Flexible Actuation System for Reconfiguration Control in Civil Transports (Pt.3)

based on “Fault Immune Flight Control System”
presented at ICAS 2006 at Hamburg, Sept.2006

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at Airbus Ind.

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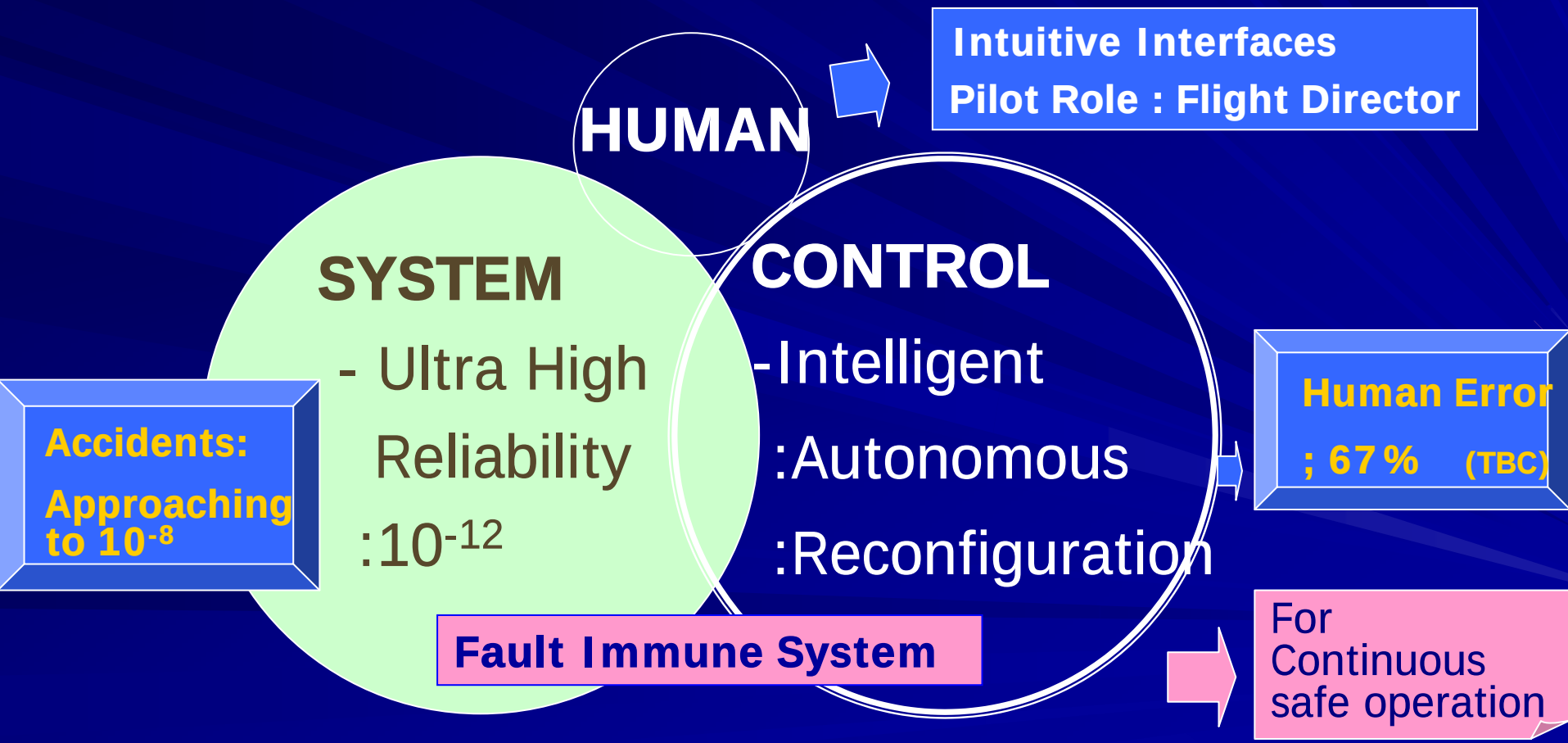
Presentation Flow

- Concept
- Flexible Actuation System
- (Double Layered Reconfiguration Control)
- (Single Pilot Operation)
- (Fault Immune System)
- Conclusions

