SYSTEM-OF-SYSTEMS ENGINEERING, OVERVIEW OF RESEARCH ACTIVITIES WITHIN THE NFFP CLUSTER OVERALL DESIGN AND SYSTEM INTEGRATION

CHRISTOPHER JOUANNET PH.D

CLUSTER GOALS

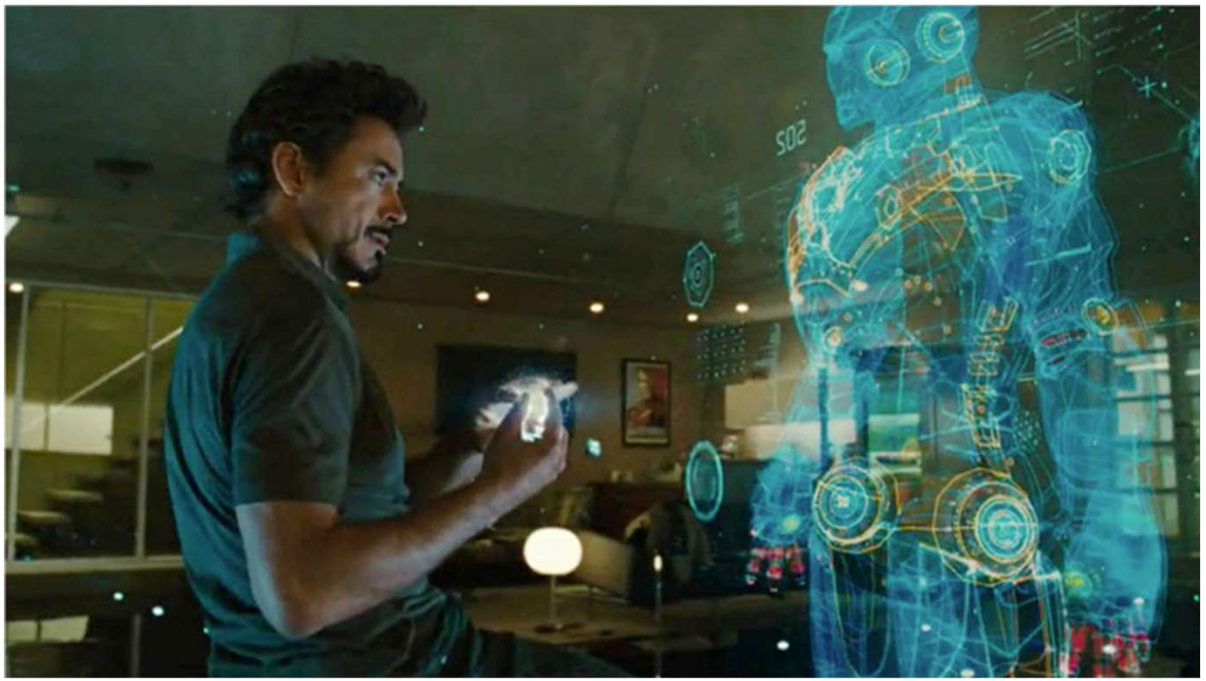
- Gather research
- Area of SoS Engineering
- Decision support

SOS ENGINEERING (SOSE)

- Overwhelming complexity & different modeling approaches
- Lack of a established process, methods & tools for holistic SoS research
- Relatively young education field (research not lead by universities but DoD…)

RESEARCH GOALS

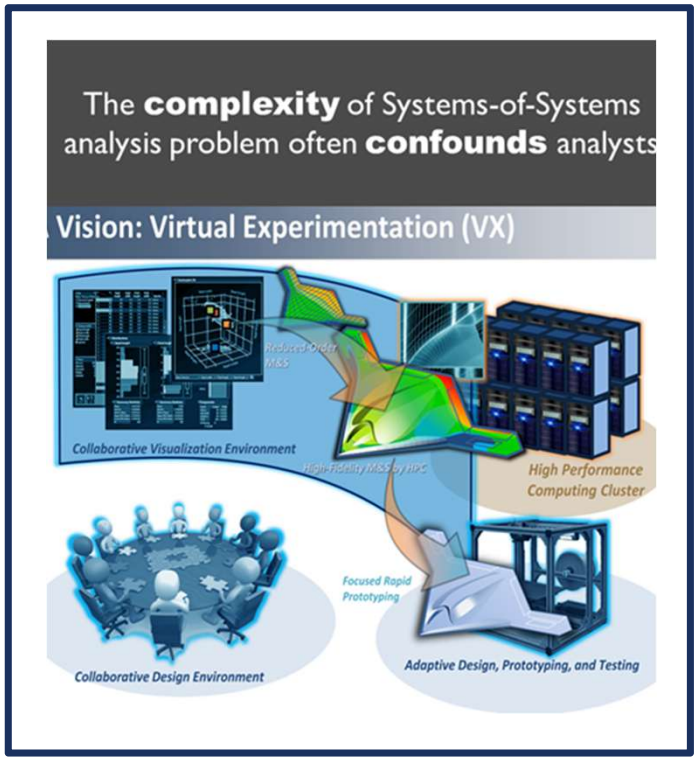
- Support decision making for advanced concepts by providing a structured set of vehicle (assets) and technology assessment processes and tools
  - Quantitative modeling of multiple, independent assets
  - Rapid evaluation and visualization of assets and trades
  - Operational needs
  - Technology needs
  - System-of-systems configuration
  - Risks and Costs
  - Capability and effectiveness



