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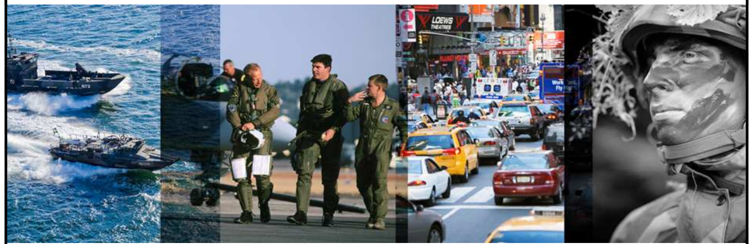
SAAB AEROSYSTEMS

Dependable Aircraft Systems



Lars Holmlund
October 12, 2009
Chalmers University

70 years of experience

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Gripen in South Africa

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Gripen Next Generation

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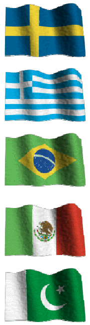
ERIEYE™ Airborne Early Warning & Control

Improved Surveillance Capability



Originally designed for the Swedish Air Force and now also in operation in; Brazil, Greece, Mexico,Pakistan

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Unmanned Aerial Vehicles

Ongoing projects

SKELDAR

NEURON

(www.youtube.com/saabgroup)

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Dependable Products

Gripen accident outside Karlskrona

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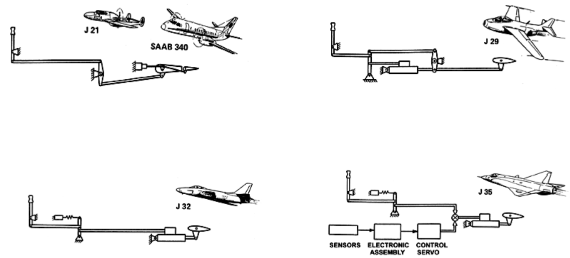
Scope

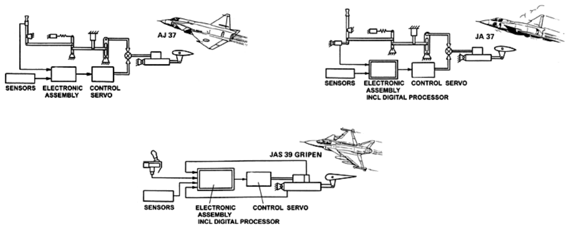
A retrospective of flight control system evolution

The Gripen Flight Control System
- Requirements
- Design decisions
- Principle of operation
- The philosophy behind redundancy - monitoring – fault accommodation
- System- and computer architecture

The Evolution of FCS 1945-1990



The Evolution of FCS 1945-1990

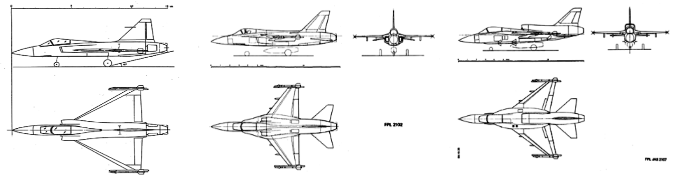


Design Drivers

- Performance
  E.g.: range, speed, altitude, acceleration, turn ratio
- Function
  operative, pilot relief functions
- Safety/Availability
  Prob. for loss of a/c , pilot survivability, "graceful degradation"
- Weight/ Volume
- Environmental
  Temp., mech., electrical (EME, EMI,) EMP
- Maintenance and Testability

Design Decision

• Different a/c configurations were suggested



Design Decision

Decision to choose an a/c with :

Relaxed stability in pitch, 7 primary control surfaces
- turn ratio, better weight/volume ratio

Electric control system
- eliminates mechanical linkage and equipment
- simplified installation and maintenance, less vulnerable

Computerized flight control system
- flexibility during development and design, good growth potential (40 years)

