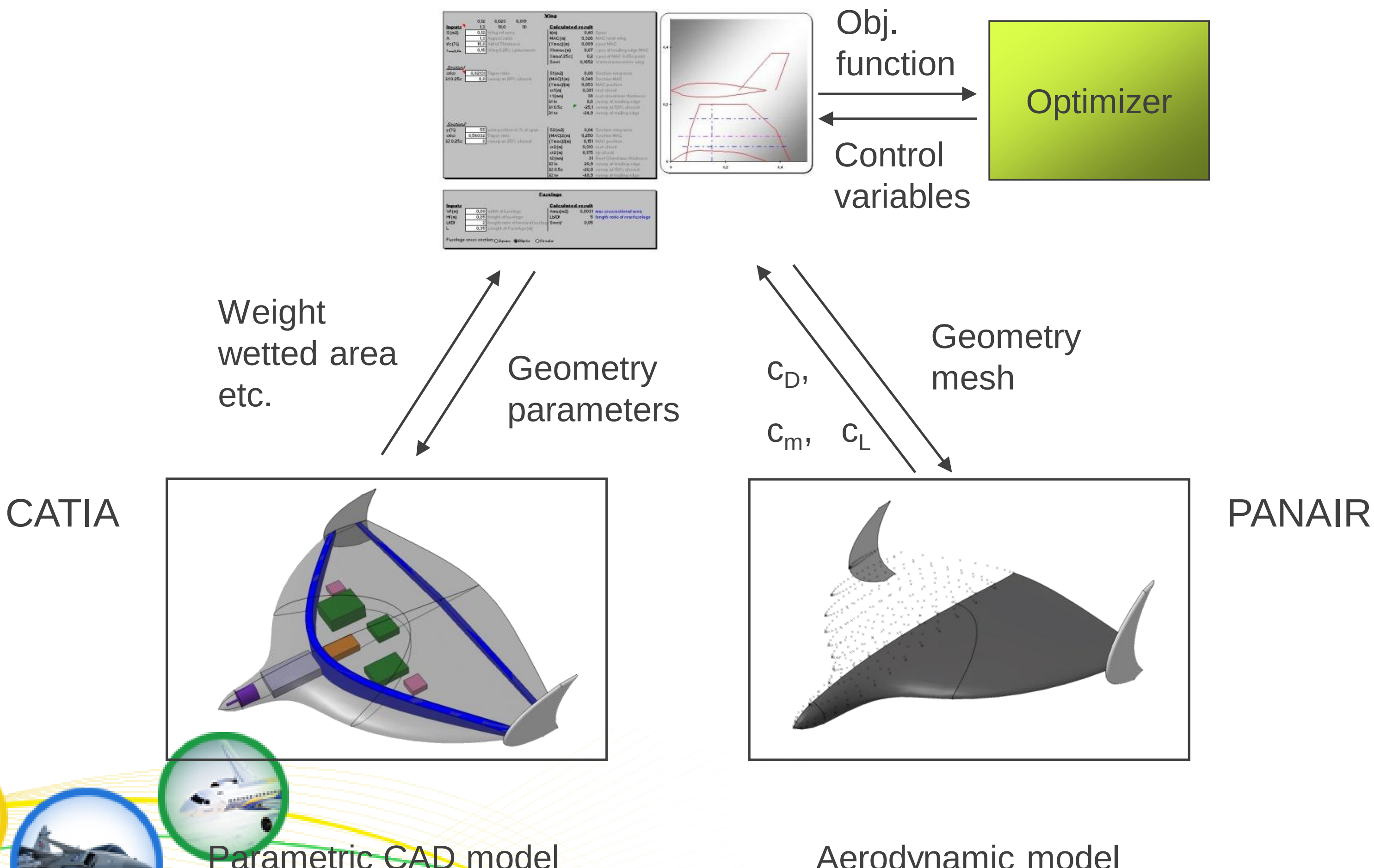








Micro / Mini Aerial Vehicle Design Automation (*Design on Demand*)