SOS CHALLENGES

- Compared to a *System*, a *System-of-Systems* might:
- Be larger in scope
- Have more complex integration
- Be subject to higher degree of uncertainty and risk
- Evolve more continuously with elements of differing lifecycles
- Lack a single management/acquisition entity and have a broader range of stakeholders
- Have elements which are not designed to fit the whole, and which are integrated post-design and deployment
- Exhibit emergent behaviours
- Have more ambiguous requirements and fuzzy boundaries
- Have continuous SE which is never finished

CHALLENGES IN SOS ENGINEERING



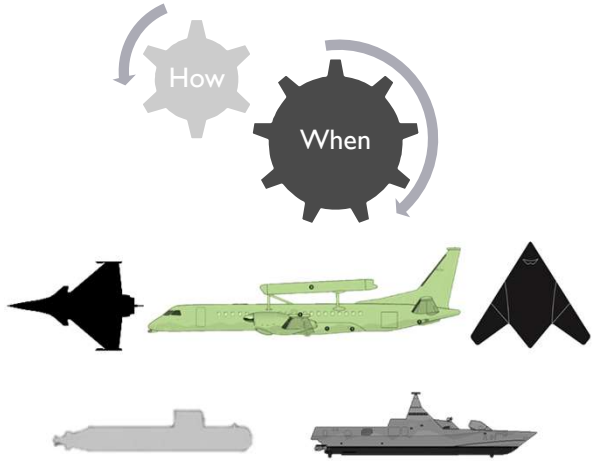
- Physical experiments are typically infeasible or limited
  - Computer simulations are required, and are often computationally intensive and time consuming
  - Verification and Validation is a challenge
- SoS are complex
  - Limits available modelling techniques
  - Often results in high dimensionality
  - Stochastic in nature
- SoS have a large and diverse alternative space
  - Unfathomable number of combinations
  - Can be challenging to visualize results
- Management can overshadow engineering
- The initial requirements are likely to be ambiguous

SOS DIFFERENT PERSPECTIVES…

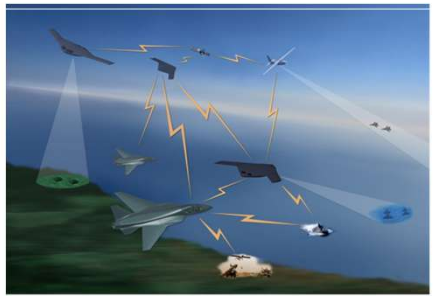
- Existing and legacy system use in SoS:
  - Analyses and tactical optimization
  - Emergent behaviours?
- Gap analyse in current and legacy system to find:
  - New product
  - Enhancement to existing product
  - New tactical usage
- Long term (almost no legacy system):
  - Needs understanding
  - Capability sensitivity from needs
  - SoS design space understanding

SOS ARCHITECTURE ALTERNATIVE SPACE

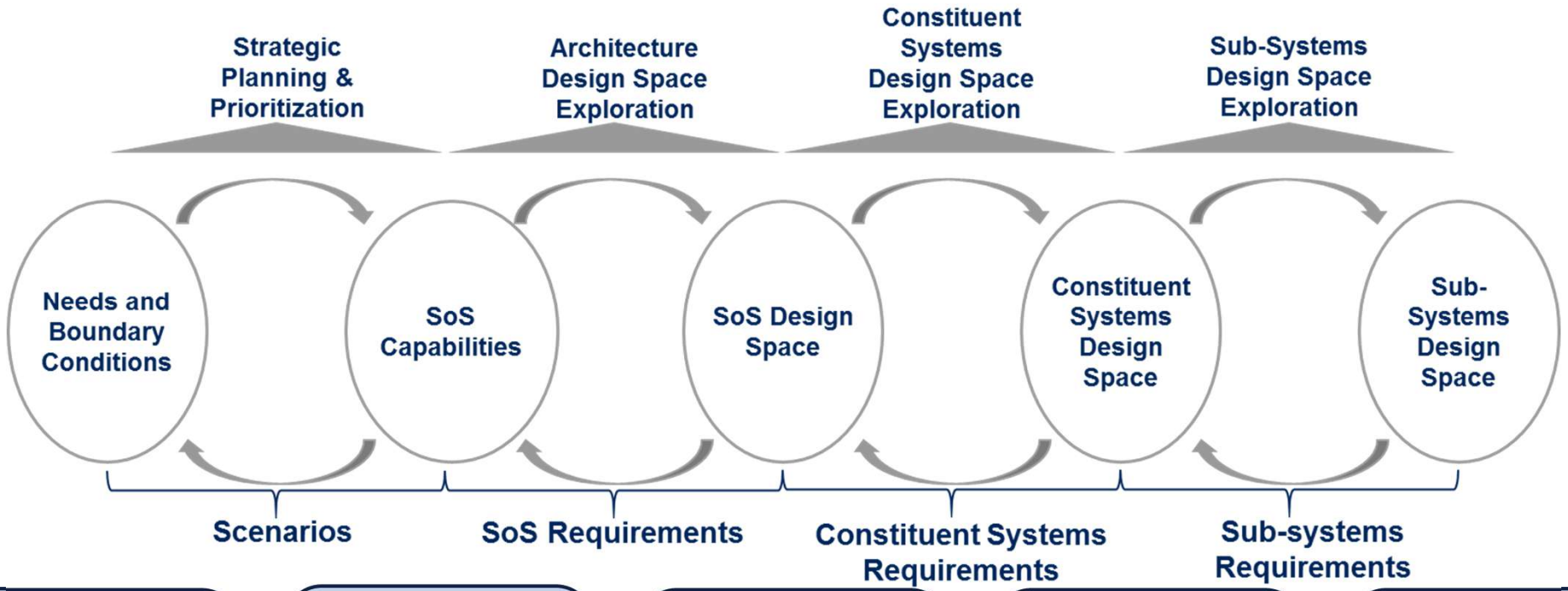
- **Operational Alternatives** (HOW and WHEN)
  - Changing the ways things are done (for example, the communication structure, or the order in which activities are performed)
- **System Alternatives** (WHAT and HOW MANY)
  - Changing the elements (physical systems, the means) of the architecture
- **Organizational Alternatives** (WHO)
  - Changing who is responsible for certain elements, activities, facilities, etc
- **Network Alternatives** (HOW)
  - Changing the network architecture that enables the information flow required by the SoS
- Combinations of the above