General Discussion on -Fault Immune Total Aircraft System

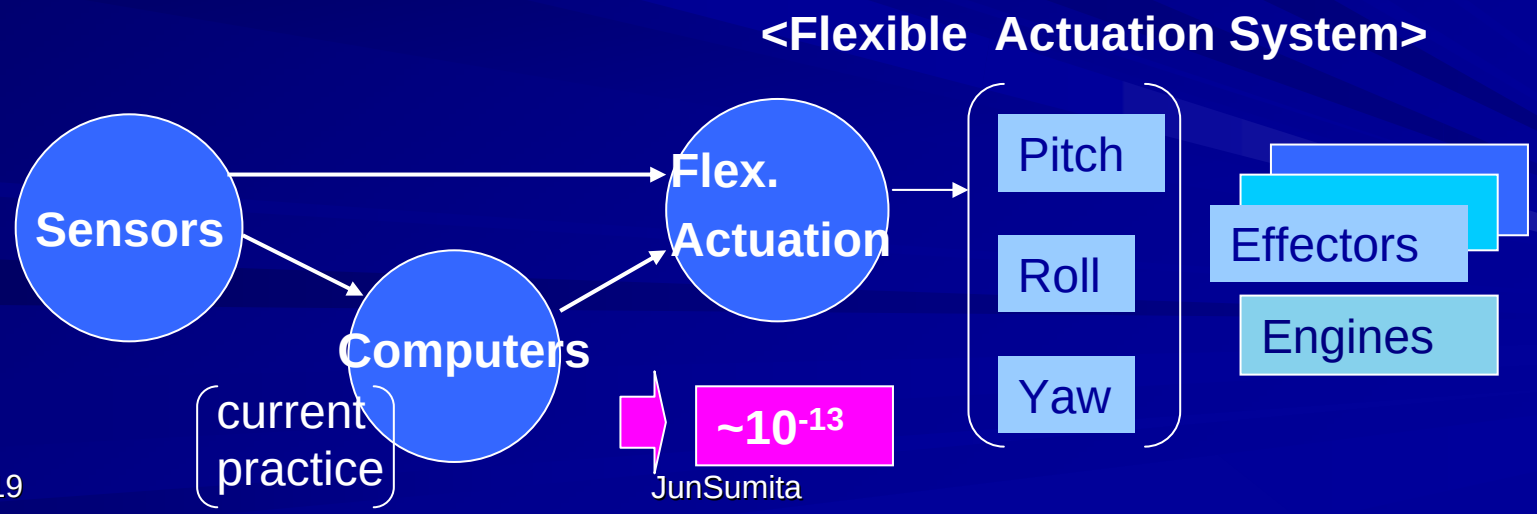
- "Min. Human Interfaces" is an important approach



Flexible Actuation System

; Actuators / Computers of the System

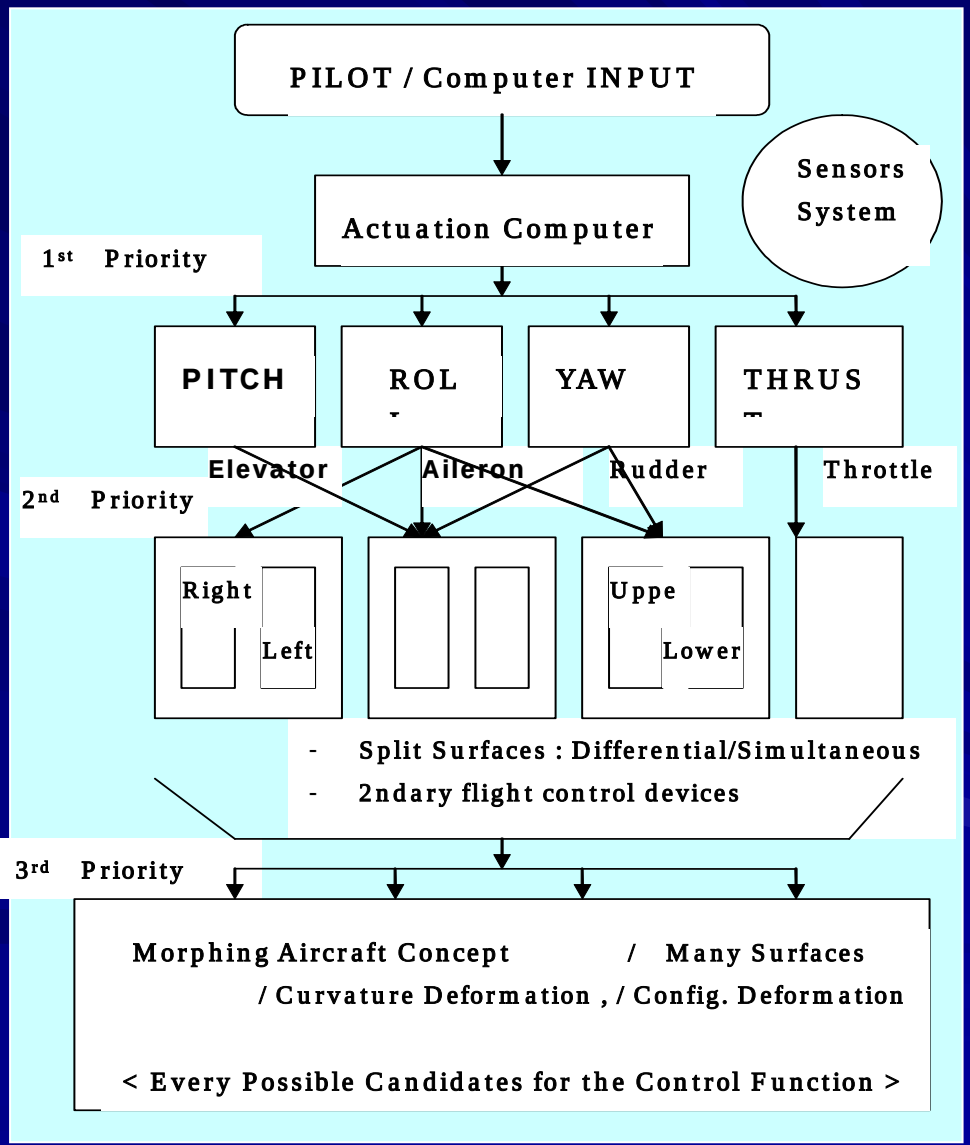
- Dispersed Arranged, with Simplex Actuators
  - Many Control Surfaces / Actuation Points
  - Elastic Structure / Morphing Aircraft
- Grouped Effectors Control each of 3 Axis



Flexible Actuation System - 2

- in Basic Layer Control

- Many Alternatives
  - Control Surfaces,
  - Curvature Bending
- Independent Actuation
  - for each surface
- Functionary Assigned Control Group
  - for Pitch/Roll/Yaw Gp.