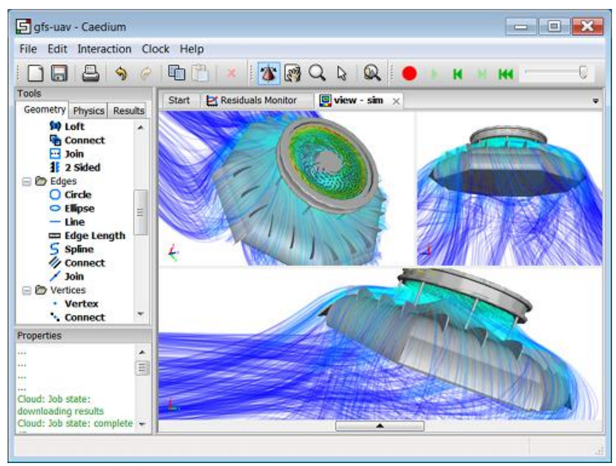


Closing the Loop - MAV Prototyping

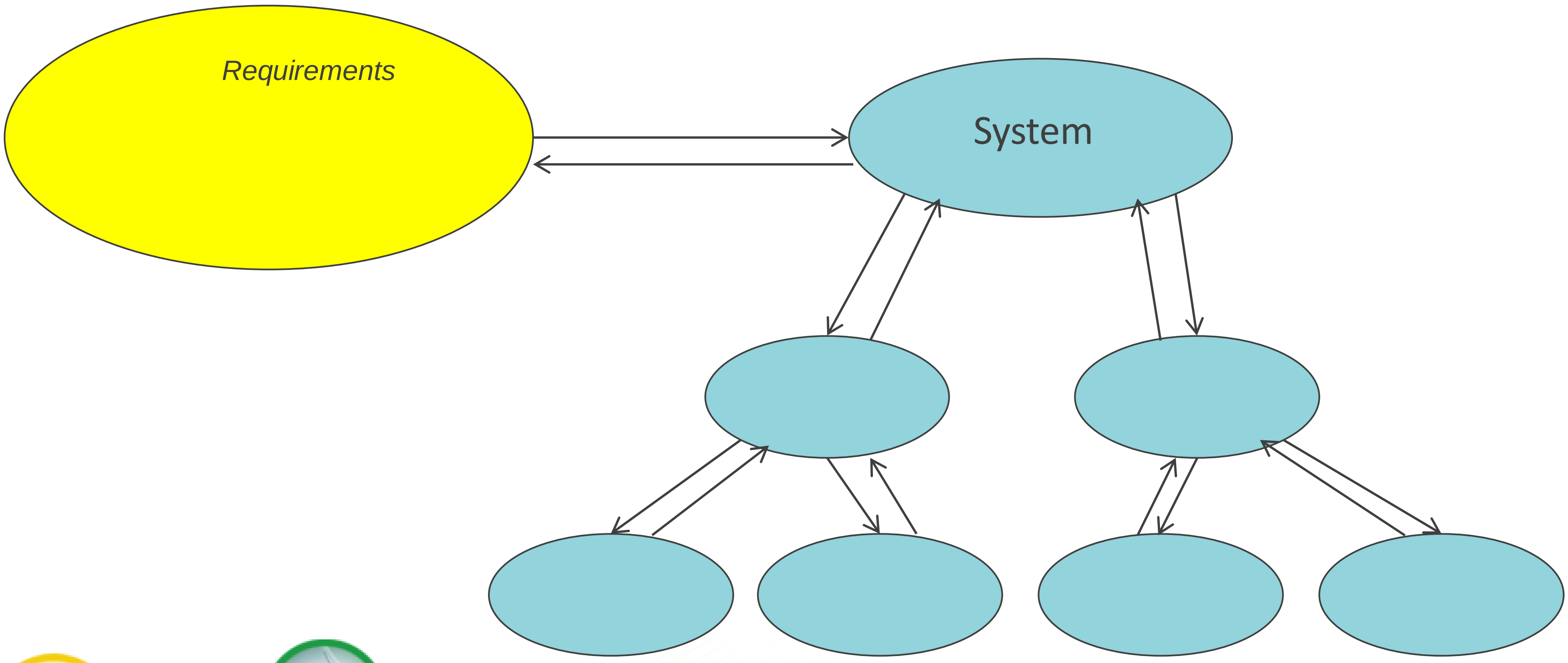
- FDM type 3D printer
- Test: 270mm MAV
- Weight: 90g
- Benefits
  - Allows easy validation
  - No ”craftsmanship” is needed
  - Geometric complexity does not ad cost
  - Good accuracy and repeatability