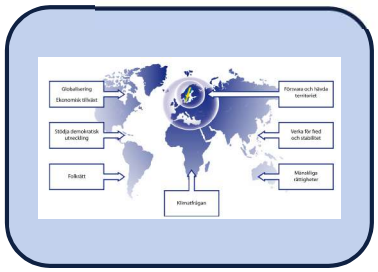


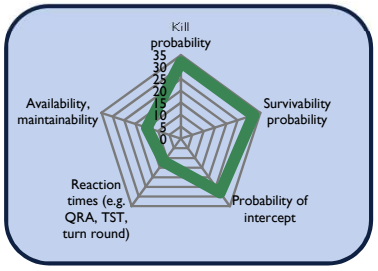
FÖRSVARSMAKTEN

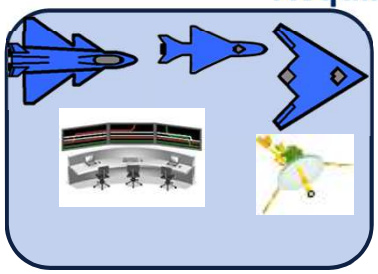


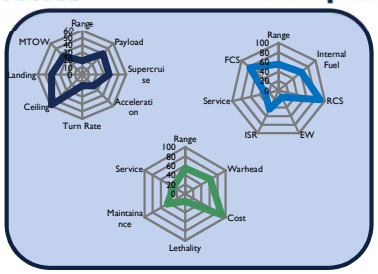
PROPOSED APPROACH…

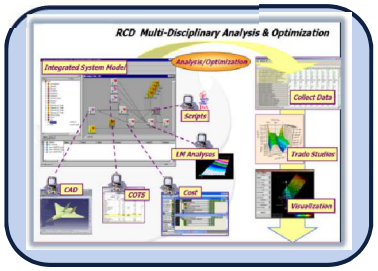


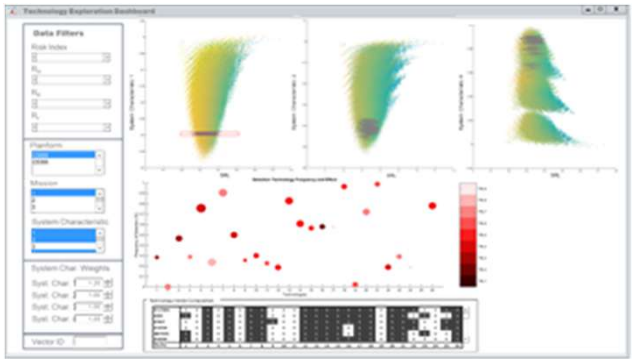


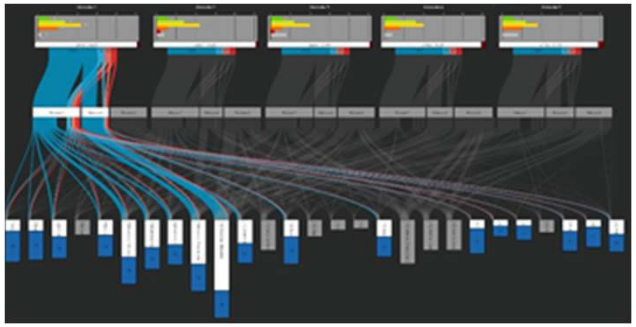


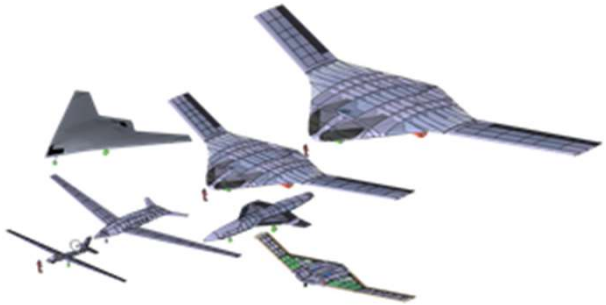










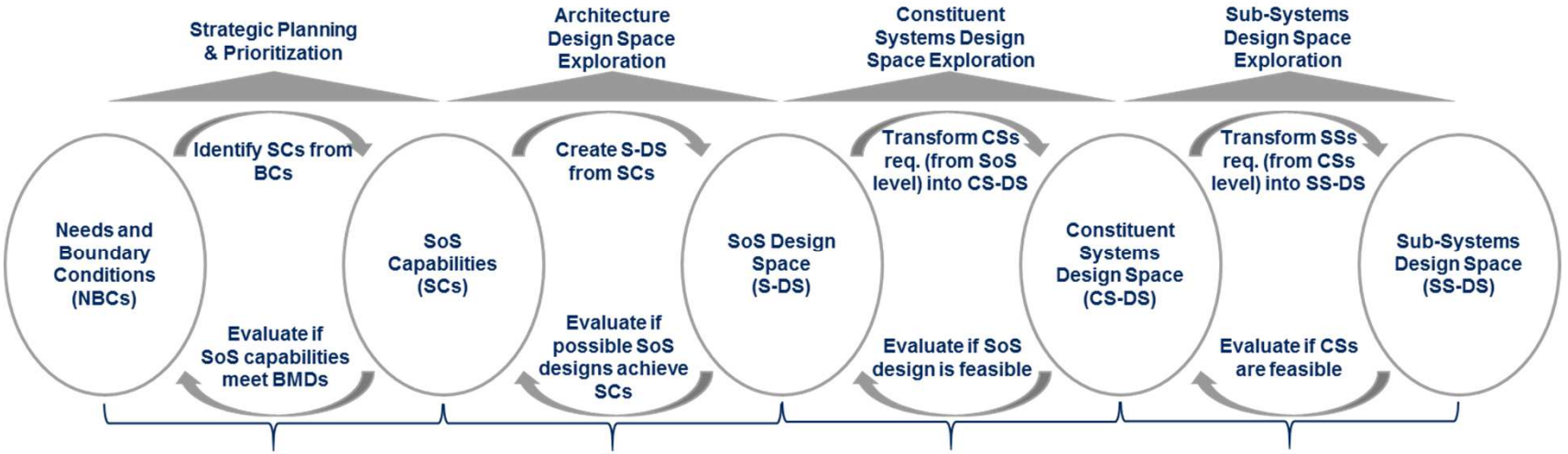


GOALS SOS IN EARLY DESIGN

- Support decision and technology assessment:
  - Quantitative modeling of multiple, independent vehicles (assets)
  - Rapid evaluation and visualization of vehicles (assets) and trades
  - Operational needs
  - Capability gap detection
  - Technology needs and portfolio selection
  - System-of-systems configuration (i.e. number and type of systems)
  - Cost, Risks and opportunities
  - Capability and effectiveness (of the system or the SoS)
  - Finding unknown unknown

Current projects

SAAB internal and international studies



HISyM: Hierarchical Integration of System Models

SMART: Sensor Models for Aircraft Tradespace Exploration

COMTE: Concept of Operation Modeling for Tradespace Exploration

S2TEP: Systems-of-Systems Tradespace Exploration

CAMESoS
Capability and mission engineering for SoS
Saab-VCE-MDH-RISE (KK)