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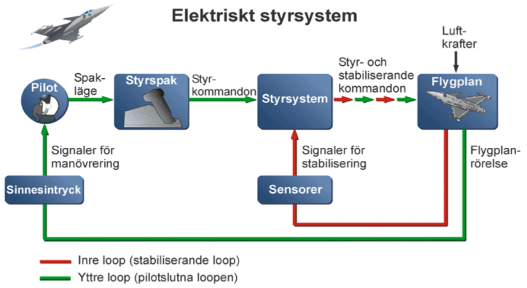
The Gripen flight control system’s control loops



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Design Decisions

Pros :
- Light and “small” system
- Advanced control law calculations
  - Automatic stability in pitch
  - Optimized control and stability characteristics
  - Gust alleviation
  - Maneuvering load limits
  - Outer loop functions
- Simplified and improved maintenance and test

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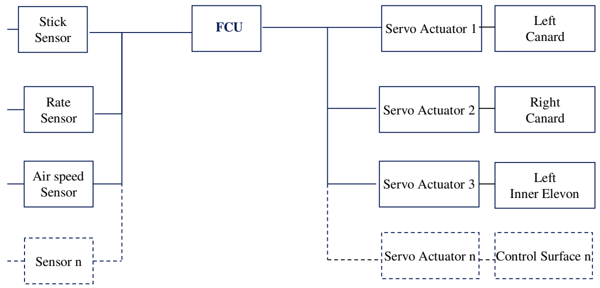
Design Decisions

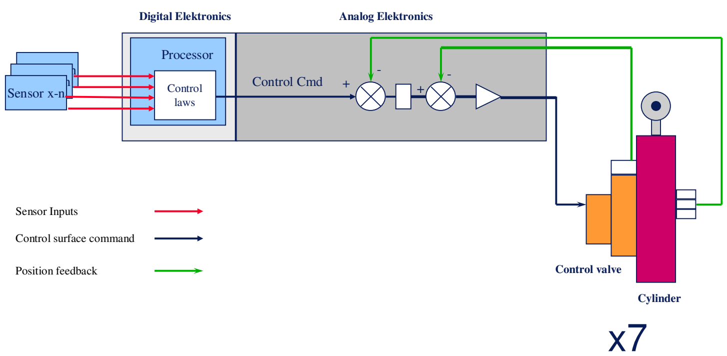
Cons:
- Requires a reliable power supply
- Needs precautions when handling:
  - EME and EMI
  - Cosmic and nuclear radiation
- Extensive qualification/verification

Fault Tolerance

A simplex system will meet functional and performance requirements



Concept of redundancy, simplex system



Fault Tolerance

Other requirements affect the design of the system, e.g. safety req. :

No single failures may cause loss of a/c
Maximum allowed probability for loss of a/c
Maximum allowed A/C transients as a result of a fault in the system

Probability for mission success

Fault Tolerance

Fault tolerance in the Gripen FCS is built up by:

- Redundancies
- Voting planes
- Monitoring
- Redundancy Management
- Asynchronous operating FCU
- Pre flight test

The Philosophy Behind The Redundancy Concept

- Good flying qualities with 6 out of 7 primary control surfaces operating
- Maneuverable with 5 out of 7 primary control surfaces operating
- Able to cope with all single faults and most double faults
- QUAD vs TRIPLEX
  - Economical system – slim as far as resources are concerned
  - Brain power instead of muscles
- Safety critical function must be tripled
- Important functions are doubled, "tie break"

Redundancies within the system

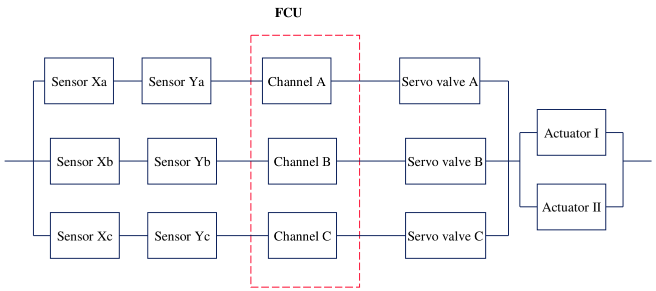
- Example of tripled functions (lack fail-safe position)
  - Three channel FCU
    - Independent BU-mode (HW/SW)
  - Control stick sensors
  - Rate gyro
  - Electrical power supply