Failure Impact Level

<The acted effectors are in memory, & applied thereafter>

The Logic : Reflex Action Type of Reconfiguration Control in Basic Layer

- **Step 1 : Reflex Action**

  - for distinct faults

  corrective action by all of active surfaces

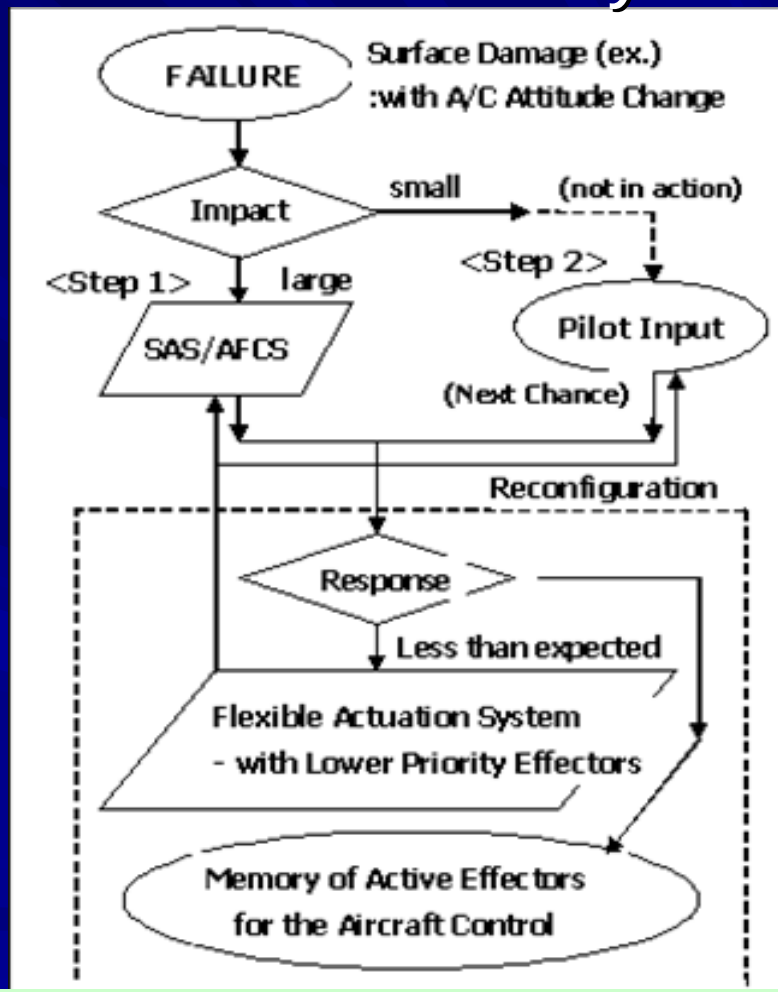
  <no pilot participation>

- **Step 2 : Pilot Control Initiative**

  - for dormant faults

  <pilot control finds faults, and evokes corrective actions>

  corrective action thru all of active surfaces/effectors

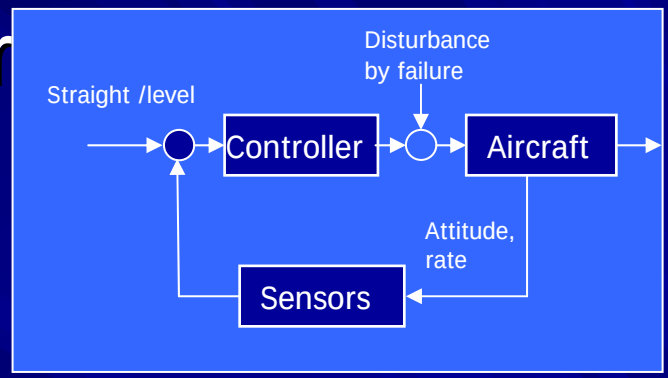


<The acted effectors are in memory, & applied thereafter for the function>

(Math) Simulation Results -1 (1)

for Basic Layer Control

- Attitude/Alt. Hold Controller
  : disturbance control,
  with “trim” reference



:

δ_a ⇒ If $\delta_a = \delta_{a,authority}$,or $\frac{\partial \delta_a}{\partial t} = 0$ Then $K\delta_r = \delta_a$ ⇒ If $\delta_r = \delta_{r,authority}$,or $\frac{\partial \delta_r}{\partial t} = 0$ Then $K\delta_{e,differential} = \delta_a$ ⇒

:For Controller

(ex.)

Add, and $\frac{\partial p}{\partial t} \le k(const.)$ (if necessary)

Used Actuator are in memories, with the amount

And applied thereafter, in the proportion

(Math) Simulation Results -1 (2)