Grand Challenge Georgia Tech-Saab

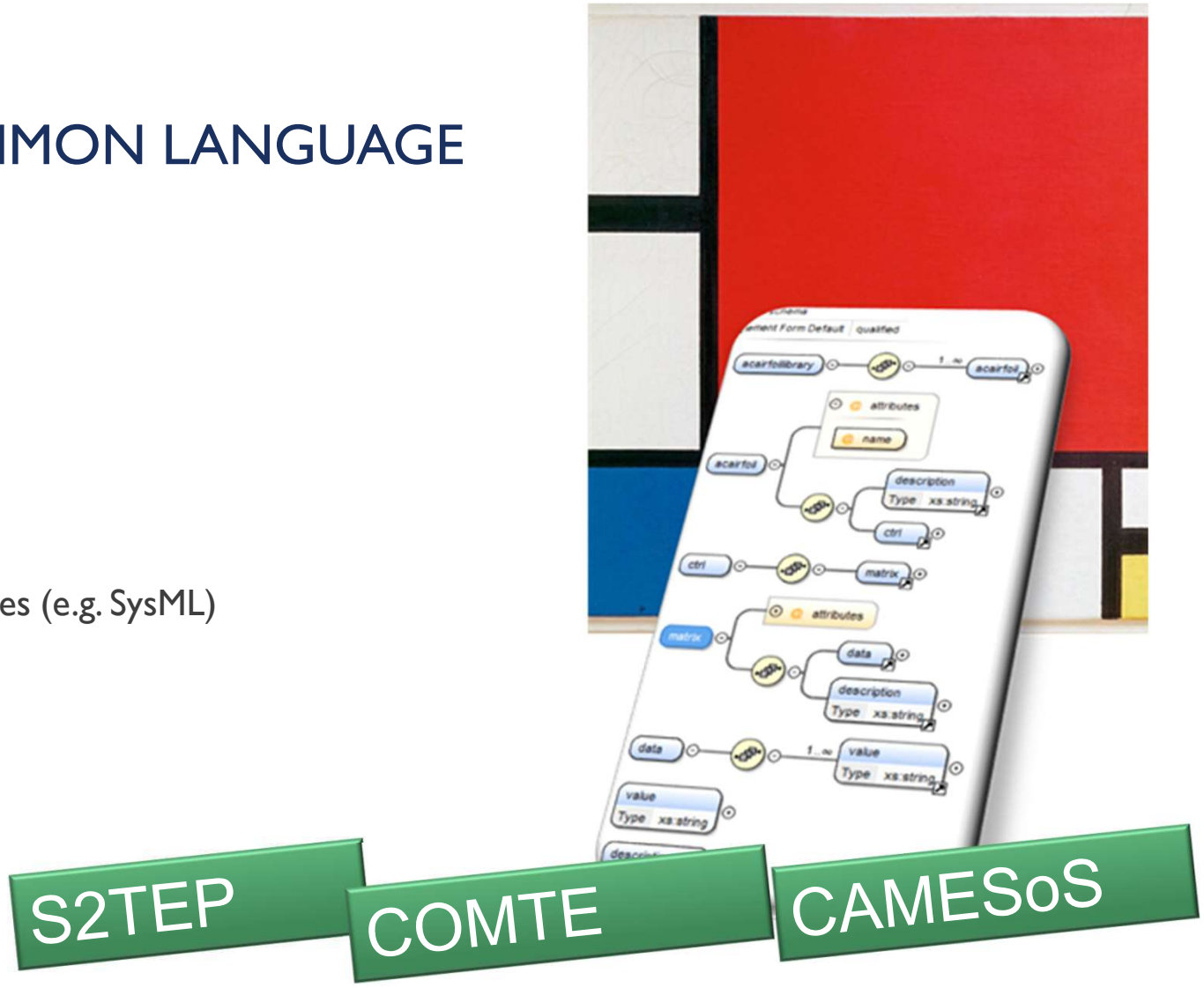
NEEDS

- higher level(s) of abstract(ion)
- focus on needs, usage and operation
- tremendous larger design space
- has to deal with different scenarios and huge uncertainties
- requires interpretation of assumptions / incomplete information
  - not longer a pure *engineering* process

S2TEP COMTE CAMESoS

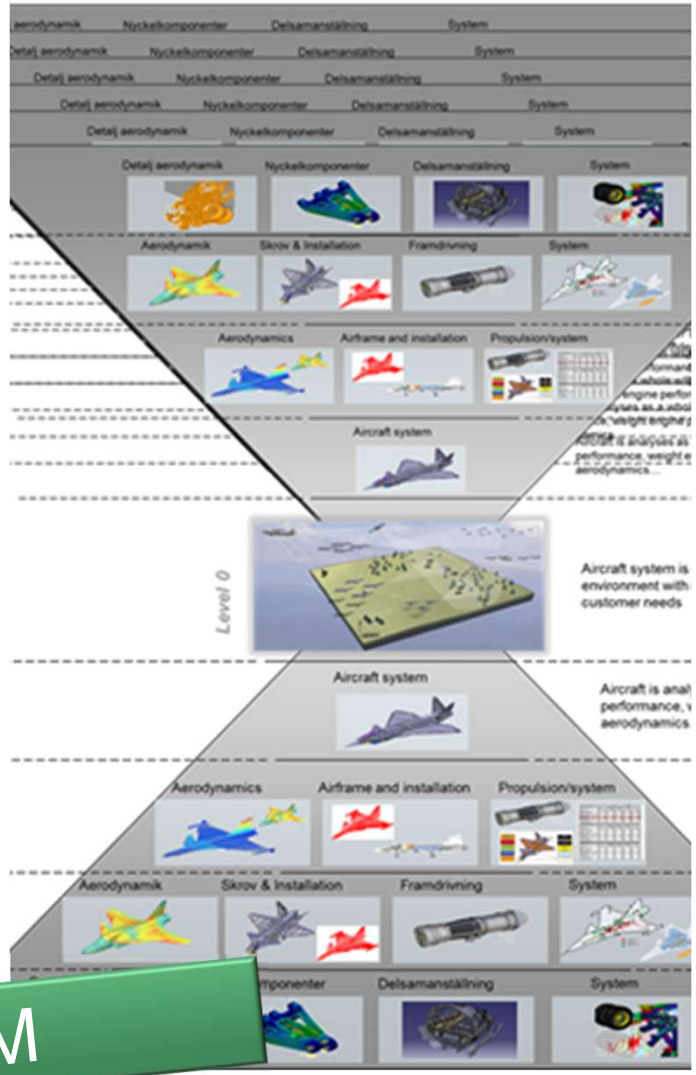
META-MODELING & COMMON LANGUAGE

- Ontology a solution?
- efficient cross-domain modeling
- category and sheaf theory
- unified (multi-domain) modeling languages (e.g. SysML)
- not only cyber-physics modeling, but …