Trends: Democratization of Analysis

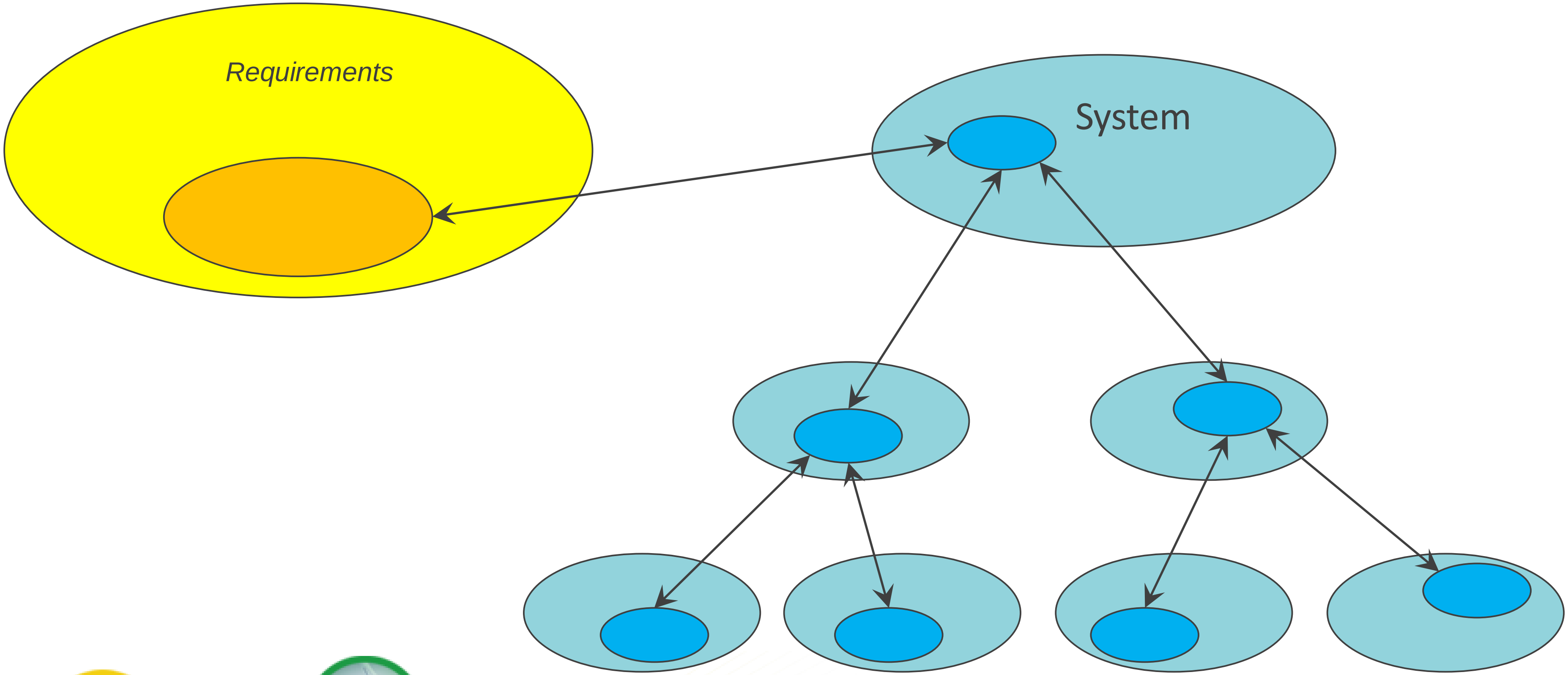
- Powerful analysis tools are available to all engineers.
- Specialist role will change to provide models with defined design spaces rather than results