for Basic Layer Control

- Altitude Recovery
  - by stabilator

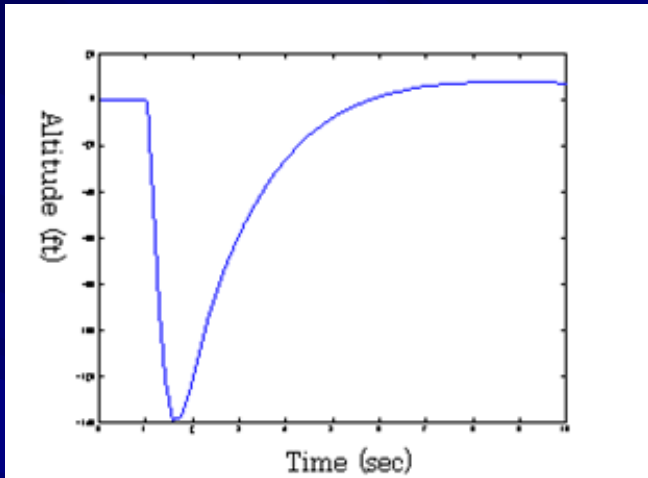
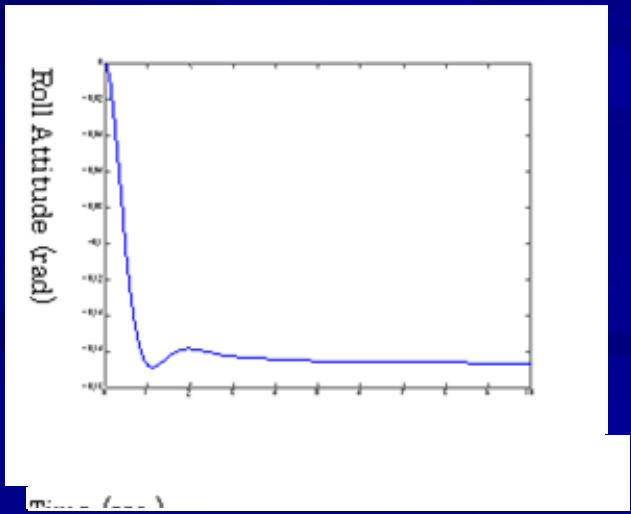


Fig. 5 Altitude Recovery by Stabilator

The alternatives have the capability !!

We should design the A/C, so that the alternative could have enough capability.

- Attitude Control for 'Roll'
  - by rudder



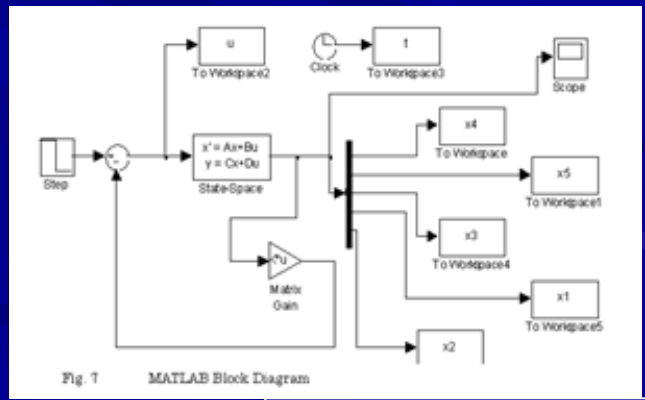


Fig. 7 MATLAB Block Diagram

; B747 / 10,000ft,250Kt.

Applying MATLAB

(Math) Simulation Results -2

by Flight Simulator

- **Test 1** : Step 1 / no peculiar feeling ; **pilot comment**

  - Monitor the simulated failure and recovery condition by the alternatives < with 0.5 sec time lag>

- **Test 2** : Pilot Control / maneuverable **; pilot comment**

  - Input to the control by the alternatives

Pilot Control → Aircraft with Alternative Control Surfaces

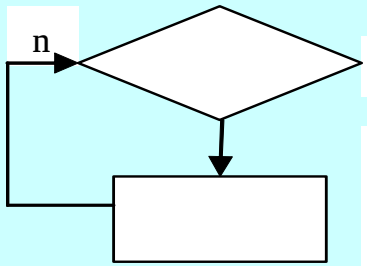
→ **Reflex Control is under Right way**

Fig. 8 NIT Flight

Total sequence tests are req'd

Core Logic for Basic Layer Control

- 1st Step Response



$$p\ ,\ q\ ,\ r\ /\ \dot{p}\ ,\ \dot{q}\ ,\ \dot{r}\ \geq\ threshold$$

$$\delta = \begin{cases} \left(\delta_{priority1}\right) & \\ 2\delta_{priority2-1} & : n = 1 \\ (n-1)\left(p_{21}\delta_{priority2-1} + p_{22}\delta_{priority2-2}\right) & : n \leq n_{switch} \\ \left(n - n_{switch}\right)\left(p_{21}\delta_{priority2-1} + p_{22}\delta_{priority2-2} + p_3\delta_{priority3}\right) & : n \geq n_{switch} \end{cases}$$

where

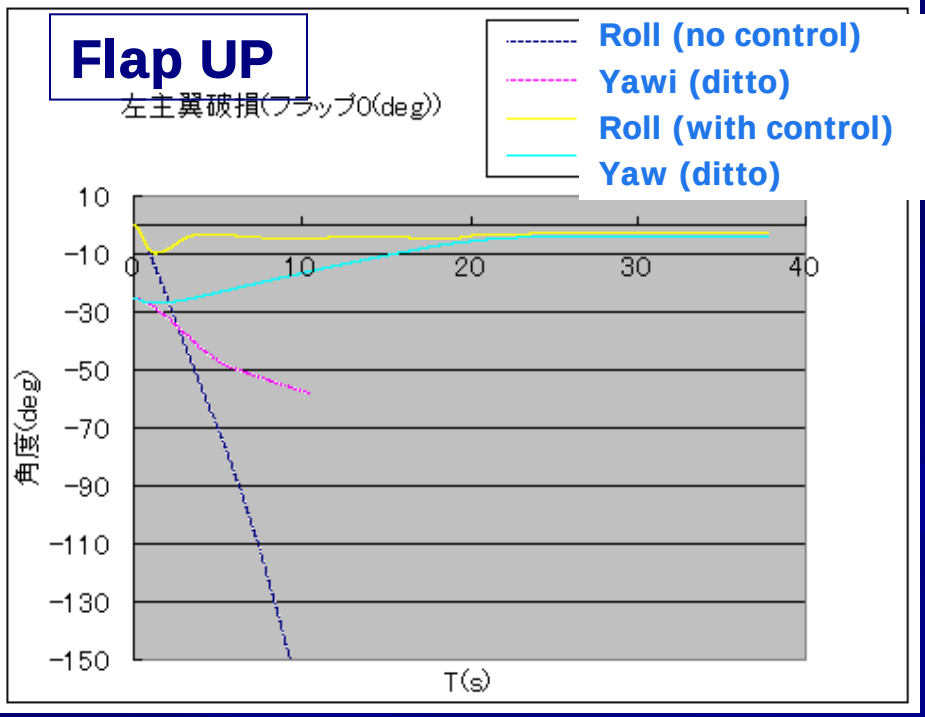
$$(n-1)p_{21} \leq 2,$$
$$(n-1)p_{22} \leq threshold$$
$$\left(n - n_{switch}\right)p_3 \leq threshold$$