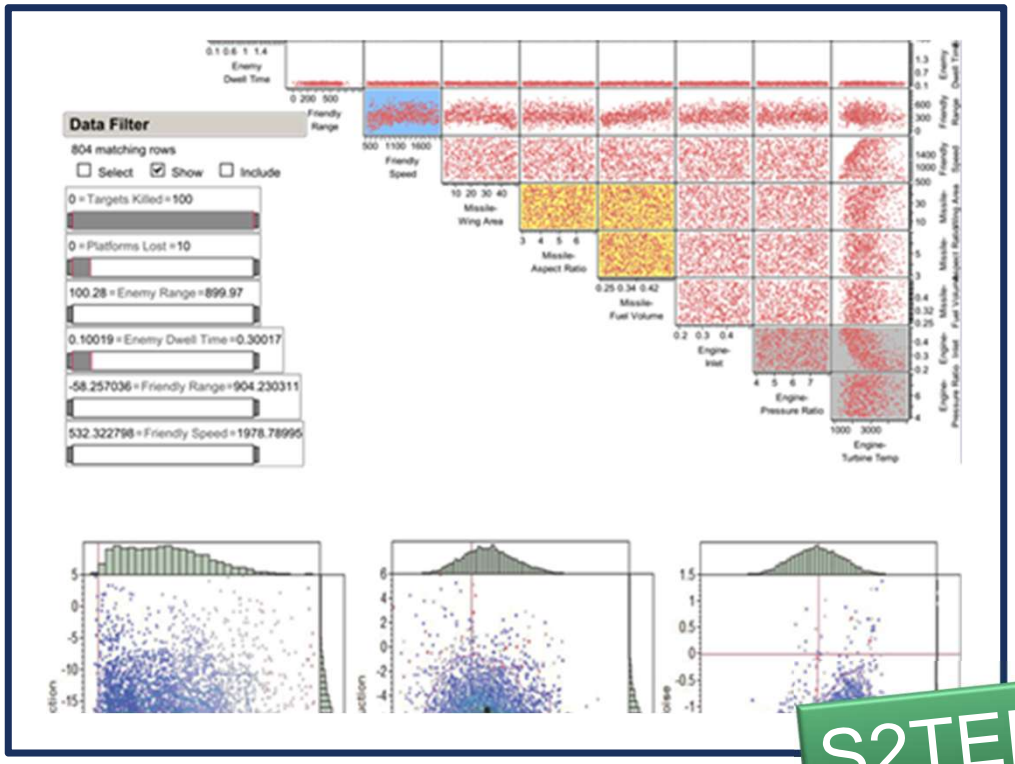
MODELLING @ MULTI-LEVELLLING

- Applying high fidelity model a different level
  - Component level
  - Assembly level
  - Aircraft level
- Create meta model to be re-use in design space exploration
  - Tradespace exploration:
  - SoS level
- System level
  - Reapply MDO on down selected configurations
  - Repopulate result in meta model



S2TEP HYSIM

NEEDS OF VISUAL ANALYTICS



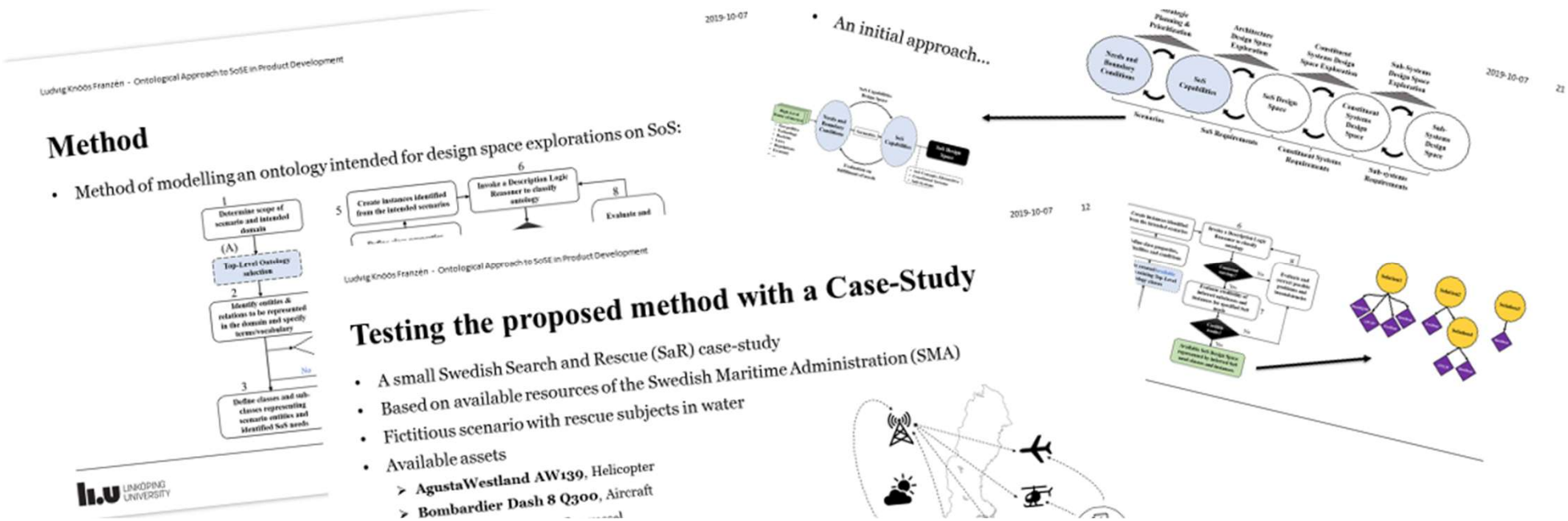
S2TEP

- The amounts of data generated is overwhelming and prevent the designer from learning about the design problem
- Data by itself has little value if it is not structured and visualized in a way that allows the designer to act upon it
- Visualization needs to be combined with analytical techniques and embedded in the analysis/reasoning process, as opposed to being an end-product of it
- Visual Analytics is "the science of analytical reasoning facilitated by interactive visual interfaces"

HYSIM HIERARCHICAL INTEGRATION OF SYSTEM-OF-SYSTEMS MODELS

Athanasios Papageorgiou
Sofia Schön

S2TEP
SOS TRADESPACE EXPLORATION



Ludvig Knöös Franzén

SMART
SENSOR MODELLING FOR AIRCRAFT TRADESPACE

Sensorn

Sensorn som funktion
- Sökområde
- Tidssteg
- Typer av mål
- Noggrannhet
- Störfasthet?

Sensorn som utrustning
- Massa
- Volym
- Effekt
- Kyla
- Signatur

} Flygprestanda !

