# MILITARY AIRCRAFT RESEARCH OPPORTUNITIES FOR THE FUTURE

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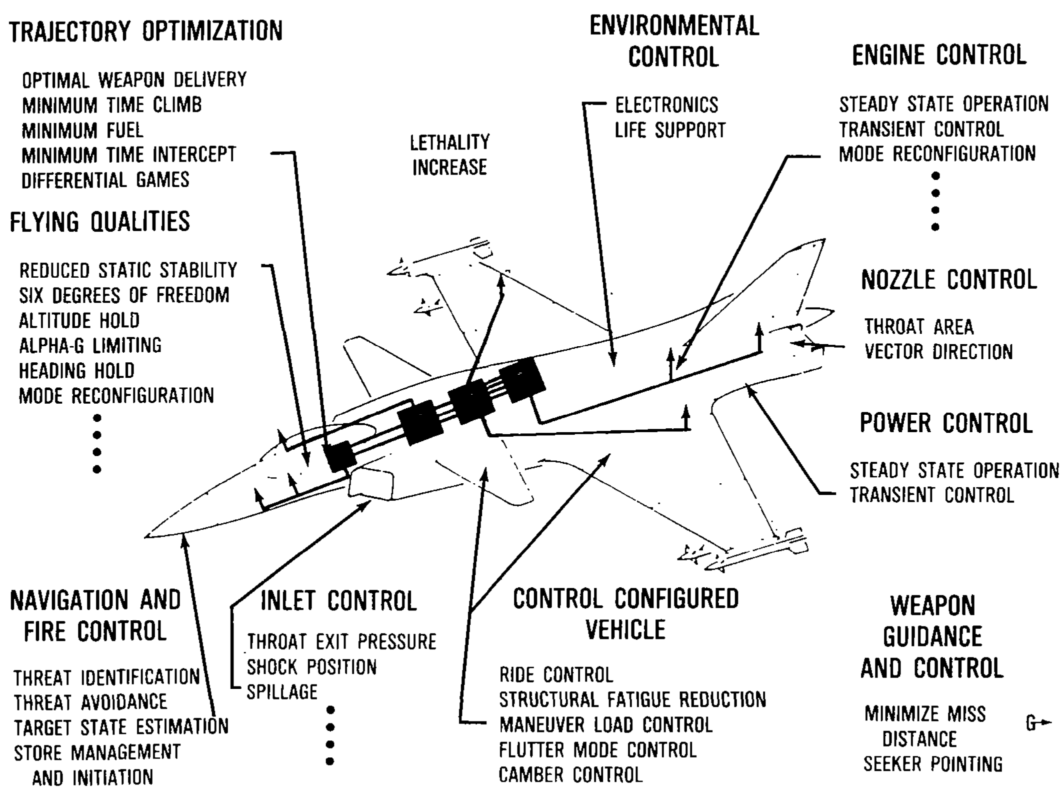
DESIGN OF DECENTRALIZED CONTROL SYSTEMS:
"INTEGRATED CONTROL"

The objective is to develop a methodology for the design of control systems for interacting dynamical systems which employ only local measurements and control devices.



## HISTORICAL PERSPECTIVE

Relative to the design of decentralized control systems, recent publications by the IEEE (e.g., ref. 1) and results of military development programs indicate that serious engineering problems prevent reliable control of interacting dynamical systems.

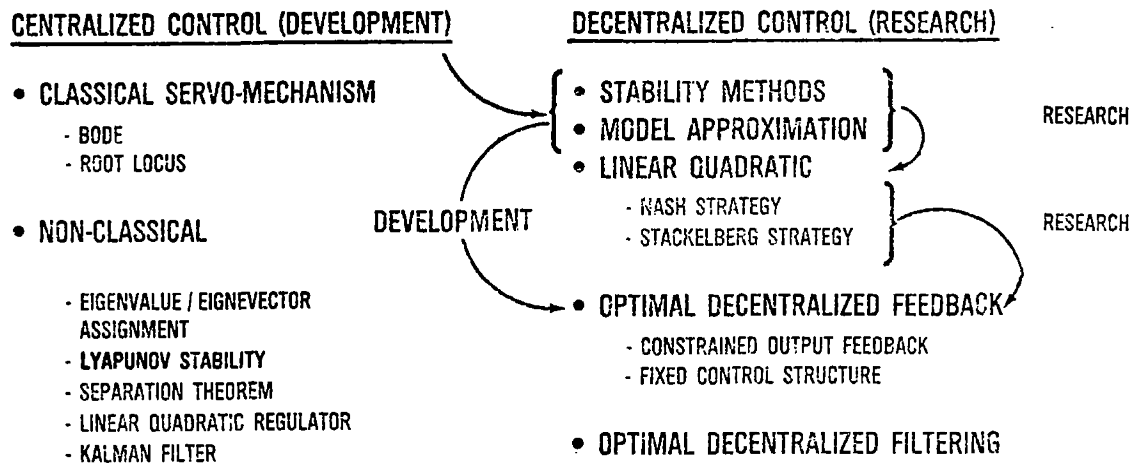
### "LARGE-SCALE SYSTEMS AND DECENTRALIZED CONTROL"