Traditional System Development



Flexible system development through use of Design Spaces. *Value driven design*

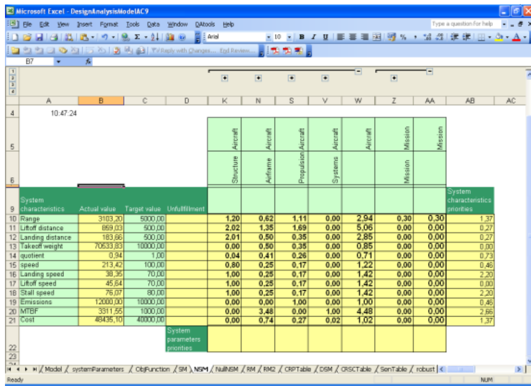


Integrated Analysis and Design

Integrated system model

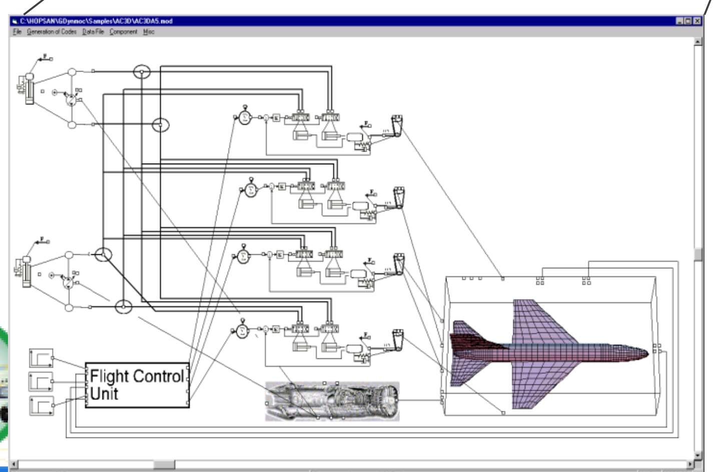
Simulation model

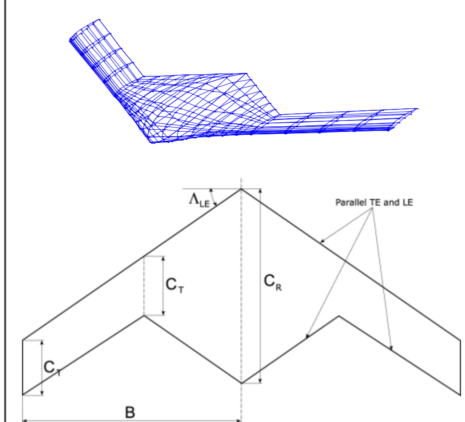
Other analysis model

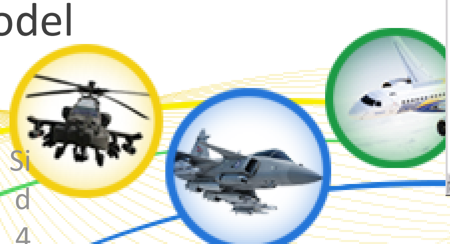


Spread sheet with design analysis and optimization tools

Integrated system analysis of an aircraft with both a aerodynamic model and a simulation model







System Level Sensitivity Analysis

System Characteristics

System characteristics group	Name	Target values	Value	Relative model uncertainty	Unit	Direction	Demand (D) or whish (W)
System Characteristics							
Performance	Range	3500,00	4543,05	0,1	km	1	D
Performance	Payload	10000,00	11800,00	0	N	1	D
Performance	Liftoff distance	500,00	395,52	0,1	m	-1	D
Performance	Landing distance	500,00	227,44	0,1	m	-1	D
Performance	Takeoff weight	120000,00	149432,32	0,1	N	-1	W
Performance	Required weight quotie	1,00	1,01	0,1		-1	D
Performance	Optimal cruise speed	100,00	149,11	0,1	m/s	1	W
Performance							
Field performance	Landing speed	70,00	32,07	0,1	m/s	-1	W
Field performance	Liftoff speed	70,00	38,17	0,1	m/s	-1	W
Field performance	Stall speed	80,00	63,62	0,1	m/s	-1	W
Field performance							
Regulations	Emissions	50000,00	0,90	0,1		-1	W
Regulations	MTBF	1000,00	5,80E+04	0,1	hour	1	W
Regulations	Consumtion	9,00E-04	4,18E-04	0,1	1/km	-1	W
Regulations	Rotation	3,00	7,43518416	0,1	m	1	D
Regulations	Stability	3,00	5,55	0,1		1	D
Regulations							