Sensormodellering

För att undersöka en specifik sensor för någon uppgift. Land, sjö, luft....

välja en av flera sensorfunktioner

Detaljer, perspektiv: inifrån
- "Allt" är med
- Avancerad modell
- Svår att använda för amatören

Funktion, prespektiv: utifrån
- Trist att finesser inte syns utifrån
- "Önskefunktioner" går att prova
- Vad händer om:
  - Räckvidden ökas
  - Sökområdet ändras

Tidssteg

- Detaljerade modeller + kort tidssteg = succé ?
  - Sökmönster
  - Nära pulsnivå
- Resultatet mycket känsligt för utförandet
- Enkel modell:
  - Ett tidssteg för sensorn
  - Sensors täckingsområde

SAAB

SAAB

LINKÖPINGS UNIVERSITET

VINNOVA

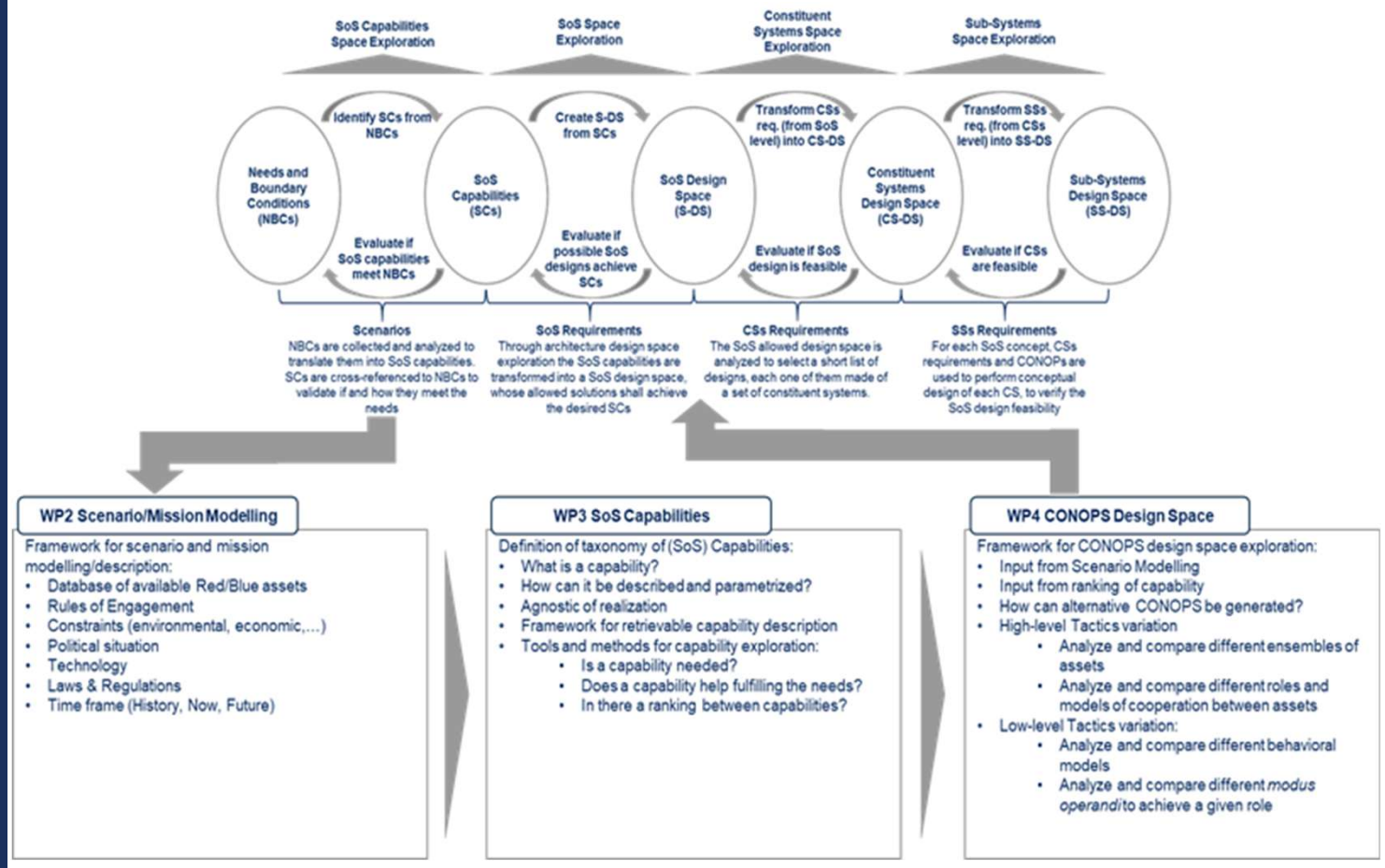
SAAB Defence and Security

FÖRSVARSHÖGSKOLAN

Carina Marcus

COMTE CONCEPT OF OPERATION MODELLING FOR TRADESPACE EXPLORATION

- Karl Kindström-Andersson



CAPABILITY AND MISSION ENGINEERING FOR SYSTEMS-OF-SYSTEMS

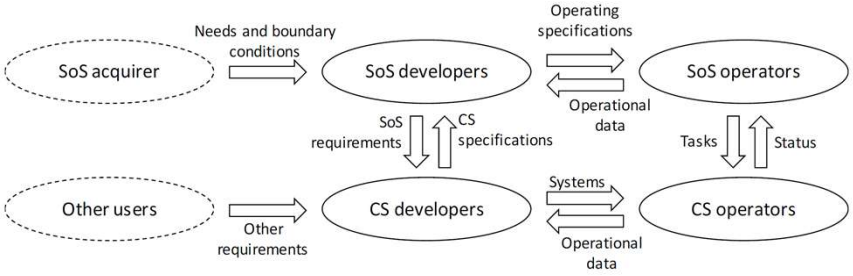


Figure 1. Roles related to an SoS, and some of their interrelations.