Redundancies within the system

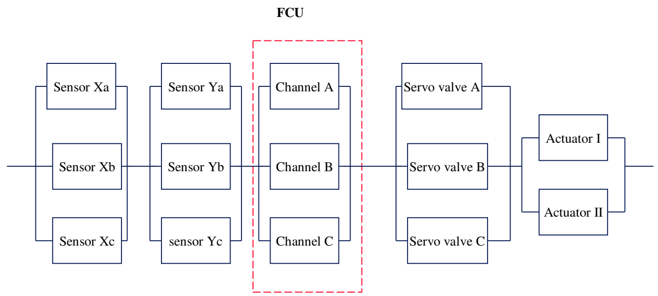
- Example of doubled functions (have a "fail-safe" position*)
  - Accelerometers
  - Angle of attack sensors
  - Air data (speed and altitude)
  - Hydraulic power supply

* as long as we can detect a fault

General simplified architecture



General simplified architecture II



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Fault Tolerance

Fault tolerance is built up by:

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Voting planes

MLV – Mid Level Voting

Input signal voting (S/W)

Voting of computed control signals (H/W)

”Flux summing” (H/W)

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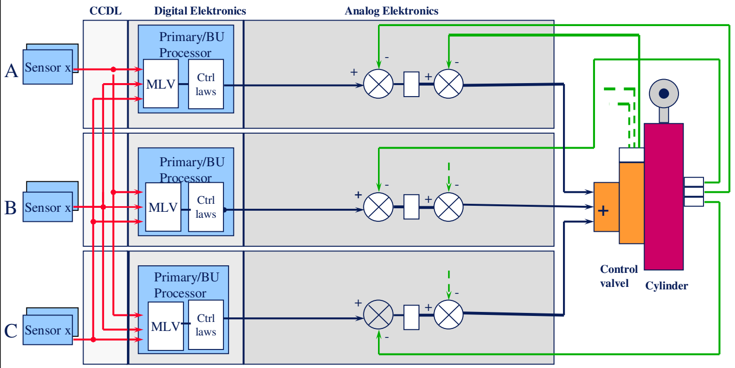
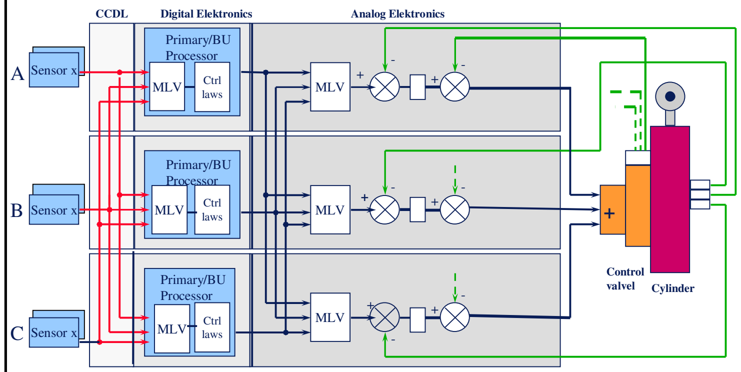
Concept of redundancy, triplex EFCS



Concept of redundancy, triplex EFCS



Fault Tolerance

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Functional Monitoring and Redundancy Management

- Extensive functional monitoring and redundancy management compensates for lack of redundancy
- Functional monitoring detects the fault and informs the A/C system and pilot about the fault.
- Redundancy management allows for reconfigurations, graceful degradation and high survivability

Functional Monitoring

- Methodology
  - Cross channel monitoring
  - In line monitoring
  - Direct monitoring
  - Reasonableness monitoring
- Self healing
  - Minimizes the effect of nuisance trips
  - Creates resilience within the system