Sequences for an aircraft response with alternatives priority

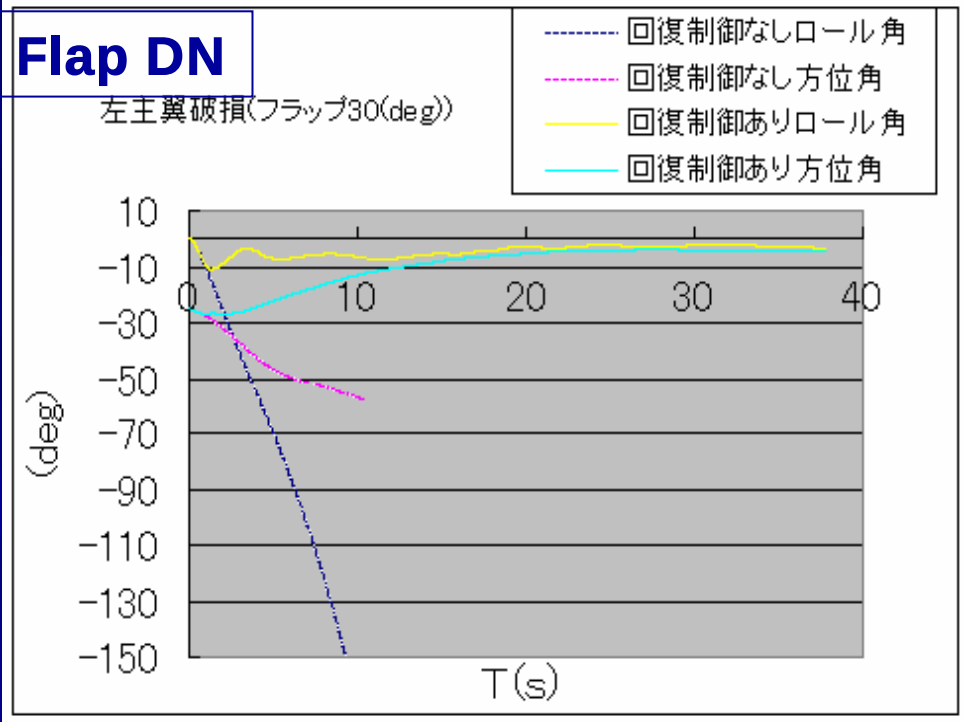
Aircraft Response Tests

in Flight Simulator

Flap UP



Flap DN

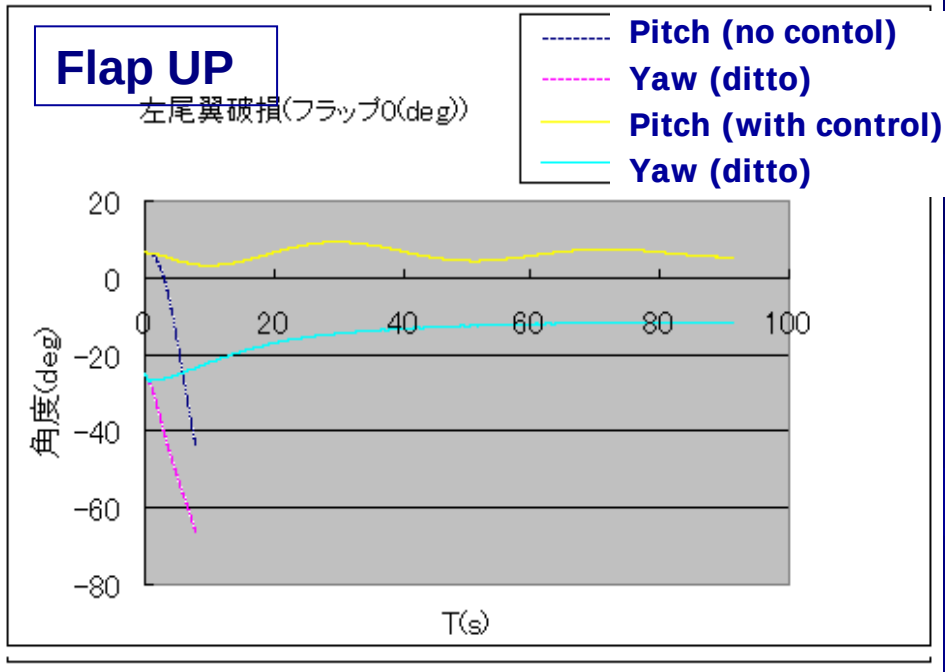


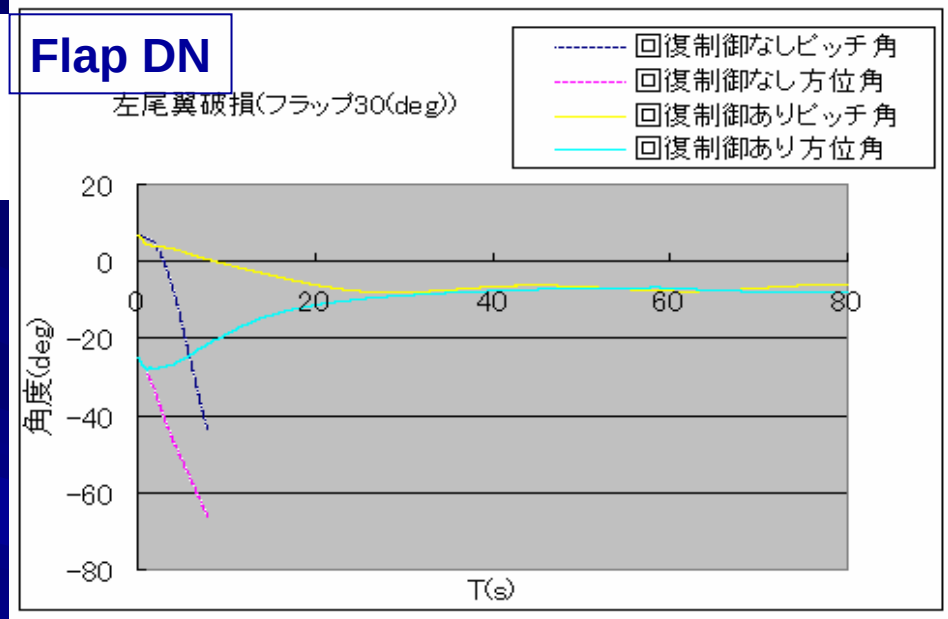