Model

System Parameters

System group	System group	System group	System parameter	Value	sdev	Unit	Type	Lower limit	Upper limit
System Parameters									
Aircraft	Structure	Wing	B	2,00E+01	0,1	m	DV	1,00E+01	2,00E+01
Aircraft	Structure	Wing	Cr	6,032316911	0,1	m	DV	1,00E+00	2,00E+01
Aircraft	Structure	Wing	Ct	2,126565664	0,1	m	DV	1,00E-01	5,00E+00
Aircraft	Structure	Wing	tc	0,014448987	0,01		DV	5,00E-02	2,00E-01
Aircraft	Structure	Wing	lambda	0,001282934	0,05	rad	DV	0,00E+00	3,00E-01
Aircraft	Structure	Wing	ClmaxC	1,5	0,3		UV	8,00E-01	3,20E+00
Aircraft	Structure	Wing	CLmaxL	3,4	0,1		UV	1,75E+00	7,00E+00
Aircraft	Structure	Wing	CLmaxLo	2,4	0,5		UV	1,25E+00	5,00E+00
Aircraft	Structure	Wing	e0	0,75	0,1		UV	3,75E-01	1,50E+00
Aircraft	Structure	Wing	emax	0,9	0,1		UV	4,50E-01	1,80E+00
Aircraft	Structure	Wing	Snom	20	2		UV	1,00E+01	4,00E+01
Aircraft	Structure	Wng	ARnom	10	2		UV	5,00E+00	2,00E+01
Aircraft	Structure	Wng	tcnom	0,1	0,02		UV	5,00E-02	2,00E-01
Aircraft	Structure	Wng	lambdanom	0	0,1	rad	UV	0,00E+00	0,00E+00
Aircraft	Structure	Wing							
Aircraft	*Structure*								
Aircraft	*Airframe*								
Aircraft	*Propulsion system*								
Aircraft	*Systems*								
Aircraft	*Load*	*Load*							
Aircraft									
Mission									

				Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Mission
				Structure	Structure	Structure	Structure	Structure	Structure	Structure	Airframe	Propulsion system	Systems		
				Wing	Wing	Wing	Wing	Wing	Wing						
				B	Cr	Ct	tc	lambda							
System characteristics	Unit	Target value	Actual value	20,00	6,89	2,07	0,02	0,00							
Range	km	5000,00	5490,87	-0,09	-0,45	-0,10	-0,02	0,00	**0,66**	**0,66**	**0,30**	**1,10**	**0,00**	**2,05**	**1,08**
Liftoff distance	m	500,00	393,93	-1,46	-0,37	-0,17	0,00	0,00	**2,01**	**2,01**	**1,26**	**1,69**	**0,00**	**4,96**	**0,00**
Landing distance	m	500,00	104,18	-0,37	-1,32	-0,32	0,00	0,00	**2,01**	**2,01**	**0,50**	**0,37**	**0,00**	**2,88**	**0,00**
Takeoff weight	N	60000,00	85865,23	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**0,50**	**0,37**	**0,00**	**0,87**	**0,00**
Required weight quotient		1,00	0,98	0,08	-0,03	-0,01	-0,04	0,00	**0,16**	**0,16**	**0,43**	**0,27**	**0,00**	**0,86**	**0,00**
Optimal cruise speed	m/s	100,00	146,68	-0,68	-0,11	-0,07	-0,01	0,00	**0,86**	**0,86**	**0,25**	**0,19**	**0,00**	**1,30**	**0,00**
Landing speed	m/s	70,00	25,48	-0,50	-0,38	-0,12	0,00	0,00	**1,00**	**1,00**	**0,25**	**0,19**	**0,00**	**1,43**	**0,00**
Liftoff speed	m/s	70,00	30,33	-0,50	-0,38	-0,12	0,00	0,00	**1,00**	**1,00**	**0,25**	**0,19**	**0,00**	**1,43**	**0,00**
Stall speed	m/s	80,00	50,55	-0,50	-0,38	-0,12	0,00	0,00	**1,00**	**1,00**	**0,25**	**0,19**	**0,00**	**1,43**	**0,00**
Emissions		10000,00	18869,74	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**0,00**	**1,00**	**0,00**	**1,00**	**0,00**
MTBF	hour	1000,00	7324,98	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**4,27**	**0,00**	**1,00**	**5,27**	**0,00**
Cost	kEUR	40000,00	57060,64	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**0,77**	**0,24**	**0,02**	**1,02**	**0,00**