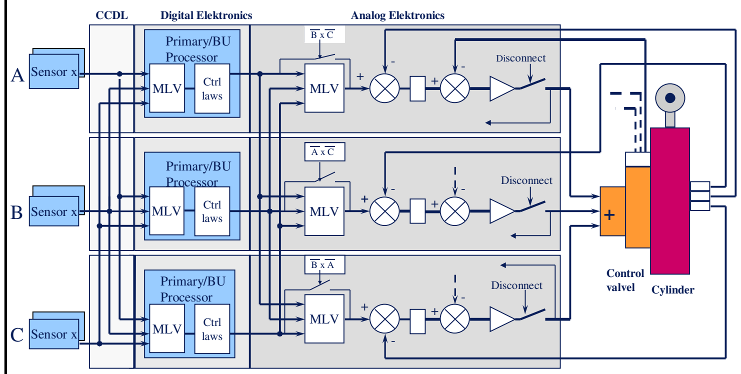
Redundancy Management

- Reconfiguration helps minimizing the possible effect of a fault
  - Selects and removes the faulty signal. Continues operation with the remaining ones or substitutes the faulty signal with another similar signal
- Reconfiguration can also compensate for lack of resources
  - Control surfaces, fail-safe values, model based signals

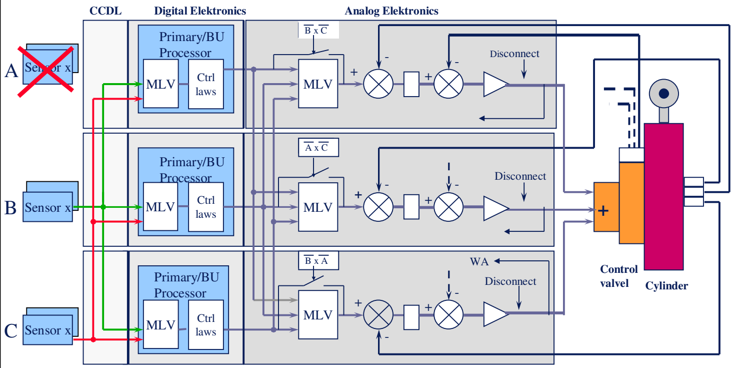
Redundancy Management

- Example of reconfigurations:
  - Sensor faults, i.e:
    - oRate gyro
    - oAngle of attack
    - oAngle of side slip
    - oAccelerometer
  - Data bus faults
  - Servo actuator faults
  - Computer faults

Concept of redundancy, triplex EFCS



Concept of redundancy, Sensor fault



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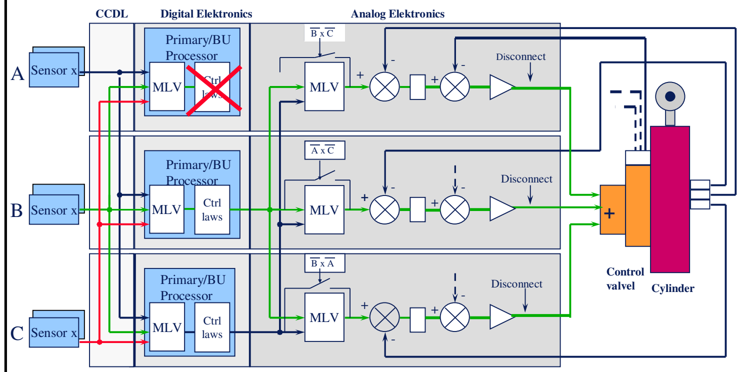
Concept of redundancy, Processor fault



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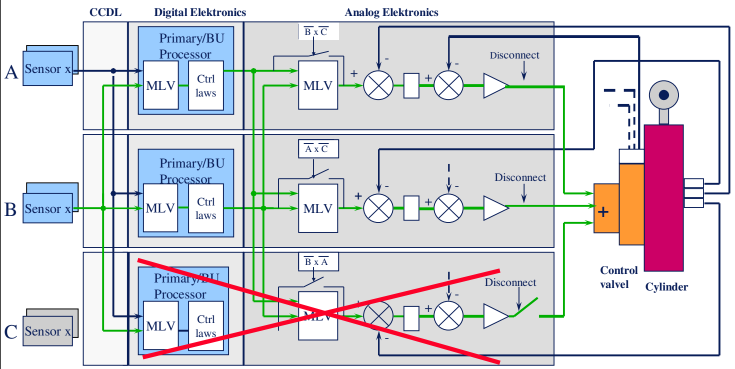
Concept of redundancy, loss of channel