- (SPECIAL ISSUE, IEEE TRANS. AUTO. CONTROL, APRIL 1978)

- INEFFICIENT OPERATION OF LARGE SCALE INTERCONNECTED SYSTEMS
  - LACK OF FUNDAMENTAL UNDERSTANDING OF PHYSICS MODELS
  - LACK OF COORDINATED CONTROL STRATEGIES
  - USE OF DETERMINISTIC STATIC STRATEGIES ON STOCHASTIC DYNAMIC SYSTEMS
- EXISTING TOOLS FOR CENTRALIZED CONTROL ARE INAPPROPRIATE
  - SERVOMECHANISM THEORY
  - RECENT THEORY
    - MAXIMUM PRINCIPLE
    - LYAPUNOV STABILITY
    - ESTIMATION
    - DYNAMIC PROGRAMMING
- IMPLEMENTATION REQUIREMENTS UNKNOWN
  - NEED FOR AND COST OF COMMUNICATION CHANNELS
  - FIDELITY AND RELIABILITY OF INFORMATION
  - ALLOWABLE TIME DELAYS IN INFORMATION

## AVAILABLE DECENTRALIZED CONTROL DESIGN METHODS

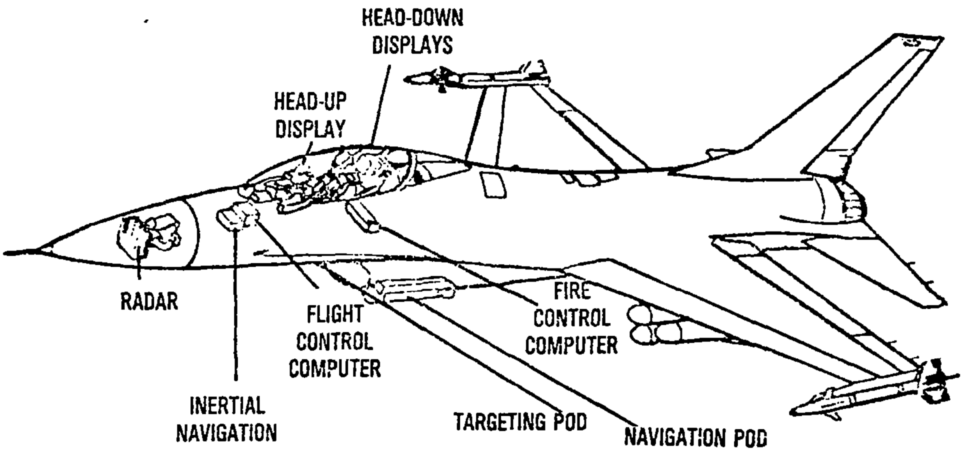
The current practice is to employ both hierarchical and heterarchical design procedures. They are evolutions of the centralized control theory design methods of the last 30 years. Current development applications depend heavily upon insight gained from centralized design of large-scale systems. Research activity seeks to understand relationships among the decentralized control theories.



RESEARCH AND DEVELOPMENT NEEDS IN
DESIGN OF DECENTRALIZED CONTROL SYSTEMS

Research needs include the development of (1) clearer mathematical relationships among the various existing methods and (2) the practical significance of the Witsenhauser nonlinear counter-example for linear Gaussian design. Development needs include the definition of (1) suitable dynamics problems of varying complexity for testing of new methods and (2) an efficient computerized methodology that minimizes mathematical complexity and presents the physics essentials of both problem and solution. This method should store user experience in a data base.

The objective is to manually employ the decentralized control of many on-board systems to achieve full dynamics control in highly maneuverable vehicles.




