Fluid and Mechatronic Systems
at Linköping University
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Increased Intelligence in Products

- New products tend to have more intelligence than before. This applies to a wide range of products. This is particularly true for:
  - Cars
  - Aircraft
  - Construction Machinery

- This is in response to increased requirements for efficiency, driven by economics, safety, and environment.
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
Partner Companies with Ongoing Projects

- Atlas Copco (Mining equipment, rock drills)
- CybAero (Unmanned helicopters)
- National Instruments (Measurement and control)
- Parker (Fluid power)
- Prevas (Testing systems)
- Saab AB (Aircraft)
- Scania AB (Trucks)
- Volvo CE (Construction Machinery)
Energy Efficient Transmissions for Construction Machinery

- Flumes/VCE project
- Hydromechanical transmission
- Hardware-in-the-Loop testbench
Energy Efficient Hydraulic Systems

- Project sponsored by Parker Hannifin-Hannifin, USA

Original Load Sensing system (LS) with closed loop controlled pump

Flow sharing system with open loop controlled pump
Autonom Styrning av Tunga Fordon (FFI, Scania)

- Aktiv styrning
- Genering av nytt koncept för servostyrning
- Minskad bränsleförbrukning
- HWIL
- Validera i rigg och lastbil
Mobile Robotics

Traversability Mapping

Map Reuse for Path-Planning
3D CFD-model vs. 1D model for Fluid Power Machines

Simulations can be in different shapes and comprehensive level with their own pros and cons.

With the knowledge from the CFD simulations and measurements, the accuracy of the fast 1D model can be increased.
Aircraft Environmental Control System

- Produce models for concept selection if aircraft environmental control system
Design Framework

Database → Spreadsheet model → Optimizer

- **Spreadsheet model**
  - Obj. function
  - Control variables

- **Optimizer**
  - Geometry mesh
  - $c_D$, $c_m$, $C_L$

- **Database**
  - Weight, wetted area, etc.

- **Geometry parameters**

- **Geometry mesh**

- **Parametric CAD model**

- **Aerodynamic model**
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 add cost
  - Good accuracy and repeatability

\[ \eta_{\text{tot}} = \eta_b \cdot \eta_d \cdot \eta_m \cdot \eta_p \]
Design Framework

Example MAV optimization. Pareto optimal front showing how endurance relates to weight. Each dot in the figure represents a full CAD design, optimal propulsion system combination, while meeting mission related performance requirements such as cruise speed, payload capacity, stall speed etc.
Eco Sports plane
Tornado
a Vortex Lattice Method implemented in Matlab

Tornado is an aerodynamic modelling software which allows for almost instantaneous computation of the aerodynamic properties of an aircraft.
Generic Future Fighter (GFF) Subscale Demonstrator

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

Project Goals

- Show a cost effective way, with short lead time, to design and manufacture a flying demonstrator of a concept, that can be used already in preliminary design, for project risk mitigation.

- Evaluate the usage of scaled demonstrators as a tool for aircraft development, e.g. as "flying wind tunnel".

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

- Methodology and instrumentation is developed on jet powered Rafael model.
- Subscale flight testing as flying wind tunnel

Tufting for flow visualisation in flight

In flight step response: Rudder deflection
Figure 5. Simulated flight path (Furthest distance about 45 km from start point). Altitude scale is amplified 20 times for the plotting.

(6000 sec simulated in 105 seconds (normal PC), time step 0.01 sec)
GFF Project Team
Student Projects:
From sketch to physical prototype in 5 months
Some Previous Student Projects
2007 Modulith
Modular light electric utility vehicle for development countries
Formula ATA Electric and Hybrid Vehicles, Class 2, Rome 2009.
The Electric and Hydraulic Propulsion Systems

36 cm$^3$/rev Gerotor

2.5 litres gas bladder accumulator

Hydraulic energy recovery system

Electrical propulsion system

Front

Rear

Acc

Ret

Motor/pump

Valve

Motof/pump

Battery storage

HPA

LPA
SSF/ProViking. Hi Performance Simulation for System Design and Operation – HiPO

-Using the same models throughout the lifecycle

**System level design**
- System simulation for design optimization and analysis
  - *High Speed Simulation HSS*
- Human in the loop simulation, *Real time simulation RTS*

**Subsystem design**
- System simulation for design
  - *HSS*
- Hardware in the loop simulation
  - *HWIL, RTS*

**Prototype testing and evaluation**
- Dynamic testing using
  - *HWIL, RTS*

**Operation**
- Training simulators, *RTS*
- Embedded simulation models for condition monitoring and control
  - *RTS and faster than real time simulation, FRTS*
- Mission planning
  - *Faster than real time simulation, FRTS*
HiPO - Research Areas

- Real-time Simulation (RTS), and Faster than Real Time Simulation (FRTS) Technologies
  - Distributed modeling
  - Parallelization of simulation models for multi-core processors
  - Hardware in the loop simulation
- Model fidelity and management
- Using bilateral delay line (transmission line modelling, TLM) for model partitioning

\[
\begin{align*}
p_1(t) &= p_2(t - T) + \frac{T}{C}[q_1(t) + q_2(t - T)] \\
p_2(t) &= p_1(t - T) + \frac{T}{C}[q_2(t) + q_1(t - T)]
\end{align*}
\]
Drivers for this Project

- Mainstream simulation technologies assume single solver strategies, which may give efficiency and instability problems for multi-domain systems, such as mechanical, hydraulic, and electric.
- High fidelity simulation in real time is not possible for other than simple systems.
- Multi-core architectures are not used effectively.
- Present technologies require central solvers and do not allow the flexibility of each model component having its own solver.
HOPSAN-NG (Next Generation)

- Bidirectional delay-lines
- Modelica support is under development
- Genuine team work
- Released on this MODPROD workshop

Friday afternoon workshop = “happy hour”
The usefulness of simulation

Simulation is going through a rapid transition from simple problem dependent models, to highly complex, multi domain, problem independent models.
Development in modelling and simulation in complex mechanical systems

- Modelling and simulation of most of the Space Shuttle hydraulic system in the 70’s. (HYTRAN).
- Hardware performance up 100 times/10 years (that is 10,000,000 times in 35 years)
- System simulation development has been remarkably slow in progress.
System Simulation in a Context

- Maintain and develop laboratory resources
- Modelling and simulation technologies
- Design analysis and optimisation
- Applications: Mechatronics, hydraulics, construction machines, road vehicles, and aircraft.
- Keywords: System dynamics, and system efficiency
  - Design – model – simulate – analyse – prototyping – evaluation and testing