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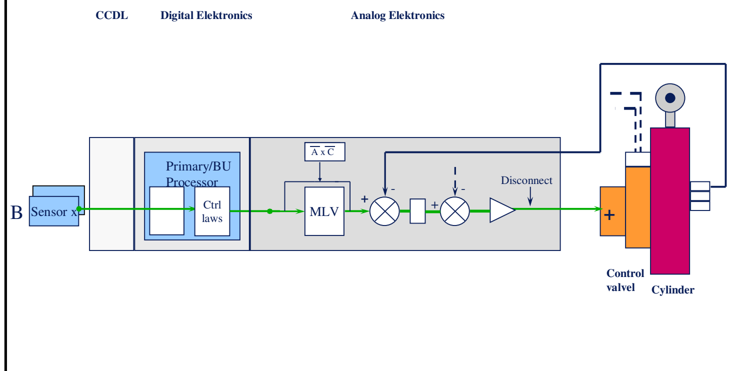
Concept of redundancy, loss of two channels



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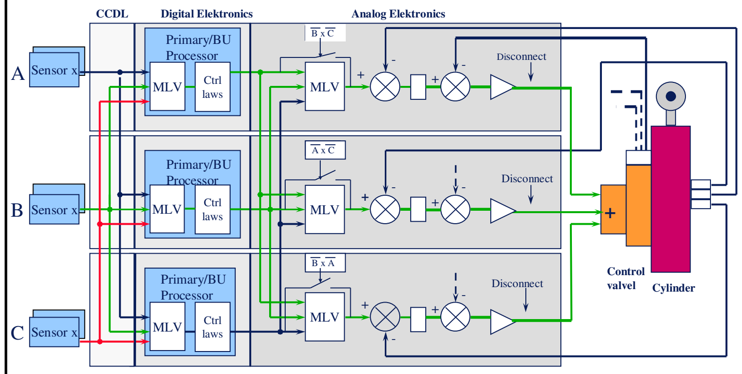
Concept of redundancy, output monitoring



Output monitoring

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Fault Tolerance

Fault tolerance is built up by:

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- Pre flight test

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Fault Tolerance

- Extensive pre-flight test guarantees safe function of flight critical functions, redundancies and monitoring circuits

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Summary: The Gripen FCS - A Hybrid System

Static Redundancy
- Basically a triplex system – but not a fully TMR system
- MLV- used to isolate faults
- Asynchronous System

Dynamic Redundancy
- Fault Detection – Application specific due to an asynchronous system
- Reconfiguration (Graceful Degradation)
- S/W redundancy – but not a real N-version programming
- Warm standby system for processor and S/W faults

Byzantine faults
- The system is not sensitive to single Byzantine faults– due to three independent asynchronous channels + MLV

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System Safety Work

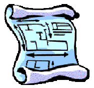
Processes – Methodology
Random and Systematic Faults
Fault Injection

System Safety Work

MIL-STD-882C

http://stinet.dtic.mil/str/dodiss4_fields.html, search for the above

- **Random failure.** Failures that result from a variety of degradation (wear out) mechanisms in hardware. System failure rates arising from random hardware failures can be quantified with reasonable accuracy based on past experience *(e.g. previous in service failure rate =* 10^{-6} */ flight hour)*



Systematic failure. Failures resulting from faults in the specification, design, construction, operation or maintenance of the system or its components. A systematic failure will always occur under a particular combination of inputs, or under some particular environmental conditions.

RTCA/DO-178B

"Software Considerations in Airborne Systems and Equipment"

www.rtca.org

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