SYSTEM INTEGRATION EMPHASIZES CONTROL USING LARGER MEASUREMENT SETS

## HISTORICAL PERSPECTIVE;
## FLYING QUALITIES/CONTROL SYSTEM DYNAMICS

Recent development programs have experienced manual control problems as the flight control system increases in complexity. If increasing complexity occurs in many control systems, can the manual control problem become easier?

| AIRCRAFT | PROBLEM AREA | PROBLEM SOURCE | PROBLEM SOLUTION |
|---|---|---|---|
| ① | TAKE OFF AND LANDING | BLENDED AOA / LOAD FACTOR COMMAND SYSTEM, | INSTALL PITCH RATE COMMAND SYSTEM, |
| | | AOA SIGNAL FADE OUT TIME = .01 SEC | INCREASE SIGNAL FADE OUT TIME TO 1.1 SEC |
| | ROLL RACHETING | TOO SENSITIVE TO SMALL INPUTS | CAS MODIFICATION |
| ② | PIO PRONE AT TOUCHDOWN | TIME DELAY IN PITCH | FCS PITCH TIME DELAY ADJUSTED |
| ③ | PITCH PROBLEMS AT TOUCHDOWN | EXCESSIVE INITIAL RESPONSE DELAY | ? |
| ④ | PIO PITCH PROBLEMS AT TOUCHDOWN | ? | ? |
| ⑤ | MANUAL TERRAIN FOLLOWING | LARGE AMPLITUDE PITCH DAMPING | RESIDUAL OSCILLATION FROM PILOT INPUTS ELIMINATED |
| | LANDING APPROACH PIO | ? | ? |

## HISTORICAL PERSPECTIVE; FLYING QUALITIES/DISPLAY DYNAMICS

Recent development programs have also been characterized by displays designed with inattention to display/computer dynamics. Displaying additional information from many decentralized systems may decrease manual flight safety.

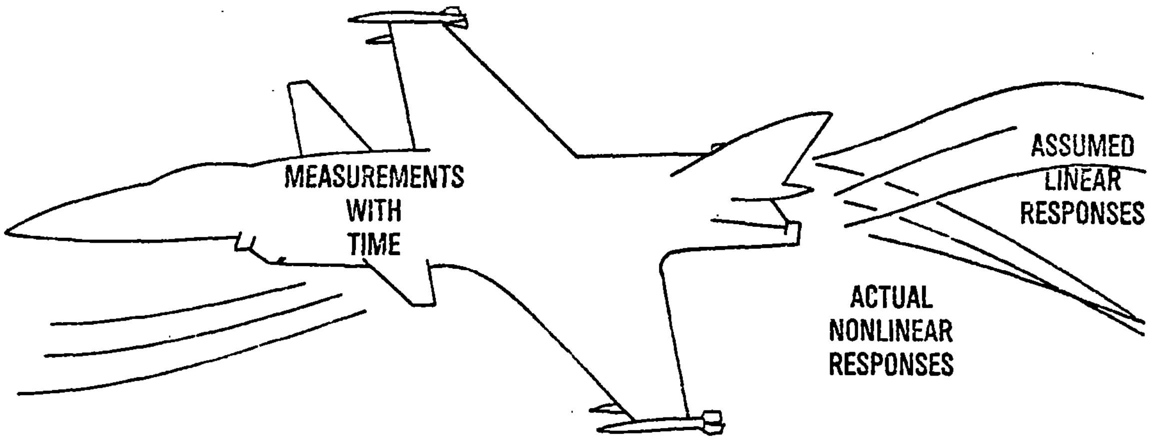
# FLYING QUALITIES - LEVEL 1 .. PILOT INPUT TO AIRPLANE RESPONSE $\leq$ 100 MS

- TYPICAL PILOT TRACKING TIME DELAY, $\tau \approx 300$ MS
  - EFFECT OF C.25 CM QUANTIZATION OF ERROR DISPLAY $\Rightarrow \Delta\tau = 34\% \approx 100$ MS
- TYPICAL DISPLAY TIME DELAYS

| AIRCRAFT | DISPLAY |
|---|---|
| 1 | FLIGHT PATH MARKER, 30 MS; AOA INDICATOR, 50 MS |
| 2 | TARGET PREDICTOR, 70 MS |
| 3 | PITCH LADDER, 50 MS CALCULATION, 20 MS REFRESH<br>NAV MAP CHANGE, 1 SEC |
| 4 | DATE UPDATE, 40 MS; REFRESH, 1 SEC |