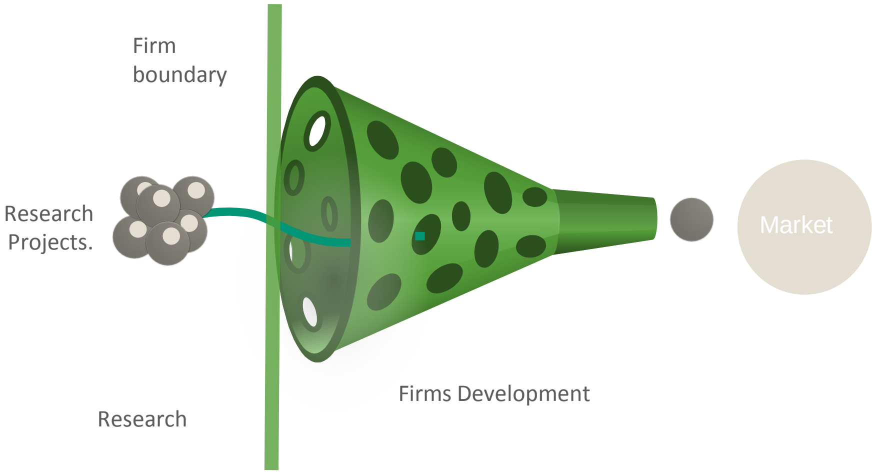
Aggregated normalized sensitivity matrix

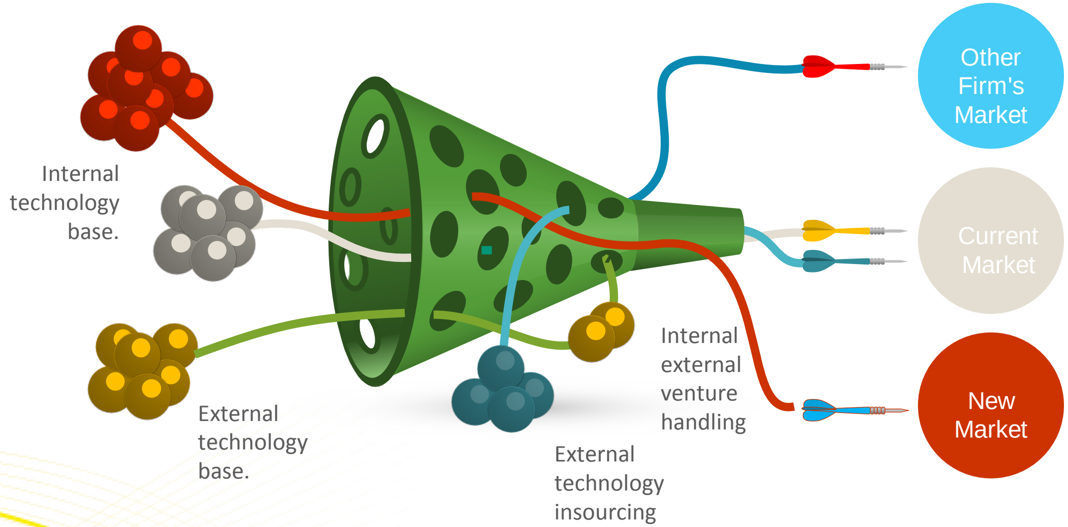
$$k_{ij}^{0} = \frac{x_{s,j}}{y_{s,i}} \frac{\partial y_{s,i}}{\partial x_{s,j}}$$