¼ of Left Wing Break-Off **at V=150Kt. H=3000ft. In MU-300**

< Recovery by Differential Elevators , Rudder >

Aircraft Response Tests

in Flight Simulator



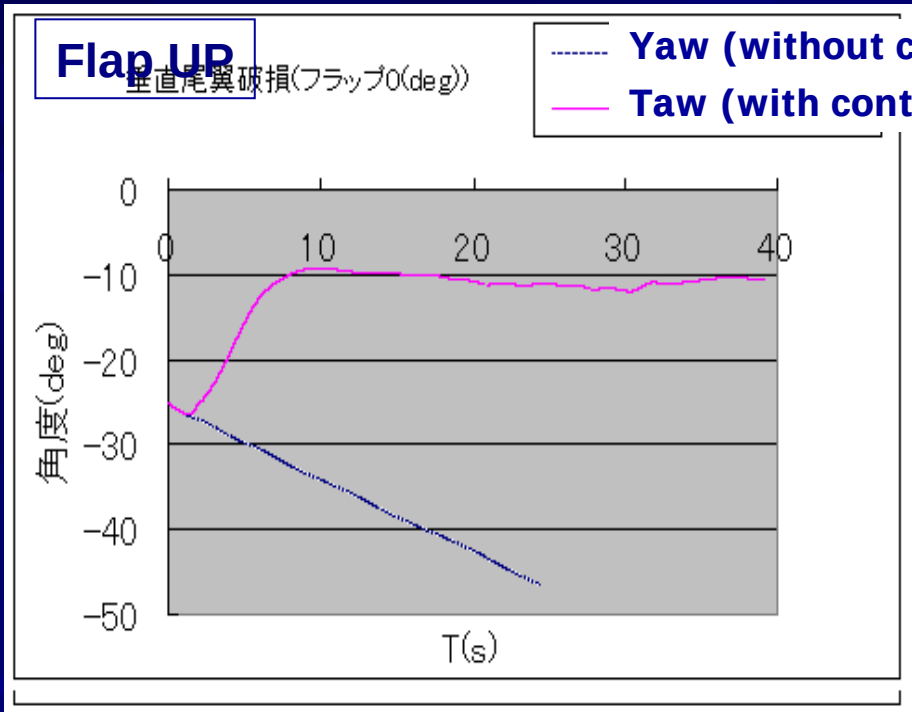


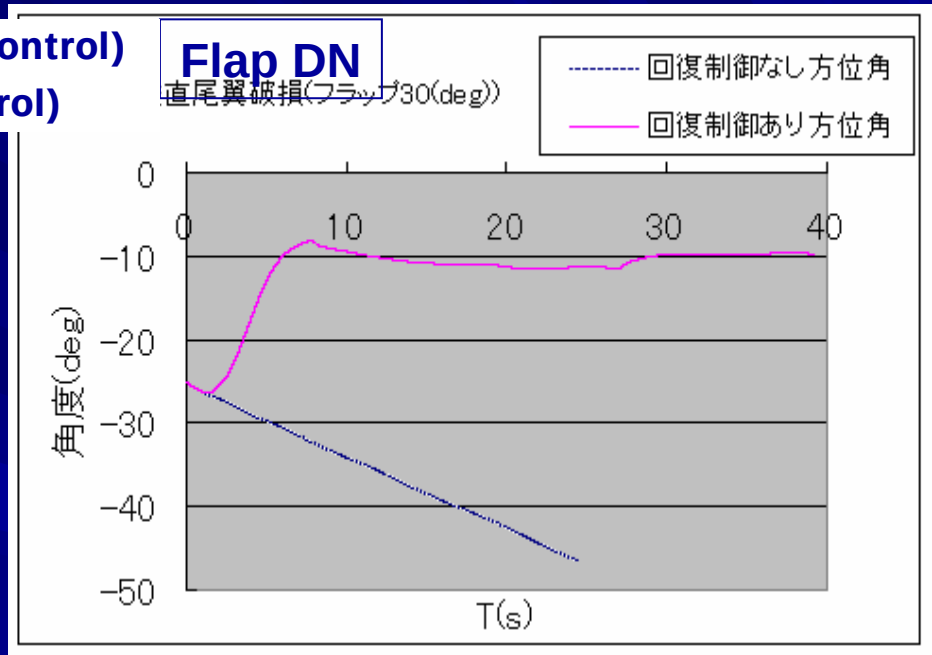
Left Stabilator Break-Off at V=150Kt. H=300ft in MU-300