## HISTORICAL PERSPECTIVE:
## FLYING QUALITIES/VEHICLE DYNAMICS

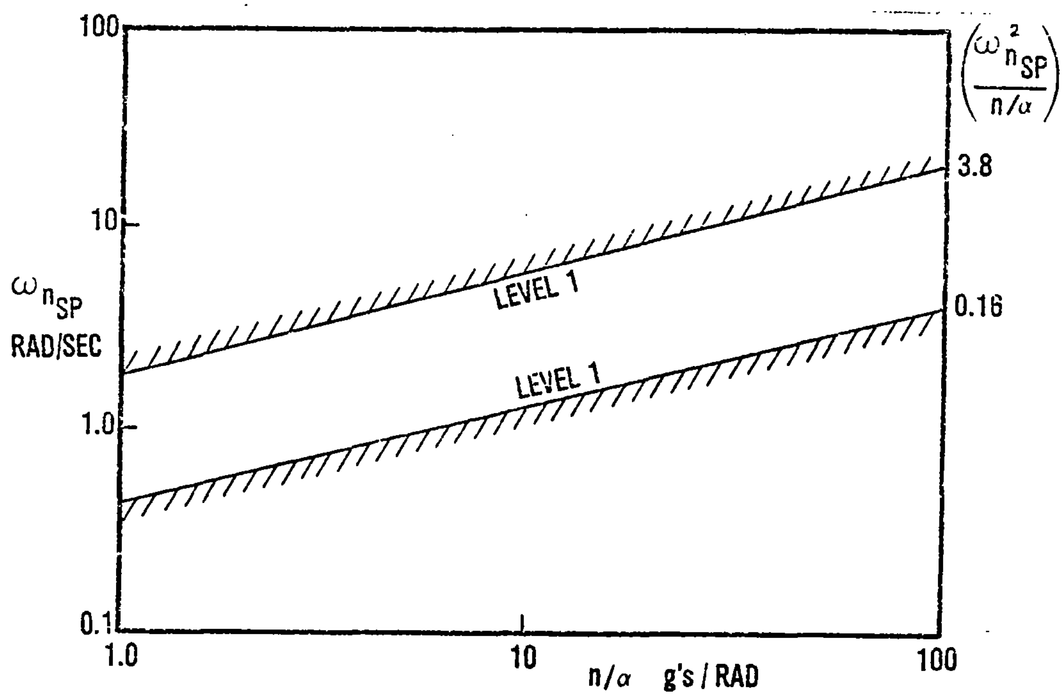
Much of the nonlinear dynamics information in the MIL SPEC/MIL STD 8785C (ref. 2) must be made more quantitative to manually control many dynamical processes in highly maneuverable tasks. What does a pilot require to utilize nonlinear dynamic phenomena? What is too much of a good thing? What does he want if some system failure occurs?




$$\begin{array}{ccccc} & & \text{LINEAR} & + & \text{NONLINEAR} & \\ \left\{\begin{array}{c}\text{RESPONSES}\\ \hline \text{MEASUREMENTS}\end{array}\right\} & = & \left[\left[\begin{array}{c|c}\dot{\theta}/F_S & \\ \hline & \end{array}\right] & + & \left[\begin{array}{c|c}\dot{\theta}^2/F_S & \\ \hline & \end{array}\right]\right] & \left\{\begin{array}{c}\text{CONTROLLERS}\\ \hline \text{COMMANDS}\end{array}\right\}\end{array}$$

HISTORICAL PERSPECTIVE:
FLYING QUALITIES/VEHICLE DYNAMICS (CONCLUDED)

The MIL SPEC/MIL STD 8785C (ref. 2) describes many design objectives as eigenvalue/eigenvector relationships. Typical of these are the n/α versus $\omega_n$ charts describing manual control requirements at "moderate frequencies."



## RESEARCH AND DEVELOPMENT NEEDS IN FLYING QUALITIES OF ADVANCED VEHICLES

Research needs include the parametric characterization of nonlinear systems:

- Volterra series
- Least-squares errors projection
- Least-squares error/orthonormal projection
- Energy concepts

Development needs include the evaluation of experimental procedures and data used to characterize flying qualities boundaries for centralized/decentralized control; the definition of metrics to identify manual/automatic system interface boundaries; and the creation of a generic, nonlinear dynamics, manned flight simulator.

## REFERENCES

1. Athans, M.: Guest Editorial on Large-Scale Systems and Decentralized Control, IEEE Transactions on Automatic Control, vol. AC-23, no. 2, April 1978, pp. 105-106.

2. Military Specifications, Flying Qualities of Piloted Airplanes, MIL-F-8785C, 5 November 1980.