Work package	2020 Q2	2020 Q3	2020 Q4	2021 Q1	2021 Q2	2021 Q3	2021 Q4	2022 Q1	2022 Q2	2022 Q3	2022 Q4	2023 Q1	Effort
				M1				M2			M3		
1. Best practice analysis													5%
2. Core modeling													10%
3. Domain modeling													20%
4. Utility function analysis													5%
5. Design space exploration													30%
6. Validation													20%
7. Dissemination													5%
8. Project management													5%

Table 1. Overview of time plan and effort of the work packages.

Volvo Construction Equipment

SAAB Defence and Security

MÄLARDALENS HÖGSKOLA ESKILSTUNA VÄSTERÅS

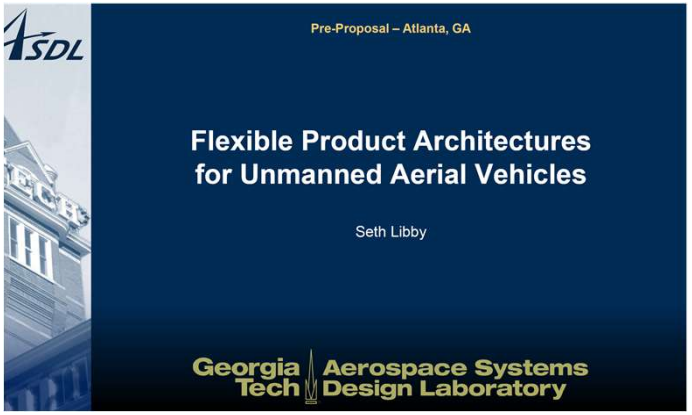
RI. SE

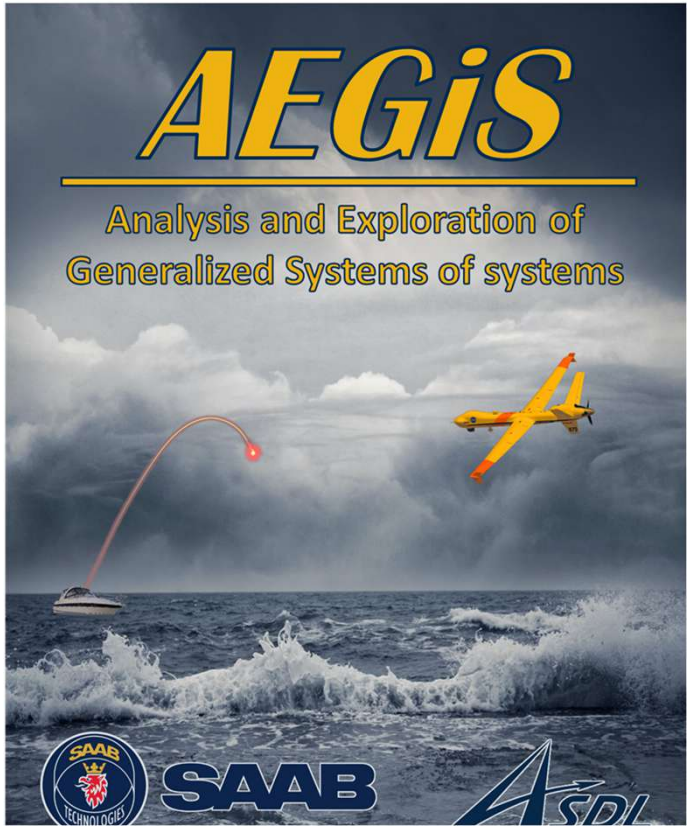
KK-stiftelsen

Jakob Axelsson

GEORGIA TECH COLLABORATION

- Grand challenges
- Ph.D. exchange





CLUSTER NETWORK

National Projects NFPP and other

S2TEP
System-of-Systems Tradespace Exploration
Saab-LiU

SMART
Sensor modelling for Aircraft tradespace
Saab-FHS

HySIM
Hierarchical Integration of System-of-Systems Models
Saab-LiU

CAMESoS
Capability and mission engineering for SoS
Saab-VCE-MDH-RISE (KK)

COMTE Concept of operation modelling for tradespace exploration
Saab-FHS-LiU (call 2)

KK-stiftelsen · VINNOVA · FMV · Försvarshögskolan · LINKÖPINGS UNIVERSITET · RI.SE · Mälardalens Högskola Eskilstuna Västerås · SAAB Defence and Security

International project

LiU-Georgia Tech colloboration

Saab-Georgia Tech Grand Challenges

OpenCPS (Eureka)

AGILE (EU H2020)

Embrace (Eureka proposal)

Georgia Institute of Technology · EUREKA innovation across borders · Seventh Framework Programme · European Commission

Possible collaboration in Sweden

INFRA SWEDEN 2030 · PiA Process Industrial IT and Automation · DRIVE SWEDEN · Medtech 4Health

Industrial project

SAAB Defence and Security

FCAS Saab project

GSS (Global System Study)

International connections

Massachusetts Institute of Technology · ONERA THE FRENCH AEROSPACE LAB · NLR · NASA · Universidade Federal de Santa Catarina · DLR

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THANK YOU

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