< Recovery by Aileron, Rudder, >

Aircraft Response Tests

in Flight Simulator



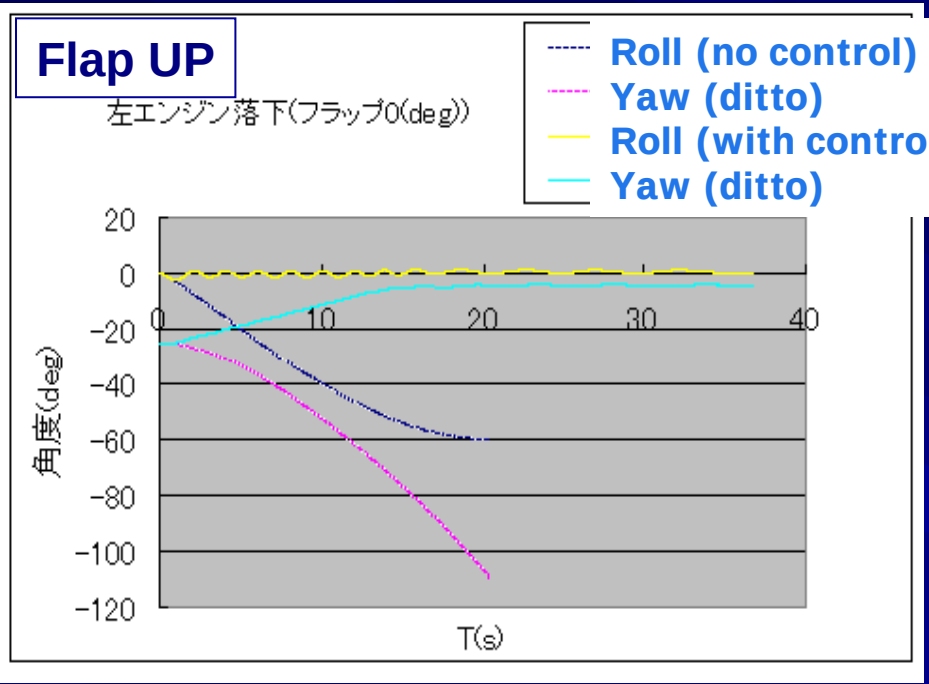


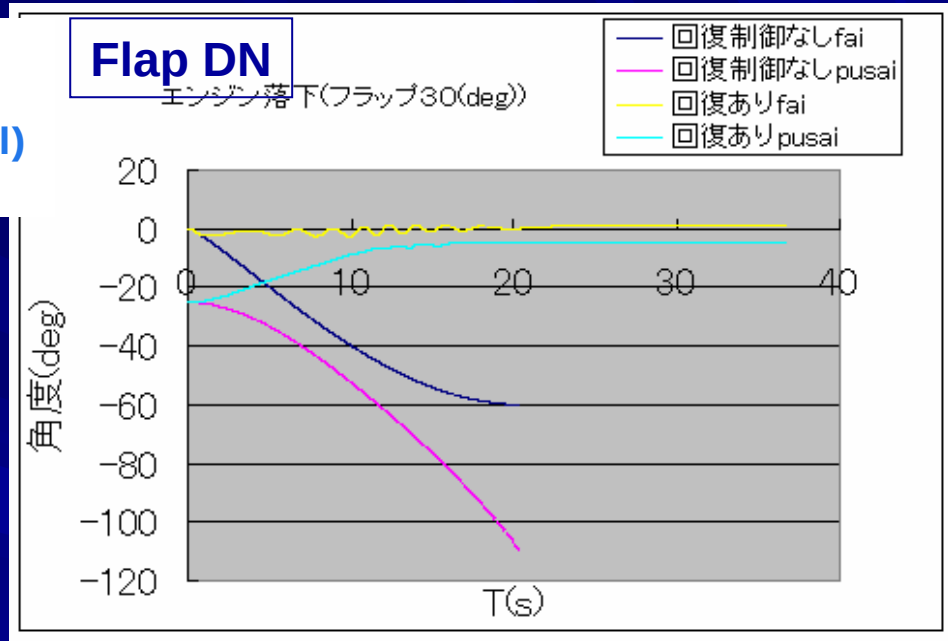
½ of Vertical Stabilator Break-Off at V=150Kt. H=300Ft

< Recovery by Differential Thrust, >

Aircraft Response Tests

in Flight Simulator





Left Engine Drop-Off at V=150Kt. H=300Ft

< Recovery by Aileron, Rudder, >

(Math) Simulation Results -2

by Flight Simulator

- **Test 1** : Step 1 / no peculiar feeling ; **pilot comment**

  - Monitor the simulated failure and recovery condition by the alternatives < with 0.5 sec time lag>

- **Test 2** : Pilot Control / maneuverable **; pilot comment**

  - Input to the control by the alternatives

Pilot Control → Aircraft with Alternative Control Surfaces

→ **Reflex Control is under Right way**

Fig. 8 NIT Flight

Total sequence tests are req'd

Double Layered Reconfiguration Control -as Core Control Law for Fault Immune Sys.