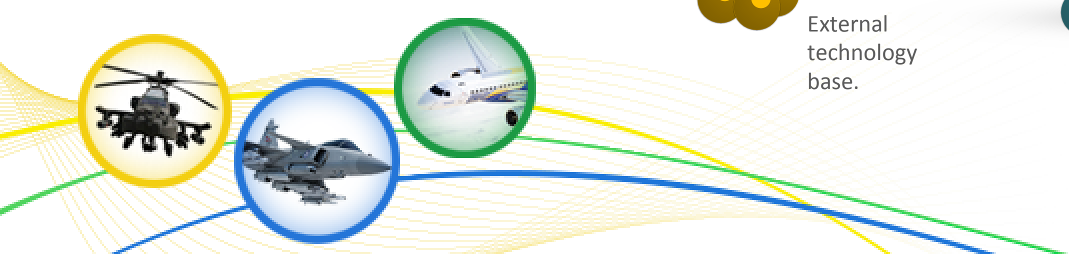
				Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Aircraft	Mission
				Structure	Structure	Structure	Structure	Structure	Structure	Structure	Airframe	Propulsion system	Systems		
				Wing	Wing	Wing	Wing	Wing	Wing						
				B	Cr	Ct	tc	lambda							
System characteristics	Unit	Target value	Actual value	20,00	6,89	2,07	0,02	0,00							
Range	km	5000,00	5490,87	-0,09	-0,45	-0,10	-0,02	0,00	**0,66**	**0,66**	**0,30**	**1,10**	**0,00**	**2,05**	**1,08**
Liftoff distance	m	500,00	393,93	-1,46	-0,37	-0,17	0,00	0,00	**2,01**	**2,01**	**1,26**	**1,69**	**0,00**	**4,96**	**0,00**
Landing distance	m	500,00	104,18	-0,37	-1,32	-0,32	0,00	0,00	**2,01**	**2,01**	**0,50**	**0,37**	**0,00**	**2,88**	**0,00**
Takeoff weight	N	60000,00	85865,23	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**0,50**	**0,37**	**0,00**	**0,87**	**0,00**
Required weight quotient		1,00	0,98	0,08	-0,03	-0,01	-0,04	0,00	**0,16**	**0,16**	**0,43**	**0,27**	**0,00**	**0,86**	**0,00**
Optimal cruise speed	m/s	100,00	146,68	-0,68	-0,11	-0,07	-0,01	0,00	**0,86**	**0,86**	**0,25**	**0,19**	**0,00**	**1,30**	**0,00**
Landing speed	m/s	70,00	25,48	-0,50	-0,38	-0,12	0,00	0,00	**1,00**	**1,00**	**0,25**	**0,19**	**0,00**	**1,43**	**0,00**
Liftoff speed	m/s	70,00	30,33	-0,50	-0,38	-0,12	0,00	0,00	**1,00**	**1,00**	**0,25**	**0,19**	**0,00**	**1,43**	**0,00**
Stall speed	m/s	80,00	50,55	-0,50	-0,38	-0,12	0,00	0,00	**1,00**	**1,00**	**0,25**	**0,19**	**0,00**	**1,43**	**0,00**
Emissions		10000,00	18869,74	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**0,00**	**1,00**	**0,00**	**1,00**	**0,00**
MTBF	hour	1000,00	7324,98	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**4,27**	**0,00**	**1,00**	**5,27**	**0,00**
Cost	kEUR	40000,00	57060,64	0,00	0,00	0,00	0,00	0,00	**0,00**	**0,00**	**0,77**	**0,24**	**0,02**	**1,02**	**0,00**

The matrix is expanded for the wing parameters. The sum of the absolute values is presented in a column to the left of the subsystem values.