- **Upper Layer**
  : Autonomous /Optimum Robust Control with Reconfiguration (current practice for control)
- **Basic Layer** / implicit FDI
  : Reflex Action Control for a failure with Flex. Act. Sys.

Hierarchy Structure for FCS

Autonomous	Flight Command System : Mission Control : Air Traffic Communicatn/Action : Flt Safety / Reconfiguratn

<Conventional Control Hierarchy>

Automation*	Flt Managemt System AFCS
Improvement (for the system characteristics)	SAS / CAS / Active Control Tech.
Sys.Operation*	Basic FCS

Safety	Reflex Control :Reconfiguration with Flex. Actuation (as inherent function)

* : Conscious Control Level

Fig. 10 Flight Control Hierarchy

Upper Layered Autonomous Control

- **Autonomous Control**

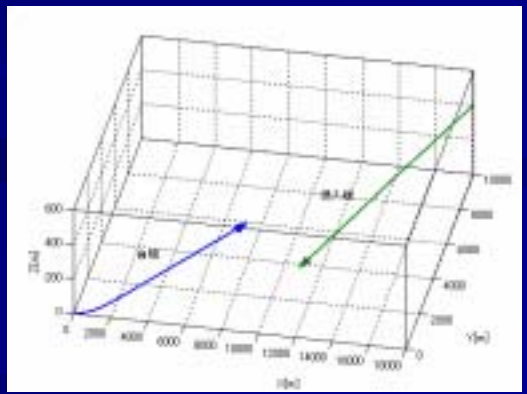
  ; judging situation of aircraft

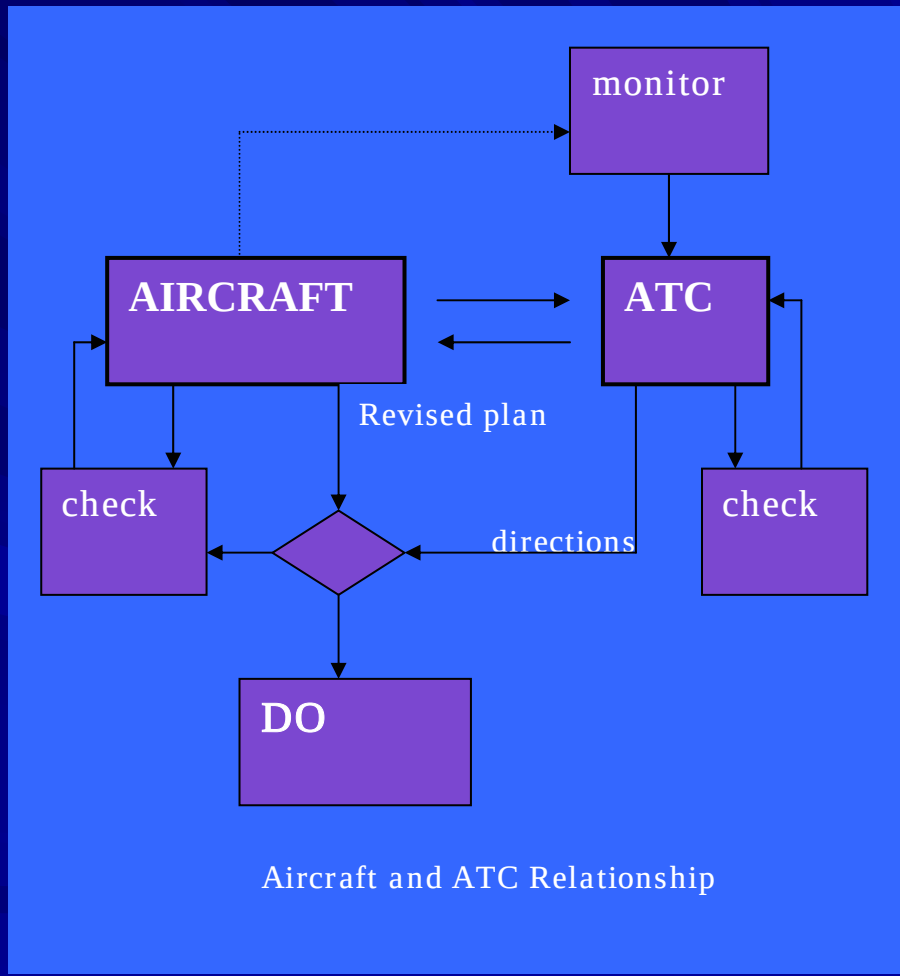
  - collision avoidance
  - flight path generation
  - reconfiguration control

- **Communicability with ATC**

  <Fuzzy Expert Control>

  @ former ICAS meeting





Aircraft and ATC Relationship

Intelligent Flight Control (summary)

- Hardware ; 10^{-12} for extremely Improbable accident
- Intelligent FCS : Autonomous
  : Reconfiguration
  / Flexible Actuation
  : High Reliability for Software
- Single Pilot Operation / Intuitive Interfaces

Conclusion -1

- Flexible Actuation System is required to enhance the reliability in control and of the flight control system, as well as advanced sensors, computers.

  ; 10^{-12} is a proposal for a critical failure.
- Intelligent Control is also required to be autonomous in normal flight, and to continue an aircraft operation thru reconfiguration.
- Fault Immune (Ultra Highly Reliable) Flight Control could be within our reach.