Closed vs Open Innovation Model



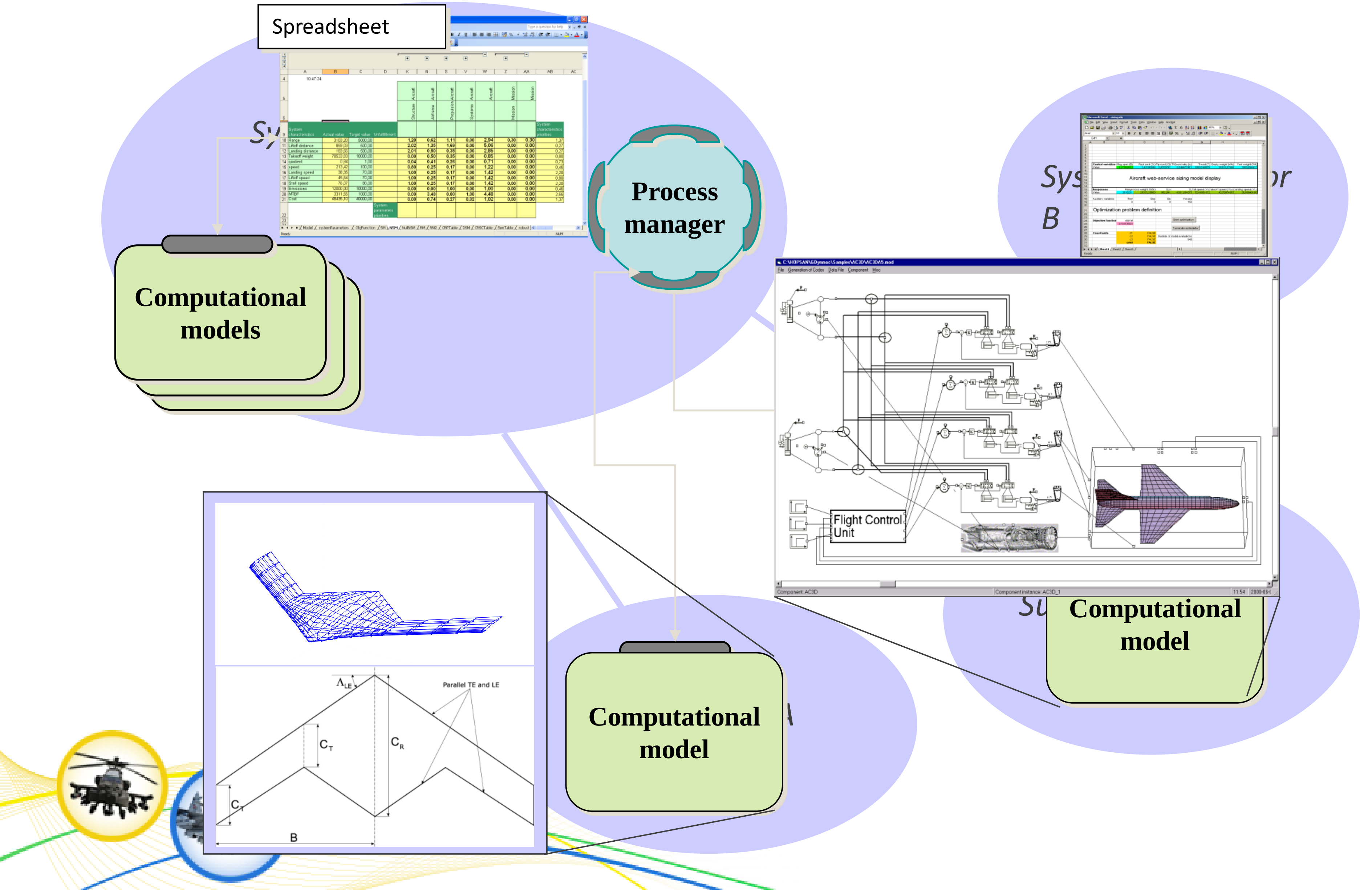




Open Innovation

- Open innovation will provide great challenges to meet the compromise between openness and confidentiality.
- There will likely be a greater emphasize on efficient business models and regulatory mechanism for IP at a micro level, to ensure correlation between value creation and reward.
- In defence industry this will be an even greater challenge.
- Design space can be dynamic as new components and technologies can be found by internet search engines during optimization.

System development for the extended enterprise



What would contribute to reduce the time for product development a factor of 10?

- ***Design automation*** based on reusable models, design analysis, design optimization, based on digital models
  - Internet will be used for *automatic* search and localisation of components and for *automatic* configuration of products, and business arrangements.
- *Virtual offices* for collaboration between participants on geographically separated locations.
- The capability to rapidly produce physical prototypes has to increase order of magnitude. Model validation will otherwise be a bottleneck.
  - And a prototype is a pretty good representation of it self for hardware in the loop simulation

Microsoft's HoloLens

Ironman (2008)

Thanks!